Delaware Post Construction Stormwater BMP Standards & Specifications

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DNREC DIVISION OF WATERSHED STEWARDSHIP

Delaware

Post Construction Stormwater BMP Standards & Specifications

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ACKNOWLEDGEMENTS

This document is the culmination of a combined effort between the Delaware Department of Natural Resources and Environmental Control and the Center for Watershed Protection. At the time of publication, it represented the best available technology for managing both the quality and quantity of stormwater runoff. Emphasis has been placed on practices that reduce stormwater runoff through infiltration, recharge and reuse in order to minimize the impacts associated with urban development. The following groups are acknowledged for their contributions:

- Delaware Sediment & Stormwater Program Staff
- Delegated Agency Staff
- Members of the Regulatory Advisory Committee & Technical Subcommittee

In addition, a special acknowledgement to the developers of the following documents which served as valuable resources:

- District Dept. of the Environment Stormwater Management Guidebook
- Virginia DCR Stormwater Design Specifications
- Maryland Dept. of the Environment Stormwater Design Manual
- Chesapeake Stormwater Network Technical Bulletin No. 4

This document has been developed with the intention that it will become a “living document”. That is, it has been structured in such a way that keeping it current and up-to-date will be much easier. As such, the Delaware Sediment & Stormwater Program will issue additions, deletions, updates, etc. as necessary. Any changes will be adopted following public notice requirements in accordance with 7 Del. C. §6004 and will be filed in the Register of Regulations pursuant to 29 Del. C. §10113.

Anyone having questions, comments or suggestions for improving this document should contact the following:

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PREAMBLE

These regulations are the product of a comprehensive review of existing Regulations and the supporting Technical Document and plan review procedures utilized by the Sediment and Stormwater program within the Watershed Stewardship Division of the Department of Natural Resources and Environmental Control (“DNREC”). This effort was undertaken by a Regulatory Advisory Committee (“RAC”) made up of stakeholders and other interested parties, supported by program staff. This revision was a direct result of the decision of the Superior Court in *Baker v. DNREC*, 2015 WL 5971784 (Oct. 7, 2015), which was affirmed by the Delaware Supreme Court on April 15, 2016. *DNREC v. Baker*, 137 A.3d 122 (Del. 2016) (TABLE). The Court found that DNREC could not rely on technical and advisory supporting materials, which had not been formally adopted as regulations pursuant to the Administrative Procedures Act, in reviewing plans and issuing permits. In a legislative response to the *Baker* holdings, the General Assembly enacted Senate Bill 253 on June 24, 2016, 80 Del. Laws Ch. 274, and House Bill 194 on August 10, 2016, 80 Del. Laws Ch. 392. And in *Trivits v. State*, C.A. No. S16C-05-048, Judge Graves of Superior Court, on July 1, 2016, rejected a challenge to the validity of emergency regulations enacted by DNREC in response to the vacuum left by the *Baker* holding, and recognized the validity of the regulatory adoption process undertaken by the RAC.

The members of the RAC, working through various technical subcommittees, have reviewed the 2014 Regulations, as well as those portions of the Technical Document and other materials that could be read to create mandatory obligations or processes or plan components. Revisions have been undertaken and adopted by consensus of the RAC. The goal of this effort has been to include all mandates within the body of the revised Regulations, as distinguished from advisory, exemplary, or supporting documents and information, not adopted as Regulations. The latter category of materials cannot be used for purposes of enforcement or to deny a stormwater plan, and compliance is strictly voluntary.

In an effort to facilitate compliance by regulated parties, the RAC has prepared a single publication containing the draft Regulations and supporting materials. The recommendation of the RAC is that this document be published (in hard copy and online) by DNREC, for the guidance of regulated parties and the public. It is a supplementary document, for the purpose of integrating language quoted from the Regulations with supporting educational and explanatory material. Whereas the Regulations can only be changed according to the APA, the non-regulatory materials can be updated and adapted as needed by the program staff. Only the Regulations themselves can be used as a basis for enforcement, or to deny a plan or permit. The advice and guidance provided in the Appendix is not intended to create a cause of action for noncompliance or a basis for prosecution of violations. Any failure of a regulated party to pursue the recommendations or suggestions or other guidance appearing in the publication cannot be used as a basis of liability.

In order to provide a single reference source for Sediment and Stormwater problems, the Appendix document quotes from the official Regulations, and provides examples, suggestions, options, and alternatives to facilitate compliance. In order to distinguish between what is mandatory and what is optional, **bold font** is used where Regulations are cited. This is the same language that will appear in the Delaware Administrative Code upon approval. Compliance with these Regulations will be required. Regular font is used for the background, examples, and explanatory material. Compliance with these materials is not required.

The Regulations set forth in **bold font** will be submitted for formal adoption, pursuant to the Administrative Procedures Act, as authorized by Chapter 40 of Title 7 of the Delaware Code, and they carry the force of law. The advice in regular font will be published for purposes of explanation and guidance, and none of the suggestions provided are mandated. The Administrative Procedures Act does not require that this advisory material be formally adopted. DNREC has published the Appendix to facilitate compliance by regulated parties, and will provide public notice of any changes to the advisory materials, which will be updated annually.

All of the material contained in the Appendix has been reviewed and approved by DNREC staff and by the RAC. The distinction between mandatory and voluntary language has been made pursuant to the ruling of the Court in *Baker v. DNREC*. Pursuant to the Court's ruling, all standards and criteria and other provisions of the former Technical Guidance Document that mandate compliance have been incorporated into the official Regulations. These provisions appear in **bold font** here for the convenience of users, together with the supporting advisory materials in regular font.

On June 26, 2018, Senate Bill 204 passed by a roll call vote in the House of Representatives and will take effect upon signature by the Governor. Section 6 of S.B. 204 adds new subsections (h) and (i) to §4006 of Title 7 of the Delaware Code. These new provisions exempt stormwater regulatory guidance documents, interpretive rules, and general statements of policy from the formal regulatory adoption process of the Administrative Procedures Act (APA) and from the Regulatory Flexibility Act (RFA). A "regulatory guidance document" is defined to include any technical manual, checklist, form, BMP standards and specifications, the Delaware Sediment and Erosion Control Handbook, and other materials used by DNREC to facilitate compliance. Such guidance documents may not be used to impose requirements beyond those set forth in Chapter 40 of Title 7 and the Regulations, nor may they be sued for enforcement purposes. Any changes to regulatory guidance materials must be posted for public notice and published in the Delaware *Register of Regulations*.

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1.0 Infiltration Practices

Definition: **Practices that capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a two day period.**

Design variants include:

- 1-A **Infiltration Trench**
- 1-B **Infiltration Basin**
- 1-C **Underground Infiltration**

Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where *measured* soil permeability rates exceed 1 inch per hour. To prevent possible groundwater contamination, infiltration should not be utilized at sites designated as stormwater hotspots. Care should be taken to assure that long-term infiltration rates are achieved through proper construction, post construction inspection and long-term maintenance.

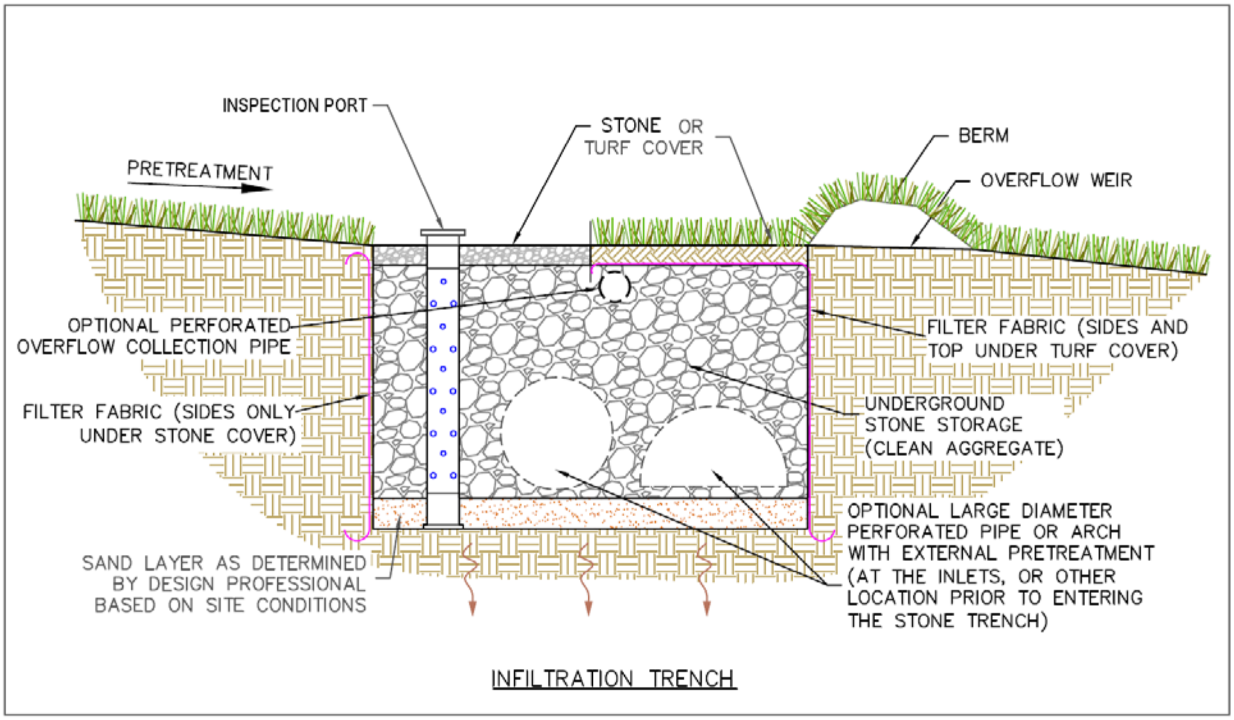

Figure 1.1 Infiltration Trench

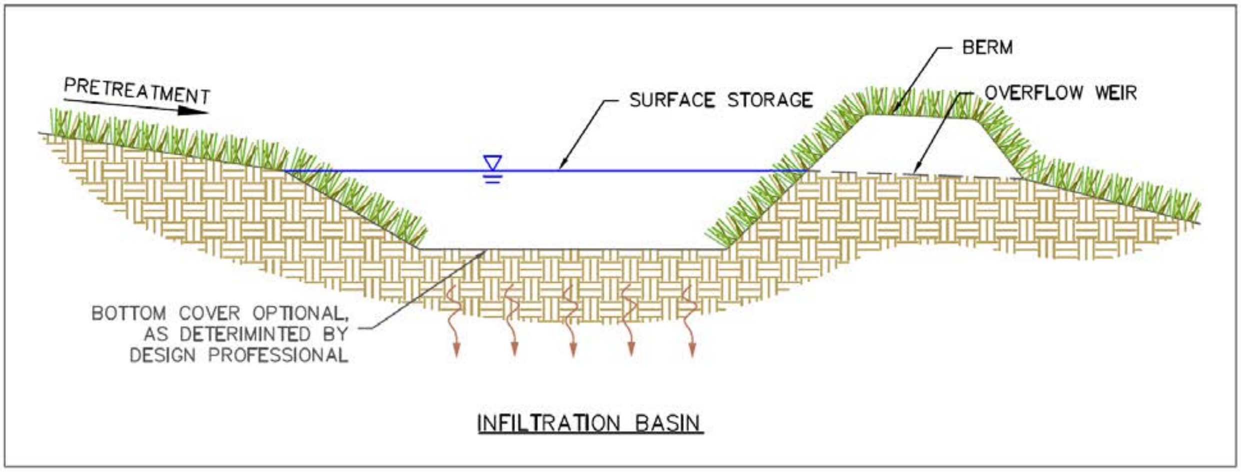

Figure 1.2 Infiltration Basin (Section View)

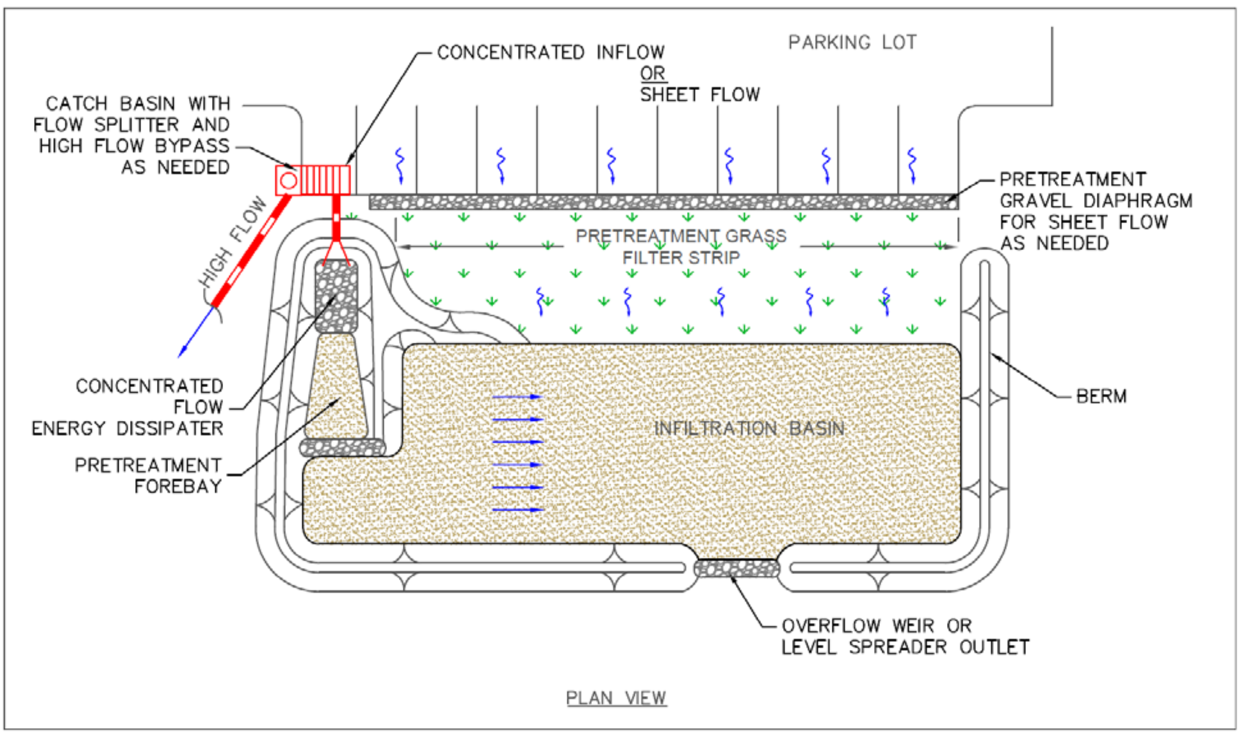

Figure 1.3 Infiltration Basin (Plan View)

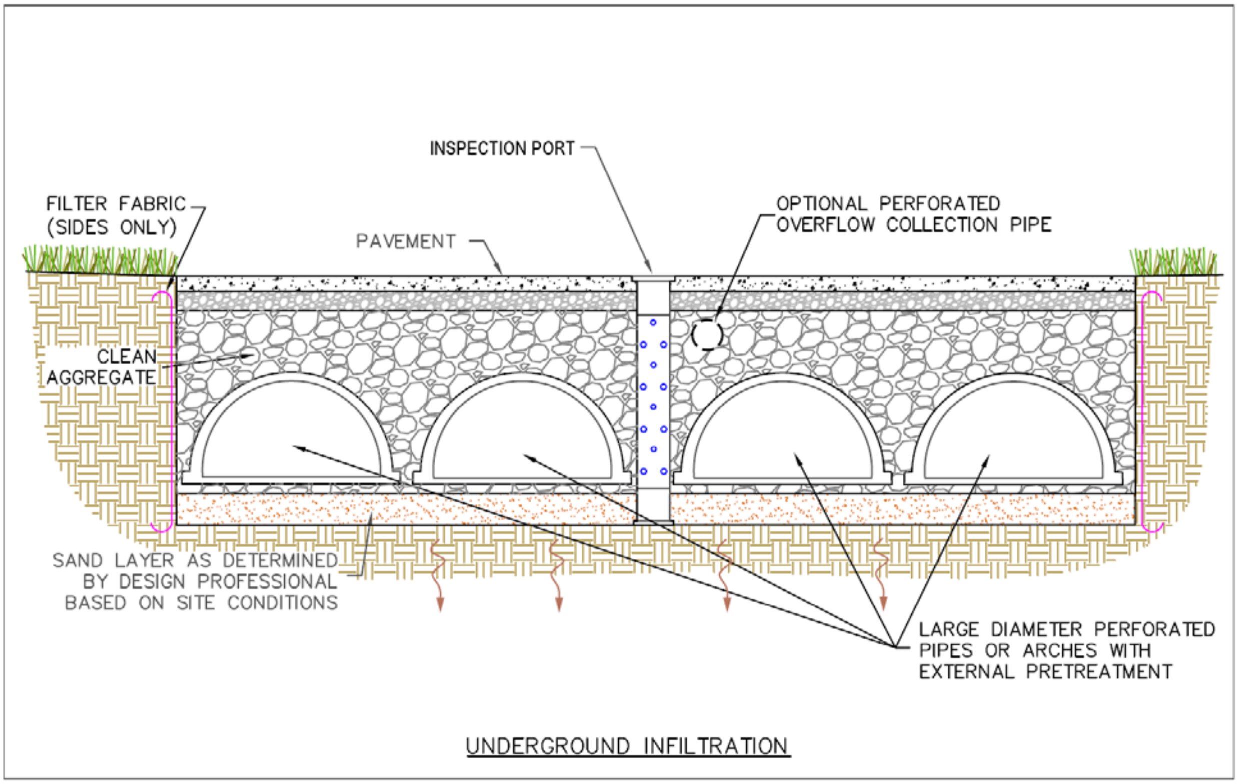

Figure 1.4 Underground Infiltration

1.1 Infiltration Stormwater Credit Calculations

Infiltration practices receive 100% retention volume credit (R_v) for the volume stored and infiltrated by the practice (Table 1.1). Where an overdrain or discharge pipe is provided, credit is not given for the volume of runoff discharged through the pipe. No additional pollutant removal credit is awarded.

Table 1.1 Infiltration Performance Credits

Runoff Reduction	
Retention Allowance	100%
RPv	**100% of Retention Storage**
Cv	**100% of Retention Storage**
Fv	**100% of Retention Storage**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

1.2 Infiltration Practices Summary

Table 1.2 summarizes criteria for infiltration practices, and Table 1.3 summarizes the materials specifications for these practices. For more detail on design criteria, consult Sections 1.3 through 1.7. Section 1.8 describes practice construction and Section 1.9 describes maintenance criteria.

Table 1.2 Infiltration Practices Summary

Feasibility Criteria (Section 1.3)	• **Infiltration practices shall be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20% unless slope stability calculations demonstrate stable conditions.** • **A minimum vertical distance of 2 feet must be provided between the bottom of the infiltration practice and the seasonal high water table as determined by the soil investigation procedures or bedrock layer.** • **The minimum vertical distance of 2 feet may be relaxed if a groundwater mounding analysis or piezometer testing has been performed by a qualified professional.** • **Native soils in proposed infiltration areas must have a minimum infiltration rate of 1 inch per hour.** • **Designers must verify soil permeability by using the on-site soil investigation methods provided in the Soil Investigation Procedures.** • Recommended setbacks from wells, buildings and utilities in Appendix 8 • Restrictions for treating hotspots, high loads, or dry weather flows
Conveyance Criteria (Section 1.4)	• **Infiltration practices must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the practice rather than bypassing.** • **An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.** • **Infiltration basins constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended.**
Pretreatment Criteria (Section 1.5)	• **Every inlet into an infiltration system shall have a pretreatment mechanism to protect the long term integrity of the infiltration rate.** • Several pretreatment options may be used • **Exit velocities from the pretreatment shall be non-erosive during the largest design storm that is routed through the facility**.

Design Criteria (Section 1.6)	• **Infiltration basin side-slopes shall be no steeper than 4H:1V.**
	• **Stone, when used for infiltration trenches or underground infiltration systems, shall consist of clean, washed aggregate with a maximum of 2.0 percent passing the #200 sieve.**
	• **Stone shall have a maximum diameter of 2.5 inches and a minimum diameter of 0.5 inches.**
	• **A porosity value of 0.4 shall be used in the design of stone reservoirs, although a larger value may be used if underground retention chambers are installed within the reservoir.**
	• **Infiltration trenches and underground infiltration practices shall include an inspection port to facilitate periodic inspection and maintenance**.
	• **Geotextile fabric shall have a flow rate greater than 110 gal/min/sf.**
	• **For design purposes, the field verified soil infiltration rate shall be divided by 2 as a factor of safety to account for potential compaction during construction and to approximate long term infiltration rates**
	• **Infiltration practices shall be designed so that the RPv infiltrates within 48 hours.**
	• **Infiltration practices shall be designed so that they will 1) infiltrate the Fv within 72 hours or 2) dewater the Fv within 72 hours, or 3) manage the Fv on site with no adverse impact.**
	• **All Infiltration practices must be designed so as to be accessible to annual maintenance.**
	• **A maintenance right-of-way or easement must extend to the Infiltration practice from a public or private road.**
	• **Adequate maintenance access must extend to the perimeter of the Infiltration practice and outlet structure, if applicable.**
	• **Maintenance access must meet the following criteria:**
	    o **Minimum width of fifteen feet.**
	    o **Profile grade that does not exceed 10H:1V.**
	    o **Minimum 10H:1V cross slope.**

Landscaping Criteria (Section 1.7)	• Maintain vegetation in the buffers and practice drainage area to minimize erosion and debris
Construction Criteria (Section 1.8)	• **During site construction, steps shall be taken to prevent compaction and sedimentation of the infiltration practice unless extensive design and construction methods are employed to protect the infiltration practices' ability to infiltrate.**

Construction Criteria (Section 1.8) *cont.*	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:** o **Pre-construction meeting** o **Initial site preparation including installation of erosion and sediment controls and sensitive area protection surrounding infiltration practice locations** o **Construction of the embankment, including installation of the principal spillway and the outlet structure, as applicable for infiltration basins** o **Excavation and grading including interim and final elevations. Observation of infiltration surface and infiltration practice verification must be completed prior to stone placement for infiltration trenches and underground infiltration.** o **Implementation of required stabilization.** o **Final construction review including development of a punch list for facility acceptance** • **The infiltration rate and separation from groundwater of the constructed infiltration practice shall be verified prior to completion of construction in accordance with the Soil Investigation Procedures.**
Maintenance Criteria (Section 1.9)	• **The infiltrating surface shall never be covered by an impermeable material, such as asphalt or concrete.** • **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

1.3 Infiltration Feasibility Criteria

Infiltration practices have very high storage and retention capabilities when sited and designed appropriately. Designers should evaluate the range of 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 Hydrologic Soil Group A or B soils shown on NRCS soil surveys should be considered as primary locations for infiltration practices. Additional information about soil and infiltration are described in more detail later in this section. During initial design phases, designers should carefully identify and evaluate constraints on infiltration, as follows:

EPA Requirements for Class V Injection Wells

Certain types of practices in this category may be classified as a Class V Injection Wells, which are subject to regulations under the Federal Underground Injection Control (UIC) program. In general, if the facility is not open at the surface, such as an underground infiltration system, or allows stormwater runoff to come in direct contact with groundwater it would meet this criterion. Facilities with a minimum 2' vadose zone separation from the groundwater table would not meet the criterion. Also, facilities that are open at the surface, such as an infiltration trench or basin, with at least one dimension greater than the depth would not meet the criterion. Designers are advised to contact the DNREC Groundwater Discharges Section for additional information regarding UIC regulations and possible permitting requirements.

Contributing Drainage Area

To be most effective minimize the contributing drainage area (CDA). The CDA should be as close to 100% impervious as possible to minimize organic capping and maintenance concerns. The facility specific design, pretreatment and maintenance requirements will differ depending on the size of the infiltration practice.

Site Topography

Infiltration should not be located on slopes greater than 5%. **Infiltration practices shall be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20% unless slope stability calculations demonstrate stable conditions.** The average slope of the contributing drainage areas should be less than 15%.

Minimum Depth to Water Table or Bedrock. **A minimum vertical distance of 2 feet must be provided between the bottom of the infiltration practice and the seasonal high water table as determined by the soil investigation procedures or bedrock layer. The minimum vertical distance of 2 feet may be relaxed if a groundwater mounding analysis or piezometer testing has been performed by a qualified professional.**

Soils. **Native soils in proposed infiltration areas must have a minimum infiltration rate of 1 inch per hour (**typically Hydrologic Soil Group A and B soils meet this criterion**).** Initially, soil infiltration rates can be estimated from NRCS soil data. **Designers must verify soil permeability by using the on-site soil investigation methods provided in the Soil Investigation Procedures.**

Use on Urban Fill Soils/Redevelopment Sites. Sites that have been previously graded or disturbed do not typically retain their original soil permeability due to compaction. Therefore, such sites are often not good candidates for infiltration practices unless the geotechnical investigation shows that the soil infiltration rate exceeds 1.0 in/hr.

Dry Weather Flows. Infiltration practices should not be used on sites receiving regular dry-weather flows from sump pumps, irrigation water, chlorinated wash-water, or other non-stormwater flows.

Proximity to Utilities. Infiltration practices should be sited to account for future maintenance of underground utilities in accordance with the utility owner's requirements. See Appendix 8 Stormwater Facility Setbacks for recommended separation distances for utilities.

Hotspots and High Loading Situations. Infiltration practices are not intended to treat sites with high sediment or trash/debris loads, because such loads will cause the practice to clog and fail. Infiltration practices are not recommended at potential stormwater hotspots that pose a risk of groundwater contamination. For a list of potential stormwater hotspot operations, consult *Appendix 4.*

1.4 **Infiltration Conveyance Criteria**

The nature of the conveyance and overflow to an infiltration practice depends on the scale of infiltration and whether the facility is on-line or off-line. Where possible, conventional infiltration practices should be designed offline to avoid damage from the erosive velocities of larger design storms.

Off-line infiltration: Overflows can either be diverted from entering the infiltration practice or dealt with via an overflow inlet. Optional overflow methods include the following:

- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design volume to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency.
- Use landscaping type inlets or standpipes with trash guards as overflow devices.

On-line infiltration: An overflow structure can be incorporated into on-line designs to safely convey larger storms through the infiltration area.

Infiltration practices must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the practice rather than bypassing. An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.

Infiltration basins constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended.

1.5 Infiltration Pretreatment Criteria

Every inlet into an infiltration system shall have pretreatment. Recommended techniques to pretreat 100% of the inflow in every facility include but are not limited to:

- Vegetated Channel with a minimum flow length of 20 feet
- Grass Filter Strip with a minimum flow length of 10 feet
- Forebay with a minimum 10% of the RPv
- Proprietary Practices that can achieve a 50% reduction in suspended solids (see Specification 15. Proprietary Practices)
- Catch Basin Sumps (applicable for perforated pipe systems for residential streets and site drainage only, minimum 2')

Exit velocities from the pretreatment shall be non-erosive during the largest design storm that is routed through the facility. Flow from the pretreatment chamber should be evenly distributed across the width of the practice (e.g., using a level spreader).

1.6 Infiltration Design Criteria

Facility Slope. The bottom of an infiltration facility should be flat (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater; however the bottom may be stepped internally per design specifications.

Infiltration Basin Geometry: The recommended maximum vertical depth to which runoff may be ponded over an open infiltration basin for the C_v is 24 inches. **Infiltration basin side-slopes shall be no steeper than 4H:1V.**

Stone, when used for infiltration trenches or underground infiltration systems, shall consist of clean, washed aggregate with a maximum of 2.0 percent passing the #200 sieve. Stone shall have a maximum diameter of 2.5 inches and a minimum diameter of 0.5 inches.

Stone Layer Porosity. **A porosity value of 0.4 shall be used in the design of stone reservoirs, although a larger value may be used if underground retention chambers are installed within the reservoir.**

Underground Storage (optional): In the underground infiltration variant, runoff is stored in the voids of the stones, and infiltrates into the underlying soil matrix. Plastic, concrete, or comparable material structures can be used in conjunction with the stone to increase the available temporary storage in infiltration trenches and underground infiltration systems. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention (ED) pond *See Specification 12. Detention Practices*.

Overflow Collection Pipe: An optional overflow collection pipe can be installed in an infiltration trench or underground infiltration system to convey collected runoff from larger storm events to a downstream conveyance system. Where an overdrain or discharge pipe is provided, RPv compliance credit is not given for the volume of runoff discharged through the pipe.

Inspection Port. **Infiltration trenches and underground infiltration practices shall include an inspection port to facilitate periodic inspection and maintenance**. It is recommended that the inspection port consist of an anchored 6-inch diameter perforated PVC pipe fitted with a cap installed flush with the ground surface.

Trench Bottom: To protect the bottom of an infiltration trench from intrusion by underlying soils, a sand layer may be used as determined by design professional based on site conditions. The underlying native soils should be separated from the stone layer by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch).

Geotextile Fabric: **Geotextile fabric when used to separate stone from native soil in an infiltration trench or underground infiltration system shall have a flow rate of 110 gal./min./sq. ft. or greater.** (see Delaware ESC Handbook, Appendix A-3)**.**
Material Specifications: Recommended material specifications for infiltration areas are shown in Table 1.3 in Section 1.2.

Practice Sizing: The proper approach for designing infiltration practices is to avoid forcing a large amount of infiltration into a small area. Therefore, individual infiltration practices that are limited in size due to soil permeability and available space need not be sized to capture the entire design volume for the contributing drainage area, as long as other stormwater treatment practices are applied at the site to meet the remainder of the design storm volume.

Infiltration Rates. **For design purposes, the field verified infiltration rate shall have a factor of safety applied in accordance with Soil Investigation Procedures to account for potential compaction during construction and to approximate long term infiltration rates.** On-site infiltration investigations should always be conducted to establish the actual infiltration capacity of underlying soils, using the methods presented in the Soil Investigation Procedures.

Infiltration practices 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. **Infiltration practices shall be designed so that the RPv infiltrates within 48 hours. Infiltration practices shall be designed so that they will 1) infiltrate the Fv within 72 hours or 2) dewater the Fv within 72 hours, or 3) manage the Fv on site with no adverse impact.** The designer can model various approaches by factoring in storage chambers within the stone aggregate layer and expected infiltration 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.

Maintenance Access. **All infiltration practices must be designed so as to be accessible for maintenance.** Good access is needed so crews can remove sediments, make repairs and preserve infiltration practice treatment capacity.

- **A maintenance right-of-way or easement must extend to the Infiltration practice from a public or private road.**
- **Adequate maintenance access must extend to the perimeter of the Infiltration practice and outlet structure, if applicable.**
- **Maintenance access must meet the following criteria:**
    - **Minimum width of fifteen feet.**
    - **Profile grade that does not exceed 10H:1V.**
    - **Minimum 10H:1V cross slope.**

Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines. When not specified in local code, the top of bank of Infiltration practices should be set back at least 15 feet from property lines to ensure maintenance access.

1.7 Infiltration Landscaping Criteria

Infiltration practices can be effectively integrated into the site plan and aesthetically designed with adjacent landscaping or turf cover. Vegetation associated with the infiltration practice buffers should be regularly mowed with clippings removed and maintained to keep organic matter out of the infiltration device and maintain enough vegetation to prevent soil erosion from occurring.

1.8 **Infiltration Construction Criteria**

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence should be followed.

During site construction, steps shall be taken to prevent compaction and sedimentation of the infiltration practice unless extensive design and construction methods are employed to protect the infiltration practices' ability to infiltrate. The following steps are recommended:

- Avoid compaction by preventing construction equipment and vehicles from traveling over the proposed location of the infiltration practice using "Sensitive Area Protection" guidelines during construction
- Infiltration trenches should remain "off-line" until construction is complete to prevent construction sediment from clogging the stone reservoir layer. Prevent sediment from entering the infiltration site by using super silt fence, diversion berms or other means. In the erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to an infiltration trench. It is recommended that the erosion and sediment control plan also indicate the specific methods to be used to temporarily keep runoff from the infiltration facility.
- Infiltration basins are not recommended to serve as temporary sediment control devices (e.g., sediment traps, etc.) during construction**.**
- Upland drainage areas are recommended to be completely stabilized with a thick layer of vegetation prior to commencing excavation for an infiltration practice.

Construction Review

Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls and sensitive area protection surrounding infiltration practice locations**
- **Construction of the embankment, including installation of the principal spillway and the outlet structure, as applicable for infiltration basins**
- **Excavation and grading including interim and final elevations. Confirmatory infiltration testing and verification must be completed prior to stone placement for infiltration trenches and underground infiltration.**
- **Implementation of required stabilization.**
- **Final construction review including development of a punch list for facility acceptance**

Review is needed during construction to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed construction checklists to include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

Infiltration Practice Verification. **The infiltration rate and separation from groundwater of the constructed infiltration practice shall be verified prior to completion of construction in accordance with the Soil Investigation Procedures. The results shall be included with the Post Construction Verification Documentation upon project completion.**

Post Construction Verification Documentation. **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the infiltration practice has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for infiltration practices are as follows:**

- **The constructed top of bank elevation may be no lower than the design elevation for top of bank.**
- **The constructed area of the infiltration surface shall be no less than 90% of the design surface area.**
- **The constructed volume of the infiltration practice surface storage shall be no less than 90% of the design volume.**
- **The constructed elevation of any structure shall be within 0.15 foot of the design.**

In the event that an allowable tolerance is exceeded the system shall be reconstructed or modified to the approved design unless supplemental calculations demonstrate compliance.

1.9 Infiltration Maintenance Criteria

Maintenance is a crucial element that ensures the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging of the stone by organic matter and sediment. The following design features can minimize the risk of clogging:

Stabilized CDA. Infiltration systems may not receive runoff until the entire contributing drainage area has been completely stabilized, unless a design and construction method can be shown to remove all clogging sediment prior to site completion.
Direct Maintenance Access. **The infiltrating surface shall never be covered by an impermeable material, such as asphalt or concrete.**

Effective long-term operation of infiltration practices requires an Operation and Maintenance Plan, including maintenance inspection schedule with clear guidelines and schedules, as shown in Table 1.5 below. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table 1.6. Typical maintenance activities for infiltration practices

Maintenance Activity	Schedule
• Replace topsoil and top surface filter fabric (when clogged). • Mow vegetated filter strips as necessary and remove the clippings.	As needed
• Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. • Ensure that the contributing drainage area is stabilized. Perform spot-reseeding if where needed. • Remove sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. • Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
• Check inspection ports 3 days after a storm event in excess of 1/2 inch in depth. Standing water observed in the observation port after three days is a clear indication of clogging. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage. • Remove trees that start to grow in the vicinity of the infiltration facility that may drop leaf litter, fruits and other vegetative materials that could clog the infiltration device.	Semi-annual inspection
• Clean out accumulated sediments from the pretreatment cell.	Annually

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Operation and Maintenance Plans should clearly outline how vegetation in the Infiltration facility and its buffer will be managed or harvested in the future. Periodic mowing of the Infiltration facility is required, unless it is managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of an Infiltration facility is driven by annual maintenance reviews that evaluate the condition and performance of the Infiltration facility. Based on maintenance review results, specific maintenance tasks may be required.

1.10 References

No references.

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2.0 Bioretention

Definition: **Practices that capture and store stormwater runoff and pass it through a bed of engineered soil media comprised of sand, lignin and organic matter, known as biosoil. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil.**

Design variants include:

- 2-A **Traditional Bioretention**
- 2-B **In-Situ Bioretention including Rain Gardens**
- 2-C **Streetscape Bioretention**
- 2-D **Engineered Tree Boxes**
- 2-E **Stormwater Planters**
- 2-F **Advanced Bioretention Systems**

Bioretention systems are typically designed to manage stormwater runoff from frequent, small magnitude storm events, but may provide stormwater detention of larger storms (e.g., Cv) in some circumstances. Bioretention practices should be designed such that larger storm events bypass the system into a separate facility where site conditions allow.

For each of the design variants above, there are two basic configurations:

- *Underdrain Designs*: Practices with a positive discharge using perforated pipe; pollutant reduction occurs through a combination of runoff reduction and treatment by the biosoil media. Addition of a 2-foot infiltration sump maximizes runoff reduction performance. Advanced systems may provide greater pollutant removal capabilities through the use of improved media components and/or internal modifications that encourage partial anaerobic conditions.

- *Infiltration Designs:* Practices with no underdrains that infiltrate the RPv within 48 hours; pollutant reduction is based solely on the load reduction provided by the design retention storage volume.

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

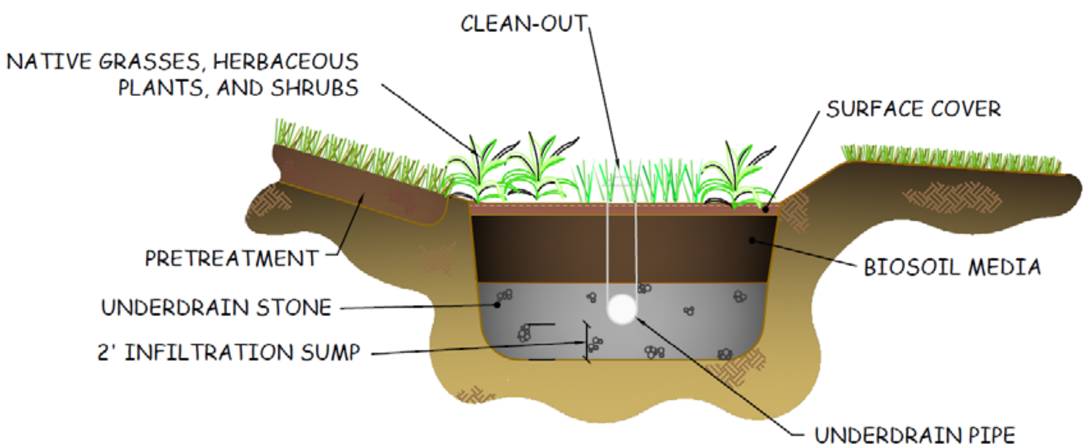

FIGURE 2.1: TRADITIONAL BIORETENTION UNDERDRAIN DESIGN

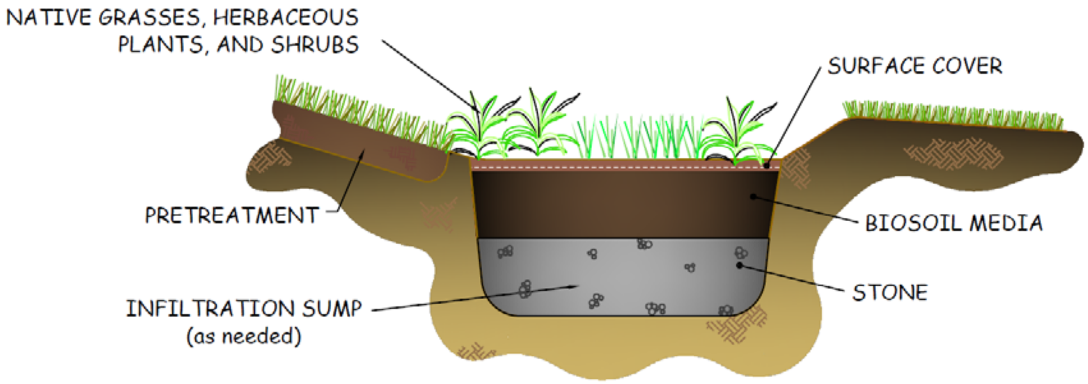

FIGURE 2.2: TRADITIONAL BIORETENTION INFILTRATION DESIGN

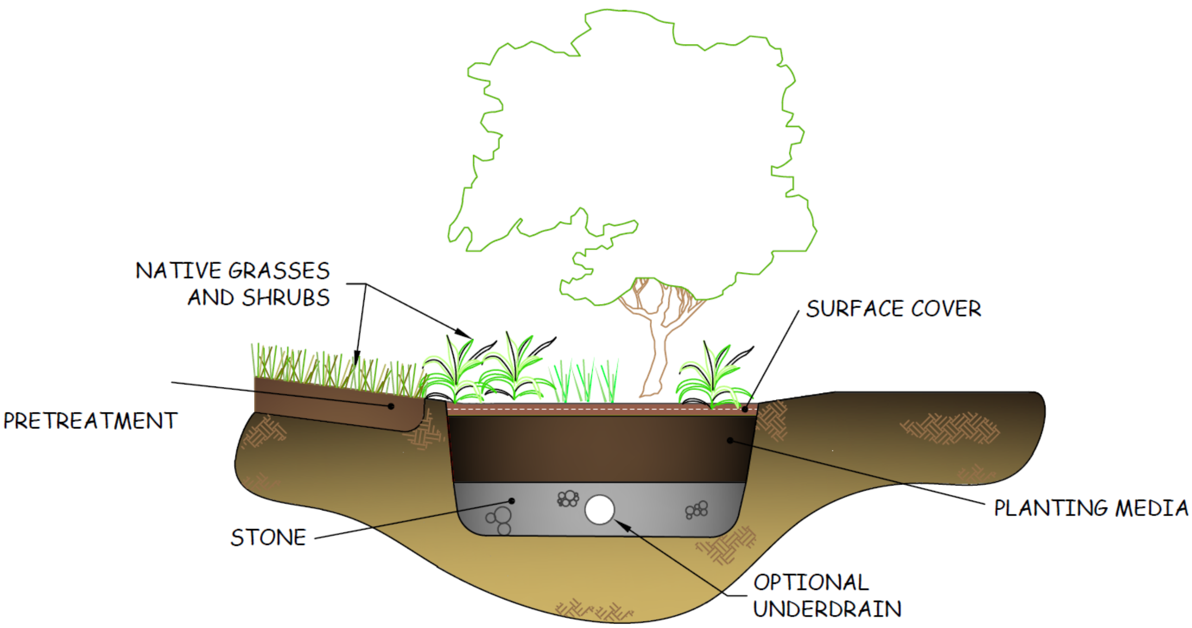

FIGURE 2.3: RAIN GARDEN

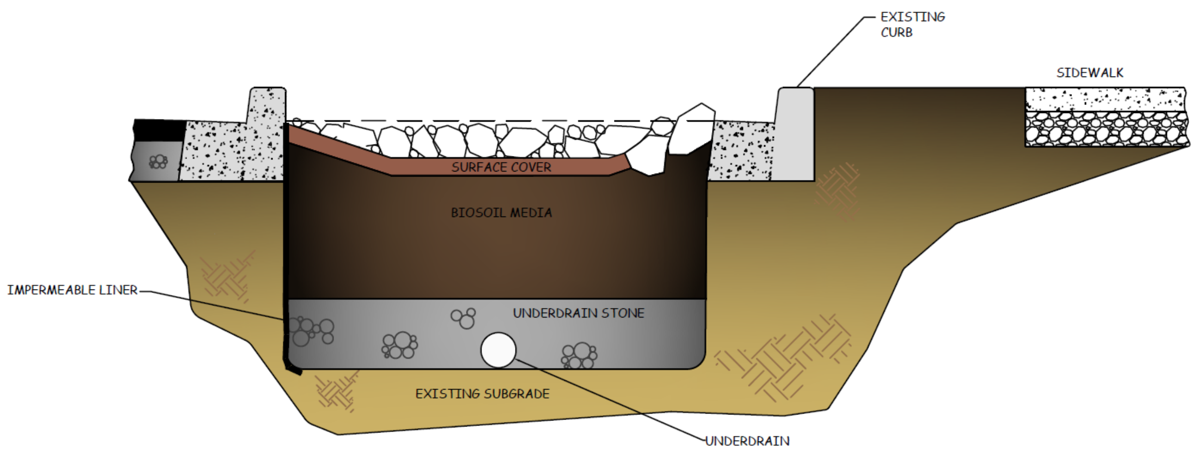

FIGURE 2.4: STREETSCAPE BIORETENTION

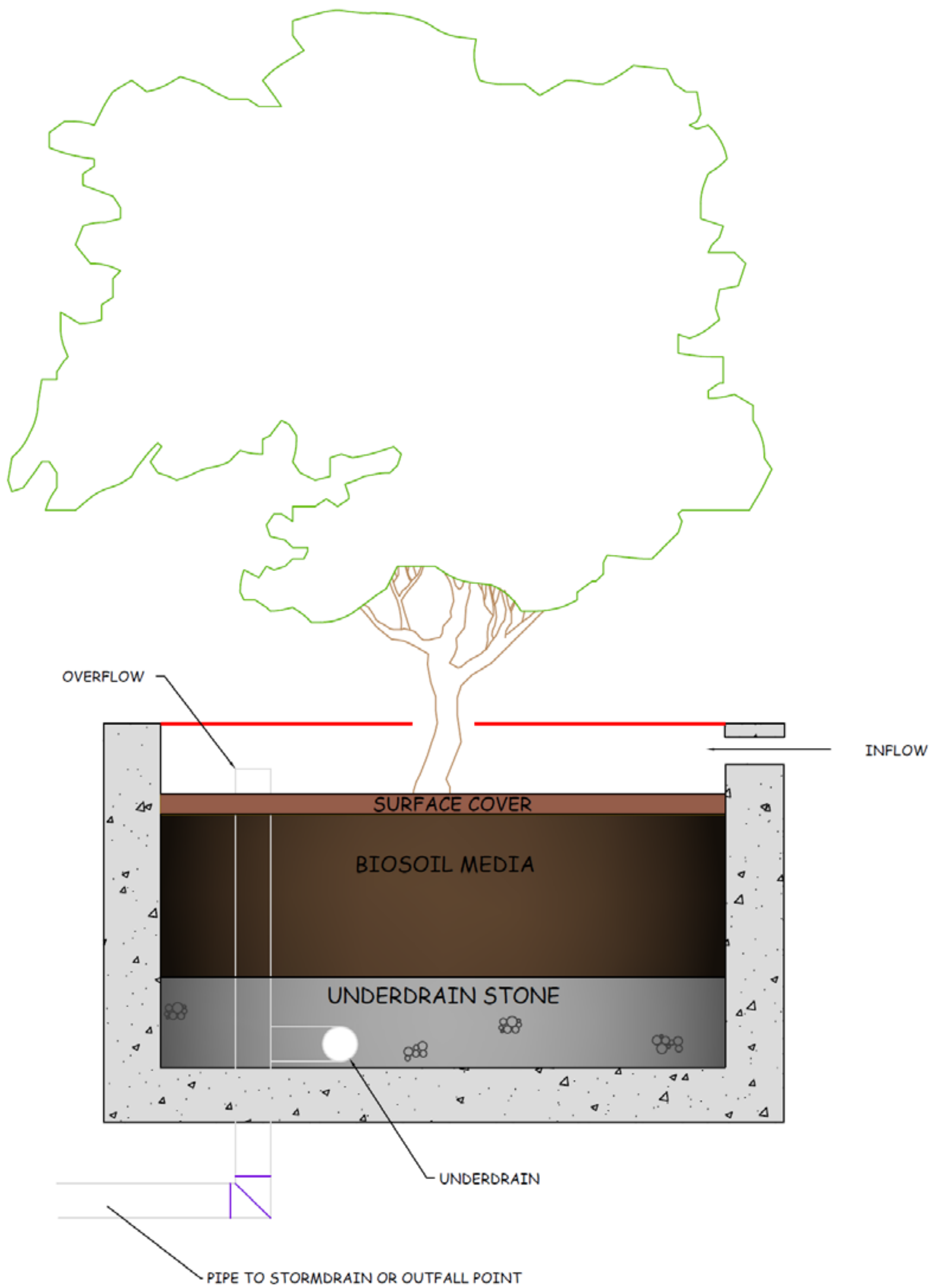

FIGURE 2.5: ENGINEERED TREE BOX

2.1 Bioretention Stormwater Credit Calculations

The volume management credit for bioretention practices shall be based upon the volume of runoff that is either slowly released or infiltrated from the practice (Table 2.1a & b). In addition, bioretention systems using an underdrain receive a removal efficiency credit for filtering pollutants as they pass through the soil media. **Advanced Bioretention Systems shall be evaluated on a case-by-case basis and assigned performance credits as deemed appropriate by the Department.**

2.1(a) Bioretention With Underdrain Performance Credits

Runoff Reduction	
Detention Allowance	100%
RPv -A/B Soil	100% of Detention Storage
RPv - C/D Soil	100% of Detention Storage
Cv	100% of Detention Storage
Fv	100% of Detention Storage
Pollutant Reduction*	
TN Reduction	Not less than 30% Removal Efficiency
TP Reduction	Not less than 40% Removal Efficiency
TSS Reduction	Not less than 80% Removal Efficiency

*Advanced systems may provide higher removal efficiencies

2.1(b) Bioretention With Infiltration Performance Credits

Runoff Reduction	
Retention Allowance	100%
RPv -A/B Soil	100% of Retention Storage
RPv - C/D Soil	100% of Retention Storage
Cv	100% of Retention Storage
Fv	100% of Retention Storage
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

2.2 Bioretention Practice Summary

Table 2.2 summarizes criteria for bioretention practices, and Table 2.3 summarizes the materials specifications for these practices. For more detail, consult the appropriate sections referenced in column 1.

Table 2.2 Bioretention Practice Summary

	Standard Underdrain Designs	Infiltration Designs
Feasibility (Section 2.3)	• **Underdrains are required if the permeability of the underlying soils does not have a minimum field-verified infiltration rate of 1 inch per hour.** • **An impermeable bottom liner and an underdrain system must be employed when a bioretention facility will receive untreated hotspot runoff.**	• **A minimum vertical distance of 2 feet must be provided between the bottom of the infiltrating bioretention practice and the seasonal high water table as determined by the soil investigation procedures or bedrock layer. The minimum vertical distance of 2 feet may be relaxed if a groundwater mounding analysis or piezometer testing has been performed by a qualified professional.** • **Infiltrating bioretention practices shall be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20% unless slope stability calculations demonstrate stable conditions.**
Conveyance (Section 2.4)	• **Bioretention practices must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the practice rather than bypassing. An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.** • **Bioretention practices constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended.** • **An overflow structure shall be incorporated into on-line designs to safely convey larger storms through the bioretention facility.** • **The maximum design discharge velocity shall be checked for a non-erosive condition at the outlet point. Outlet protection shall be provided as necessary.**	
Pretreatment (Section 2.5)	• **Every inlet into a bioretention practice shall have pretreatment.** • **Exit velocities from the pretreatment shall be non-erosive during the largest design storm that is routed through the facility.**	
Design Criteria (Section 2.6)	• **Bioretention practices shall have energy dissipation provided at all inlets.** • **Bioretention practices shall be designed so that the RPv either infiltrates or discharges within 48 hours.** • **Bioretention practices shall be designed so that they will infiltrate the Fv within 72 hours, or dewater the Fv within 72 hours, or manage the Fv on site with no adverse impact.** • **Traditional and advanced bioretention facilities and rain gardens shall be constructed with side slopes above biosoil media of 3:1 or flatter.** • **Advanced Bioretention Systems shall be evaluated on a case-by-case basis and assigned performance credits as deemed appropriate by the Department** • **Traditional sizing approaches using design volume considering void ratio of the stone and biosoil media shall be used when sizing bioretention.** • **All Bioretention practices must be designed so as to be accessible for maintenance.** o **A maintenance right-of-way or easement must extend to the Bioretention practice from a public or private road.**	

Design Criteria (Section 2.6) *cont.*	o **Adequate maintenance access must extend to the perimeter of the Bioretention practice and outlet structure.** o **Maintenance access must meet the following criteria:** ▪ **Minimum width of fifteen feet.** ▪ **Profile grade that does not exceed 10H:1V.** • **Minimum 10H:1V cross slope.**
Landscaping (Section 2.7)	• **A planting plan shall be provided for all bioretention facilities.** • **Minimum elements of a planting plan include the following:** o **The proposed bioretention template to be used** o **Delineation of planting areas** o **Size and spacing of plant material** o **The planting sequence, including post-nursery care and initial maintenance requirements** • **Planting plans must be certified by a qualified professional.**
Construction Criteria (Section 2.8)	• **When a bioretention system is used as a sediment trap or basin during construction, the Sediment & Stormwater Plan must include notes and graphic details specifying that:** o **the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the final invert or bottom of the facility, and** o **the bottom of the facility shall be ripped, tilled or otherwise scarified upon final excavation** • **The plan shall include the proper procedures for converting the temporary sediment control practice to a permanent bioretention facility, including dewatering, cleanout and stabilization.** • **For infiltrating bioretention systems, confirmatory infiltration testing and verification must be completed prior to completion of construction in accordance with the Soil Investigation Procedures.** • **The final bottom elevation of any bioretention facility shall not be traversed by construction equipment.** • **Biosoil media must be obtained from a Department approved vendor.** • **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:** o **Pre-construction meeting** o **Initial site preparation including installation of erosion and sediment controls, sensitive area protection surrounding bioretention locations, and blockage of inlets to bioretention locations** o **Excavation and grading including interim and final elevations. For infiltrating bioretention systems, confirmatory infiltration testing and a verification must be completed prior to gravel and biosoil media placement.** o **Construction of the underdrain, including inspection ports and installation of the overflow structure, as applicable** o **Installation of gravel and biosoil media** o **Implementation of required stabilization and planting plan** • **Final construction review including development of a punch list for facility acceptance** • **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the bioretention practice has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for bioretention practices are as follows:** o **The constructed top of bank elevation may be no lower than the design elevation for top of bank.** o **The constructed area of the bioretention surface shall be no less than 90%of the design surface area.**

Construction Criteria (Section 2.8) *cont.*	o **The constructed volume of the bioretention storage shall be no less than 90% of the design volume.** • **The constructed elevation of any structure shall be within 0.15 foot of the design.** • **In the event that an allowable tolerance is exceeded the system shall be reconstructed or modified to the approved design unless supplemental calculations demonstrate compliance.**
Maintenance Criteria (Section 2.9)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.** • **Supplemental fertilizer applications shall consist of a 0% phosphorus formulation only as needed to maintain plant vigor.**

Table 2.3. Bioretention Material Specifications

Material	Specification
Biosoil Media	• **Biosoil-14 soil mixture shall have the following volumetric composition:** o **60% concrete sand; fineness modulus > 2.75** o **30% triple-shredded hardwood mulch** o **10% aged, STA certified compost, meeting the requirements of Delaware Erosion and Sediment Control Handbook Appendix A-6 Compost Material Properties.** • **Biosoil media must be obtained from a Department approved vendor.** • **The design permeability rate for biosoil media shall be 2.83 inches per hour.** • **The biosoil media bed depth shall be a minimum of 24 inches for traditional bioretention and advanced bioretention systems.** • **Gravel layers used for extending the bioretention facility into a more permeable layer shall meet the same requirements as those for an underdrain design.**
Biosoil Media Testing	• **Biosoil media must be obtained from a Department approved vendor.** • **The design permeability rate for biosoil media shall be 2.83 inches per hour.**
Surface Cover	• **A surface cover shall be provided over the biosoil media.** • **Mulch if used as a surface cover, shall be triple shredded hardwood aged for a minimum of six months.** • **Use of alternative surface cover shall be shown on the approved plan.**
Underdrain Stone (as needed)	• **Underdrains shall be incased in a layer of clean, washed nominal 1/4" gravel with a maximum of 2.0 percent passing the #200 sieve** • **Minimum of 3" of cover over underdrain** • **The gravel layer in traditional bioretention shall be extended a minimum of 2' below the invert of the underdrain.**
Storage Layer (optional)	• To increase storage for larger storm events, chambers, perforated pipe, stone, or other acceptable material can be incorporated below the biosoil media layer
Underdrains, Cleanouts, and Inspection ports	• **The underdrain shall be a minimum of 4-inch perforated corrugated polyethylene pipe (CPP)** • **All traditional bioretention practices shall include at least one inspection port and/or cleanout pipe.**

2.3 Bioretention Feasibility Criteria

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

EPA Requirements for Class V Injection Wells. Certain types of practices in this category may be classified as a Class V Injection Wells, which are subject to regulations under the Federal Underground Injection Control (UIC) program. In general, if the facility is not open at the surface, such as an underground infiltration system, or allows stormwater runoff to come in direct contact with groundwater it would meet this criterion. Facilities with a minimum 2' vadose zone separation from the groundwater table would not meet the criterion. Also, facilities that are open at the surface with at least one dimension greater than the depth would not meet the criterion. Designers are advised to contact the DNREC Groundwater Discharges Section for additional information regarding UIC regulations and possible permitting requirements.

Required Space. Designers can assess the feasibility of using bioretention facilities based on a simple relationship between the contributing drainage area and the corresponding required surface area. The bioretention surface area will usually be between 3% to 6% of the contributing drainage area (CDA), depending on the imperviousness of the CDA and the desired bioretention ponding depth.

Available Hydraulic Head. Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice. In general, 4 to 5 feet of elevation above this invert is needed to accommodate the required ponding and biosoil media depths. If an inverted or elevated underdrain design is used to accommodate an internal water storage (IWS) design, less hydraulic head may be adequate.

Water Table. Bioretention should always be separated from the water table to ensure that groundwater does not intersect the biosoil media. This could otherwise lead to possible groundwater contamination or failure of the bioretention facility. **A minimum vertical distance of 2 feet must be provided between the bottom of the infiltrating bioretention practice and the seasonal high water table as determined by the soil investigation procedures or bedrock layer. The minimum vertical distance of 2 feet may be relaxed if a groundwater mounding analysis or piezometer testing has been performed by a qualified professional.**

Soils and Underdrains. Soil conditions do not typically constrain the use of bioretention, although they do determine whether an underdrain is needed. **Underdrains are required if the permeability of the underlying soils does not have a minimum field-verified infiltration rate of 1 inch per hour**. A stone sump can be used to extend an infiltrating facility to a more permeable layer, as needed. When designing a bioretention practice, designers should verify soil permeability by using the methods provided in *Appendix 1, Soil Investigation*

Procedures for Stormwater BMPs.

Contributing Drainage Area. Bioretention facilities work best with smaller contributing drainage areas, where it is easier to achieve flow distribution over the biosoil media bed. Typical drainage area size for traditional bioretention facilities (2-A) can range from 0.1 to 5 acres and consist of up to 100% impervious cover. Drainage areas to smaller bioretention practices (2-B, 2-C, 2-D, and 2-E) typically range from 0.5 acre to 1.0. The maximum recommended impervious area to a single bioretention basin or single cell of a bioretention facility is 2.5 acres due to limitations in the ability of bioretention to effectively manage large volumes and peak rates of runoff. However, if hydraulic considerations are adequately addressed to manage the potentially large peak inflow of larger drainage areas (such as off-line or low-flow diversions, forebays, etc.), there may be case-by-case instances where these recommended maximums can be adjusted.

Table 2.4. Maximum Recommended CDA to Bioretention

	Traditional Bioretention	Small-scale and Urban Bioretention
Design Variants	2-A, 2-F	2-B, 2-C, 2-D, and 2-E
Maximum CDA	10.0 acres (2.5 ac. impervious)	1.0 acres (0.25 ac. impervious)

Hotspot Land Uses. **An impermeable bottom liner and an underdrain system must be employed when a bioretention facility will receive untreated hotspot runoff.** However, Bioretention can still be used to treat "non-hotspot" parts of the site. For a list of potential stormwater hotspots, see *Appendix 4, Stormwater Hotspots Guidance*.

Floodplains. Bioretention facilities should be constructed outside the limits of the 100-year floodplain.

No Natural Stream Baseflow or Chlorinated Water. The bioretention facility should not receive natural stream baseflow or chlorinated water.

Site Topography. Bioretention is best applied when the grade of contributing slopes is greater than 1% and less than 5%. **Infiltrating bioretention practices shall be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20% unless slope stability calculations demonstrate stable conditions.**

Setbacks. To avoid the risk of seepage, bioretention facilities should not be hydraulically connected to structure foundations. The designer should check to ensure footings and foundations of adjacent buildings do not encroach within an assumed 4:1 phreatic zone drawn from the maximum design water elevation in the bioretention facility. See Appendix 8 Stormwater Facility Setbacks for recommended setbacks.

Proximity to Utilities. Bioretention practices should be sited to account for future maintenance of underground utilities in accordance with the utility owner's requirements. See Appendix 8 Stormwater Facility Setbacks for recommended separation distances for utilities.

Additionally, designers should ensure that future tree canopy growth in the bioretention facility will not interfere with existing overhead utility lines.

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

2.4 **Bioretention Conveyance Criteria**

Bioretention practices must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the practice rather than bypassing. An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.

Bioretention practices constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended.

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

1. Off-line: Flow is split or diverted so that only the runoff from the design storm enters the bioretention area. Larger flows by-pass the bioretention facility.

2. On-line: All runoff from the drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir.

Off-line Bioretention. Alternative overflow methods include the following:

- Create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility.
- Utilize a low-flow diversion or flow splitter at the inlet to allow the RPv to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination

with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. Determining the peak flow rate will be necessary in order to ensure proper design of the diversion structure.

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

- Common overflow systems within bioretention practices consist of an outlet structure, where the top of the structure is set so as to control the maximum ponding depth within the bioretention facility. The crest of the outlet structure is therefore typically set at 6 to 18 inches above the surface of the biosoil media.
- The overflow capture device should be scaled to the application – this may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.
- **The maximum design discharge velocity shall be checked for a non-erosive condition at the outlet point. Outlet protection shall be provided as necessary.**

2.5 **Bioretention Pretreatment Criteria**

Every inlet into a bioretention practice shall have pretreatment. Pre-treatment of runoff entering bioretention facilities is necessary to trap coarse sediment particles before they reach and prematurely clog the biosoil media. Ideally, pre-treatment measures should be designed to evenly spread runoff across the entire width of the bioretention area. Several pre-treatment measures are feasible, depending on the type of the bioretention practice and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. **Exit velocities from the pretreatment shall be non-erosive during the largest design storm that is routed through the facility**. The following are appropriate pretreatment options:

For Traditional Bioretention (2-A, 2-F):

- Pre-treatment Cells (channel flow): Similar to a forebay, this cell is located at piped inlets or curb cuts leading to the bioretention area and may include an energy dissipater sized for the expected rates of discharge. Storage volume should be equivalent to at least 10% of the RPv with a recommended 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen berm. Pretreatment cells do not need underlying engineered soil media, in contrast to the main bioretention cell.
- Grass Filter Strips (sheet flow): Grass filter strips that are perpendicular to incoming sheet flow extend from the edge of pavement (with a slight drop at the pavement edge) to the bottom of the bioretention basin at a 5:1 slope or flatter. Alternatively, if the bioretention facility has side slopes that are 3:1 or flatter, a 5 foot grass filter strip at a maximum 5% (20:1) slope can be used.
- Gravel or Stone Diaphragms (sheet flow). A gravel diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 1 to 2 inch drop from the pavement edge to the top of the stone.
- Proprietary Practices: Structures that meet the pre-treatment requirements of *Specification 15.0, Proprietary Practices* may be used for pre-treatment.

For Small-Scale Bioretention (2-B, 2-C, 2-D, 2-E):

- Leaf Screens as part of the gutter system serve to keep the heavy loading of organic debris from accumulating in the bioretention cell.
- Grass Filter Strips (for sheet flow), applied on residential lots, where the lawn area can serve as a grass filter strip adjacent to a rain garden.
- Gravel or Stone Diaphragm (for either sheet flow or concentrated flow); this is a gravel diaphragm at the end of a downspout or other concentrated inflow point that should run perpendicular to the flow path to promote settling.
- Trash Racks (for either sheet flow or concentrated flow) between the pre-treatment cell and the main biosoil media bed or across curb cuts. These will allow trash to collect in specific locations and create easier maintenance.
- Pre-treatment Cell (see below) located above ground or covered by a manhole or grate. This type of pretreatment is not recommended for residential rain gardens (B-5).

2.6 **Bioretention Design Criteria**

Design Geometry. Bioretention facilities should be designed with aninternal flow path geometry such that the treatment mechanisms provided by the bioretention are not bypassed or short-circuited during the Resource Protection Event (RPv). In order for these bioretention facilities to have an acceptable internal geometry, the "travel time" from each inlet to the outlet should be maximized by locating the inlets and outlets as far apart as possible. In addition, incoming flow should be distributed as evenly as possible across the entire biosoil media surface area.

Inlets and Energy Dissipation. **Bioretention practices shall have energy dissipation provided at all inlets.** Inlet and energy dissipation practices that could be considered include:

- Downspouts to stone energy dissipaters.
- Sheet flow over a depressed curb with a 3-inch drop.
- Curb cuts allowing runoff into the bioretention area.
- Covered drains that convey flows across sidewalks from the curb or downspouts.
- Grates or trench drains that capture runoff from a sidewalk or plaza area.
- Gravel or Stone Diaphragms.
- Gravel or Stone Flow Spreaders.

Ponding Depth. The maximum recommended surface ponding depth is 12" for the RPv, 18" for the Cv, and 24" for the Fv. However, if these greater ponding depths are used, the designer should carefully consider issues such as safety, aesthetics, the viability and survival of plants, and erosion and scour of side slopes. Shallower ponding depths (typically 6" to 12") are recommended for Streetscape Bioretention (2-C), Engineered Tree Boxes (2-D), and Stormwater Planters (2-E).

Bioretention practices shall be designed so that the RPv either infiltrates or discharges within 48 hours. Bioretention practices shall be designed so that they will 1) infiltrate the

Fv within 72 hours or 2) dewater the Fv within 72 hours, or 3) manage the Fv on site with no adverse impact.

Side Slopes. **Traditional and advanced bioretention facilities** (2-A, 2-F) **and rain gardens** (2-B) **shall be constructed with side slopes above biosoil media of 3:1 or flatter.** In highly urbanized or space constrained areas, a drop curb design or a precast structure can be used to create stable, vertical side walls.

Biosoil Media. The following are key factors to consider in determining an acceptable biosoil media mixture.

Biosoil Media Composition. **The Biosoil-14 soil mixture shall have the following volumetric composition:**

- **60% coarse concrete sand having a Fineness Modulus > 2.75**
- **30% triple shredded hardwood mulch**
- **10% aged, STA certified compost, meeting the requirements of Delaware Erosion and Sediment Control Handbook Appendix A-6 Compost Material Properties.**

Biosoil media must be obtained from a Department approved vendor.

Phosphorus Content. The recommended range for phosphorus content for the soil component is between 7 mg/kg and 23 mg/kg.

Cation Exchange Capacity (CEC). The CEC of a soil refers to the total amount of positively charged elements that a soil can hold; it is expressed in milliequivalents per 100 grams (meq/100g) of soil. For agricultural purposes, these elements are the basic cations of calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+1}) and sodium (Na^{+1}) and the acidic cations of hydrogen (H^{+1}) and aluminum (Al^{+3}). The CEC of the soil is determined in part by the amount of clay and/or humus or organic matter present. Soils with CECs exceeding 10 are preferred for pollutant removal. Increasing the organic matter content of any soil will help to increase the CEC.

Biosoil Media Permeability Rate. **The design permeability rate for biosoil media shall be 2.83 inches per hour.**

Biosoil Media Depth. **The biosoil media bed depth shall be a minimum of 24 inches for traditional bioretention and advanced bioretention systems** (variants 2-A and 2-F). This depth may be reduced for small-scale bioretention practices (variants 2-B, 2-C, 2-D and 2-E) as noted elsewhere in this specification. A sand or gravel layer may be added below the biosoil media if a greater depth is required to reach a more permeable layer in the soil profile. If sand is used, it should be more permeable than the underlying soil. **Gravel layers used for extending the bioretention facility into a more permeable layer shall meet the same requirements as those for an underdrain design.** If trees are included in the bioretention planting plan, tree planting holes in the biosoil media should be deep enough to provide enough soil volume for the root structure of the selected mature trees. Trees are not recommended for systems having underdrains. Native grasses, perennials or shrubs should be used instead of trees to landscape shallower biosoil media beds and systems with underdrains.

Surface Cover. **A surface cover shall be provided over the biosoil media.** The surface cover combined with the biosoil media will ensure long term performance of the bioretention system.

Mulch. A minimum 2 inch layer of mulch on the surface of the biosoil media bed is the preferred surface cover. Mulch enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the biosoil media. Shredded hardwood mulch makes a very good surface cover, as it retains a significant amount of pollutants and typically will not float away. **Mulch, if used as a surface cover, shall be triple shredded hardwood aged for a minimum of six months.**

Alternative to Mulch Cover. In some situations, designers may consider alternative surface covers such as native groundcover, river rock, or pea gravel. **Use of alternative surface cover shall be shown on the approved plan.**

Underdrains. For bioretention designs that require an underdrain (see Section 2.3)**, the underdrain shall be a minimum of 4-inch perforated corrugated polyethylene pipe (CPP). The underdrain shall be encased in a layer of clean, washed nominal 1/4" gravel with a maximum of 2.0 percent passing the #200 sieve with a minimum of 3" of cover. The gravel layer in traditional bioretention shall be extended a minimum of 2' below the invert of the underdrain.** The 2' sump enhances the infiltration capabilities of the system and may also serve as an aerobic/anaerobic zone for situations in which the water table fluctuates below the invert.

Each underdrain should be located no more than 20 feet from the next pipe.

All traditional and advanced bioretention systems (Variants 2-A and 2-F) **shall include at least one inspection port or cleanout pipe.** The inspection ports and/or cleanouts should be appropriately sized PVC tied into any T's or Y's if an underdrain system is used, and should extend slightly above the surface, with a screw-on or locking cap.

Underground Storage Layer (optional). An underground storage layer consisting of chambers, perforated pipe, stone, or other acceptable material can be incorporated below the biosoil media layer. For bioretention facilities with an underdrain, the underground storage layer should be above the underdrain invert to increase storage for larger storm events. The depth and volume of the storage layer will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria.

Impermeable Liner. This material should be used only for appropriate hotspot designs, In-Situ Bioretention (2-B), Streetscape Bioretetion (2-C) that do not meet the necessary separation requirements from buildings, or in fill applications where deemed necessary by a geotechnical investigation.

Signage. Bioretention facilities in highly urbanized areas may be stenciled or permanently marked to designate them as a stormwater management facility in order to avoid potential complaints about an otherwise properly functioning system. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

Specific Design Issues for In-Situ Bioretention, including Rain Gardens (2-B):
In some cases, the native soil profile may be adequate to support infiltration of the RPv without the need for a more elaborate traditional-type system. Certified yard waste compost may also be mixed with the native soils instead of biosoil media. It is generally recommended that this practice be used for individual lots that do not require a detailed Sediment and Stormwater Plan. For some residential applications, front, side, and/or rear yard bioretention may be an acceptable option. This form of bioretention captures roof, lawn, and driveway runoff from low- to medium- density residential lots in a depressed area (6 to 12 inches) between the home and the primary stormwater conveyance system (roadside ditch or pipe system).

The planting media should be deep enough to extend below the topsoil and into the more permeable subsoil. If the permeable soil layer is relatively close to the surface, it may be possible to simply excavate to provide the necessary design storage volume and incorporate 3”-4” of certified yard waste compost into the native soil. Although this type of system is particularly conducive to the inclusion of trees in the planting plan, tree planting holes should be deep enough to provide enough soil volume for the root structure of the selected mature trees. Shredded hardwood mulch may be added as a top dressing to complete the installation.

It is preferred that this category of bioretention be designed as an infiltration practice. However, When an underdrain is necessary based upon field verified infiltration rates, or to retro-fit a failing system, it may be connected to a storm drain or open channel conveyance system.

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

Specific Design Issues for Engineered Tree Boxes (2-D):
Engineered Tree Boxes are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree box is increased and used to capture and treat

stormwater. Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

When designing Engineered Tree Boxes, the following criteria should be considered:

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

Specific Design Issues for Stormwater Planters (2-E):
Stormwater Planters are a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. They consist of confined planters that store and/or infiltrate runoff in a soil bed to reduce runoff volumes and pollutant loads. Stormwater Planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater Planters generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation. The two basic design variations for stormwater planters are the infiltration Stormwater Planter and the filter Stormwater Planter.

An infiltration Stormwater Planter filters rooftop runoff through biosoil media in the planter followed by infiltration into soils below the planter. The recommended minimum depth of biosoil media is 24 inches, with the shape and length determined by architectural considerations. Infiltration planters should have an impermeable barrier placed to prevent possible flooding or basement seepage damage.

A filter Stormwater Planter does not allow for infiltration and is constructed with a watertight concrete shell or an impermeable liner on the bottom to prevent seepage. Since a filter Stormwater Planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building. The minimum planter depth is 24 inches, with the shape and length determined by architectural considerations. Runoff is captured and temporarily ponded above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded. In addition, an underdrain is used to carry runoff to the storm sewer system.

All planters should be placed at or above finished grade elevation. Plant materials should be capable of withstanding moist and seasonally dry conditions. The planter can be constructed of stone, concrete, brick, wood or other durable material.

Specific Design Issues for Advanced Systems (2-F):
Recent research on bioretention has led to more advanced systems that are capable of greater reductions of certain targeted pollutants. One promising technology for reducing phosphorus levels in stormwater runoff involves the use of *water treatment residuals (WTR)* in the media mix. Other media supplements such as activated charcoal, sawdust and even shredded paper have also been shown to improve removal of certain constituents from stormwater runoff. Another approach employs modifications to the configuration of the bioretention system to retain a portion of the accumulated stormwater. This so-called *internal water storage (IWS)* design has been shown to reduce soluble nitrogen levels by inducing an anaerobic condition within the bioretention facility itself. While this research looks promising, design specifications have not been developed to date. However, the Department recognizes that the technology in this field is evolving rapidly and encourages the use of the latest advances in science. **Advanced Bioretention Systems shall be evaluated on a case-by-case basis and assigned performance credits as deemed appropriate by the Department** until formally adopted into these Standards and Specifications.

Practice Sizing. Bioretention will typically be sized to treat all or a portion of the RP_v, and can also partially meet the C_v through volume contained in the surface ponding area, biosoil media, and gravel reservoir layers of the practice. **Traditional sizing approaches using design volume considering void ratio of the stone and biosoil media shall be used when sizing bioretention.**

Maintenance Reduction Features: The following Bioretention maintenance issues can be addressed during the design, in order to make on-going maintenance easier:

- Maintenance Access. **All Bioretention practices must be designed so as to be accessible for maintenance.** Good access is needed so crews can remove sediments, make repairs and preserve treatment capacity.
  - **A maintenance right-of-way or easement must extend to the Bioretention practice from a public or private road.**
  - **Adequate maintenance access must extend to the perimeter of the bioretention practice and outlet structure.**
  - **Maintenance access must meet the following criteria:**
    - **Minimum width of fifteen feet.**
    - **Profile grade that does not exceed 10H:1V.**
    - **Minimum 10H:1V cross slope.**
  - Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines. When not specified in local code, the top of bank of Bioretention practice should be set back at least 15 feet from property lines to ensure maintenance access.

2.7 Bioretention Landscaping Criteria

Landscaping is critical to the performance and function of bioretention areas. **A planting plan shall be provided for all bioretention facilities. Minimum elements of a planting plan include the following:**

- **The proposed bioretention template to be used,**
- **Delineation of planting areas,**

- **Size and spacing of plant material**
- **The planting sequence, including post-nursery care and initial maintenance requirements**

Planting plans must be certified by a qualified professional, including landscape architects, horticulturists, or other disciplines that possess the necessary knowledge, skills and training**.**

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. Some popular native species that work well in bioretention areas and are commercially available can be found in *Appendix 2, Stormwater BMP Landscaping Criteria*. Plants selected for planting in bioretention areas should be able to withstand 72 hours of inundation of runoff without causing harm to the plant.

The degree of landscape maintenance that will be provided will also determine some of the planting choices for urban bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. Spaces for herbaceous flowering plants can be included.

2.8 Bioretention Construction Criteria

Erosion and Sediment Controls. Bioretention facilities should be fully protected by silt fence or construction fencing. Ideally, bioretention facilities should remain undisturbed during construction to prevent soil compaction by heavy equipment. Large bioretention facilities may be used as small sediment traps or basins during construction. **When a bioretention system is used as a sediment trap or basin during construction, the Sediment & Stormwater Plan must include notes and graphic details specifying that: (1) the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the final invert or bottom of the facility, and (2) the bottom of the facility shall be ripped, tilled or otherwise scarified upon final excavation. The plan shall include the proper procedures for converting the temporary sediment control practice to a permanent bioretention facility, including dewatering, cleanout and stabilization.**

Verification of bioretention with infiltration design. **For infiltrating bioretention systems, confirmatory infiltration testing and verification must be completed prior to completion of construction in accordance with the Soil Investigation Procedures. The results shall be included with the Post Construction Verification Documentation upon project completion.**

Bioretention Installation. The following is a typical construction sequence to properly install a bioretention facility (also see Figure 2.3). The construction sequence for small-scale bioretention is more simplified. These steps may be modified to reflect different bioretention applications or expected site conditions:

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

Step 2. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed bioretention facility. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

Step 3. Temporary erosion and sediment controls (e.g., diversion dikes, reinforced silt fence) are needed during construction of the bioretention facility to divert stormwater away from the bioretention facility until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the construction process.

Step 4. Any pre-treatment cells should be excavated first.

Step 5. **The final bottom elevation of any bioretention facility shall not be traversed by construction equipment.** Equipment should work from the sides to excavate the bioretention facility to its appropriate design depth and dimensions. Excavating equipment should have adequate reach so they do not have to sit inside the footprint of the bioretention facility. A cell construction approach may be used in larger bioretention basins, whereby the basin is split into 500 to 1,000 sq. ft. temporary cells with a 10-15 foot earth bridge in between, so that cells can be excavated from the side.

Step 6. It may be necessary to rip or till the bottom soils to a depth of 6 to 12 inches to promote greater infiltration if a bucket without teeth is used for excavation.

Step 7. If a stone storage layer will be used for an underdrain design, place the appropriate depth of nominal 1/4" gravel with a maximum of 2.0 percent passing the #200 sieve on the bottom, install the perforated underdrain pipe, pack gravel layer to 3 inches above the underdrain pipe. A layer of gravel may also be necessary for an infiltrating design if the 24" biosoil media does not reach a permeable layer in the soil profile.

Step 8. **Biosoil media must be obtained from a Department approved vendor.** If not used upon delivery, store it on an adjacent impervious area or plastic sheeting. Apply the media in 12-inch lifts until the desired top elevation of the bioretention facility is achieved. Wait a few days to check for settlement, and add additional media, as needed, to achieve the design elevation. Wetting the biosoil media between lifts may reduce the amount of settling that occurs.

Step 9. Prepare planting holes for any shrubs and plants, install the vegetation, and water accordingly. Install any temporary irrigation.

Step 10. Place the surface cover in both cells (mulch, river rock, etc.), in accordance with the design. If stabilization matting will be used in areas that will be planted, the matting will need to be installed prior to planting (Step 9), and holes or slits will have to be cut in the matting to install the plants.

Step 11. If curb cuts or inlets are blocked during bioretention installation, unblock these after the drainage area and side slopes have 70% vegetative cover. It is recommended that unblocking curb cuts and inlets take place after two to three storm events if the drainage area includes newly installed asphalt, since new asphalt tends to produce a lot of fines and grit during the first several storms.

Step 12. Conduct the final construction inspection (see below), then log the GPS coordinates for each bioretention facility and submit them for entry into the local maintenance tracking database.

Construction Review. An example construction phase review checklist is available.

Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls, sensitive area protection surrounding bioretention locations, and blockage of inlets to bioretention locations**
- **Excavation and grading including interim and final elevations. For infiltrating bioretention systems, confirmatory infiltration testing and a verification must be completed prior to gravel and biosoil media placement.**
- **Construction of the underdrain, including inspection ports and installation of the overflow structure, as applicable**
- **Installation of gravel and biosoil media**
- **Implementation of required stabilization and planting plan**
- **Final construction review including development of a punch list for facility acceptance**

Post Construction Verification Documentation. **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the bioretention practice has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for bioretention practices are as follows:**

- **The constructed top of bank elevation may be no lower than the design elevation for top of bank.**

- **The constructed area of the bioretention surface shall be no less than 90% of the design surface area.**
- **The constructed volume of the bioretention storage shall be no less than 90% of the design volume.**
- **The constructed elevation of any structure shall be within 0.15 foot of the design.**

In the event that an allowable tolerance is exceeded the system shall be reconstructed or modified to the approved design unless supplemental calculations demonstrate compliance.

2.9 Bioretention Maintenance Criteria

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Operation and Maintenance Plans should clearly outline how vegetation in the bioretention Practice will be managed or harvested in the future. The Operation and Maintenance Plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of bioretention practices is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 2.6. Typical Bioretention Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the bioretention perimeter area • Fertilizer application should be kept to a minimum during establishment. **Supplemental fertilizer applications shall consist of a 0% phosphorus formulation only as needed to maintain plant vigor.** • Water trees and shrubs planted in the bioretention planting bed during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris and blockages • Repair undercut, eroded, and bare soil areas
Twice a year	• Mowing of the bioretention vegetated perimeter area and banks (as directed in approved O&M plan)
Annually	• Cleanup to remove trash, debris and floatables • A full maintenance review • Check condition of outlet structure • Repair broken mechanical components, if needed
One time –during the second year following construction	• Bioretention planting bed replacement/reinforcement plantings
Every 5 to 7 years	• Forebay sediment removal (as applicable) • Flush underdrain system (as applicable)
From 5 to 25 years	• Repair pipes, outlet structure and spillway, as needed • Remove any accumulated sediment within facility, as needed

2.10 References

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3.0 Permeable Pavement Systems

Definition: **Paving surfaces that capture and temporarily store stormwater by filtering runoff through voids in the pavement surface into an underlying reservoir.** Filtered runoff is either collected and returned to the conveyance system, or allowed to infiltrate into the soil.

Design variants include:

- ■ 3-A **Porous Asphalt (PA)**
- ■ 3-B **Pervious Concrete (PC)**
- ■ 3-C **Permeable interlocking concrete Pavers (PP) or Concrete grid Pavers (CP)**
- ■ 3-D **Plastic Grid Pavers (GP)**

For each of the design variants above, there are two basic configurations:

- Parking lots and roadways primarily intended for vehicular traffic.
- Minor linear paved areas such as sidewalks and trails with a maximum width of ten (10) feet primarily intended for non-vehicular traffic.

Other variations of permeable pavement surface materials that meet the design requirements of these variants are also encompassed in this section.

Permeable pavement systems may be designed to provide stormwater detention for all design storm events. Permeable pavement practices that are unable to infiltrate all design storms are often combined with separate facilities to provide controls for larger runoff events.

Regardless of which design variant is chosen, the runoff reduction credit applied to the practice is the volume of runoff that is being stored in the reservoir layer. It is recommended that an overdrain and control structure be constructed within the reservoir layer to prevent larger storm events from surcharging through the permeable pavement surface.

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the native soils.

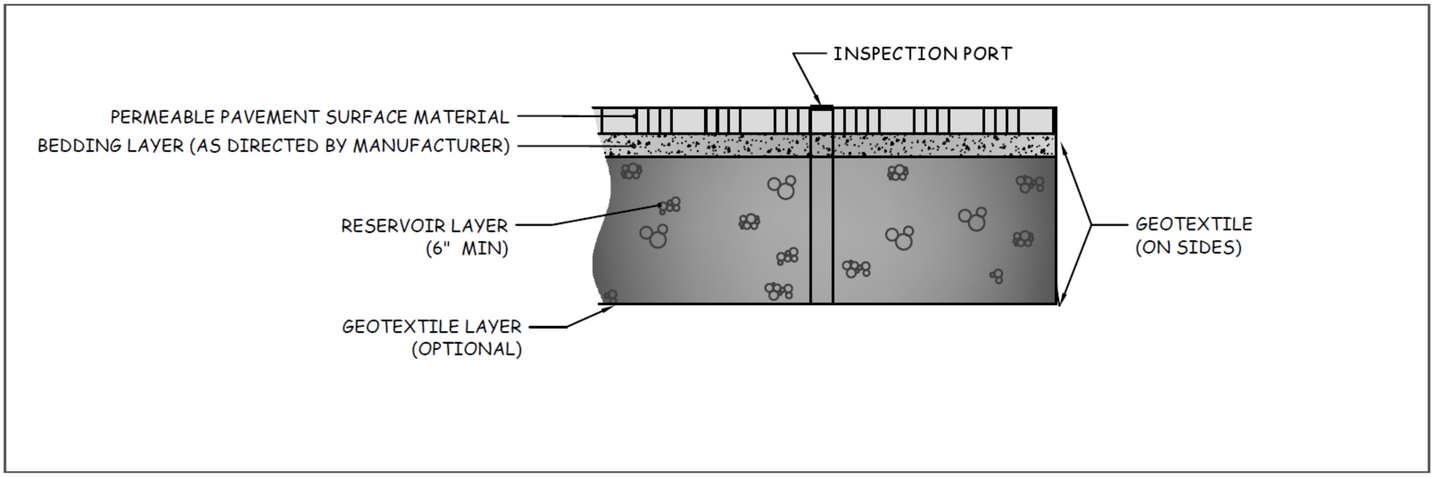

Figure 3.1 Permeable Pavement – Infiltrating

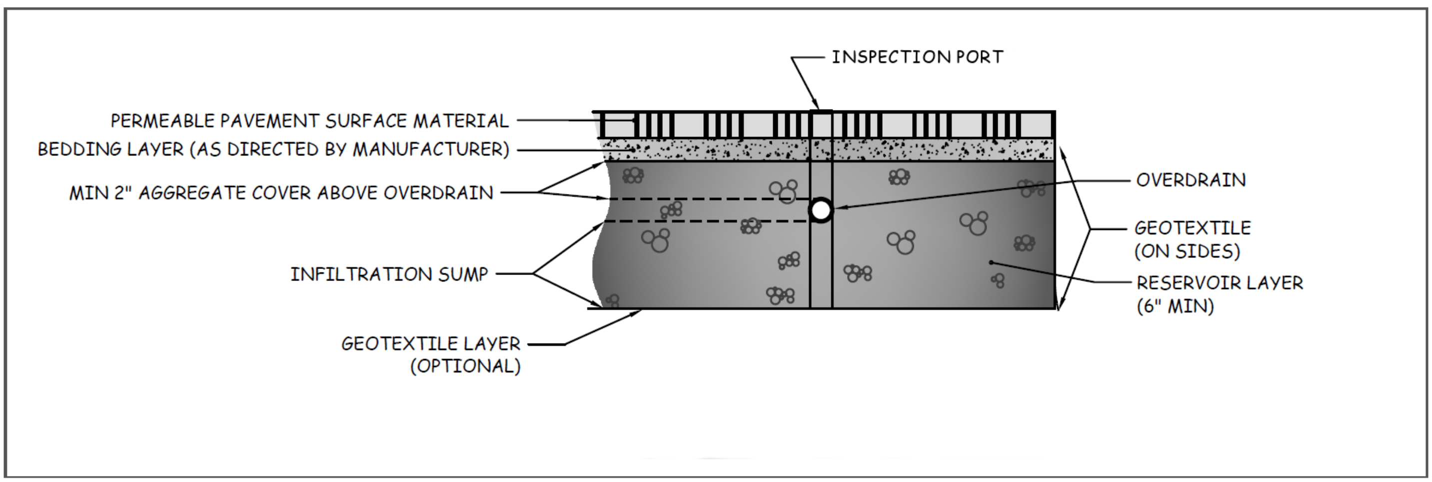

Figure 3.2 Permeable Pavement with Infiltration Sump and Overdrain

3.1 Permeable Pavement Stormwater Credit Calculations

Permeable Pavement Systems receive 100% retention volume credit (R_v) for the volume stored and infiltrated by the practice (Table 3.1).

3.1 Permeable Pavement Performance Credits

Runoff Reduction	
Retention Allowance	100%
RPv -A/B Soil	**100% of Retention Storage**
RPv - C/D Soil	**100% of Retention Storage**
Cv	**100% of Retention Storage**
Fv	**100% of Retention Storage**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

The practice must be sized using the guidance detailed in *Section 3.6. Permeable Pavement Design Criteria.*

3.2 Permeable Pavement Practice Summary

Table 3.2 summarizes design criteria for Permeable Pavement Systems, and Tables 3.3 and 3.4 summarize the materials specifications for this practice. For more detail, consult Sections 3.3 through 3.7. Sections 3.8 and 3.9 describes practice construction and maintenance criteria.

Table 3.2 Permeable Pavement Practice Summary

Feasibility (Section 3.3)	• **For parking lots and roadways configurations** o **The contributing drainage area to permeable pavement shall not exceed five times the surface area of the permeable pavement** o **Pervious areas shall be diverted from the permeable pavement area such that the total contributing drainage area is at least 90% impervious** • **Parking lot and roadway configurations utilizing permeable pavement shall meet the following requirements:** o **Infiltration testing in accordance with the Soil Investigation Procedures shall be required** o **Overdrains are required if the permeability of the underlying soils does not have a minimum infiltration rate of 1 inch per hour** • **The surface slope shall be no greater than 5 percent** • **The bottom slope of a permeable pavement installation shall be no greater than 1 percent** • **If an overdrain is not provided, a separation distance of 2 feet is required between the bottom of the reservoir layer and the seasonal high water table as determined in accordance with the Soil Investigation Procedures** • **Permeable pavements shall not be used to treat hotspot runoff**
Conveyance (Section 3.4)	• **Permeable pavement designs shall include methods to safely convey the Cv and Fv**
Pretreatment (Section 3.5)	• Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below • If the permeable pavement receives run-on from adjacent high pollutant loading situations, a gravel or grass buffer strip can be placed to trap these pollutants before they reach the pavement surface, in order to minimize clogging
Design Critera (Section 3.6)	• **Permeable pavement shall be designed according to DelDOT specifications or the product manufacturer's recommendations as applicable** • **For design purposes, the field verified infiltration rate shall have a factor of safety applied in accordance with the Soil Investigation Procedures to account for potential compaction during construction and to approximate long term infiltration rates** • **Permeable pavement practices shall be designed so that the RPv infiltrates within 48 hours** • **Permeable pavement practices shall be designed so that they will 1) infiltrate the Fv within 72 hours or 2) dewater the Fv within 72 hours, or 3) manage the Fv on site with no adverse impact** • **The suitability of the soil subgrade shall be determined by a qualified geotechnical engineer** • **The reservoir layer shall be composed of clean, washed gravel with a maximum of 2.0 percent passing the #200 sieve and sized for both the maximum storm event to be managed and the structural requirements of the expected traffic loading** • **The depth of the reservoir layer shall be a minimum of 6 inches**

Design Critera (Section 3.6) *cont.*	• **If an overdrain is not provided, a separation distance of 2 feet is required between the bottom of the reservoir layer and the seasonal high water table as determined in accordance with the Soil Investigation Procedures.** • **Overdrains shall be a minimum of 4 inches in diameter** • **All parking lot and roadway configurations shall include inspection ports** • **The permeable pavement shall be designed to support the maximum anticipated traffic load** • **The reservoir layer shall be sized to temporarily store and then infiltrate the RPv**
Landscaping Criteria (Section 3.7)	Not applicable

Construction Criteria
(Section 3.8)
	• **All permeable pavement areas shall be fully protected from sediment intrusion by silt fence or construction fencing to prevent construction traffic tracking**
	• **During site construction, steps shall be taken to prevent compaction of the underlying soil and sedimentation of the permeable pavement practice**
	• **The infiltration rate and separation from groundwater of the constructed permeable pavement practice shall be verified prior to completion of construction in accordance with the Soil Investigation Procedures. The results shall be included with the Post Construction Verification Documentation upon project completion.**
	• **During construction, care shall be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging**
	• **When locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 1 foot above the final design elevation of the bottom of the reservoir course**
	• **Permeable pavement shall be installed according to DelDOT specifications or the product manufacturer's recommendations as applicable**
	• **Construction of the permeable pavement shall only begin after the entire contributing drainage area has been stabilized**
	• **The proposed permeable pavement area shall be kept free from sediment during the entire construction process**
	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**
	  o **Pre-construction meeting**
	  o **Initial site preparation including installation of erosion and sediment controls, sensitive area protection surrounding permeable pavement locations.**
	  o **Excavation and grading including interim and final elevations. Observation of infiltrating surface and permeable pavement practice verification must be completed prior to gravel placement.**
	  o **Construction of the overdrain, including inspection ports and installation of the overflow structure, as applicable**
	  o **Installation of gravel**
	  o **Implementation of required stabilization**
	  o **Final construction review including development of a punch list for facility acceptance**
	• **Upon project completion, the owner shall submit Post Construction verification documents to demonstrate that the permeable pavement has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for permeable pavement are as follows:**
	  o **The constructed permeable pavement surface area shall be no less than the design permeable pavement surface area**

Construction Criteria (Section 3.8) *cont.*	o **The contributing drainage area as constructed shall be no greater than the design contributing drainage area** o **The constructed storage volume of the reservoir layer shall be no less than 90% of the design volume** o **The constructed elevation of the overdrain or any structure shall be within 0.15 foot of the design** • **When the allowable tolerances are exceeded for permeable pavement surface area or volume or structure elevations, supplemental calculations and provisions of adequate maintenance must be submitted to the approval agency to determine if the permeable pavement, as constructed, meets the design requirements.**
Maintenance Criteria (Section 3.9)	• **Activities that have the potential to clog the permeable pavement surface, including but not limited to sanding, re-sealing, re-surfacing, storage of snow piles containing sand, storage of mulch or soil material, or construction staging, shall be prohibited** • **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

Material Properties: Permeable pavement material properties vary according to the specific pavement product selected. A general comparison of different permeable pavements is provided in Table 3.3, but designers should consult manufacturer's technical specifications for specific criteria and guidance.

Table 3.3. Permeable Pavement Materials

Material	Typical Material Properties	Notes
Porous Asphalt (PA)	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer provides additional support for the structural load.
Pervious Concrete (PC)	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer provides additional support for the structural load.
Permeable Interlocking Concrete Pavers (PP)	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Should conform to ASTM C936 specifications. Reservoir layer provides additional support for the structural load.
Concrete Grid Pavers (CP)	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa. Open void fill media: aggregate, topsoil and grass, coarse sand.	Should conform to ASTM C 1319 specifications. Reservoir layer provides additional support for the structural load.
Plastic Reinforced Grid Pavers (GP)	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 provides additional support for the structural load.

Table 3.4 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 on the type of surface material.

Table 3.4. Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57 stone PC: None PA: 2 in. depth of No. 8 stone	ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Should be double-washed and free of all fines.
Reservoir Layer	PP: No. 57 stone PC: No. 57 stone PA: No. 2 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. The reservoir layer shall be at least 6" deep.
Overdrain	Use 4 to 6 inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. 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 overdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Infiltration Sump	An aggregate storage layer below the overdrain invert. The depth of the reservoir layer above the invert of the overdrain must be at least 12 inches. The material specifications are the same as Reservoir Layer.	
Filter Layer (optional)	The underlying native soils may require separation from the stone reservoir by a thin layer of choker stone as determined by geotechnical investigation.	The choker stone layer should be a minimum of 1" thick, and a minimum of 1" per foot of reservoir depth.
Non-woven Geotextile (optional)	Use a needled, non-woven, polypropylene geotextile 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).	
Inspection Port	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface or just beneath PP.	

3.3 Permeable Pavement Feasibility Criteria

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.

Required 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.

Drainage Area. For parking lots and roadways configurations,

1. **The contributing drainage area to permeable pavement shall not exceed five times the surface area of the permeable pavement.**
2. **Pervious areas shall be diverted from the permeable pavement area such that the total contributing drainage area is at least 90% impervious.**

Pervious areas draining to minor permeable pavements such as sidewalk and trails configurations should be minimized to the extent practicable.

Soils and Overdrains. Soil conditions do not typically constrain the use of Permeable Pavement, although they do determine whether an overdrain is needed. The reservoir layer can be extended to a more permeable layer, as needed. **Parking lot and roadway configurations utilizing permeable pavement shall meet the following requirements:**

- **Infiltration testing in accordance with the Soil Investigation Procedures shall be required.**
- **Overdrains are required if the permeability of the underlying soils does not have a minimum infiltration rate of 1 inch per hour.**

Infiltration testing and overdrains are not required for minor linear permeable pavements such as sidewalk and trail configurations.

Pavement Surface Slope. Steep pavement surface slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. **The surface slope shall be no greater than 5 percent.**

Pavement Bottom Slope. **The bottom slope of a permeable pavement installation shall be no greater than 1 percent.** It is preferred that the bottom slope be as flat as possible (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or terraces can be incorporated into the subsurface to encourage infiltration.

Minimum Depth to Water Table. Permeable Pavement should be separated from the water table to ensure that groundwater does not intersect the reservoir layer. This could otherwise lead to possible groundwater contamination or failure of the Permeable Pavement facility. **If an overdrain is not provided, a separation distance of 2 feet is required between the bottom of the reservoir layer and the seasonal high water table as determined in accordance with the Soil Investigation Procedures.**

Setbacks. To avoid the risk of seepage, Permeable Pavement facilities should not be hydraulically connected to structure foundations. The designer should check to ensure footings and foundations of adjacent buildings do not encroach within an assumed 4:1 phreatic zone drawn from the top of the reservoir layer, or invert of the overdrain if used. See Appendix 8 Stormwater Facility Setbacks for recommended setbacks.

Hotspot Land Uses. **Permeable pavements shall not be used to treat hotspot runoff.** 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, etc. Additional information on hotspots is contained in Appendix 4. Stormwater Hotspots.

High Pollutant Loading Situations. Permeable pavement is not intended to treat sites with sediment or trash/debris loads, since such loads will cause the practice to clog and fail. Sites with significant pervious area (newly established turf and landscaping) are considered high loading sites and the pervious areas should be diverted from the permeable pavement area. If unavoidable, an increased maintenance schedule to check for clogging may be required on a case-by-case basis. The landscaping in the contributing drainage area should be carefully planned to minimize the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the surface area.

3.4 Permeable Pavement Conveyance Criteria

Permeable pavement designs shall include methods to safely convey the Cv and Fv. The following methods may be used to convey the Cv and Fv:

- Place an overdrain; a perforated pipe horizontally near the top of the reservoir layer, to pass excess flows after stormwater has filled the reservoir layer.
- Increase the thickness of the reservoir layer to increase storage (i.e., create freeboard) to accommodate the Cv and Fv events.
- Create additional underground detention within the reservoir layer of the permeable pavement system using structural void space. Reservoir storage may be augmented by plastic or concrete arch structures, etc.
- Route excess flows to another detention or conveyance system that is designed for the management of greater 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. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

3.5 Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below. If the permeable pavement receives run-on from adjacent high pollutant loading situations, a gravel or grass buffer strip can be placed to trap these pollutants before they reach the pavement surface, in order to minimize clogging.

3.6 Permeable Pavement Design Criteria

Type of Surface Pavement: The type of pavement should be selected based on a review of the pavement specifications and properties. **Permeable pavement shall be designed according to DelDOT specifications or the product manufacturer's recommendations as applicable.**

Internal Geometry and Drawdown:

Infiltration Rates. **For design purposes, the field verified infiltration rate shall have a factor of safety applied in accordance with the Soil Investigation Procedures to account for potential compaction during construction and to approximate long term infiltration rates.**

- Permeable pavement practices 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. **Permeable pavement practices shall be designed so that the RPv infiltrates within 48 hours. Permeable pavement practices shall be designed so that they will 1) infiltrate the Fv within 72 hours or 2) dewater the Fv within 72 hours, or 3) manage the Fv on site with no adverse impact.** The designer can model various approaches by factoring in storage chambers within the stone aggregate layer and expected infiltration 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.

Reservoir layer: The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer or underlying soils. The total thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of native soils, structural requirements of the pavement sub-base, depth to the seasonal high water table and bedrock, and frost depth conditions. **The suitability of the soil subgrade shall be determined by a qualified geotechnical engineer.**

- **The reservoir layer shall be composed of clean, washed gravel with a maximum of 2.0 percent passing the #200 sieve and sized for both the maximum storm event to be managed and the structural requirements of the expected traffic loading.**
- The bottom of the reservoir layer should be as flat as possible so that runoff will be able to infiltrate evenly through the entire surface. For sites with native slope that do not allow for a flat bottom, the bottom can either be terraced or check dams can be installed.
- **The depth of the reservoir layer shall be a minimum of 6 inches.**
- **If an overdrain is not provided, a separation distance of 2 feet is required between the bottom of the reservoir layer and the seasonal high water table as determined in accordance with the Soil Investigation Procedures.**

Overdrains: Most permeable pavement designs will require an overdrain (see Section 3.3). Overdrains can be used to keep detained stormwater from surcharging permeable pavement during extreme events. Flat terrain may affect proper drainage of permeable pavement designs, so overdrains should have a minimum 0.5% slope. **Overdrains shall be a minimum of 4 inches in diameter.**

All parking lot and roadway configurations shall include inspection ports. The inspection port is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. It is recommended that the inspection port consist of an anchored 6-inch diameter perforated PVC pipe fitted with a cap installed flush with the ground surface. Inspection ports located in vehicular traffic areas should be traffic-bearing. The port should extend vertically to the bottom of the reservoir layer and extend upwards to be flush with the surface (or just under pavers) with a lockable cap.

Filter Layer: To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer can be used. The native soils should be separated from the stone reservoir by a thin, (minimum 1", or 1"/foot of reservoir) layer of choker stone (No. 8 or approved equal).

Non-woven Geotextile: Filter fabric is not recommended for the bottom of the reservoir layer as filter fabric can become a future plane of clogging within the system. Permeable non-woven filter fabric is recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. A needled, non-woven, polypropylene geotextile 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) is recommended. The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" soil subgrade, using FHWA or AASHTO selection criteria.

Permeable Pavement Sizing: The thickness of the reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. Permeable pavement structural and hydraulic sizing criteria are discussed below:

Structural Design. **The permeable pavement shall be designed 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. 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;
- Native soil strength;
- Environmental elements; and
- Bedding and Reservoir layer design.

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

- 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 stormwater runoff in the reservoir layer. **The reservoir layer shall be sized to temporarily store and then infiltrate the RPv.** The storage volume in the permeable pavement system must account for the underlying infiltration and flow through any overdrain or overflow structure. The design storm may be routed through the permeable pavement system to accurately determine the required reservoir depth.

For design with overdrains, calculate the drawdown times using the hydrological routing or modeling procedures used for detention systems with the depth and head adjusted for the porosity of the aggregate.

Detention Storage Design: Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with Cv and/or Fv requirements. Various approaches can be modeled 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.

3.7 Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs associated with it. However, large-scale permeable pavement applications should be carefully planned to integrate the typical landscaping features of a parking lot (such as trees and islands) 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.

3.8 Permeable Pavement Construction

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

Erosion and Sediment Controls. The following erosion and sediment control guidelines are recommended to be followed during construction:

- **All permeable pavement areas shall be fully protected from sediment intrusion by silt fence or construction fencing to prevent construction traffic tracking.**
- **During site construction, steps shall be taken to prevent compaction of the underlying soil and sedimentation of the permeable pavement practice.** The following steps are recommended:
    - o Avoid compaction by preventing construction equipment and vehicles from traveling over the proposed location of the permeable pavement practice using “Sensitive Area Protection” guidelines during construction

  - Permeable pavement should remain “off-line” until construction is complete to prevent construction sediment from clogging the stone reservoir layer. Prevent sediment from entering the permeable pavement site by using super silt fence, diversion berms or other means. In the erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to a permeable pavement practice. It is recommended that the erosion and sediment control plan also indicate the specific methods to be used to temporarily keep runoff from the permeable pavement practice.
  - Upland drainage areas are recommended to be completely stabilized with a thick layer of vegetation prior to commencing excavation for a permeable pavement practice.
- **The infiltration rate and separation from groundwater of the constructed permeable pavement practice shall be verified prior to completion of construction in accordance with the Soil Investigation Procedures. The results shall be included with the Post Construction Verification Documentation upon project completion.**
- **During construction, care shall be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.**
- Permeable pavement areas are not recommended to serve as temporary sediment control devices (e.g., sediment traps, etc.) during construction. **When locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 1 foot above the final design elevation of the bottom of the reservoir course.** All sediment deposits in the excavated area shall be carefully removed prior to installing the subbase.

Permeable Pavement Installation**. Permeable pavement shall be installed according to DelDOT specifications or the product manufacturer’s recommendations as applicable.** The following is a typical construction sequence, which may be modified per manufacturer’s recommendations:

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. Temporary erosion and sediment controls should be implemented during installation to divert stormwater away from the permeable pavement area until it is completed. Additional protective 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 shall be kept free from sediment during the entire construction process.**

Step 3. Heavy equipment should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions to minimize compaction of the subsoil. For small 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. For larger pavement applications, 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 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 of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches. Install geotextile as applicable. Filter strip sections should have a minimum 2 feet of overlap.

Step 5. Spread 6-inch lifts of clean, washed stone with a maximum of 2.0 percent passing the #200 sieve. Table 3.4 contains recommended stone sizes for the reservoir layer based on the type of permeable surface. Provide a minimum of 2 inches of aggregate above and below the overdrain, as applicable. The overdrain should slope towards the outlet at a grade of 0.5% or steeper. The up-gradient ends of the overdrain should be capped. Where an overdrain pipe is connected to a structure, there should be no perforations within 1 foot of the structure. There should be no perforations in the clean-outs and inspection ports within 1 foot of the surface.

Step 6. Compact until there is no visible movement of the aggregate, but do not crush the aggregate with the compaction equipment.

Step 7. Install and compact the bedding layer, in accordance with the approved plan. Table 3.4 contains recommended stone sizes for the bedding

Step 8. Paving materials shall be installed in accordance with manufacturer, industry, or engineer's specifications for the particular type of pavement. Examples as shown below:

- Installation of Porous Asphalt**.** The following has been excerpted from various documents, most notably Jackson (2007).
  - Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the bedding course. The laying temperature should be between 230^{o}F and 260^{o}F, with a minimum air temperature of 50^{o}F.
  - 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.
  - 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.
  - 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.
  - Test the permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface.
  - Inspect the facility 18 to 30 hours after a rainfall greater than 1/2 inch, to determine if 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:

- Drive the concrete truck as close to the project site as possible.
- Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid pervious concrete.
- After the concrete is placed, approximately 3/8 to 1/2 inch is struck off, using a vibratory screed to allow for compaction.
- Compact the pavement with a steel pipe roller per manufacturer's recommendation.
- Cut joints for the concrete to a depth of 1/4 inch.
- 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.
- Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a rainfall greater than 1/2 inch, to determine if the facility is draining properly.
- Testing???

- Installation of Permeable Interlocking Concrete Pavers. The basic installation process is described in greater detail by Smith (2006).
  - 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 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.
  - 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.
  - Place and screed the bedding course material (typically No. 8 stone).
  - Fill gaps at the edge of the paved areas with cut pavers or edge units. Cut pavers no smaller than one-third (1/3) of the full unit size.
  - Fill the joints and openings with stone. Joint openings must be filled with ASTM D 448 No. 8 stone, although No. 8P or No. 9 stone may be used where needed to fill narrower joints.
  - Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
  - Do not compact within 6 feet of the unrestrained edges of the pavers.
  - The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.

- Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
- Inspect the facility 18 to 30 hours after a rainfall greater than 1/2 inch, to determine if the facility is draining properly.

Construction Inspection.

Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls, sensitive area protection surrounding permeable pavement locations.**
- **Excavation and grading including interim and final elevations. Observation of infiltrating surface and permeable pavement practice verification must be completed prior to gravel placement.**
- **Construction of the overdrain, including inspection ports and installation of the overflow structure, as applicable.**
- **Installation of gravel.**
- **Implementation of required stabilization.**
- **Final construction review including development of a punch list for facility acceptance.**

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 it is double washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the overdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the permeable pavement surface is even and the storage bed drains within 48 hours.
- Ensure caps are placed on the upstream end of the overdrain.
- Inspect any pretreatment structures 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 is recommended 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 often produced shortly after conventional asphalt is laid down.

Permeable Pavement Verification. **The infiltration rate and separation from groundwater of the constructed permeable pavement shall be verified prior to completion of construction in accordance with the Soil Investigation Procedures. The results shall be included with the Post Construction Verification Documentation upon project completion.**

Post Construction Verification Documentation. **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the permeable pavement has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.**

Allowable tolerances for permeable pavement are as follows:

- **The constructed permeable pavement surface area shall be no less than the design permeable pavement surface area.**
- **The contributing drainage area as constructed shall be no greater than the design contributing drainage area.**
- **The constructed storage volume of the reservoir layer shall be no less than 90% of the design volume.**
- **The constructed elevation of the overdrain or any structure shall be within 0.15 foot of the design.**

In the event that the allowable tolerances are exceeded for permeable pavement surface area or volume or structure elevations, supplemental calculations and provisions of adequate maintenance must be submitted to the approval agency to determine if the permeable pavement, as constructed, meets the design requirements.

3.9 Permeable Pavement Maintenance Criteria

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. Periodic street sweeping will remove accumulated sediment and help prevent clogging, however, it is also critical to ensure that surrounding land areas remain stabilized.

Activities that have the potential to clog the permeable pavement surface, including but not limited to sanding, re-sealing, re-surfacing, storage of snow piles containing sand, storage of mulch or soil material, or construction staging, shall be prohibited.

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper

maintenance is not performed.

Maintenance of Permeable Pavement practices is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Recommended maintenance tasks are outlined in Table 3.6.

Table 3.6. Recommended maintenance tasks for permeable pavement practices.

Maintenance Tasks	Frequency[1]
▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice and after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.	After installation
▪ Mow grass in grid paver applications	As needed during the growing season
▪ Stabilize the contributing drainage area to prevent erosion ▪ Remove any soil or sediment deposited on pavement. ▪ Replace or repair any necessary pavement surface areas that are degenerating or spalling	As needed
▪ Vacuum pavement with a standard street sweeper to prevent clogging	2-4 times per year (depending on use)
▪ Conduct a maintenance inspection ▪ Spot weeding of grass applications	Annually
▪ Remove any accumulated sediment in pretreatment cells and inflow points	Once every 2 to 3 years
▪ Conduct maintenance using a regenerative street sweeper ▪ Replace any necessary joint material	If clogged
▪ Locate snow storage piles in adjacent grassy areas so that sediments and pollutants in snowmelt are deposited before they reach the permeable pavement	As needed
▪ Do not apply sand or cinders over permeable pavement drainage area	As needed
[1] Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use.	

Winter Maintenance Considerations: Winter maintenance on permeable pavements is similar to standard pavements, with a few additional considerations:

- Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are deposited before they reach the permeable pavement.
- Sand or cinders should not be applied for winter traction over permeable pavement or areas of impervious pavement that drain toward permeable pavement.
- 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 permeable interlocking concrete pavers (PICP) can be plowed similar to traditional pavements, using similar equipment and settings.
- Permeable pavement applications will generally require less salt application than traditional pavements. 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. Salt can be applied but environmentally sensitive deicers are recommended.

When permeable pavements are installed on private residential lots, homeowners should be (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a maintenance agreement as described above.

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications. Example maintenance inspection checklists for permeable pavements can be found in *Article 5.*

3.10 References

Hunt, W. and K. Collins. 2008. “Permeable Pavement: Research Update and Design Implications.” *North Carolina Cooperative Extension Service Bulletin.* Urban Waterways Series.

Jackson, N. 2007. *Design, Construction and Maintenance Guide for Porous Asphalt Pavements*. National Asphalt Pavement Association. Information Series 131. Lanham, MD.

Smith, D. 2006. *Permeable Interlocking Concrete Pavement-selection design, construction and maintenance. Third Edition*. Interlocking Concrete Pavement Institute. Herndon, VA.

American Concrete Institute (2008).

4.0 Vegetated Roofs

Definition: **Practices on top of buildings that capture and store rainfall in an engineered growing media, which is designed to support plant growth. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.** Vegetated Roofs, also known as green roofs, typically are layered assemblies installed over a waterproof membrane. The assemblies are designed to support plant growth, slow the release of runoff, and detain rainfall for plant uptake and eventual elimination by evapotranspiration (ET). The Vegetated Roofs are designed so that water drains vertically through the growth media layer and then horizontally through a specialized drainage layer towards the outlet. Two types of Vegetated Roofs exist: Extensive and Intensive. They vary based on the depth of soil and type of plants.

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Design variants include:

- 4-A **Extensive Vegetated Roofs which contain shallow growth media with drought resistant plants, such as Sedum**
- 4-B **Intensive Vegetated Roofs which contain deep growth media with a wide range of plant varieties and typically include irrigation**

Vegetated Roofs provide runoff reduction and water quality treatment for small storms, including the Resource Protection event (RPv). Typically they are not designed to provide stormwater detention of the larger Cv and Fv storms although some Intensive Vegetated Roof systems may be designed to meet or partially meet these criteria. Vegetated roofs can be integrated with rainwater harvesting systems, for reducing runoff volume from larger events and minimizing irrigation requirements. However, Vegetated Roof designs are frequently combined with separate facilities located away from the building to provide control of larger storms.

This specification is intended for situations where the primary design objective of the Vegetated Roof is stormwater management. Vegetated Roof benefits go beyond just stormwater management, but the ancillary benefits are not covered within this specification.

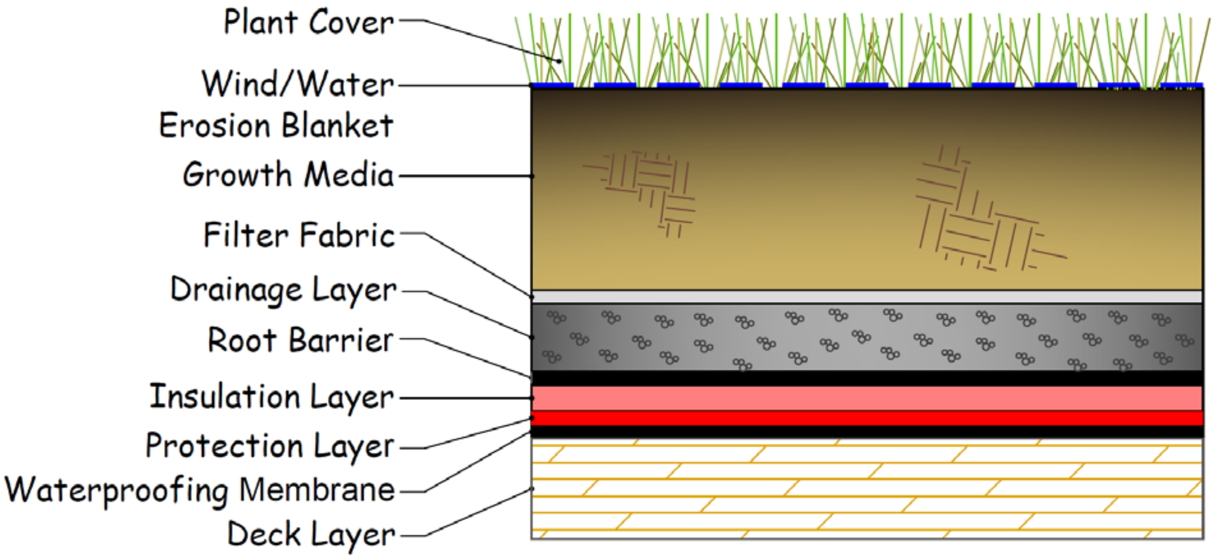

Figure 4.1. Example Layers for a Vegetated Roof.

4.1 Vegetated Roof Stormwater Credit Calculations

Vegetated Roofs receive annual runoff reduction credit (RR) for the contributing roof area, along with associated pollutant removals as follows:

4.1(a) Extensive Vegetated Roof Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil[1]	**50% Annual Runoff Reduction**
RPv - C/D Soil[1]	N/A
Cv	**5% of RPv Allowance**
Fv	**1% of RPv Allowance**
Pollutant Reduction	
TN Reduction	**Not less than 0%**
TP Reduction	**Not less than 0%[2]**
TSS Reduction	N/A
Retention Allowance	0%

4.1(b) Intensive Vegetated Roof Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil[1]	**75% Annual Runoff Reduction**
RPv - C/D Soil[1]	N/A
Cv	**8% of RPv Allowance**
Fv	**2% of RPv Allowance**
Pollutant Reduction	
TN Reduction	**Not less than 0%**
TP Reduction	**Not less than 0% [2]**
TSS Reduction	N/A
Retention Allowance	0%

[1] The growing media used for Vegetated Roofs is classified as an A/B soil for calculation purposes. Therefore, the Vegetated Roof performance is not dependent on the existing soil conditions and the credit for C/D soils is not applicable (N/A).

[2] **If the phosphorous (P) content of mature growth media is 2 mg/l (Saturated Paste Extraction), or less, then the Vegetated Roof will be assumed to be neutral with respect to P loadings. If the P content of mature growth media exceeds 2 mg/l, a supplemental phosphorus-reducing BMP, such as an activated alumina or hematite filter, will be required.**

4.2 Vegetated Roof Practice Summary

Table 4.2 summarizes various criteria for Vegetated Roofs, and Table 4.3 summarizes the materials specifications for this practice. For more detail, consult Sections 4.3 through 4.7. Sections 4.8 and 4.9 describe practice construction and maintenance criteria.

Table 4.2 Vegetated Roof Practice Summary

Feasibility Criteria (Section 4.3)	• **Structural capability of the roof must be assessed by a qualified licensed professional and included with building permit documentation.** • **Safe access to the Vegetated Roof shall be available to allow for delivery of construction materials and performance of routine maintenance reviews and maintenance operations.** • **A permanent source of water (e.g., hydrant, hose-bib) shall be provided to all Vegetated Roof areas.** • **A minimum 1-foot wide vegetation-free zone is required along the perimeter of all Vegetated Roofs and around all roof penetrations.** • **The Vegetated Roof design must comply with all federal, state and local building codes** • Roof Deck Slope, Extensive: Minimum 1% (1/8" per foot); Preferred 2% slope (1/4" per foot); Maximum 16% (2" per foot). • Roof Deck Slope, Intensive: Minimum 0%; Preferred 1% slope (1/8" per foot); Maximum 10% slope (1.2" per foot) • Recommended slope of growth media is 2.5:1 or less; slope stabilization needed for slopes steeper than 2.5:1
Conveyance Criteria (Section 4.4)	• **The Vegetated Roof drainage layer shall convey flow from under the growth media layer to an outlet or overflow system.** • **All drains and scuppers shall be accessible through enclosures that include lids that are level with the surface of the growth media layer.** • **Emergency drains or emergency scuppers shall have inverts that are high enough above the waterproofing surface to prevent discharge during the RPv event.**
Pretreatment Criteria (Section 4.5)	• Not needed
Design Criteria (Section 4.6)	• **All Vegetated Roof systems must include an effective and reliable waterproof membrane to prevent water damage to the building structure.** • **Root barriers are required in combination with some waterproof membranes.** • **A drainage layer shall underlie the growth media to control the release of water that percolates into the Vegetated Roof assembly.** • **Roof drains and any emergency overflow shall be designed in accordance with state and local building codes** • **The growth media shall be the uppermost layer in a Vegetated Roof assembly.** • **Designer shall certify that growth media meets or exceeds all required specifications prior to placement.** • **The upper 1 inch of a growth media profile shall consist of an engineered mineral soil.** • **For a Vegetated Roof to be regarded as neutral with respect to phosphorous (P) loading in runoff, the P content of the growth media must be controlled.** • **If trees are included in the Vegetated Roof landscape plan, the growth media must be at least 30 inches deep.** • **Initial planting plan shall be designed such that mature plant coverage within 24 months of initial planting shall be:** o **Minimum 75% warm season plant coverage for Extensive Vegetated Roofs** o **Minimum 90% plant coverage for turf intensive Vegetated Roofs**

Design Criteria (Section 4.6) *cont.*	o **Uniform cover with vigorous plants conforming to the design plant density for non-turf Intensive Vegetated Roofs.** • **The size of the Vegetated Roof, both Extensive and Intensive, shall be a minimum 66% of the total contributing drainage area. No runoff reduction credit shall be given for runoff from bare areas of the roof that do not come in contact with root zone.**
Landscaping Criteria (Section 4.7)	• **The planting plan for Vegetated Roofs must be certified by a qualified professional.** • **Irrigation is required for Vegetated Roofs for the first year after planting.** • **The minimum plant coverage shall be achieved 24 months after initial planting and maintained throughout the life of the Vegetated Roof.**
Construction Crteria (Section 4.8)	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:** o **Pre-construction meeting** o **During placement of the waterproof membrane, to ensure that it is properly installed and watertight;** o **During placement of the drainage layer and drainage system, to prevent future ponding water;** o **During placement of the growing media, to confirm that it meets the approved plan;** o **Upon installation of plants, to ensure they conform to the planting plan;** o **Final construction review including development of a punch list for facility acceptance.** • **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the Vegetated Roof has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for Vegetated Roofs are as follows:** o **Growth media thickness within 15% of design thickness.** o **Plant density no less than specified on the planting plan.** o **No less than 66% of the total contributing drainage area shall be Vegetated Roof.** • **The post construction verification shall confirm that temporary or permanent irrigation has been installed in accordance with the approved plan. Certification of growth media shall be submitted with post construction verification**
Maintenance Criteria (Section 4.9)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.** • **A minimum of one maintenance review is required each year for Vegetated Roofs.** • **Maintenance reviews shall be performed by a qualified reviewer.** • **The completed maintenance review report shall be sent to the Department or the appropriate Delegated Agency.** • **Vegetated Roofs must be reviewed at the end of the first 24 months to confirm minimum vegetated surface cover specified in the Operation and Maintenance Plan has been achieved, and to look for leaks, drainage problems and any rooftop structural concerns.** • **Growth media shall be routinely tested for P as part of the Operation and Maintenance Plan.** • **Phosphorous-removing BMPs (e.g., activated alumina or hematite filters) must be installed for Vegetated Roofs, 24 months and older, with phosphorous concentrations that are consistently higher than 2 mg/l.**

Table 4.3. Vegetated Roof Material Specifications

Material	Specification
Waterproof Membrane	• Waterproofing layer should have an expected life span as long as any other element of the Vegetated Roof system
Protection Layer	• **Protection Layer shall have a puncture resistance in accordance with ASTM D4833 >220 lbs.**
Root Barrier	• **Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals shall not be used.** • **The waterproof membrane or the root-barrier shall be certified as root-resistant based on the two-year ANSI/SPRI VR-1; Procedure for Investigating the Root Penetration Resistance of Vegetated Roofs or the two-year European FLL root-security test** • **If certification is not available at the time the system is permitted, a root barrier shall be provided as follows: HDPE membrane, 30 mil or thicker, with seams overlapped at least 3 inches and continuously hot-air welded.**
Drainage Layer	• The drainage layer should consist of durable, frost-resistant, and biologically resistant synthetic or inorganic materials (e.g., gravel, recycled polyethylene, etc.) that can provide efficient drainage. • Designers should consult the performance metrics as outlined in ASTM E2396 and E2398.
Filter Fabric	• Needled, non-woven, geotextile. • Density (ASTM D3776) between 3 and 6 oz./sq. yd.,. • Puncture resistance (ASTM D4833) <150 lbs.,. • Some manufacturers may combine with the drainage layer.
Growth Media	• **The growth media must maintain minimum 6% air filled porosity (ASTM E2399) to avoid anoxic conditions when wetted.** • **To minimize the potential for clogging of fabrics and migration of fine particles, the silt-size fraction (0.063mm) of engineered mineral soils shall not exceed 15% and the clay fraction (2 micron) shall not exceed 5%** • Extensive: Media depth between 3 and 6 inches; not more than 10% biodegradable matter by dry mass (loss on ignition based on Methods of Soil Analysis. An alternate method of evaluating biodegradability content may be proposed for growth media containing polymeric materials such as associated with agri-polymer matrices. • Intensive: Media depth upwards of 6 inches; biological organic content not more than 15%. • **Organic amendments used in preparing growth media must be stable. The respiration rate of organic ingredients must be 3 mg CO2-C/g OM/day (TMECC 05.08.B), or less.** • **The initial available P content of the growth media may not exceed 200 ppm dry weight (Mehlich III). Otherwise, provide a supplemental phosphorus-reducing water quality BMP.** • **Chemical fertilizers containing phosphorous may not be added to the growth media during blending or used subsequently during maintenance unless a phosphorus deficiency in the plants has been documented. Only nitrogen fertilizers may be used and these must be applied according to soil test. If the P limit for the media layer cannot meet compliance, the Vegetated Roof must be treated as a P source and a supplemental water quality BMP must be introduced.**

Material	Specification
Plant Materials	• Extensive: Drought-tolerant plants, such as Sedum and Phedimus, that are tolerant of direct sunlight, drought, wind, and frost. • Intensive: Any non-invasive plantings, though the media depth should be appropriate for selected plantings, and the building's height and sun and wind exposure should be accounted for.
Irrigation	• **Irrigation is required for Vegetated Roofs for the first year after planting.** • Permanent irrigation is recommended for Intensive Vegetated Roofs..

4.3 Vegetated Roof Feasibility Criteria

Vegetated Roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings, although they can also be incorporated on single family residential homes. They are particularly well-suited for use on urban development and redevelopment sites. Key constraints with Vegetated Roofs include the following:

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 shall demonstrate that the building will be able to support the additional live and dead structural load. Structural capability of the roof must be assessed by a qualified licensed professional and included with building permit documentation.**

Typically, the weight of fully-saturated engineered mineral soils will range from 5.5 to 7 pounds per square foot per inch of thickness. Therefore, a 3-inch thick growth media layer can be expected to weight between 16.5 and 21 psf. Weights will vary and may be lighter when specialty growth media components are used. These loads are comparable to rooftops where the waterproof membrane or insulation layer is anchored with stone ballast (12 to 15 lbs./sq. ft.). Intensive systems vary widely depending on the soil depth and landscape features, and may weigh upwards of 100 lbs/sq.ft. For a discussion of Vegetated Roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009). Use ASTM E-2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems as the basis for estimating structural loads induced by complete Vegetated Roof assembly*. In addition, use standard test methods ASTM E2398 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*, and ASTM E2399 for *Maximum Media Density for Dead Load Analysis*.

Roof Pitch. Vegetated Roof detention storage and runoff volume reduction is maximized on relatively flat roofs. Low pitches delay the discharge of water that percolates do the bottom of the Vegetated Roof assembly, thereby maximizing water uptake and ultimately reducing runoff volume by evapotranspiration (ET). Evapotranspiration is the process by which water is lost to evaporation from leaf surfaces. On roofs, it is the only mechanism that reduces runoff volume. Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growth media on Extensive Vegetated Roofs. However, flat concrete roof decks may be appropriate for Intensive Vegetated Roofs. Intentional ponding of water to depths of up to several inches within the drainage layer may be advantageous for improving both stormwater performance and plant health. Flat roofs are never appropriate for steel or wood roof decks.

The recommended minimum roof deck slope for Extensive Vegetated Roofs is 1% (1/8" per foot), while the preferred roof deck slope for Extensive Vegetated Roofs is 2% slope (1/4" per foot) and the maximum recommended roof deck slope for Extensive Vegetated Roofs is 16% (2" per foot).

The recommended minimum roof deck slope for Intensive Vegetated Roofs is 0%, while the preferred roof deck slope for Intensive Vegetated Roofs is 1% slope (1/8" per foot) and the maximum recommended roof deck slope for Intensive Vegetated Roofs is 10% (1.2" per foot).

The recommended slope of growth media is 2.5:1 or less. Slope stabilization is needed for growth media slopes steeper than 2.5:1.

Roof Access. **Safe access to the Vegetated Roof shall be available to allow for delivery of construction materials and performance of routine maintenance reviews and maintenance operations**. Designers should also consider how they will get construction and maintenance materials up to the roof (e.g., by elevator or crane) and how materials will be stockpiled in the confined space.

A permanent source of water shall be provided to all Vegetated Roof areas. This may be a hydrant or hose-bib. Water will be required for irrigation during the establishment period, for general maintenance functions, and as a precaution against roof fires.

Roof Deck Type. The roof deck layer is the foundation of a Vegetated Roof. It may be composed of concrete, wood, metal, plastic, gypsum or a composite material. The type of deck material determines the strength, load bearing capacity, longevity and potential need for insulation in the 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. Certain roof materials, including exposed treated wood and galvanized metal, are not appropriate for Vegetated Roofs due to pollutant leaching through the growth media (Clark et al, 2008). The roof deck type should be coordinated with the building's designers, only requirement is that it complies with the applicable building codes.

Buffers. Rooftop electrical and HVAC systems should not be located within in a zone of concentrated surface or seepage flow. **A minimum 1-foot wide vegetation-free zone is required along the perimeter of all Vegetated Roofs and around all roof penetrations**. Wider buffers at Vegetated Roof margins may be warranted where wind scour is a concern or where the vegetated zone is adjacent to flammable building materials.

Building Codes. Building codes differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. **The Vegetated Roof design must comply with all federal, state and local building codes.**

4.4 Vegetated Roof Conveyance Criteria

The Vegetated Roof drainage layer shall convey flow from under the growth media layer to an outlet or overflow system such as a rooftop drain, scupper or gutter/downspout drainage system. It is beneficial to include perforated or slotted "French-drain" conduits within the drainage layer to control the pattern and rate of seepage flow. Seepage collection systems should be enclosed in filter fabric to protect them from clogging. It is common to enclose conduit in drainage stone and wrap the stone in filter fabric. It is frequently a good design to create a serpentine flow pathway in order to increase water residence time and improve plant uptake. **All drains and scuppers shall be accessible through enclosures that include lids that are level with the surface of the growth media layer.**

Emergency drains or emergency scuppers shall have inverts that are high enough above the waterproofing surface to prevent discharge during the RPv event.

It is a common practice to introduce drain restrictors on the primary drains for one of two reasons: 1) To temporarily impound a volume of water and release it a slower predetermined rate following the peak of the rain event, or 2) to permanently impound a volume of water on the Vegetated Roof. In the latter case, the volume will be eventually removed by evapotranspiration and will not contribute to annual runoff.

4.5 Vegetated Roof Pretreatment Criteria

Pretreatment is not necessary for Vegetated Roofs.

4.6 Vegetated Roof Design Criteria

Functional Elements of a Vegetated Roof Assembly: A Vegetated Roof assembly may be composed of many components or layers that are combined to protect the roof and provide soil and plant conditions that can reduce the impervious effects of the building. These components are placed on top the roof deck layer, as mentioned in Section 4.3. Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. Some manufacturers offer proprietary systems which contain many of the below elements, or in other cases the components are installed individually. Additional information can be found in Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004). The design layers include:

1. Waterproof Membrane: **All Vegetated Roof systems must include an effective and reliable waterproof membrane to prevent water damage to the building structure.** A wide range of waterproofing materials have been successfully used for decades in conjunction with Vegetated Roofs. The waterproofing layer should have an expected life span as long as any other element of the Vegetated Roof system.

2. Protection layer: The protection layer is a puncture resistant layer that is frequently a dense non-woven geotextile. However, depending on the waterproofing material, may also be reinforced bituminous sheet membrane, a thermoplastic membrane, or other. When no root barrier is present, it will be placed directly over the finished waterproof membrane. Some very dense fabrics may exhibit significant capillary potential and can be exploited to enhance moisture distribution at the bottom of the Vegetated Roof assembly profile. **Protection Layer shall have a puncture resistance in accordance with ASTM D4833 >220 lbs.**

3. Insulation Layer: Many Vegetated Roofs contain an insulation layer, usually located above, but sometimes below, the waterproof membrane. The insulation increases the energy efficiency of the building, and can protect the roof deck, particularly for metal roofs. Whether to use insulation and its location if installed should be coordinated with the building designers, and is not a requirement of this specification.

4. Root Barrier: **Waterproof membranes designed for burial in Vegetated Roofs do not require supplemental root barriers; however root barriers are required in combination with some waterproof membranes.** The root barrier protects the waterproof membrane from root penetration and ultimately failure. A wide range of root barrier options are available. Common root-barriers are thermoplastic membranes, because these can be hot air welded to provide a continuous shield against roots. **Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals shall not be used as those chemicals can leach into stormwater runoff and will slowly lose effectiveness over time. To insure that a building is adequately protected against damage from roots, the waterproof membrane or the root-barrier shall be certified as root-resistant based on the two-year ANSI/SPRI VR-1; *Procedure for Investigating the Root Penetration Resistance of Vegetated Roofs* or the two-year European FLL root-security test (*Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., Richlinien fuer die Planung, Ausfuehrung und Pflege von Dachbegruenung)*. If certification is not available at the time the system is permitted, a root barrier shall be provided as follows: HDPE membrane, 30 mil or thicker, with seams overlapped at least 3 inches and continuously hot-air welded.**

5. Drainage Layer and Drainage System: **A drainage layer shall underlie the growth media to control the release of water that percolates into the Vegetated Roof assembly**. The drainage layer should consist of durable and frost-resistant synthetic or inorganic materials (e.g., clean, washed granular material, such as ASTM D 448 size No. 8 stone, or polyethylene or polystyrene drainage mats) that are capable of providing efficient drainage. The drainage layer should convey the seepage flow horizontally toward an outlet at a roof drain, scupper or gutter. Some Vegetated Roof assemblies incorporate "French-drain" style perforated conduit to intercept seepage flow and direct to the outfall locations. American Society for Testing and Materials (ASTM) E2396 and E2398 can be used to

evaluate alternative material specifications. Many drainage layers include receptacles in their upper surface that will permanently retain a portion of percolated rainfall (or irrigation water) for uptake by plants. **Roof drains and any emergency overflow shall be designed in accordance with state and local building codes.**

6. Filter Fabrics: Filter fabrics are used to prevent the migration of fine particles and to maintain the layered organization in Vegetated Roof assemblies. They may be placed at various horizons in the assemblies, but are commonly placed: 1) between the growth media layer and the drainage layer, 2) between components of the growth media layer, or on top of the insulation. Many manufactured drainage layers come with a filter fabric attached, which is acceptable. Filter fabrics are lightweight low-tensile-strength geotextiles that are intended to prevent particle migration, while allowing free infiltration of plant roots.

7. **Growth Media: The growth media shall be the uppermost layer in a Vegetated Roof assembly. The designer shall certify that growth media meets or exceeds all required specifications prior to placement.** The purpose of this layer is to: 1) support plant growth, and 2) absorb rainfall for uptake by plants. Modern Vegetated Roof assemblies may use a wide variety of component materials and may be assembled in multiple layers. Growth media should be durable and maintain its critical properties, including water holding capacity, porosity, density, permeability and hydraulic properties for decades, since replacement of growth media is not a practical option for most projects. A high-performing growth media layer will improve over time, as it matures biologically and develops a complex mixture of matrix materials, roots, bacteria, and fungi. The growth media layer should be sufficiently well drained to prevent surface ponding during the RPv event, but retain moisture and dry down slowly in order to support the plants. **The growth media must maintain minimum 6% air filled porosity (ASTM E2399) to avoid anoxic conditions when wetted.** Some components encountered in modern Vegetated Roof assemblies, include:

    a. **The upper 1 inch of a growth media profile shall consist of an engineered mineral soil.** Engineered mineral soil media, contains porous lightweight expanded aggregate (i.e., ESCS), volcanic rock, crushed brick, porous ceramic granules, or foamed glass, blended with an organic material. **To minimize the potential for clogging of fabrics and migration of fine particles, the silt-size fraction (0.063mm) of engineered mineral soils shall not exceed 15% and the clay fraction (2 micron) shall not exceed 5%. Organic amendments used in preparing growth media must be stable. The respiration rate of organic ingredients must be 3 mg CO2-C/g OM/day (TMECC 05.08.B), or less.**
    b. <u>Uncoated</u> rock wool batts (only uncoated rock wool fibers remain hydrophilic)
    c. Polyurethane agri-polymer matrices

    The biodegradable portion of the growth media layer should not exceed 10% for Extensive Vegetated Roof assemblies, or 15% for intensive assemblies. Some specialty media (e.g., for use in agricultural or in conjunction with some ornamental plants) may contain higher percentages. The biodegradable constituent will most commonly be a mature yard waste or agricultural compost. The appropriate method for measuring the biodegradable fraction in engineered mineral soil media, is loss on ignition (Methods of Soil Analysis). Alternative methods may be proposed to evaluate biodegradable content of growth media containing polymeric materials (e.g., polyurethane agri-polymer matrices). Growth Media with excessively high organic content may suffer from inadequate air porosity, loss of permeability, degradation and compression.

Unless specified and controlled during the construction process, most Vegetated Roof media will typically contain excess phosphorus (P), and will become a significant source of P over an extended period. **For a Vegetated Roof to be regarded as neutral with respect to P loading in runoff, the P content of the growth media must be controlled.** In particular, **the initial available P content of the growth media may not exceed 200 ppm dry weight (Mehlich III)**. Furthermore **chemical fertilizers containing phosphorus may not be added to the growth media during blending or used subsequently during maintenance unless a phosphorus deficiency in the plants has been documented**. Otherwise, **only nitrogen fertilizers[1] may be used and these must be applied according to soil test. If the P limit for the media layer cannot meet compliance, the Vegetated Roof must be treated as a P source and a supplemental water quality BMP must be introduced.** One option for reducing available phosphorus would be to blend alum into the media or drainage layer. Alternatives for treating runoff include activated alumina or hematite filters or an approved biological BMP.

For an Extensive system, the growth media layer ranges from 3 to 6 inches deep, with 3 to 4 inches being most common. The growing media layer should have a maximum water retention capacity of at least 30% (ASTM E2399). It is advisable to mix engineered mineral soil media in a batch facility prior to delivery to the roof. More information on growth media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and McIntyre (2010), Roehr and Fassman-Beck (2015), and ASTM E2777,

If trees are included in the Vegetated Roof landscape plan, the growth media must be at least 30 inches deep. Depending on the requirements of the tree, the licensed professional may specify a specialty media. Method for stabilizing newly planted trees against wind-throw should be included in the design.

8. Wind Resistance: Consult ANSI/SPRI RP-14, *Wind Design Standard for Vegetative Roofing Systems*, for guidance in developing wind resistance designs.

9. Plant Cover: Initial planting plan shall be designed such that mature plant coverage within 24 months of initial planting shall be:

- **Minimum 75% warm season plant coverage for Extensive Vegetated Roofs.**

[1] These may include other macro- and micro-nutrients including potassium, calcium, magnesium, etc.

- **Minimum 90% plant coverage for turf intensive Vegetated Roofs**
- **Uniform cover with vigorous plants conforming to the design plant density for non-turf Intensive Vegetated Roofs.**

Pre-grown vegetated mats or sod are recommended for roofs with: 1) pitches equal or exceeding 5%, or 2) high wind exposure. Pre-grown mats should be delivered with 90% plant coverage. Alternatively, wind or water erosion blankets may be exploited to stabilize the media surface until plants can establish. Examples of media blankets, including coir mats, hydro-mulch, nets or meshes.
Plants may be installed as individuals (plugs or containers), as pre-grown vegetated mats, as pre-planted modules or trays, or established from seed or cuttings. Cuttings are plant stem fragments from selected Sedum and Phedimus plant varieties. . See *Section 4.7 Vegetated Roof Landscaping Criteria* for additional extensive plant information. For Intensive Vegetated Roofs, the plant type can be broadened to any non-invasive plant, though the plants survivability on the roof top should be accounted for. **The planting plan for Vegetated Roofs must be certified by a qualified professional**, including landscape architects, horticulturists, or other disciplines that possess the necessary knowledge, skills and training

Material Specifications: Standard 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 ASTM has recently issued several overarching Vegetated Roof standards. Designers and reviewers should also fully understand manufacturers' specifications for each system component, particularly if they choose to install proprietary "complete" Vegetated Roof systems or modules.

Vegetated Roof Sizing: The size of the Vegetated Roof, both Extensive and Intensive, shall be a minimum 66% of the total contributing drainage area. No runoff reduction credit shall be given for runoff from bare areas of the roof that do not come in contact with root zone. If the guidance is followed, Extensive Vegetated Roofs have been shown to reduce the annual runoff in the Mid-Atlantic climate by 50% (Berghage et al, 2009), and Intensive Vegetated Roofs by 75% (Mentens et al, 2005).

Vegetated Roofs, especially Intensive systems, can have dramatic rate attenuation effects on larger storm events, and may be used, in part, to manage a portion of the 10- and 100-year events. This benefit is the result of lengthening of the "time of concentration" for the roof area and of introducing storage/detention processes. There is no established method for modeling Vegetated Roofs and designers may propose and validate a method that best represents the performance of their design. In general, models will consider: 1) permeability and available moisture storage capacity of the growth media, 2) horizontal transmissivity and storage capacity of the drainage layer, and 3) seasonal ET rates. See Roehr and Fassman-Beck (2015) for information on predicting Vegetated Roof performance.

4.7 Vegetated Roof Landscaping Criteria

Plant selection, placement and maintenance are critical to the performance and function of Vegetated Roofs. **The planting plan for Vegetated Roofs must be certified by a qualified professional,** including landscape architects, horticulturists, or other disciplines that possess the necessary knowledge, skills and training.

Plant selection for Vegetated Rooftops is an integral design consideration, which is governed by local climate and design objectives. The ground cover for Extensive Vegetated Roof installations are hardy, low-growing succulents, such as *Sedum, Phedimus (formerly in the Sedum genus) Talinum, Dianthus, Achillea, Deschampsia,* or *Hieracium,* that can tolerate the difficult growing conditions found on building rooftops. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*. Additional guidance on selecting the appropriate Vegetated Roof plants for hardiness zones in the Delaware region can be found in Snodgrass and Snodgrass (2006).

A list of some common Extensive Vegetated Roof plant species that work well in the Delaware region are provided. Following is a list of varieties that have proven to be the most vigorous and long-lived on unirrigated Extensive Vegetated Roofs in the Mid-Atlantic and Great Lakes regions. Large drifts of any single variety should be avoided. Mixtures of succulent and non-succulent plants will provide the most durable plant communities. The appropriateness for any variety will depend on the exposure (e.g., sun and wind). Consult an experienced green roof designer for advice on planting design.

Sedum (all plants in this list were formerly included in the genus Sedum; starred species are deciduous)
Petrosedum rupestre (specifically var Blue Spruce [aka reflexum Blue Spruce)
Sedum sexangulare
Sedum album
Hylotelephium telephoides *
Hylotelephium matrona *
Hylotelephium cauticola (specifically var Lidakense)
Phedimus kamtschaticus kamtschaticum *
Phedimus kamtschaticus floriferus (specifically var Weihenstephaner Gold)
Phedimus takesimensis
Phedimus spurius (specifically var John Creech or Fuldaglut)
Phedimus hybridus (specifically var Immergruenchen)
Phedimus sichotense
Phedimus ellacombeanus *
Phedimus middendorffianus *
Phedimus aizoon *
(Note: Phedimus species are the most durable and successful succulents in this climate for media depths of three inches and thicker)

Achillea millefolium
Allium cernuum
Allium schoenoprasum
Aster (Symphyotrichum) ericoides
Bouteloua curtipendula
Coreopsis grandiflora
Dianthus carthusianorum
Dianthus deltoides
Dianthus arenarius
Hieracium aurantiacum
Festuca glauca
Monarda punctata
Gaillarda pulchella
Phlox subulata
Schizachyrium scoparium
Talinum calycinum
Delosperma nubigenum
Bigelowia nuttallii
Petrorhagia saxifraga
Opuntia compressa
Opuntia humifusa
Phacelia campanularia
Andropogon ternarius
Echinacea purpurea
Eragrostis spectabilis
Festuca longifolia
Festuca ovina
Lespedeza virginica
Penstemmon digitalis
Sporobolus heterolepis

While the exposed conditions associated with Extensive Vegetated Roofs will limit the range of plants that can be reliably included, Intensive Vegetative Roofs can be tailored to offer hospitable environments for a much wider variety of plants. In the Mid-Atlantic Region, typical intensive plant lists may include turf, ornamental grasses and perennials, shrubs, and trees. With proper design, even facultative and wetland plants can be installed on Intensive Vegetative Roofs.

Plant choices can be much more diverse for 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 than an Extensive system.

Additional Landscaping Criteria and Notes:

- The species and layout of the landscape 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 can withstand heat, cold and high winds.
- Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The landscape 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 Extensive Vegetated Roof plant species will *not* be native to the Delaware region (which contrasts with *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, it is advisable to determine the lead time for delivery and to have the plant materials contract-grown.
- **Irrigation is required for Vegetated Roofs for the first year after planting.** When appropriate species are selected, most Extensive Vegetated Roofs in Delaware will not require supplemental irrigation, except for temporary watering during the first year of establishment. It is recommended to have a permanent watering or irrigation system for especially dry conditions. Many manufacturers offer drainage products that have limited water storage capacity. These may be useful in optimizing irrigation designs for Intensive Vegetated Roofs.
- Permanent irrigation is recommended for Intensive Vegetated Roofs. It is recommended to explore *Specification 5.0 Rainwater Harvesting*, for irrigation needs to increase water reuse and stormwater credit.
- The planting window extends from the spring to mid-fall, as it is important to allow plants to root before the first killing frost.
- Plants can be established using cuttings, plugs, and mats. Several vendors also sell mats, rolls, or proprietary pre-vegetated roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006). **The minimum plant coverage shall be achieved 24 months after initial planting and maintained throughout the life of the Vegetated Roof.** Where access to roof-top equipment, such as HVAC units is required, non-vegetated pathways should be provided. Otherwise, repeated foot-falls along the access route will destroy the plant cover.

4.8 Vegetated Roof Construction

Installation. Given the diversity of 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 waterproof membrane, according to manufacturer's specifications.
- Conduct a watertightness test. If flood tests are used place at least 3 inches of water over the membrane for 72 hours to confirm the integrity of the waterproofing system. Low-voltage

electrical vector mapping of the membrane may also be used as an alternative or supplemental construction quality control measure, provided the waterproof membrane is compatible with the method.

- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric), taking care not to damage the waterproof membrane. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growth media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. Planting should occur immediately after placement of media. If this is not possible (e.g., due to weather or construction delays), the growth media should be covered until planting to prevent wind erosion and weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic, although the traffic should be limited over the growing media to reduce compaction.
- The growing media should be moistened prior to planting, and then planted per the landscape plan, or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- **Irrigation is required for Vegetated Roofs for the first year after planting.** Temporary watering may also be needed beyond the first year if drought conditions persist.

Construction Review. Reviews during construction are needed to ensure that the Vegetated Roof is built in accordance with these specifications.

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 oversight is needed during several steps of Vegetated Roof installation. **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**

- **Pre-construction meeting**
- **During placement of the waterproof membrane, to ensure that it is properly installed and watertight;**
- **During placement of the drainage layer and drainage system, to prevent future ponding water;**
- **During placement of the growing media, to confirm that it meets the approved plan;**
- **Upon installation of plants, to ensure they conform to the planting plan;**
- **Final construction review including development of a punch list for facility acceptance.**

Post Construction Verification Documentation. Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the Vegetated Roof has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for Vegetated Roofs are as follows:

- **Growth media thickness within 15% of design thickness.**
- **Plant density no less than specified on the planting plan.**

- **No less than 66% of the total contributing drainage area shall be Vegetated Roof.**

The post construction verification shall confirm that temporary or permanent irrigation has been installed in accordance with the approved plan. Certification of growth media shall be submitted with post construction verification.

4.9 **Vegetated Roof Maintenance Criteria**

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Maintenance Reviews. Maintenance of Vegetated Roofs is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required. **A minimum of one maintenance review is required each year for Vegetated Roofs.** Because Vegetated Roofs are living systems on top of a building, it is recommended that two reviews per year are performed. **Maintenance reviews shall be performed by a qualified reviewer**. **The completed maintenance review report shall be sent to the Department or the appropriate Delegated Agency.**

Vegetated Roofs must be reviewed at the end of the first 24 months to confirm minimum vegetated surface cover specified in the Operation and Maintenance Plan has been achieved, and to look for leaks, drainage problems and any rooftop structural concerns.

Maintenance Operations. Hand weeding is critical throughout the life of the roof, but is especially important in the first 24 months (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds). Timely maintenance, before weeds can go to seed is important in reducing overall maintenance cost. 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 (ASTM, 2006)).

The use of herbicides, insecticides, and fungicides are to 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 plants.

Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first 24 months of species planted and a minimum effective vegetative cover of 75% for flat roofs and 90% for roofs with pitches in excess of 5%.

It generally takes 12 to 24 months to establish a Vegetated Roof. To achieve biological maturity (i.e., development of a community of beneficial bacteria, fungi, and micro-invertebrates) and maximum performance may take 3 to 5 years. Fertilization with N-only fertilizers are encouraged one or twice a year, until the plant cover is vigorous and root systems well developed. Use a combination of rapid release (e.g., blood meal) and slow release (e.g., methyl-urea) fertilizers. Fertilizer additions should be planned to adjust the total N level within the range of 1 and 5 mg/L (Saturate Media Extraction, or SME). Higher soil concentrations may be required for turf. **Growth media shall be routinely tested for P as part of the Operation and Maintenance Plan.** Phosphorus SME concentrations in excess of 2 mg/L indicate that the Vegetated Roof is becoming a significant source of P loading in runoff, and potential sources of P additions should be strictly curtailed. **Phosphorous-removing BMPs (e.g., activated alumina or hematite filters) must be installed for Vegetated Roofs, 24 months and older, with phosphorous concentrations that are consistently higher than 2 mg/l.** After the roofs attain biological maturity, which may take 3 to 5 years, the quantity of fertilizer additions needed to maintain plant nutrition can be reduced, but not eliminated entirely.

Table 4.5. Typical Maintenance Activities Associated with Vegetated Roofs

Frequency	Maintenance Items
As Needed	• Water to promote plant growth and survival. • Replace dead or dying vegetation (may include transplantation, new plant installation, or distribution of seed or cuttings..
Semi-Annually	• Inspect the waterproof membrane flashings for leaking or cracks. • Fertilization (annually, or semi-annually, based on soil test. • Hand weeding to remove invasive plants (no digging or using pointed tools). • Check roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Replace any dead or dying vegetation.

4.10 References

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Snodgrass, E., and McIntyre, L., 2010., *The Green Roof Manual: A Professional Guide to Design, Installation, and Maintenance.* Timber Press, Portland, OR.

5.0 Rainwater Harvesting

Definition: **Rainwater Harvesting systems intercept, divert, store and release rainfall for future use. Rainwater that falls onto impervious surfaces is collected and conveyed into an above- or below-ground cistern where it can be used for non-potable water uses and on-site stormwater disposal or infiltration.** Non-potable uses may include landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), flushing of toilets and urinals, fire suppression (sprinkler) systems, supply for chilled water cooling towers, replenishing and operation of water features, distribution to a green wall or living wall system, and laundry. In many instances, Rainwater Harvesting can be combined with a secondary stormwater practice to enhance stormwater retention and/or provide treatment of overflow from the Rainwater Harvesting system. **Runoff collected and temporarily stored in more traditional stormwater management practices constructed in accordance with the Post Construction Stormwater BMP Standards and Specifications, such as wet ponds, can also be used for irrigation purposes to achieve these same goals.**

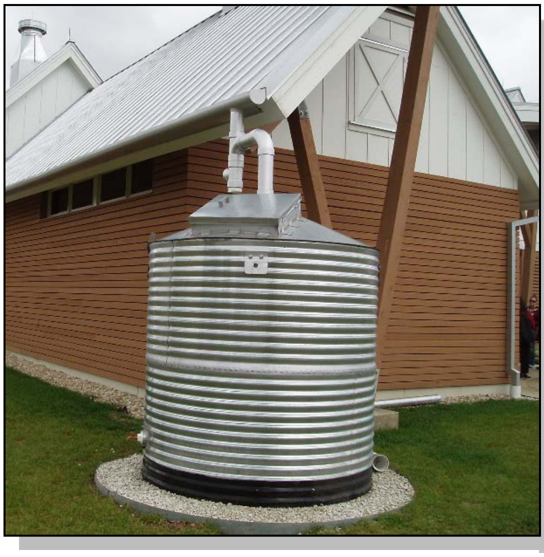

Photo courtesy of Lake County (IL) Stormwater Management Commission

Design variants include:

- 5-A **Seasonal Rainwater Harvesting Systems**
- 5-B **Continuous Rainwater Harvesting Systems**

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

5.1 Rainwater Harvesting Stormwater Credit Calculations

The performance credits for Rainwater Harvesting systems are based upon a design prepared in accordance with the guidelines of Section 5.6. Tables 5.1(a) and 5.1(b) list the credits for retention and pollutant reduction. **If not protected from freezing, Rainwater Harvesting systems must be taken offline for the winter and credited as seasonal systems.**

5.1(a) **Seasonal Rainwater Harvesting Performance Credits***

Runoff Reduction	
Retention Allowance	50%
RPv -A/B Soil	**50% of Retention Storage**
RPv - C/D Soil	**50% of Retention Storage**
Cv	**0%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

*Includes wet pond storage used for seasonal irrigation purposes.

5.1(b) **Continuous Rainwater Harvesting Performance Credits****

Runoff Reduction	
Retention Allowance	75%
RPv -A/B Soil	**75% of Retention Storage**
RPv - C/D Soil	**75% of Retention Storage**
Cv	**0%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

**Includes wet pond storage in conjunction with spray irrigation applied to forested areas.

5.2 Rainwater Harvesting Practice Summary

Table 5.2 summarizes criteria for Rainwater Harvesting, and Table 5.3 summarizes the materials specifications for this practice. For more detail on design criteria, consult Sections 5.3 through 5.7. Sections 5.8 and 5.9 describes practice construction and maintenance criteria respectively.

Table 5.2 Rainwater Harvesting Practice Summary

Feasibility Criteria (Section 5.3)	• **Designers and plan reviewers shall consult all applicable local, State and Federal regulations to determine the allowable indoor uses and required treatment for harvested rainwater.** • **Pipes and spigots using rainwater must be clearly labeled as non-potable.** • **The final invert of the outlet pipe from the cistern must be at an elevation that will not allow water from the discharge point to backflow into the cistern.** • **In areas where a below-ground cistern will be buried partially below the water table, buoyancy calculations must be conducted for the empty cistern and special design features must be employed, as applicable, to secure the cistern.** • **Cisterns must be installed according to the manufacturer's specifications.** • **The bearing capacity of the soil upon which the full cistern will be placed must be considered.** • **Cisterns shall be designed to be watertight.**
Conveyance Criteria (Section 5.4)	• **All conveyance pipes to the cistern, including gutters and downspouts, must be kept clean and free of sediment, debris and rust.** • **An overflow mechanism must be included in the Rainwater Harvesting system design to handle flows that exceed the capacity of the cistern.** • **Overflow pipes must have a capacity equal to or greater than the total capacity of the inflow pipes and have a diameter and slope sufficient to drain the cistern before it reaches full capacity.** • **The overflow pipe must be screened to prevent access to the cistern by rodents and birds.**
Pretreatment Criteria (Section 5.5)	• **Pretreatment is required to keep sediment, leaves, and other debris from the system.** • **Small cistern systems of 2,500 gallons or less shall have leaf screens or gutter guards for pretreatment as a minimum. Large tank systems requires full capture pretreatment** • **Large cistern systems of greater than 2,500 gallons shall include a pretreatment system capable of treating and conveying the flow rate generated by the RPv from the contributing impervious surface drainage area without creating a backup or bypass condition.**
Cisterns (Section 5.6)	• **Rainwater Harvesting Systems shall comply with all applicable local, State, and Federal regulations.** • **Above-ground cisterns must be impact resistant or protected from impact using bollards or other physical barriers.** • **Below-ground cisterns must be designed to support the overlying soil and any other anticipated loads.** • **Below-ground cisterns must have a standard size manhole or equivalent opening to allow access for cleaning, inspection, maintenance, and repair purposes.** • **Cisterns must be screened to discourage mosquito breeding and reproduction.** • **A suitable foundation must be provided to support the cistern when it is filled to capacity.** • **Dead storage below the outlet to the distribution system and an air gap at the top of the cistern must be added to the total volume.**

	• **Any hookup to a municipal backup water supply must have a backflow prevention device to keep municipal water separate from stored rainwater.**
Distribution Systems (Section 5.6)	• **The Rainwater Harvesting system must be equipped with an appropriately-sized pump, if necessary, that produces sufficient pressure for all intended end-uses.** • **A backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.** • **Distribution lines for Continuous Rainwater Harvesting Systems must be buried beneath the frost line.** • **A drain plug or cleanout sump, also draining to a pervious area, must be installed to allow the system to be completely emptied, if needed.** • **Above-ground outdoor pipes must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter.** • **Distribution lines and above ground outdoor pipes for Seasonal Rainwater Harvesting Systems shall be drained or otherwise winter-proofed during the non-operational period.**
Sizing Criteria (Section 5.6)	• **For seasonal rainwater harvesting systems, weekly irrigation demand shall be at least 50% of the stored volume.** • **For Continuous Rainwater Harvesting Systems, a minimum of 50% of the demand shall be met through non-irrigation needs, such as plumbing, process water, car washing, or other uses that are present throughout the year.**
Maintenance Access (Section 5.6)	• **All Rainwater Harvesting Systems must be designed so as to be accessible to annual maintenance.** • **A maintenance right-of-way or easement must extend to the Rainwater Harvesting System from a public or private road.** • **Adequate maintenance access must extend toall components of the Rainwater Harvesting System.** • **Maintenance access must meet the following criteria:** o **Minimum width of fifteen feet.** o **Profile grade that does not exceed 10H:1V.** o **Minimum 10H:1V cross slope.**
Landscaping Criteria (Section 5.7)	• **If the harvested rainwater is to be used for irrigation, the design plan must include the delineation of the proposed planting areas to be irrigated and quantification of the expected water demand based upon the area to be irrigated.**
Construction Criteria (Section 5.8)	• **Rainwater Harvesting system components connecting to the internal plumbing system shall be installed by a licensed plumber** • **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction** o **Pre-construction meeting** o **Initial site preparation including installation of erosion and sediment controls** o **Excavation and grading including interim and final elevations for cistern foundations** o **Installation of cistern, pretreatment system and conveyance system** o **Implementation of required stabilization** o **Final construction review including development of a punch list for facility acceptance** • **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the rainwater harvesting practice has been constructed in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Items to be checked and verified are as follows** o **Presence of a pretreatment device**

Construction Criteria (Section 5.8) *cont.*	o **Capacity of any cisterns matches the design plan** o **For ponds, the constructed volume shall be no less than 90% of the design volume.** o **For continuous systems, all pumps, controls, and other appurtenances installed in accordance with the plan** o **For irrigation systems, area of coverage is within ninety percent of that shown on the plan**
Maintenance Criteria (Section 5.9)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system** • **Operation and Maintenance Plans shall clearly outline how Rainwater Harvesting Systems will be managed taking into account seasonal variations and cistern location** • **Rainwater Harvesting Systems that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use**

Table 5.3. Material Specifications for Rainwater Harvesting systems

Item	Specification
Pipes, Gutters and Downspouts	• Common conveyance materials for non-roof runoff include concrete, HDPE, PVC, aluminum and galvanized steel • Common roof runoff conveyance materials: polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel • Recommended roof runoff conveyance materials: aluminum, round-bottom gutters and round downspouts • Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply
Cisterns	• **Cisterns must be structurally sound, watertight, and sealed using a water-safe, non-toxic material.** • **Re-purposed tanks used to store rainwater for reuse must be acceptable for potable water or food-grade products.** • **Above-ground cisterns must be UV resistant and opaque to prevent the growth of algae in the tank.** • **Below-ground cisterns shall be located below the frost line.**
Note: This table does not address indoor systems or pumps.	

5.3 Rainwater Harvesting Feasibility Criteria

A number of site-specific features influence how Rainwater Harvesting systems are designed and/or utilized. These should not be considered comprehensive and conclusive considerations, but rather some recommendations that should be considered during the process of planning to incorporate Rainwater Harvesting systems into the site design. The following are key considerations for Rainwater Harvesting feasibility:

Requirement for Water Allocation Permit. Wet Ponds used for rainwater harvesting may be subject to regulations under the Department's Water Supply Section. In general, if the facility withdraws water from groundwater sources it would need a permit if certain thresholds are

exceeded. Designers are advised to contact the DNREC Water Supply Section for additional information regarding possible permitting requirements.
Water Reuse. Harvested rainwater may be used for non-potable uses. This specification does not address indoor plumbing or disinfection issues. **Designers and plan reviewers shall consult all applicable local, State and Federal regulations to determine the allowable indoor uses and required treatment for harvested rainwater. Pipes and spigots using rainwater must be clearly labeled as non-potable.**

Available Space. Adequate space is needed to house the cistern and any overflow. Space limitations are rarely a concern with Rainwater Harvesting systems if they are considered during the initial building design and site layout. Cisterns can be placed below-ground, indoors, on rooftops that are structurally designed to support the added weight, and adjacent to buildings. Designers can work with architects and landscape architects to creatively site the cistern. Underground utilities or other obstructions should always be identified prior to final determination of the cistern location. When the rainwater harvesting system occurs on a private residential lot, its existence and purpose should be noted on the deed of record.

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

The final invert of the outlet pipe from the cistern must be at an elevation that will not allow water from the discharge point to backflow into the cistern. The elevation drops associated with the various components of a Rainwater Harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the Rainwater Harvesting system is feasible for the particular site.

Site topography and cistern location will also affect pumping requirements. Locating cisterns in low areas will make it easier to convey runoff from impervious surfaces and roofs of buildings to cisterns. However, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing cisterns at higher elevations may require larger diameter conveyance systems with flatter slopes. However, this will also reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the impervious source, ensuring that minimal conveyance lengths are needed.

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

Water Table. Below-ground cisterns are most appropriate in areas where the cistern can be buried above the water table. The cistern should be located in a manner that will not subject it to flooding.

In areas where a below-ground cistern will be buried partially below the water table, buoyancy calculations must be conducted for the empty cistern and special design features must be employed, as applicable, to secure the cistern. The cistern may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. **Cisterns must be installed according to the manufacturer's specifications.**

Soils. Cisterns should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. **The bearing capacity of the soil upon which the full cistern will be placed must be considered.** This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete base, may be appropriate depending on the soils. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Cold Climate Considerations. Rainwater Harvesting systems have a number of components that can be impacted by freezing winter temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs. For above-ground systems, winter-time operation may be more challenging, depending on cistern size and whether heat tape is used on piping.

Proximity of Underground Utilities. Rainwater harvesting system components should be sited to account for future maintenance of underground utilities in accordance with the utility owner's requirements. See Appendix 8 Stormwater Facility Setbacks for recommended separation distances for utilities.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the cistern. Areas of any size, including portions of drainage areas, can be used based on the sizing guidelines in this design specification. Runoff should be routed directly from impervious surfaces to Rainwater Harvesting systems in closed roof drain systems or storm drain pipes, avoiding surface drainage, which could allow for increased contamination of the water.

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

Chemicals, sealants, salts or other potential pollutants that may be applied to impervious surfaces should be considered prior to reuse or irrigation of harvested rainwater. Collection systems from non-rooftop sources should include pretreatment to remove sediment and hydrocarbons that may be present on driving surfaces. Acidic rainfall may result in leaching of metals from the roof surface, cistern lining or water laterals to interior connections. Limestone or other materials may be added in the cistern to buffer acidity, following the results of a pH test, if desired.

Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation. In some cases, however, industrial roof surfaces may also be designated as stormwater hotspots. Runoff from roof surfaces that may be contaminated should not be collected for reuse without first evaluating the effect that the pollutants in the runoff will have on the reuse system.

Setbacks from Buildings. Cistern overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. **Cisterns shall be designed to be watertight.** See Appendix 8 Stormwater Facility Setbacks for recommended setbacks if located outside of building.

Vehicle Loading. Whenever possible, below-ground Rainwater Harvesting systems should be placed in areas without vehicle traffic or be designed to support live loads from heavy trucks, a requirement that may significantly increase construction costs.

Cistern Material. Rainwater Harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. Table 5.4 below compares the advantages and disadvantages of different cistern materials.

Table 5.4. Advantages and Disadvantages of Various Cistern Materials
(Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009)

Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Should be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; should be painted or tinted for above-ground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Aluminized Steel	Commercially available; designs for above- and below-ground applications; aluminum alloy layer protects from corrosion; long service life	May need to be lined for potable use; soil pH may reduce service life
Steel Drums	Commercially available, alterable and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above- or below-ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above- or below-ground installations; neutralizes acid rain	Potential to crack and leak; permanent; provide adequate platform and design for placement in clay soils

Stone or Concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build
Steel Reinforced Polyethylene	Commercially available; can create very large cisterns (greater than 100,000 gallons); long service life; can support high cover and shallow burial depths	Not available for above-ground applications

5.4 Rainwater Harvesting Conveyance Criteria

Collection and Conveyance. The collection and conveyance system consists of the gutters, downspouts and pipes that channel rainfall into cisterns. Roof gutters and downspouts should be designed as they would for a building without a Rainwater Harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for Rainwater Harvesting.

Conveyance pipes to the cistern should have adequate size and slope to convey the necessary stormwater runoff and keep them clear of debris. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. **All conveyance pipes to the cistern, including gutters and downspouts, must be kept clean and free of sediment, debris and rust.**

Overflow. An overflow mechanism must be included in the Rainwater Harvesting system design to handle flows that exceed the capacity of the cistern. Overflow pipes must have a capacity equal to or greater than the total capacity of the inflow pipes and have a diameter and slope sufficient to drain the cistern before it reaches full capacity. The overflow pipe must be screened to prevent access to the cistern by rodents and birds.

5.5 Rainwater Harvesting Pretreatment Criteria

Pretreatment is required to keep sediment, leaves, and other debris from the system. Minimum pretreatment requirements differ between small and large cistern systems. All pretreatment devices should be low-maintenance or maintenance-free. The purpose of pretreatment is to significantly cut down on maintenance by preventing organic buildup in the cistern, thereby decreasing microbial food sources.

Small Cistern Rainwater Harvesting Systems. **Small cistern systems of 2,500 gallons or less shall have leaf screens or gutter guards for pretreatment as a minimum.** Leaf screens and gutter guards should be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the cistern. Built-up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005). Other acceptable pretreatment devices for small cistern systems include:

- First Flush Diverters: First flush diverters direct the initial pulse of rainfall away from the cistern. While leaf screens effectively remove larger debris such as leaves, twigs and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and bird and rodent feces (Figure 5.2). Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm.

- Roof Washers: Roof washers are placed just ahead of cisterns and are used to filter small debris from rainwater harvested from roof surfaces (Figure 5.3). Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers should be cleaned on a regular basis.

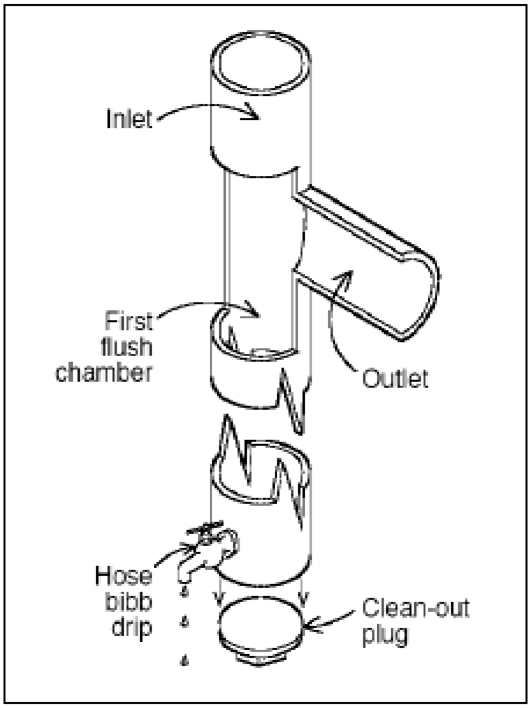

Figure 5.2. First Flush Diverter (Source: TWRB, 2005)

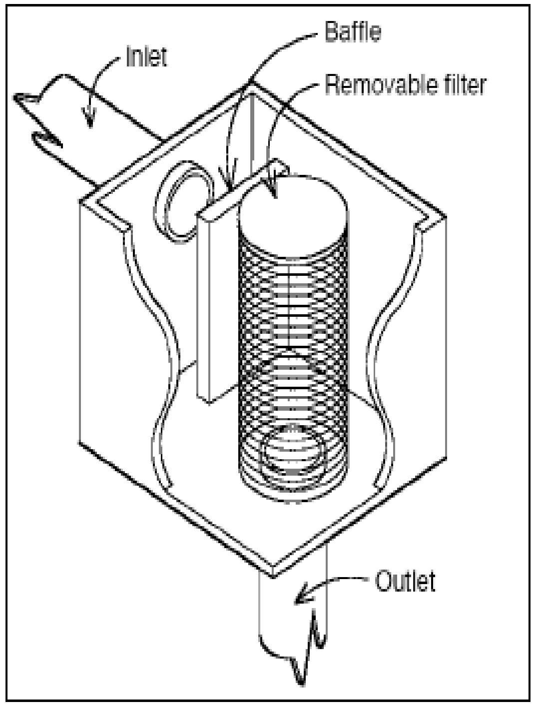

Figure 5.3. Roof Washer (Source: TWRB, 2005)

Large Cistern Rainwater Harvesting Systems. **Large cistern systems of greater than 2,500 gallons shall include a pretreatment system capable of treating and conveying the flow rate generated by the RPv from the contributing impervious surface drainage area without creating a backup or bypass condition.**

- Proprietary vortex devices and filters can provide filtering of harvested rainwater from larger impervious areas.

5.6 **Rainwater Harvesting Design Criteria**

System Components:

Rainwater Harvesting systems typically include the following components

- Impervious surface
- Collection and conveyance system (e.g., gutter and downspouts, storm drain)
- Pretreatment
- Cisterns
- Distribution system
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

1. Impervious Surface: Only runoff from impervious surfaces should be collected for reuse on the site. Collection of runoff from roofs and sidewalk areas are preferred over roads, driveways and parking lots because runoff from these areas requires less pretreatment prior to reuse on the site. Runoff from impervious surfaces that are treated with salt or other chemicals detrimental to plant health should not be reused on site for landscape irrigation. When collecting runoff from roofs, the rooftop should be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality.

2. Collection and Conveyance System: Runoff collected from impervious areas should be conveyed to the cistern in a closed pipe conveyance system to prevent further contamination of the runoff. Roof gutters and downspouts should be designed as they would for a building without a Rainwater Harvesting system. If the system will be used for management of larger storm events, the conveyance pipes should be designed to convey the appropriate storm intensities. Pipes connecting downspouts to the cistern should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. See *Section 5.4. Rainwater Harvesting Conveyance Criteria.*

3. Pretreatment: **Pretreatment is required to keep sediment, leaves, contaminants and other debris from the system.** Minimum pretreatment requirements differ between small and large cistern systems. All pretreatment devices should be low-maintenance or maintenance-free. The purpose of pretreatment is to significantly cut down on maintenance by preventing organic buildup in thecistern, and decrease microbial food sources, thereby improving the quality of the stored water resource. Leaf screens and gutter guards meet the minimal requirement for pretreatment of small cistern systems (less than 2,500 gallons), although direct water filtration is preferred. For large cistern systems (greater than 2,500 gallons), should include a full-capture pretreatment system capable of treating and conveying the flow rate generated by the Resource Protection event from the contributing impervious surface drainage area. A design intensity of 1.2 inches/hour is necessary to capture the Resource Protection event. See *Section 5.5. Rainwater Harvesting Pretreatment Criteria.*

4. Cisterns: The cistern is the most important and typically the most expensive component of a Rainwater Harvesting system. Cistern capacities range from 250 to over 30,000 gallons. Multiple cisterns can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage on-site as needed. Typical Rainwater Harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Cistern volumes are calculated to meet the water demand and stormwater storage volume credit objectives, as described in further detail below in this specification.

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

- **Rainwater Harvesting Systems shall comply with all applicable local, State, and Federal regulations.**
- **Above-ground cisterns must be impact resistant or protected from impact using bollards or other physical barriers.**
- **Below-ground cisterns must be designed to support the overlying soil and any other anticipated loads** (e.g., vehicles, pedestrian traffic, buoyancy, etc.).
- **Below-ground cisterns must have a standard size manhole or equivalent opening to allow access for cleaning, inspection, maintenance, and repair purposes.** This access point should be secured or locked to prevent unwanted access.
- Rainwater Harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. Table 5.4 in 5.3 Rainwater Harvesting Feasibility Criteria compares the advantages and disadvantages of different cistern materials.
- **Cisterns must be screened to discourage mosquito breeding and reproduction.**
- **A suitable foundation must be provided to support the cistern when it is filled to capacity.**
- **Dead storage below the outlet to the distribution system and an air gap at the top of the cistern must be added to the total volume.** For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth should be based on the pump specifications.
- **Any hookup to a municipal backup water supply must have a backflow prevention device to keep municipal water separate from stored rainwater.** This may include incorporating an air gap to separate the two supplies.

5. Distribution Systems: Most distribution systems require a pump to convey harvested rainwater from the cistern to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary stormwater treatment practice. **The Rainwater Harvesting system must be equipped with an appropriately-sized pump, if necessary, that produces sufficient pressure for all intended end-uses.**

The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the cistern and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. **A backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.**

Distribution lines for Continuous Rainwater Harvesting Systems must be buried beneath the frost line. Lines from the Rainwater Harvesting system to the building should have shut-off valves that are accessible when snow cover is present. **A drain plug or cleanout sump, also draining to a pervious area, must be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter. Distribution lines and above-ground outdoor pipes for Seasonal Rainwater Harvesting Systems shall be drained or otherwise winter-proofed during the non-operational period.**

Rainwater Harvesting Material Specifications: Gutters and downspouts used to convey roof runoff to the cistern may be composed of polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel. Lead may not be used as gutter and downspout solder, due to the possibility of contamination of runoff. Common conveyance materials for non-roof runoff include concrete, HDPE, PVC, aluminum and galvanized steel.

Cisterns must be structurally sound, watertight, and sealed using a water-safe, non-toxic material. Re-purposed tanks used to store rainwater for reuse must be acceptable for potable water or food-grade products. Above-ground cisterns must be UV resistant and opaque to prevent the growth of algae in the tank. Below-ground cisterns shall be located below the frost line.

The basic material specifications for Rainwater Harvesting systems are presented in Table 5.3. Designers should consult with experienced Rainwater Harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated cisterns and other system components.

Sizing of Rainwater Harvesting Systems

Size the cistern to meet the required runoff reduction volume generated from the contributing drainage area based on the Resource Protection Event. However, any storage provided in a Rainwater Harvesting system, either not meeting or exceeding the RPv volume, will be accounted. In addition, the designer needs to consider both the water supply (i.e., runoff volume) and the demand (i.e., the irrigation and other water use needs). The water demand component is critical, and the designer needs to determine both how much water is needed, and whether that demand is seasonal or throughout the year. Even though more intense rainfall typically occurs during the growing season, it is desirable to use at least a portion of the volume in the cistern throughout the year.

Seasonal Rainwater Harvesting Systems:

In the Seasonal Rainwater Harvesting System design, water demand is for landscape irrigation, and occurs only during the growing season. **For seasonal rainwater harvesting systems, weekly irrigation demand shall be at least 50% of the stored volume.**

Continuous Rainwater Harvesting Systems:
For Continuous Rainwater Harvesting Systems, a minimum of 50% of the demand shall be met through non-irrigation needs, such as plumbing, process water, car washing, or other uses that are present throughout the year.

Maintenance Access. **All Rainwater Harvesting Systems must be designed so as to be accessible for maintenance.** Good access is needed so crews can remove sediments, make repairs and preserve infiltration practice treatment capacity.

- **A maintenance right-of-way or easement must extend to the Rainwater Harvesting System from a public or private road.**
- **Adequate maintenance access must extend to all components of the Rainwater Harvesting System.**
- **Maintenance access must meet the following criteria:**
    - **Minimum width of fifteen feet.**
    - **Profile grade that does not exceed 10H:1V.**
    - **Minimum 10H:1V cross slope.**

Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines. When not specified in local code, all components of the Rainwater Harvesting System should be set back at least 15 feet from property lines to ensure maintenance access.

5.7 Rainwater Harvesting Landscaping Criteria

If the harvested rainwater is to be used for irrigation, the design plan must include the delineation of the proposed planting areas to be irrigated and quantification of the expected water demand based upon the area to be irrigated. Native plants are recommended for the planting plan as they will best tolerate dry periods and will not require supplemental irrigation from another water source. Calculations to determine expected irrigation demand may be completed in accordance with the procedure provided in U.S. Green Building Council's document "LEED for Homes Rating System", January 2008.

5.8 **Rainwater Harvesting Construction**

Rainwater Harvesting Installation. It is advisable to have a single contractor to install the Rainwater Harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with Rainwater Harvesting system sizing, installation, and placement. **Rainwater Harvesting system components connecting to the internal plumbing system shall be installed by a licensed plumber.**

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

1. Properly install the cistern at the design location.
2. Route all downspouts, roof drains, and conveyance pipes to pretreatment devices.
3. Route all pipes from pretreatment devices to the cistern.
4. Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release). Test system for proper function.
5. Flush roof drains, downspouts, conveyance pipes and cistern.
6. Stormwater should not be allowed to overflow until the overflow filter path has been stabilized with vegetation.

Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls**
- **Excavation and grading including interim and final elevations for cistern foundations**
- **Installation of cistern, pretreatment system and conveyance system**
- **Implementation of required stabilization**
- **Final construction review including development of a punch list for facility acceptance**

Construction Inspection. The following items should be inspected prior to final sign-off and acceptance of a Rainwater Harvesting system:

- Collected impervious area matches plans
- Diversion system is installed in accordance with the plan
- Pretreatment system is installed
- Mosquito screens are installed on all cistern openings
- Overflow device is directed as shown on plans
- Rainwater Harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Landscape / lawn irrigation system and/or secondary stormwater treatment practice(s) is installed as shown on plans
- Piping to reuse system constructed as designed on the plan

Post Construction Verification Documentation. **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the rainwater harvesting practice has been constructed in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Items to be checked and verified are as follows:**

- **Presence of a pretreatment device.**

- **Capacity of any cisterns matches the design plan.**
- **For ponds, the constructed volume shall be no less than 90% of the design volume.**
- **For continuous systems, all pumps, controls, and other appurtenances installed in accordance with the plan.**
- **For irrigation systems, area of coverage is within ninety percent of that shown on the plan.**

5.9 Rainwater Harvesting Maintenance Criteria

Maintenance Agreements

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.
The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Operation and Maintenance Plans shall clearly outline how Rainwater Harvesting Systems will be managed taking into account seasonal variations and cistern location. Maintenance of a Rainwater Harvesting Systems is driven by annual maintenance reviews that evaluate the condition and performance of the system. Based on maintenance review results, specific maintenance tasks may be required. It is highly recommended that periodic self-inspections and maintenance be conducted for each system as well.

Rainwater Harvesting System Maintenance Schedule

Maintenance requirements for Rainwater Harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. Table 5.5 describes routine maintenance tasks to keep Rainwater Harvesting systems in working condition. Inspections of proprietary components of the Rainwater Harvesting system should be conducted by a qualified inspector as determine by the manufacturer.

Table 5.5. Suggested maintenance items for Rainwater Harvesting systems

Frequency	Maintenance Items
Twice a year	Keep gutters, downspouts, and conveyance pipes free of leaves and other debris
Four times a year	Inspect and clean pretreatment devices
Once a year	Inspect and clean cistern lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately
Once a year	Inspect condition of overflow pipes, overflow filter path and/or secondary stormwater treatment practices
Every third year	Inspect cistern for sediment buildup
Every third year	Check integrity of backflow preventer

Every third year	Inspect structural integrity of cistern, pump, pipe and electrical system
As needed	Replace damaged or defective system components
As needed	Clear overhanging vegetation and trees over impervious surface

Mosquitoes. In some situations, poorly designed Rainwater Harvesting systems can create habitat suitable for mosquito breeding and reproduction. Screens on above- and below-ground cisterns may prevent mosquitoes and other insects from entering the cisterns. However, if screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.

At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions should be disconnected and drained. It may be possible to reconnect the former roof leader systems for the winter.

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

5.10 References

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

Cabell Brand Center. 2009. *Virginia Rainwater Harvesting Manual, Version 2.0*. Salem, VA. (Draft Form) http://www.cabellbrandcenter.org

Forasté, J. Alex and Lawson, Sarah. 2009. *Cistern Design Spreadsheet*, McKee-Carson, Rainwater Management Systems, Inc., and Center for Watershed Protection, Inc.

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

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

U. S. Green Building Council. 2008. LEED for Homes Rating System January 2008.

6.0 Restoration Practices

Definition: **Restoration Practices include Regenerative Stormwater Conveyance Systems (RSCS), also known as Coastal Plain Outfalls, and other practices that restore existing degraded natural systems to their former functional condition. Streambank stabilization is also included as a Restoration Practice.**

Photo: Hala Flores, Anne Arundel Co., MD

Regenerative Stormwater Conveyance Systems (RSCS) are open-channel conveyance structures that convert, through attenuation ponds and a sand seepage filter, surface storm flow to shallow groundwater flow. In doing so, these systems safely convey, attenuate, and treat the quality of stormwater runoff. These structures utilize a series of constructed shallow aquatic pools, riffle grade control, native vegetation, and an underlying sand/woodchip mix filter bed media. The physical characteristics of the RSCS channel are best characterized by the Rosgen A or B stream classification types, where "bedform occurs as a step/pool, cascading channel which often stores large amounts of sediment in the pools associated with debris dams" (Rosgen, 1996). The pretreatment, recharge, and water quality sizing criteria presented in these guidelines are similar to criteria for a typical stormwater filtering device. These structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles.

Streambank stabilization includes bioengineering techniques as well as structural solutions to abate the mass wasting of soil as a result of the movement of water. Despite the name, many of these practices can be used to stabilize shorelines as well as streambanks.

Design variants fnclude:

- 6-A **Step Pool RSCS**
- 6-B **Seepage Wetland RSCS**
- 6-C **Streambank Stabilization**

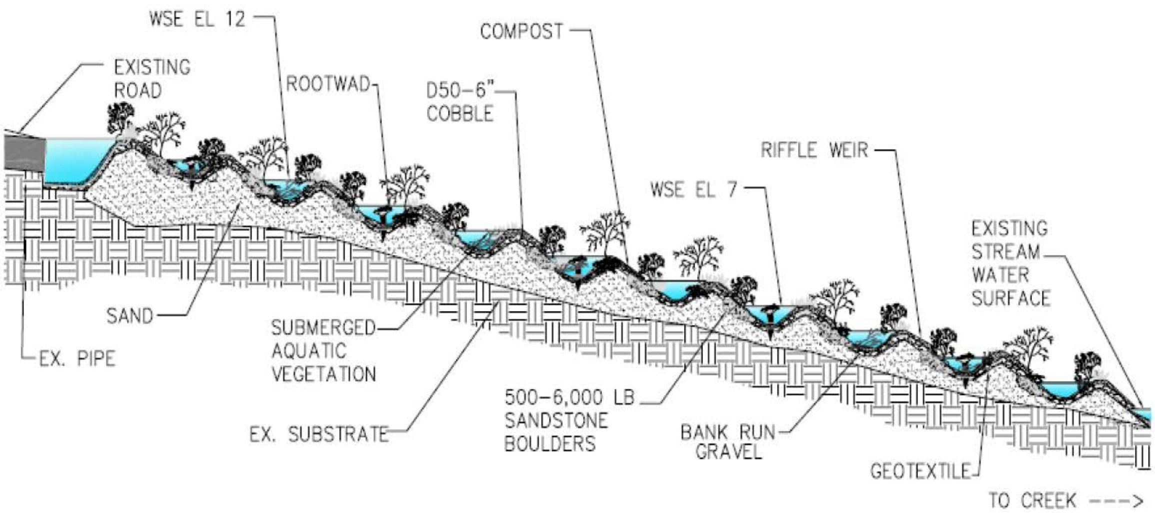

Figure 6.1 Example of a Step Pool RSCS

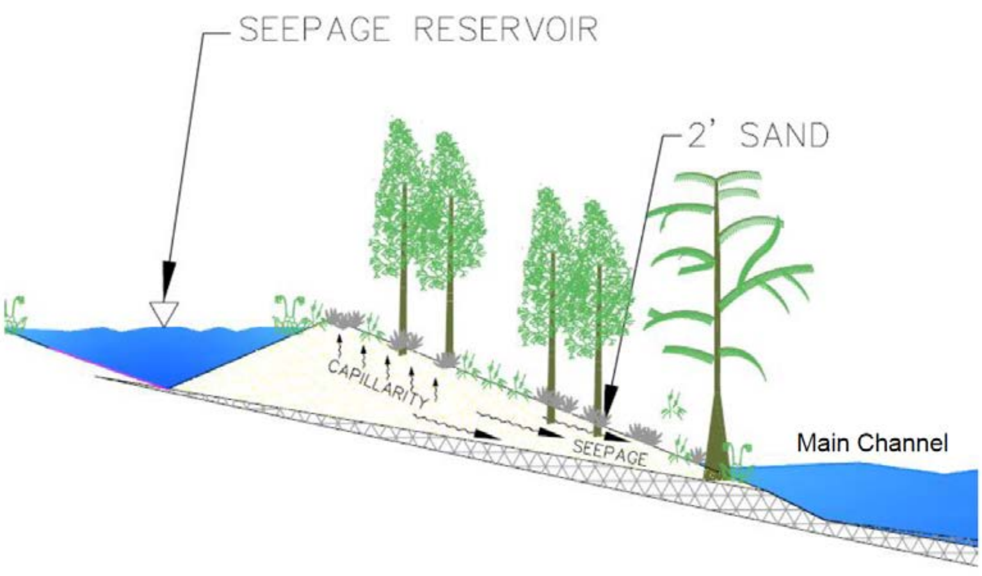

Figure 6.2 Example of a Seepage Wetland RSCS

6.1 Restoration Practices Credit Calculations

The performance of Restoration Practices from both a runoff reduction and pollutant reduction standpoint is highly dependent on the design and site characteristics for a given application; therefore, **runoff reduction and pollutant reduction performance credits for Restoration Practices shall be determined by the Department on a case-by-case basis** until more data becomes available.

6.1 Restoration Practices Performance Credits

Runoff Reduction	
Retention Allowance	TBD on Case-by-Case Basis
RPv -A/B Soil	TBD on Case-by-Case Basis
RPv - C/D Soil	TBD on Case-by-Case Basis
Cv	TBD on Case-by-Case Basis
Fv	TBD on Case-by-Case Basis
Pollutant Reduction	
TN Reduction	TBD on Case-by-Case Basis
TP Reduction	TBD on Case-by-Case Basis
TSS Reduction	TBD on Case-by-Case Basis

6.2 Restoration Practices Design Criteria

The design of Regenerative Stormwater Conveyance Systems and Streambank Stabilization Practices requires specialized knowledge and skills. However, some general awareness of these systems and how they function may be helpful in evaluating potential applications for this practice.

As of this date, the best available design criteria for Regenerative Stormwater Conveyance Systems have been developed by Anne Arundel County, Maryland. Design Guidelines for Regenerative Step Pool Storm Conveyance, latest edition, developed by Anne Arundel County, Maryland may be used as the primary design tool for Step Pool RSCS and Seepage Wetland RSCS variants. This document is frequently updated. Therefore, designers are advised to check Anne Arundel County's Website to see if a newer version has been released prior to initiating a proposed design.

The USDA Natural Resources Conservation Service (NRCS) latest design guidance for streambank and shoreline protection in Chapter 16 of its Engineering Field Handbook may be used as the primary design tool for the Streambank Stabilization variant. This chapter is included as Design Guide 3 in the *Delaware Erosion & Sediment Control Handbook.*

6.3 Restoration Practices Construction Criteria

Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the restoration practice has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.

6.4 References

Anne Arundel County, Dept. of Public Works, Bureau of Engineering. "Design Guidelines for Regenerative Step Pool Storm Conveyance (SPSC)". Rev. 5, December 2012.

USDA, Natural Resource Conservation Service, Part 650, Engineering Field Handbook, Chapter 16, "Streambank and Shoreline Protection". 1996.

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7.0 Rooftop Disconnection

Definition: **Rooftop Disconnection involves managing runoff close to its source by intercepting, infiltrating, filtering, treating, or reusing it as it moves from the rooftop to the drainage system. Rooftop Disconnection can reduce the volume of runoff that enters the combined or separate storm sewer systems.**

Photo courtesy of Montgomery County, Maryland

Rooftop Disconnection reduces a portion of the Resource Protection Volume (RPv). In order to meet requirements for larger storm events, Rooftop Disconnection should be combined with additional practices. There are no additional variants for this practice.

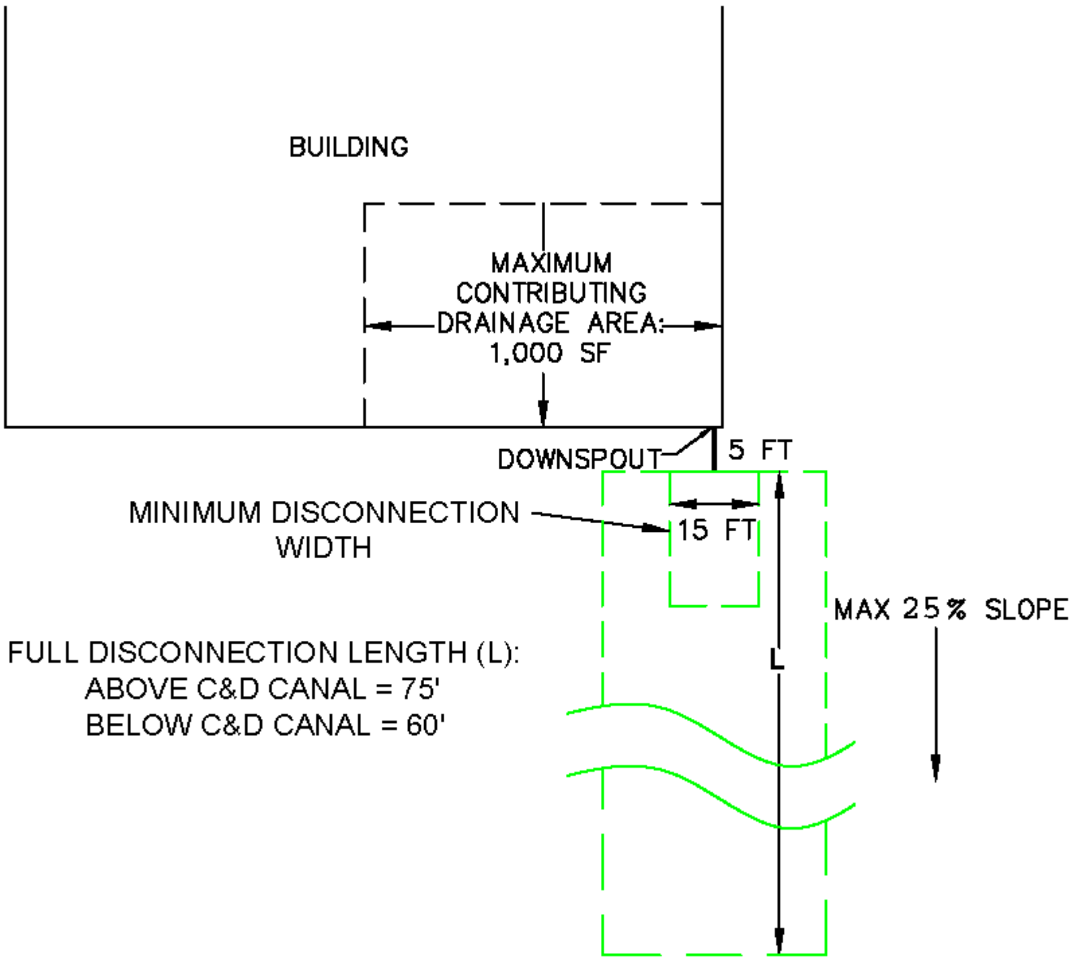

Figure 7.1 Simple Rooftop Disconnection

7.1 Rooftop Disconnection Stormwater Credit Calculations

Rooftop Disconnection that meets the minimum full disconnection length shall receive the following annual runoff reduction and pollutant reduction credits (see Table 7.1 and Table 7.3). **Partial RPv runoff reduction credit shall be based on the ratio of the disconnection length provided to the full disconnection length.** For example, if the disconnection length provided is half the minimum full disconnection length shown in Table 7.3, the RPv runoff reduction credit would be 50%. Pollutant reduction credits are based upon the load reduced through runoff reduction.

Table 7.1 Rooftop Disconnection Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv	**100% Annual Runoff Reduction***
Cv	**10% of RPv Allowance**
Fv	**1% of RPv Allowance**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

*Based on meeting full disconnection length shown in Table 7.3.

7.2 Rooftop Disconnection Practice Summary

Table 7.2 summarizes the various criteria for Rooftop Disconnection.

Table 7.2 Rooftop Disconnection Practice Summary

Feasibility Criteria (Section 7.3)	• **Minimum disconnection width = 15ft.** • **5 foot transition section from downspout point of discharge to beginning of disconnection area.** • **If used as RPv credit in residential subdivision, Record Plan shall include a note identifying Rooftop Disconnection as a BMP.** • **Max. 25% slope on disconnection area.** • All soil types eligible. • **Max. 1,000 sq. ft. roof area per downspout.** • **Receiving area graded away from structure per local requirements.**
Conveyance Criteria (Section 7.4)	• **Safely convey RPv, Cv, and Fv over receiving area without causing erosion.** • Provide turf reinforcement or other measures as necessary.
Pretreatment Criteria (Section 7.5)	• **Downspout energy dissipater required at discharge point of downspout.**
Design Criteria (Section 7.6)	• **Maximum 1,000 sq. ft. rooftop per disconnection.** • **Full disconnection length above C&D Canal = 75'.** • **Full disconnection length below C&D Canal = 60'.** • **No imperviousness within disconnection area.** • **Disconnection area vegetatively stabilized for non-erosive condition.** • Use sensitive area protection to prevent compaction during construction.
Landscaping Criteria (Section 7.7)	• **All pervious disconnection areas receiving rooftop runoff shall be vegetatively stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems.**
Construction Criteria (Section 7.8)	• **The post construction verification for Rooftop Disconnection shall visually verify that no impervious surface exists within the rooftop disconnection area.**

Maintenance Criteria (Section 7.9)	• **The Sediment and Stormwater Plan shall include the following operation and maintenance notes for Rooftop Disconnection:**
	    o **The rooftop disconnection area shall be maintained in a stabilized vegetative condition.**
	    o **Commercial or common-area parcels shall ensure that downspouts remain disconnected and pervious filtering/infiltrating areas are not converted to impervious surface or disturbed.**

7.3 Rooftop Disconnection Feasibility Criteria

Rooftop Disconnection is ideal for use on commercial, institutional, municipal, multi-family residential, and single-family residential buildings. Key constraints with Rooftop Disconnection include available space, soil permeability, and soil compaction. For Rooftop Disconnection, the following feasibility criteria exist:

Required Space. **Regardless of rooftop area collected the available pervious disconnection area at the point of discharge for any downspout must be at least 15 feet wide. A 5 foot long transition section from the downspout point of discharge shall be provided prior to the beginning of the disconnection area.** The pervious disconnection area length may be decreased as needed to achieve partial runoff reduction credit**. If being used for RPv credit in a residential subdivision, a Record Plan shall include a note identifying Rooftop Disconnection as a BMP.** A sample Record Plan note is as follows: "A minimum unobstructed pervious, vegetated area of fifteen feet wide should be provided at each downspout conveying rooftop runoff to allow for runoff reduction."

Site Topography. Rooftop Disconnection is best applied when the grade of the receiving pervious area is on relatively low gradient. **The disconnection area shall have a maximum slope of 25%.** Turf reinforcement or other stabilization measures may include appropriate reinforcing materials that are confirmed by the designer to be non-erosive for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan approving authority.

Soils. Rooftop Disconnection can be used on any post-construction Hydrologic Soil Group.

Contributing Drainage Area. **The maximum impervious rooftop area treated may not exceed 1,000 sq. ft. per downspout.**

Receiving Area. **Receiving area shall be graded away from the structure per local requirements.**

7.4 Rooftop Disconnection Conveyance Criteria

Rooftop Disconnection areas shall be designed to safely convey all design storm events (RPv, Cv, and Fv) over the receiving area without causing erosion. In some applications, turf reinforcement matting or other appropriate reinforcing materials may be needed to prevent erosion of the pervious area anticipated during larger design storms.

7.5 Rooftop Disconnection Pretreatment Criteria

Pretreatment is not needed for Rooftop Disconnection; however, a transition area should be provided between the downspout discharge point and the disconnection area. **A downspout energy dissipater shall be located at the discharge point of the downspout.**

7.6 Rooftop Disconnection Design Criteria

The maximum impervious rooftop area treated shall not exceed 1,000 sq. ft. per downspout. Regardless of rooftop area collected the available pervious disconnection area at the point of discharge for any downspout must be at least 15 feet wide. A 5 foot long transition section from the downspout point of discharge shall be provided prior to the beginning of the disconnection area. The minimum full disconnection lengths shall be as follows (see Table 7.3):

Table 7.3 Minimum Full Rooftop Disconnection Lengths

	Disconnection Length (ft.)
Above C&D Canal	**75**
Below C&D Canal	**60**

Partial RPv runoff reduction credit shall be based on the ratio of the disconnection length provided to the full disconnection length. Impervious areas shall not be constructed within the area designated as the pervious rooftop disconnection area. The pervious rooftop disconnection area must be stabilized with vegetation for a non-erosive condition (see Table 7.4).

During site construction, care should be taken not to compact the receiving pervious area. To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of the receiving pervious area both during and after construction. This can be accomplished by clearly delineating the pervious areas to receive disconnected runoff on all development plans and protecting them in accordance with sensitive area protection details prior to the start of land disturbing activities. If compaction within the rooftop disconnection area occurs, the soils may be amended or aerated post-construction to increase permeability.

7.7 Rooftop Disconnection Landscaping Criteria

All pervious disconnection areas receiving rooftop runoff shall be vegetatively stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several types of grasses appropriate for Rooftop Disconnection areas are listed in Table 7.4. The maximum flow velocities should not exceed the values listed in the table for the selected grass species and the specific site slope.

Table 7.4. Recommended Vegetation for Pervious Disconnection Areas.

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Kentucky Bluegrass	0-5	7	5
	5-10	6	4
	>10	5	3
Tall Fescue Grass Mixture	0-5	6	4
	5-10	4	3
Annual and Perennial Rye	0-5	4	3
Sod		4	3
Source: USDA, TP-61, 1954; City of Roanoke Virginia Stormwater Design Manual, 2008.			

7.8 Rooftop Disconnection Construction Criteria

Construction Review. Construction review is critical to ensure compliance with design standards. Construction reviewers should evaluate the performance of the disconnection after the first substantial storm to look for evidence of gullies, undercutting, or sparse vegetative cover. Spot repairs should be made, as needed.

Post Construction Verification. Post construction verification may be provided through visual inspection by the construction reviewer. When proper construction of the disconnection area is questioned, the construction reviewer may request for spot grade elevations to be surveyed at the beginning and end of the delineated disconnection area, including spot grades at intervals necessary to determine that the design criteria have been met. **The post construction verification for Rooftop Disconnection shall visually verify that no impervious surface exists within the rooftop disconnection area.**

7.9 Rooftop Disconnection Maintenance Criteria

Maintenance of Rooftop Disconnection areas involves the regular lawn or landscaping maintenance in the filter path from the rooftop to the street. In some cases, runoff from a Rooftop Disconnection may be directed to a more natural, undisturbed setting (i.e., where lot grading and clearing is “fingerprinted” and the proposed filter path is protected).

The Sediment and Stormwater Plan shall include the following operation and maintenance notes for Rooftop Disconnection:

- **The rooftop disconnection area shall be maintained in a stabilized vegetative condition.**
- **Ensure that downspouts remain disconnected and pervious filtering/infiltrating areas are not converted to impervious surface.**

The Sediment and Stormwater Plan should clearly outline how vegetation in the Rooftop Disconnection pervious area will be managed in the future. Maintenance of Rooftop Disconnection is driven by regular maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

7.10 References

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Virginia DCR Stormwater Design Specification No. 1: Rooftop (Impervious Surface) Disconnection, Version 1.9, March 1, 2011

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8.0 Vegetated Channels

Definition: **Vegetated channels are open conveyances planted with grass or other suitable vegetation and having a shallow depth of flow to allow runoff to be filtered and recharged along the length of the channel.**

Design variants include:

- 8-A **Bioswale**
- 8-B **Grassed Channel**

Vegetated channels systems are not typically designed to provide stormwater detention. Vegetated channels can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets, and pipes. The performance of vegetated channels will vary depending on the underlying soil permeability. Their runoff reduction performance can be boosted when compost amendments are added to the bottom of the channel. Where development density, topography, soils, and water table permit, vegetated channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system.

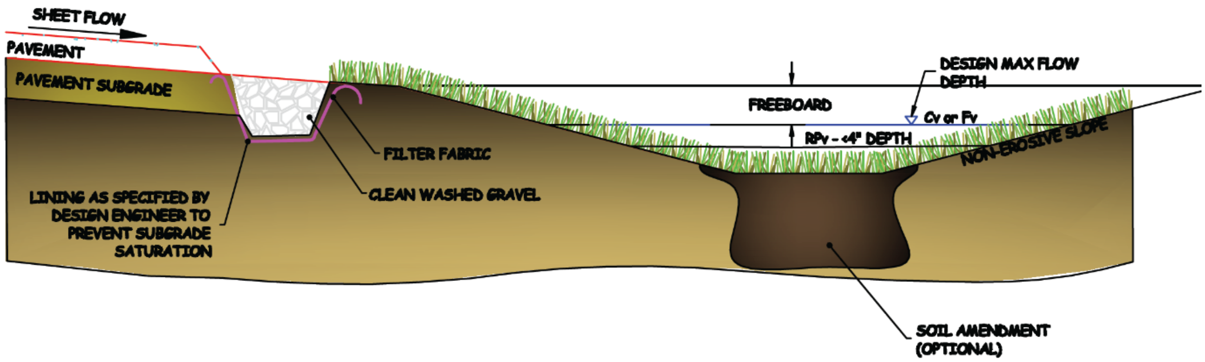

Figure 8.1. Typical Section for Bioswale / Grassed Channel

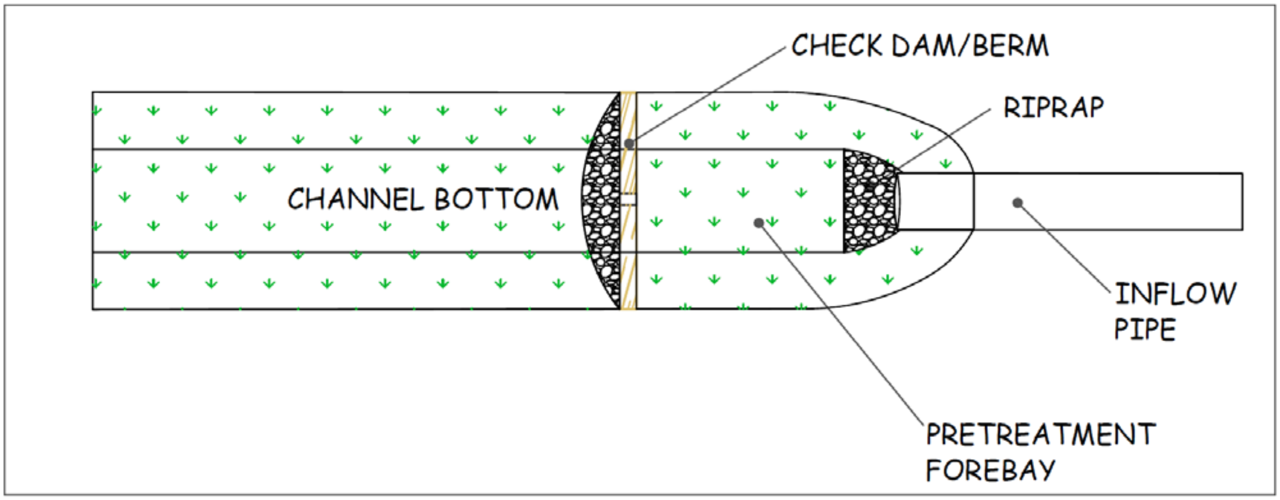

Figure 8.2. Example Check Dam and Forebay

8.1 Vegetated Channel Stormwater Credit Calculations

Vegetated channels receive the following annual runoff reduction and pollutant reduction credits. The credits vary depending upon the specific type employed as listed in Table 8.1.

Table 8.1 Vegetated Channel Performance Credits

Runoff Reduction*	
Retention Allowance	0%
RPv - A/B Soil or Compost Amended C Soil	**Bioswale : 50% Annual Runoff Reduction Grassed Channel: 20% Annual Runoff Reduction**
RPv - C/D Soil	**Bioswale: 25% Annual Runoff Reduction Grassed Channel: 10% Annual Runoff Reduction**
Cv	**10% of RPv Allowance**
Fv	**1% of RPv Allowance**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

The following tables may be used to compute the Resource Protection event (RPv) surface recharge reductions. The BMP Performance percentage is based on the soil classification of the BMP and the Runoff Volume entering the BMP in the RPv event.

1. Bioswale:

RPv Bioswale Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	44%	21%
0.76 - 1.50 in / acre	47%	23%
0.16 - 0.75 in / acre	57%	27%
0.00 - 0.15 in / acre	95%	95%

2. Grassed Channel:

RPv Grassed Channel Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	16%	8%
0.76 - 1.50 in / acre	18%	9%
0.16 - 0.75 in / acre	22%	11%
0.00 - 0.15 in / acre	100%	100%

*See Appendix A-7 Alternative Methods for RPv Compliance for additional information on modeling this practice using traditional hydrologic methods.

8.2 Vegetated Channel Practice Summary

Table 8.2 summarizes various criteria for Vegetated Channels, and Table 8.3 summarizes the materials specifications for these practices. For more detail, consult Sections 8.3 through 8.7. Section 8.8 describes practice construction and maintenance criteria.

Table 8.2 Vegetated Channel Practice Summary

Feasibility Criteria (Section 8.3)	• Can convey runoff from hotspots but does not qualify as hotspot treatment. • **The bottom of vegetated channels shall be above the seasonal high water table.** • Recommended longitudinal slopes are <4%. • Longitudinal slope <0.5% on C/D soils should be designed as Wetland Swale. • **Approval from the applicable utility company or agency is required if utility lines will run below the vegetated channel.**
Conveyance Criteria (Section 8.4)	• **The bottom width and slope of a vegetated channel shall be designed such that the flow depth based on 50% of RPv peak flow rate, does not exceed 4 inches.** • **Vegetated channels shall convey the Cv and Fv peak flow rate at non-erosive velocities for the soil and vegetative cover provided.**
Pretreatment Criteria (Section 8.5)	• **Every inlet into a vegetated channel system shall have pretreatment.**
Design Criteria (Section 8.6)	• **The bottom width of a trapezoidal channel shall be a minimum of 2 feet wide to ensure that an adequate surface area exists along the bottom of the channel for filtering.** • **If a channel bottom will be wider than 8 feet, benches, check dams, level spreaders, or multi-level cross sections shall be incorporated to prevent braiding and erosion along the channel bottom.** • **Vegetated channel side slopes shall be no steeper than 3H:1V.** • **Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom to prevent hydrostatic head from pushing out the underlying soils.** • **Check dams must be designed to pass the Cv design storm peak flow.** • **Check dams shall be composed of wood, concrete, stone, or other non-erodible material.** • **Each check dam shall have a weep hole or similar drainage feature, to allow for dewatering following a storm event.** • **All seeded vegetated channels require a minimum SSM-III biodegradable erosion control matting conforming to Delaware Erosion and Sediment Control Handbook.** • **Soil amendments, when used, shall extend over the length and width of the channel bottom, and the compost shall be incorporated to the depth as shown on the approved plan.** • **Hydraulic capacity shall be verified using Manning's equation or an accepted equivalent method, such as tractive forces and vegetal retardance.** • **Design storm flow depth based on 50% of RPv peak flow rate shall be maintained at 4 inches or less.**

Design Criteria (Section 8.6) *cont.*	• **Manning's "n" value for vegetated channels shall be 0.2 for flow depths up to 4 inches, decreasing to 0.03 above 4 inches of flow depth.**
	• **If alternative vegetation is used to increase the Manning's "*n*" value and decrease the resulting channel width, material specifications and construction oversight shall be provided to ensure that the denser vegetation is actually established.**
	• **Peak flow rates for the Cv and Fv storms shall be non-erosive.**
	• **The Cv peak flow rate shall be contained within the channel banks.**
	• **If the Fv storm event is not contained within the channel, the area of inundation shall be shown.**
	• **The total peak discharge at the outlet shall be used to calculate the depth of flow and velocity for the channel unless lateral flow along the channel is calculated incrementally.**
	• **Hydraulic residence time is the time for runoff to travel the full length of the channel. For both Bioswales and Grassed Channels hydraulic residence time is computed based upon 50% of the RPv peak flow rate.**
	    o **For Bioswales, the hydraulic residence time shall be a minimum of 9 minutes. If flow enters the channel at several locations, a 9-minute minimum hydraulic residence time shall be demonstrated for each entry point.**
	    o **For Bioswales, adjusted RPv runoff reduction credit based on the ratio of the computed residence to the minimum residence time shall be applied to Bioswales that meet the maximum depth of flow criteria. The maximum adjusted RPv runoff reduction credit is 75% for HSG A/B soils and 40% for HSG C/D soils. Adjusted RPv reduction credit shall not be granted for computed residence times of less than 5 minutes.**
	    o **For Grassed Channels, the hydraulic residence time for concentrated flow entering the Grassed Channel shall be a minimum of 5 minutes.**
	    o **Lateral flow entering the Grassed Channel as sheet flow may be excluded from residence time calculations but shall be accounted for in the channel depth and velocity calculations.**
	    o **For Grassed Channels with in-line culverts, the proportion of grassed channel flow length shall be a minimum of 80% of the total flow length.**
	• **All Vegetated Channels must be designed so as to be accessible for maintenance.**
	    o **A maintenance right-of-way or easement must extend to the Vegetated Channel from a public or private road**
	    o **Adequate maintenance access must extend to the full Vegetated Channel length.**
	    o **Maintenance access must meet the following criteria:**
	        ▪ **Minimum width of 15 feet.**
	        ▪ **Profile grade that does not exceed 10H:1V.**
	        ▪ **Minimum 10H:1V cross slope.**

Landscaping Criteria (Section 8.7)	• **A planting plan must be provided that indicates the methods used to establish and maintain vegetative stabilization of the vegetated channel.** • **Vegetated channels shall be established at such a density to achieve a 90% vegetated cover for project completion.** • **All seeded vegetated channels require a minimum SSM-III biodegradable erosion control matting conforming to Delaware Erosion and Sediment Control Handbook.**

Construction Criteria (Section 8.9)	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**
	  o **Pre-construction meeting**
	  o **Initial site preparation including installation of erosion and sediment controls, sensitive area protection surrounding vegetated channel locations, and blockage of inlets to vegetated channels**
	  o **Excavation and grading including interim and final elevations**
	  o **Construction of check dams and pretreatment practices, as applicable**
	  o **Implementation of required stabilization and planting plan**
	  o **Implementation of required stabilization and planting plan**
	• **Upon facility completion, the owner shall submit post construction verification documents as follows to demonstrate that the vegetated channel has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency:**
	  o **Spot elevations of top of bank, bottom of bank, and centerline of the vegetated channel every 25 feet throughout the length of the channel**
	  o **Additional spot elevations that demonstrate positive downstream drainage beyond the end of the vegetated channel**
	  o **Cross section of the vegetated channel at the midpoint**
	  o **Photo documentation of the vegetated channel depicting the channel bottom width and verification of achievement of the required 90% vegetated cover**
	• **The constructed slope, bottom width, depth, and length of the vegetated channel shall be within 90% of the design geometrics for those parameters.**
	• **In the event that the constructed allowable tolerances are exceeded for the vegetated channel, supplemental calculations shall be submitted to determine if the vegetated channel, as constructed, meets the design requirements. The computed residence time rounded to the nearest minute shall be no less than the minimum design residence time.**
	• **Performance of a vegetated channel shall be evaluated by the Department or Delegated Agency if requested in writing to determine if reconstruction of a vegetated channel that exceeds allowable tolerances is necessary.**

Maintenance Criteria (Section 8.9)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system.** • **Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

Table 8.3. Vegetated Channel Materials Specifications

Component	Specification
Grass	A dense cover of water-tolerant, erosion-resistant grass. The selection of an appropriate species or mixture of species is based on several factors including climate, soil type, topography, and sun or shade tolerance. Grass species should have the following characteristics: • Deep root system to resist scouring • High stem density with well-branched top growth • Water-tolerance • Resistance to being flattened by runoff • An ability to recover growth following inundation • Salt tolerant for any channel receiving runoff from roadways
Check Dams	• **Check dams shall be composed of wood, concrete, stone, or other non-erodible material.** • **Each check dam shall have a weep hole or similar drainage feature, to allow for dewatering following a storm event.** • Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak, or locust.
Erosion Control Matting	• **All seeded vegetated channels require a minimum SSM-III biodegradable erosion control matting conforming to Delaware Erosion and Sediment Control Handbook.**

8.3 Vegetated Channel Feasibility Criteria

Vegetated channels are primarily applicable for land uses such as roads, highways, and residential development. Some key feasibility issues for vegetated channels are discussed below.

Contributing Drainage Area. The recommended maximum contributing drainage area to a vegetated channel is 10 acres. Smaller drainage areas are preferred. The design criteria for maximum channel velocity and depth are applied along the entire length (see Section 8.6). These criteria will determine the maximum drainage area to a specific vegetated channel.

Available Space. Vegetated channel footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Vegetated channels can be incorporated into linear development applications (e.g., roadways) by using the space typically required for an open section drainage feature. The footprint required will likely be greater than that of a typical conveyance channel, but the benefit of the runoff reduction may reduce the footprint requirements for stormwater management elsewhere on the development site.

Site Topography. Vegetated channels should be used on sites with longitudinal slopes of less than 4%. Check dams can be used to reduce the effective slope of the channel and lengthen the contact time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to maintain a continuous grade, in order to avoid flat areas with pockets of standing water. Sites with longitudinal slopes less than 0.5% on HSG ‘C’ or ‘D’ soils may need to be designed as a wetland swale in accordance with Specification 12. Constructed Wetlands based on site conditions.

Land Uses. Vegetated channels can be used in residential, commercial, or institutional development settings.

If there is adequate width and distance between driveways, the linear nature of vegetated channels makes them well-suited to treat highway or low- and medium-density residential road runoff. As long as drainage area limitations and design criteria can be met, typical applications of vegetated channels include the following:

- Within a roadway easement
- Along the margins of small parking lots
- Oriented from the roof (downspout discharge) to the street
- Disconnecting small impervious areas

Vegetated channels are not recommended for high density residential development due to a lack of available land and the frequency of driveway crossings along the channel.

Vegetated channels having a minimum length of 20 feet may provide pretreatment for other stormwater management systems.

Hotspot Land Use. Vegetated channels may be used to convey runoff from stormwater hotspots but are typically part of a treatment train rather than a stand-alone practice. For a list of designated stormwater hotspot operations, consult Appendix 4 Stormwater Hotspots.

Hydraulic Capacity. Vegetated channel surface dimensions are typically determined by the need to adequately convey the Cv storm event, which can be a constraint in the siting of vegetated channels within existing rights-of-way (e.g., constrained by sidewalks).

Soils. Soil conditions do not constrain the use of vegetated channels. However, to improve performance, vegetated channels situated on low-permeability soils may incorporate compost amendments.

Depth to Water Table. **The bottom of vegetated channels shall be above the seasonal high water table.**

Utilities. Interference with underground utilities should be avoided, particularly water and sewer lines. **Approval from the applicable utility company or agency is required if utility lines will run below the vegetated channel**.

Floodplains. Vegetated channels should be constructed outside the limits of the 100-year floodplain.

Avoidance of Irrigation or Baseflow. Vegetated channels should be located so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other dry weather flows.

8.4 Vegetated Channel Conveyance Criteria

The bottom width and slope of a vegetated channel shall be designed such that the flow depth based on 50% of RPv peak flow rate, does not exceed 4 inches. Vegetated channels shall convey the Cv and Fv peak flow rate at non-erosive velocities for the soil and vegetative cover provided. Additionally, tractive force calculations may be provided to show that a channel is capable of supporting velocities in excess of 3 fps in a non-erosive condition. Check dams may be provided to reduce flow velocities. If check dams are employed, flow depths should be calculated through the check dams to ensure that the maximum flow depth of 4 inches is not exceeded for the RPv.

8.5 Vegetated Channel Pretreatment Criteria

Every inlet into a vegetated channel system shall have pretreatment.
The selection of a pretreatment method depends on whether the channel will experience sheet flow or concentrated flow. Several options are as follows:

- Grass Filter Strip (sheet flow): Grass filter strips extend from the edge of the pavement to the bottom of the vegetated channel at a slope of 5:1 or flatter. Alternatively, a combined 5 feet of grass filter strip at a maximum 5% (20:1) cross slope and 3:1 or flatter side slopes on the vegetated channel should be provided.
- Gravel or Stone Flow Spreaders (shallow concentrated flow). The gravel flow spreader may be located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2- to 4-inch elevation drop from a hard-edged surface into the gravel or stone-flow spreader. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the channel.
- Vegetated Channel (shallow concentrated flow or channel flow). A minimum 20-foot length of vegetated channel designed in accordance with this specification may provide pretreatment prior to the vegetated channel length. The 20-foot pretreatment length may not be included in the computed residence time.
- Initial Sediment Forebay (channel flow). This reinforced or otherwise stabilized cell is located at the upper end of the vegetated channel segment with a 2:1 length to width ratio and

a storage volume equivalent to at least 10% of the RPv. Typically, this cell is used when a concentrated flow from a pipe or other conveyance system enters a vegetated channel.

8.6 Vegetated Channel Design Criteria

Channel Geometry. Design guidance regarding the geometry and layout of vegetated channels is provided below:

- Vegetated channels should be designed with a trapezoidal or parabolic cross section. A parabolic shape is preferred for aesthetic, maintenance, and hydraulic reasons.
- **The bottom width of a trapezoidal channel shall be a minimum of 2 feet wide to ensure that an adequate surface area exists along the bottom of the channel for filtering.**
- **If a channel bottom will be wider than 8 feet, benches, check dams, level spreaders, or multi-level cross sections shall be incorporated to prevent braiding and erosion along the channel bottom.**
- **Vegetated channel side slopes shall be no steeper than 3H:1V.** Flatter slopes are encouraged, where adequate space is available, for ease of maintenance and to enhance pretreatment of sheet flows entering the channel.

Channel Slope. Design guidance regarding the channel slope of vegetated channels is provided below:

- Special design considerations such as drop structures or check dams may be needed for vegetated channels with slopes greater than 4% to maintain non-erosive flows.
- Longitudinal slopes of less than 2% may eliminate the need for check dams.
- To avoid flat areas with pockets of standing water, vegetated channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to maintain a continuous grade
- Sites with longitudinal slopes less than 0.5% on HSG 'C' or 'D' soils may need to be designed as a wetland swale in accordance with Specification 12. Constructed Wetlands based on site conditions.

Check Dams. Check dams may be used to break up slopes and to increase the hydraulic residence time in the channel. When required, design criteria for check dams are as follows:

- In typical spacing, the ponded water at a downhill check dam should not touch the toe of the upstream check dam.
- The maximum recommended check dam height is 12 inches (for maintenance purposes). Designs with check dams with a height greater than 12 inches may be submitted with design calculations showing that the surrounding soils can withstand the tractive forces applied from the increased hydraulic pressure head.
- To prevent erosion, armoring may be needed at the downstream toe of the check dam.

- **Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom to prevent hydrostatic head from pushing out the underlying soils.**
- **Check dams must be designed to pass the Cv design storm peak flow.**
- **Check dams shall be composed of wood, concrete, stone, or other non-erodible material.**
- **Each check dam shall have a weep hole or similar drainage feature, to allow for dewatering following a storm event.**
- Check dams for vegetated channels should be spaced to reduce the effective slope to less than 2%, as indicated below in Table 8.4.

Table 8.4. Typical Check Dam (CD) Spacing to Achieve Effective Channel Slope

Channel Longitudinal Slope	Spacing of 12-inch High (max.) Check Dams to Create an Effective Slope of 2%	Spacing of 12-inch High (max.) Check Dams to Create an Effective Slope of 0 to 1%
0.5%	–	200 ft. to –
1.0%	–	100 ft. to –
1.5%	–	67 ft. to 200 ft.
2.0%	–	50 ft. to 100 ft.
2.5%	200 ft.	40 ft. to 67 ft.
3.0%	100 ft.	33 ft. to 50 ft.
3.5%	67 ft.	30 ft. to 40 ft.
4.0%	50 ft.	25 ft. to 33 ft.
4.5%	40 ft.	20 ft. to 30 ft.
5.0%	40 ft.	20 ft. to 30 ft.

Material Specifications. **All seeded vegetated channels require a minimum SSM-III biodegradable erosion control matting conforming to Delaware Erosion and Sediment Control Handbook**. Material specifications for vegetated channels are shown in Table 8.3.

Enhancement using Soil Amendments. Soil compost amendments serve to increase the runoff reduction capability of a vegetated channel. The following design criteria apply when soil amendments are used:

- **The soil amendments, when used, shall extend over the length and width of the channel bottom, and the compost shall be incorporated to the depth as shown on the approved plan.** For soil amendment depth of incorporation refer to Specification 14. Soil Amendments.
- For vegetated channels on steep slopes, it may be necessary to install a protective biodegradable stabilization matting to protect the compost-amended soils. Care should be taken to consider the erosive characteristics of the amended soils when selecting appropriate turf reinforcement matting.

Sizing. Unlike other stormwater practices, vegetated channels are designed based on a peak rate of flow. **Adequate conveyance and treatment capacity shall be provided in accordance with the following guidelines:**

- **Hydraulic capacity shall be verified using Manning's equation or an accepted equivalent method, such as tractive forces and vegetal retardance.**
- **Design storm flow depth based on 50% of RPv peak flow rate shall be maintained at 4 inches or less.**
- **Manning's "n" value for vegetated channels shall be 0.2 for flow depths up to 4 inches, decreasing to 0.03 above 4 inches of flow depth. If alternative vegetation is used to increase the Manning's "*n*" value and decrease the resulting channel width, material specifications and construction oversight shall be provided to ensure that the denser vegetation is actually established.**
- **Peak flow rates for the Cv and Fv storms shall be non-erosive.** Non erosive velocity can be demonstrated with flows of less than 3 fps, or through a site-specific analysis of the channel lining material and vegetation. Examples of site-specific analysis ranges can be found in Table 8.5 below (see Section 8.7 Vegetated Channel Landscaping Criteria).
- **The Cv peak flow rate shall be contained within the channel banks.**
- **If the Fv storm event is not contained within the channel, the area of inundation shall be shown.**
- Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel, as appropriate. **The total peak discharge at the outlet shall be used to calculate the depth of flow and velocity for the channel unless lateral flow along the channel is calculated incrementally.**
- **Hydraulic residence time is the time for runoff to travel the full length of the channel. For both Bioswales and Grassed Channels hydraulic residence time is computed based upon 50% of the RPv peak flow rate.**
    - **For Bioswales, the hydraulic residence time shall be a minimum of 9 minutes. If flow enters the channel at several locations, a 9-minute minimum hydraulic residence time shall be demonstrated for each entry point.**
    - **For Bioswales, adjusted RPv runoff reduction credit based on the ratio of the computed residence to the minimum residence time shall be applied to Bioswales that meet the maximum depth of flow criteria. The maximum adjusted RPv runoff reduction credit is 75% for HSG A/B soils and 40% for HSG C/D soils. Adjusted RPv reduction credit shall not be granted for computed residence times of less than 5 minutes.**
    - **For Grassed Channels, the hydraulic residence time for concentrated flow entering the Grassed Channel shall be a minimum of 5 minutes.**
    - **Lateral flow entering the Grassed Channel as sheet flow may be excluded from residence time calculations but shall be accounted for in the channel depth and velocity calculations.**

- For Grassed Channels, in-line culverts (such as driveway crossings) that do not introduce any new flow can be excluded from concentrated flow pretreatment requirements and residence time calculations.
- For Grassed Channels, pipe length should not be included in residence time calculations.
- **For Grassed Channels with in-line culverts, the proportion of grassed channel flow length shall be a minimum of 80% of the total flow length.**

Maintenance Access. **All Vegetated Channels must be designed so as to be accessible for maintenance.** Good access is needed so crews can remove sediments, make repairs and preserve Vegetated Channel treatment capacity.

- **A maintenance right-of-way or easement must extend to the Vegetated Channel from a public or private road.**
- **Adequate maintenance access must extend to the full Vegetated Channel length.**
- **Maintenance access must meet the following criteria:**
    - **Minimum width of 15 feet.**
    - **Profile grade that does not exceed 10H:1V.**
    - **Minimum 10H:1V cross slope.**

Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines. When not specified in local code, the top of bank of Vegetated Channels should be set back at least 15 feet from property lines to ensure maintenance access.

8.7 Vegetated Channel Landscaping Criteria

Several types of grasses appropriate for vegetated channels are listed in Table 8.5. Designers should choose plant species that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Designers should check that the maximum flow velocities do not exceed the recommended values listed in the table for the selected grass species and the specific site slope.

Table 8.5. Recommended vegetation for vegetated channels.

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Bermuda Grass	0-5	8	6
	5-10	7	5
	>10	6	4
Kentucky Bluegrass	0-5	7	5
	5-10	6	4
	>10	5	3
Tall Fescue Grass	0-5	6	4

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Mixture	5-10	4	3
Annual and Perennial Rye	0-5	4	3
Source: USDA, TP-61, 1954			

If roadway salt will be applied to the contributing drainage area, vegetated channels should be planted with salt-tolerant plant species.

A planting plan must be provided that indicates the methods used to establish and maintain vegetative stabilization of the vegetated channel. The planting plan should specify proper grass species based on specific site soils and hydric conditions present along the channel.

Vegetated channels shall be established at such a density to achieve a 90% vegetated cover for project completion.

Seeded vegetated channels should be protected by a biodegradable erosion control matting to provide immediate stabilization of the channel bed and banks. **All seeded vegetated channels require a minimum SSM-III biodegradable erosion control matting conforming to Delaware Erosion and Sediment Control Handbook**.

8.8 **Vegetated Channel Construction**

Vegetated Channel Installation. The following is a typical construction sequence to properly install vegetated channels although steps may be modified to reflect different site conditions or design variations. Vegetated channels should be installed at a time of year that is best to establish cover without irrigation.

> *Step 1:* Ideally, the area of the vegetated channel should remain undisturbed during general site construction prior to vegetated channel construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, designers should integrate temporary erosion and sediment controls such as dikes, silt fences, and other erosion control measures into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control matting should be used to protect the channel.

Step 2. It is preferred that installation will begin after the entire contributing drainage area has been stabilized with vegetation. Stormwater flows should be diverted away from the channel until the bottom and side slopes are fully stabilized with either vegetation or a temporary erosion control matting

Step 3. Grade the vegetated channel to the final dimensions shown on the plan. Excavators or backhoes should work from the sides to grade and excavate the vegetated channels to the appropriate design dimensions. It is preferred that excavating equipment have adequate reach, so they do not have to sit inside the footprint of the vegetated channel area.

Step 4 (Optional). Apply soil amendments in accordance with Specification 14, Soil Amendments, if specified.

Step 5. Install check dams and pretreatment features as shown on the plan. The top of each check dam should be constructed level at the design elevation.

Step 6. Seed the bottom and banks of the vegetated channel and install erosion control matting.

Step 7. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

Step 8. Conduct the final construction inspection and develop a punch list for facility acceptance.

Vegetated Channel Construction Inspection. **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls, sensitive area protection surrounding vegetated channel locations, and blockage of inlets to vegetated channels**
- **Excavation and grading including interim and final elevations**
- **Construction of check dams and pretreatment practices, as applicable**
- **Implementation of required stabilization and planting plan**

- **Final construction review including development of a punch list for facility acceptance**

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

- Check that the desired coverage of vegetation or erosion control matting has been achieved following construction, both on the channel beds and their contributing side-slopes.
- Inspect check dams and pretreatment structures to check that they are at correct elevations, are properly installed, and are working effectively.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

Any accumulation of sediment that occurs within the channel should be removed during the final stages of grading to achieve the design cross-section. The real test of a vegetated channel occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows, or fully concentrated flows assumed in the plan actually occur in the field. Minor adjustments are often needed as part of this post-storm inspection (e.g., spot re-seeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams).

Post Construction Verification Documentation. Upon facility completion, the owner shall submit post construction verification documents as follows to demonstrate that the vegetated channel has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency:

- **Spot elevations of top of bank, bottom of bank, and centerline of the vegetated channel every 25 feet throughout the length of the channel**
- **Additional spot elevations that demonstrate positive downstream drainage beyond the end of the vegetated channel**
- **Cross section of the vegetated channel at the midpoint**
- **Photo documentation of the vegetated channel depicting the channel bottom width and verification of achievement of the required 90% vegetated cover**

The constructed slope, bottom width, depth, and length of the vegetated channel shall be within 90% of the design geometrics for those parameters.

In the event that the constructed allowable tolerances are exceeded for the vegetated channel, supplemental calculations shall be submitted to determine if the vegetated channel, as constructed, meets the design requirements. The computed residence time rounded to the nearest minute shall be no less than the minimum design residence time.

Performance of a vegetated channel shall be evaluated by the Department or Delegated Agency if requested in writing to determine if reconstruction of a vegetated channel that exceeds allowable tolerances is necessary.

8.9 Vegetated Channel Maintenance Criteria

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Operation and Maintenance Plans should clearly outline how vegetation in the vegetated channel will be managed or harvested in the future. The Operation and Maintenance Plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of vegetated channels is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 8.6. Suggested Maintenance Activities and Schedule for Vegetated Channels

Maintenance Activity	Schedule
• Mow vegetated channels during the growing season to maintain minimum grass height of 4".	As needed
• Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. • Ensure that the contributing drainage area is stabilized. Perform spot-reseeding if and where needed. • Remove accumulated sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. • Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
• Add reinforcement planting to maintain 90% vegetative cover. Reseed any salt-killed vegetation. • Remove any accumulated sand or sediment deposits behind check dams. • Inspect upstream and downstream of check dams for evidence of undercutting or erosion and remove trash or blockages at weep holes. • Examine channel bottom for evidence of erosion, braiding, excessive ponding, or dead grass. • Check inflow points for clogging and remove any sediment. • Inspect side slopes and pretreatment areas for evidence of any rill or gully erosion and repair. • Look for any bare soil or sediment sources in the contributing drainage area and stabilize immediately.	Annual inspection

Annual inspections are used to trigger maintenance operations such as sediment removal, spot re-vegetation and inlet stabilization. Example maintenance inspection checklists for vegetated channels can be found in Article 5.

8.10 References

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9.0 Sheet Flow to Vegetated Filter Strip or Vegetated Open Space

Definition: **Vegetated areas can treat sheet flow delivered from adjacent impervious and managed turf areas by slowing runoff velocities and allowing sediment and attached pollutants to settle or be filtered by the vegetation. Vegetation can consist of grasses, planted trees, or existing forest.** The design, installation, and management of these design variants are quite different, as outlined in this specification.

Design variants include:

- 9-A **Sheet Flow to Grassed Filter Strip**
- 9-B **Sheet Flow to Afforested Filter Strip**
- 9-C **Sheet Flow to Forested Filter Strip**
- 9-D **Sheet Flow to Grassed Open Space**
- 9-E **Sheet Flow to Afforested Open Space**
- 9-F **Sheet Flow to Forested Open Space**

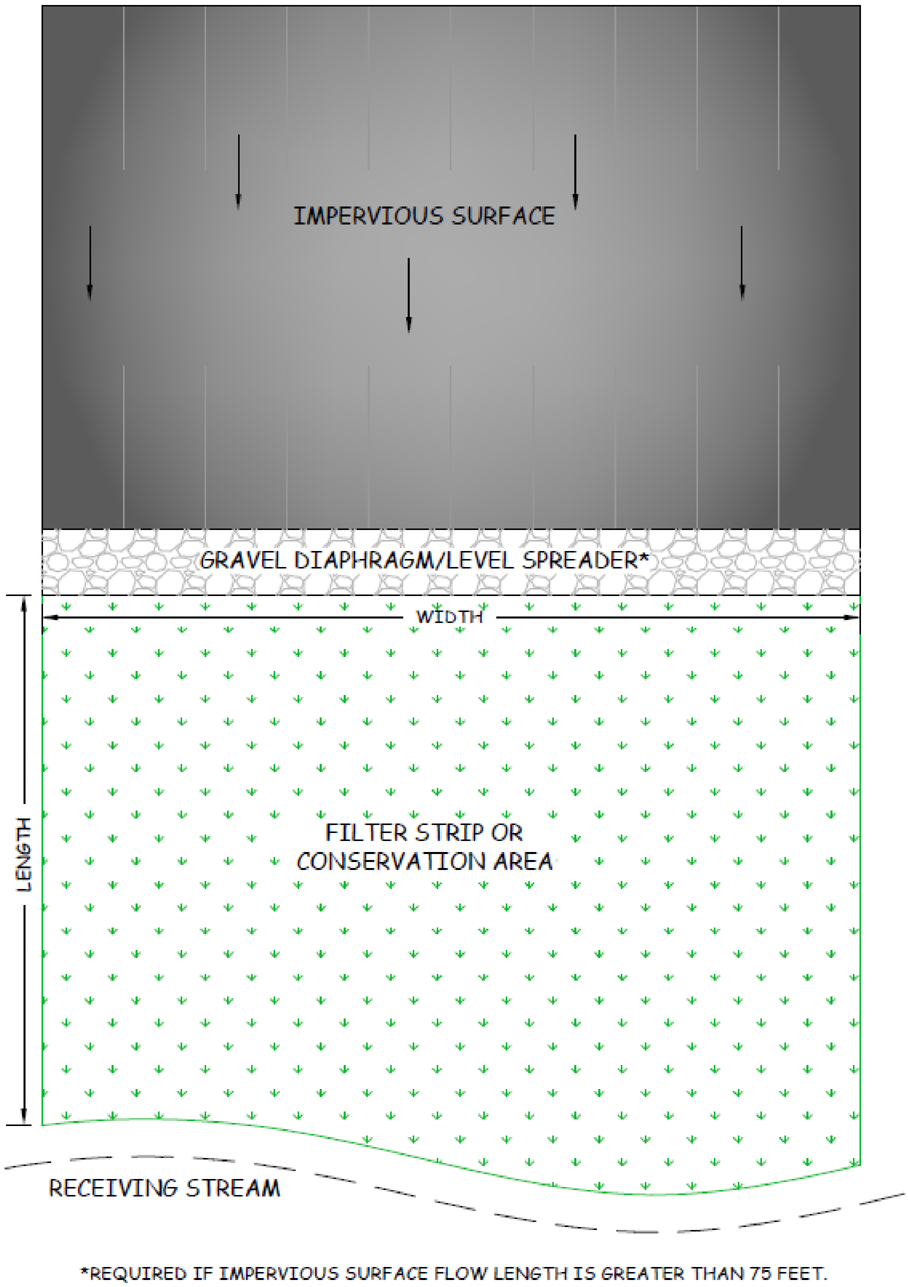

Figure 9.1. Sheet Flow to Vegetated Filter Strip or Vegetated Open Space

9.1 Sheet Flow Stormwater Credit Calculations

Sheet flow practices receive varying Runoff Reduction credit depending upon the specific type employed (see Table 9.1(a) and Table 9.1(b)). **Sheet Flow practices receive the following annual runoff reduction and pollutant reduction credits.**

9.1(a) Sheet Flow to Vegetated Filter Strip Performance Credits*

Runoff Reduction	
Retention Allowance	**0%**
RPv - A/B Soil or Compost Amended C Soil	**Grassed: 25% Annual Runoff Reduction Afforest: 30% Annual Runoff Reduction Forest: 40% Annual Runoff Reduction**
RPv - C/D Soil	**Grassed: 10% Annual Runoff Reduction Afforest: 15% Annual Runoff Reduction Forest: 20% Annual Runoff Reduction**
Cv	**10% of RPv Allowance**
Fv	**1% of RPv Allowance**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

9.1(b) Sheet Flow to Vegetated Open Space Performance Credits*

Runoff Reduction	
Retention Allowance	**0%**
RPv - A/B Soil or Compost Amended C Soil	**Grassed: 50% Annual Runoff Reduction Afforest: 60% Annual Runoff Reduction Forest: 65% Annual Runoff Reduction**
RPv - C/D Soil	**Grassed: 20% Annual Runoff Reduction Afforest: 30% Annual Runoff Reduction Forest: 40% Annual Runoff Reduction**
Cv	**10% of RPv Allowance**
Fv	**1% of RPv Allowance**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**

*See Appendix A-7 Alternative Methods for RPv Compliance for additional information on modeling this practice using traditional hydrologic methods.

9.2 Sheet Flow Practice Summary

Table 9.2 summarizes various criteria for Sheet Flow practices. For more detail, consult Sections 9.3 through 9.7. Sections 9.8 and 9.9 describe practice construction and maintenance criteria.

Table 9.2 Sheet Flow Practice Summary

<table>
<tr><th></th><th>Filter Strips</th><th>Sheet Flow to Open Space</th></tr>
<tr><td rowspan="3">Feasibility Criteria (Section 9.3)</td><td>Typically <5,000 sf impervious cover</td><td>Hydrologically Connected areas</td></tr>
<tr><td>Max. 8% slopes unless additional calculations submitted</td><td>Max. 3% slope</td></tr>
<tr><td colspan="2">Not used in structural fill areas compacted to meet specific structural criteria
Should not receive hotspot runoff
Restrictions may apply if adjacent to jurisdictional wetlands</td></tr>
<tr><td>Conveyance Criteria (Section 9.4)</td><td colspan="2">Generally intended for RPv compliance
Check for non-erosive conditions for Cv and Fv based on vegetation</td></tr>
<tr><td>Pretreatment Criteria (Section 9.5)</td><td colspan="2">Not required</td></tr>
<tr><td rowspan="2">Design Criteria (Section 9.6)</td><td>Length dependent on slope and practice option (See Table 9.3)</td><td>1:1 equivalent to impervious area in CDA</td></tr>
<tr><td colspan="2">Stormwater shall enter as sheet flow.
Max. 150’ sheet flow length from impervious surfaces
Gravel diaphragm or level spreader for impervious sheet flow lengths greater than 75’
Engineered level spreader if inflow from pipe or channel
Max. 100’ sheet flow length in filter strip
For filter strips using Computational Method of Compliance:
Max. depth of flow = 0.5”
Min. residence time = 2.5 min.
Adjusted RPv credit based on ratio of computed residence time to minimum residence time
Max. 75% adjusted RPv credit for HSG A/B soils
Max. 30% adjusted RPv credit for HSG C/D soils
No additional credit for filter strips length > 100’
Soil amendments, when used, shall extend over the length and width of the Vegetated Filter Strip or Vegetated Open Space, and compost shall be incorporated to the depth as shown on the approved plan.
All Vegetated Filter Strips and Vegetated Open Spaces must be designed so as to be accessible for maintenance.</td></tr>
<tr><td>Landscaping Criteria (Section 9.7)</td><td colspan="2">Grassed Filter Strips and Grassed Open Space shall be established at such a density to achieve a 90% vegetated cover for project completion.
Afforested Filter Strips and Afforested Open Space shall be planted in accordance with Afforestation requirements.
Forested Filter Strips and Forested Open Space shall have no grading or clearing of native vegetation and shall have at least 80% tree canopy coverage.
All Vegetated Filter Strips and Vegetated Open Spaces must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems.
A planting plan shall be provided that indicates the methods used to establish and maintain vegetative stabilization of the Vegetated Filter Strip or Vegetated Open Space.</td></tr>
</table>

Construction Criteria (Section 9.8)	• **No clearing or grading shall take place in Vegetated Open Space except temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation.**
	• **The Vegetated Open Space area shall not be stripped of topsoil.**
	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**
	  o **Pre-construction meeting**
	  o **Initial site preparation including installation of erosion and sediment controls and sensitive area protection surrounding vegetated filter strip locations**
	  o **Excavation and grading including interim and final elevations**
	  o **Implementation of required stabilization and planting plan**
	  o **Final construction review including development of a punch list for facility acceptance**
	• **Post Construction Verification Documentation. Upon facility completion, the owner shall submit Post Construction Verification Documents at the discretion of the Department or Delegated Agency as follows to demonstrate that the Vegetated Filter Strip or Vegetated Open Space has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.**
	• **The following items, as applicable, shall be included in the Post Construction Verification Documentation for Sheet Flow Practices:**
	  o **Dimensions of Vegetated Filter Strips (length and width)**
	  o **Area of Vegetated Open Space**
	  o **Cross-slope**
	  o **Elevations of any structural components, such as gravel diaphragms or engineered level spreaders**
	  o **Photo documentation of the grassed filter strip or grassed open space providing verification of achievement of the required 90% vegetated cover**
	• **Constructed allowable tolerances for vegetated filter strips and vegetated open spaces, if disturbed, shall be within the tolerances of design geometrics for the following parameters:**
	  o **Slope shall be no greater than 2% steeper than design slope**
	  o **Length shall be no less than 90% of design length**
	  o **Width shall be no less than 90% of design width**
	  o **Elevations of any structural components shall be within 0.15 feet of design elevation**
	• **In the event that the constructed allowable tolerances are exceeded for the vegetated filter strip, supplemental calculations shall be submitted to determine if the vegetated filter strip, as constructed, meets the minimum residence time; the computed residence time rounded to the nearest minute shall be no less than the minimum design residence time.**
	• **Performance of a vegetated filter strip shall be evaluated by the Department or Delegated Agency if requested in writing to determine if reconstruction of a vegetated filter strip that exceeds allowable tolerances is necessary.**

Maintenance Criteria (Section 9.9)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system.** • **Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

9.3 Sheet Flow Feasibility Criteria

Sheet flow to a filter strip or open space can be employed on commercial, institutional, municipal, multi-family residential and single-family residential buildings. Key constraints include available space, soil permeability, and soil compaction.

Filter Strips. Filter strips are best suited to treat runoff from small segments of impervious cover adjacent to road shoulders, small parking lots, and rooftops. Filter strips may also be used as pretreatment for another stormwater practice such as a wet pond, bioswale, bioretention, or infiltration areas. If a sufficient pervious area is available at the site, larger areas of impervious cover can be treated by filter strips, using an engineered level spreader to recreate sheet flow. Filter strips are also well suited to treat runoff from turf-intensive land uses, such as the managed turf areas of sports fields, golf courses, and parkland. Filter strips tend to have more linear configurations and greater cross-slopes than areas that qualify as Vegetated Open Space.

The grassed filter strip variant typically consists of native grasses intended to be maintained in a meadow condition. In some cases a more turf like condition can be used if proper maintenance measures are taken.

Another filter strip variant is the afforested filter strip. This variant includes areas not currently in a forested condition that are planted with new trees rather than grasses to eventually become forest cover.

Forested filter strips are a variant in which the vegetation cover consists mostly of established tree species with an organic duff layer having greater hydrologic storage capacity than a non-forested filter strip. Runoff through a forested filter strip would be more likely to occur as interflow than as true surface runoff.

Slopes. **To maintain sheet flow through the practice, maximum slope for Filter Strips shall be 8% unless additional calculations are submitted showing the maximum depth and minimum residence time can be met.**

Soils. **Filter Strips shall not be used in structural fill areas where material must be compacted to meet specific structural criteria.** Otherwise filter strips are appropriate for all soil types. . The runoff reduction rate, however, is dependent on the underlying Hydrologic Soil Groups (see Table 9.1 above) and whether soils receive compost amendments.

Open Space. The most common design applications of Sheet Flow to Vegetated Open Space are on sites that are hydrologically connected to a protected stream buffer, wetland buffer, floodplain, forest conservation area, or other protected lands. Open space is an ideal component of the "outer zone" of a stream buffer, which normally receives runoff as sheet flow. Care should be taken to locate all energy dissipaters or flow spreading devices outside of the protected area. Vegetated Open Space generally has a less linear configuration and flatter cross-slope than

Vegetated Filter Strips. Runoff reduction in Vegetated Open Space is achieved mainly through storage and/or extended residence time. Therefore, these areas require minimal slope or even slight sump conditions to allow shallow ponding to occur. Similar to Vegetated Filter Strips, Vegetated Open Space can be either in the form of grass-type vegetation, newly planted trees or preserved forested areas.
Slopes. **To maintain sheet flow through the practice, maximum slope for Open Space shall be 3%.**

The following applies to both Vegetated Filter Strips and Vegetated Open Space:

- *Hotspot Land Uses.* Filter Strips and Open Space should not receive hotspot runoff if there is a risk that the infiltrated runoff could cause groundwater contamination.
- *Jurisdictional Wetlands.* Restrictions may apply when these practices are located adjacent to jurisdictional wetlands that are sensitive to increased inputs of stormwater runoff (e.g., bogs and fens).

9.4 Sheet Flow Conveyance Criteria

Vegetated Filter Strips and Vegetated Open Space are generally intended to satisfy RPv requirements. However, it is important that they also be stable against erosive forces for larger storm events. Designers should check to make sure the velocities generated during the Cv and Fv are at non-erosive levels for the type of vegetation in the filter strip or open space.

9.5 Sheet Flow Pretreatment Criteria

Pretreatment is not needed for sheet flow to Filter Strips or Open Space.

9.6 **Sheet Flow Design Criteria**

Vegetated Filter Strips and Vegetated Open Space are used to treat small drainage areas of a few acres or less. The limiting design factor is the length of flow directed to the filter. As a rule, flow tends to concentrate after 75 feet of flow length for impervious surfaces, and 150 feet for pervious surfaces (Claytor and Schueler, 1996). When flow concentrates, it moves too rapidly to be effectively treated, unless an engineered level spreader is used. **Stormwater shall enter the filter strip or open space as sheet flow. Sheet flow length from impervious surfaces shall be limited to 150 feet. A gravel diaphragm or other level spreading device shall be provided for impervious sheet flow lengths greater than 75 feet. When the inflow is from a pipe or channel, an engineered level spreader or other device shall be used to convert the concentrated flow to sheet flow.**

Vegetated Filter Strip. The maximum length of a Vegetated Filter Strip shall be 100 feet. Vegetated Filter Strips shall have the following minimum lengths, measured in the direction of flow, unless calculations are provided in accordance with the Computational Method of Compliance.

Table 9.3 Minimum Length of Filter Strips

Slope of Filter Strip	Minimum Length
< 3%	20 feet
3% - 8%	30 feet

Vegetated Open Space. Vegetated Open Space shall have a maximum slope of 3%. The minimum area of the Vegetated Open Space shall be equivalent to the impervious area of the contributing drainage area to the Vegetated Open Space.

Computational Method of Compliance. This section describes a computational method to show RPv compliance in cases where a site specific design is warranted or desired. The basic procedure involves the following steps:

Step 1: Calculate peak discharge from the impervious contributing area.
Step 2: Calculate peak discharge from the Vegetated Filter Strip (VFS)
Step 3: Sum the total peak discharge from Steps 1 and 2 above
Step 4: Check that the depth of flow criterion has been met
Step 5: Check that residence time criterion has been met

For the purposes of this section, runoff from the impervious contributing area is assumed to be a maximum of 1". A design storm of 1.2" of rainfall will generate 1" of runoff from an impervious surface with a Runoff Curve Number (RCN) of 98 using the NRCS runoff equation. Assuming the minimum Time of Concentration (Tc) of 6 minutes, the rainfall intensity for a 1.2" rainfall event is 1.64 in/hr using the standard NRCS rainfall distribution curve. This rainfall intensity can then be used with the Rational Method to calculate the peak discharge for Steps 1 and 2 above. Once the total peak discharge is determined, the Continuity Equation can be combined with the Manning Equation to determine depth of flow and velocity for Step 4. A recommended solution for the Computation Procedure for Compliance is presented below:

Given:

- Maximum sheet flow length for impervious contributing area is 150'.
- Maximum sheet flow length for Vegetated Filter Strip (VFS) is 100'.

Determine:

- Depth of flow in VFS
- Residence time in VFS

Procedure:

1. Calculate the peak discharge from the impervious contributing area using Eq, 9.1

$$Q = ciA \qquad \text{(Eq. 9.1)}$$

Where,

Q = peak discharge (cfs)
c = cover factor (dimensionless) = 0.95
i = rainfall intensity (in/hr) = 1.64 in/hr
A = contributing area (ac)

2. Calculate the peak discharge from the VFS using Eq, 9.1 with cover factor ("c") for lawn and appropriate soil and slope condition.

Typical "c" Factors for Lawns*		
HSG A/B Soils	s < 2%	0.05
	s = 2% - 7%	0.10
	s > 7%	0.15
HSG C/D Soils	s < 2%	0.13
	s = 2% - 7%	0.18
	s > 7%	0.25

*Source: DelDOT Road Design Manual

3. Sum peak discharges calculated above.
4. Use Eq. 9.2 to calculate depth of flow in the VFS.

$$y = \left[\frac{Qn}{1.49ws^{0.5}}\right]^{0.6} \quad \text{(Eq. 9.2)}$$

Where,
y = depth of flow (ft)
Q = peak discharge calculated at Step 3 (cfs)
n = Manning's "n" value for lawn = 0.24
w = width of VFS (perpendicular to flow) (ft)
s = slope of VFS (ft/ft)

5. Determine residence time in the VFS.
   a. Use Eq. 9.3 to calculate velocity.

$$v = \frac{Q}{wy} \quad \text{(Eq. 9.3)}$$

Where,
v = velocity (fps)
Q = peak discharge (cfs)
w = width of VFS (perpendicular to flow) (ft)
y = depth of flow in VFS (ft)

   b. Use Eq. 9.4 to calculate residence time.

$$Tt = \frac{L}{v} \quad \text{(Eq. 9.4)}$$

Where,

Tt = residence time (sec)
L = length of VFS (parallel to flow) (ft)
v = velocity (fps)

Vegetated Filter Strips using the Computational Method of Compliance shall meet the following criteria in order to receive RPv runoff reduction credits listed above:

- **The maximum depth of flow shall be 0.5" (0.04').**
- **The minimum residence time shall be 2.5 minutes.**

Adjusted RPv runoff reduction credit based on the ratio of the computed residence to the minimum residence time shall be applied to Vegetated Filter Strips that meet the maximum depth of flow criteria. The maximum adjusted RPv runoff reduction credit is 75% for HSG A/B soils and 30% for HSG C/D soils. RPv runoff reduction credit shall not be adjusted for lengths greater than 100 feet.

Gravel Diaphragms. The gravel diaphragm is created by excavating a 2-foot wide and 1-foot deep trench that runs on the same contour at the top of the filter strip. The diaphragm serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.

- The flow should travel over the impervious area and to the practice as sheet flow and then drop at least 3 inches onto the gravel diaphragm. The drop helps to prevent runoff from running laterally along the pavement edge, where grit and debris tend to build up (thus allowing by-pass of the filter strip).
- A layer of filter fabric should be placed between the gravel and the underlying soil trench.
- If the contributing drainage area is steep (6% slope or greater), then larger stone should be used in the diaphragm.

Engineered Level Spreaders. The design of engineered level spreaders should conform to the following design criteria based on recommendations of Hathaway and Hunt (2006), in order to provide non-erosive sheet flow into the vegetated area. At times, it may be necessary to include a bypass structure (see Figure 9.1 above) that diverts the runoff from the Resource Protection Event to the level spreader, and bypasses the larger storm events around the Vegetated Filter Strip or Vegetated Open Space through an improved channel. An alternative approach would be to direct the entire flow through a stilling basin energy dissipater and then a level spreader such that runoff from the entire Conveyance Event is discharged as sheet flow through the buffer.

Key design elements of the engineered level spreader, as provided in Figures 9.3 and 9.4, include the following:

- The length of the level spreader should be determined by the type of filter area and the design flow:
  - 13 feet of level spreader length per every 1 cubic foot per second (cfs) of inflow for discharges to a filter strip or turf conservation area;
  - 40 feet of level spreader length per every 1 cfs of inflow when the spreader discharges to a forested conservation area (Hathaway and Hunt, 2006).
  - The minimum level spreader length is 13 feet and the maximum is 130 feet.
  - For the purposes of determining the level spreader length, the peak discharge should be determined using the Rational Method with an intensity of 1.37-inch/hour.

- The level spreader lip should be concrete, wood or pre-fabricated metal, with a well-anchored footer, or other accepted rigid, non-erodible material.
- The ends of the level spreader section should be tied back into the slope to avoid scouring around the ends of the level spreader; otherwise, short-circuiting of the facility could create erosion.The width of the level spreader channel on the up-stream side of the level lip should be three times the diameter of the inflow pipe, and the depth should be 9 inches or one-half the culvert diameter, whichever is greater.

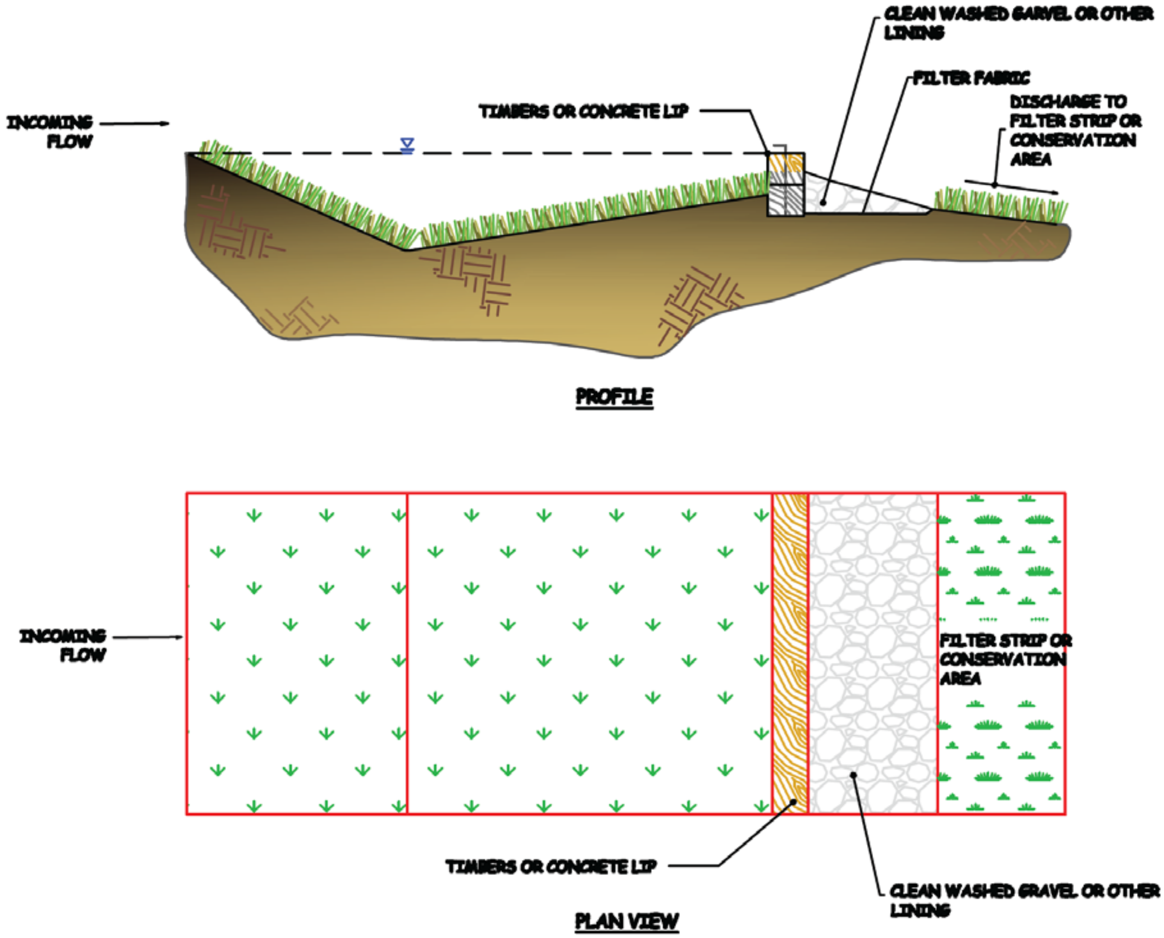

Figure 9.3: Example Level Spreader

Permeable Berm

Vegetated Filter Strips should be designed with a permeable berm at the toe of the filter strip to create a shallow ponding area. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm or through a gravel lens in the berm with a perforated pipe. During larger storms, runoff may overtop the berm (Cappiella *et al.,* 2006). The permeable berm should have the following properties:

- A wide and shallow trench, 6 to 12 inches deep, should be excavated at the upstream toe of the berm, parallel with the contours.
- Media for the berm should consist of 40% excavated soil, 40% sand, and 20% pea gravel.
- The berm 6 to 12 inches high should be located downgradient of the excavated depression and

should have gentle side slopes to promote easy mowing (Cappiella *et al*., 2006).
- Stone may be needed to armor the top of berm to handle extreme storm events.
- A permeable berm is not needed when vegetated filter strips are used as pretreatment to another stormwater practice.

Enhancement using Soil Amendments. Soil compost amendments serve to increase the runoff reduction capability of a Vegetated Filter Strip or Vegetated Open Space. The following design criteria apply when soil amendments are used:
- **Soil amendments, when used, shall extend over the length and width of the Vegetated Filter Strip or Vegetated Open Space, and compost shall be incorporated to the depth as shown on the approved plan.** For soil amendment depths of incorporation refer to Specification 14. Soil Amendments.
- For Vegetated Filter Strips on steep slopes, it may be necessary to install a protective biodegradable stabilization matting to protect the compost-amended soils. Care should be taken to consider the erosive characteristics of the amended soils when selecting appropriate turf reinforcement matting.

Maintenance Access. **All Vegetated Filter Strips and Vegetated Open Spaces must be designed so as to be accessible for maintenance.** Good access is needed so crews can remove sediments, make repairs and preserve Vegetated Filter Strip treatment capacity. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines.

9.7 Sheet Flow Landscaping Criteria

Grassed Filter Strips and Grassed Open Space shall be established at such a density to achieve a 90% vegetated cover for project completion. The vegetation may consist of turf grasses or meadow grasses, as long as the primary goal of at least 90% vegetated coverage is achieved. Designers should choose vegetation that stabilizes the soil and is salt tolerant. Vegetation at the toe of the filter, where temporary ponding may occur behind the permeable berm, should be able to withstand both wet and dry periods. The planting areas can be divided into zones to account for differences in inundation and slope.

Afforested Filter Strips and Afforested Open Space shall be planted in accordance with Afforestation requirements.

Forested Filter Strips and Forested Open Space shall have no grading or clearing of native vegetation and shall have at least 80% tree canopy coverage. An invasive species management plan should be developed and approved as part of plan review.

Stabilization. **All Vegetated Filter Strips and Vegetated Open Spaces must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems.** Several types of grasses appropriate for filter strips or turf conservation areas are listed in Table 9.5**.** Maximum flow velocities should not exceed the values listed in the table for the selected grass species and the specific site slope.

A planting plan shall be provided that indicates the methods used to establish and maintain vegetative stabilization of the Vegetated Filter Strip or Vegetated Open Space. The planting plan should specify proper grass species based on specific site soils and hydric conditions present within the footprint for the filter strip.

Table 9.5. Recommended Vegetation for Filter Strips and Turf Conservation Areas

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Bermuda Grass	0-5	8	6
	5-10	7	5
	>10	6	4
Kentucky Bluegrass	0-5	7	5
	5-10	6	4
	>10	5	3
Tall Fescue Grass Mixture	0-5	6	4
	5-10	4	3
Annual and Perennial Rye	0-5	4	3
Sod		4	3
Source: USDA, TP-61, 1954; City of Roanoke Virginia Stormwater Design Manual, 2008.			

9.8 Sheet Flow Construction

Construction Sequence for Vegetated Filter Strips. Vegetated Filter Strips can be within the limits of disturbance during construction. The following procedures should be followed during construction:

- Before site work begins, filter strip boundaries should be clearly marked.
- Only vehicular traffic used for filter strip construction should be allowed within the filter strip boundary.
- If existing topsoil is stripped during grading, it should be stockpiled for later use.
- Construction runoff should be directed away from the proposed filter strip site, using perimeter silt fence, or, preferably, a diversion dike.
- Construction of the gravel diaphragm or engineered level spreader should not commence until the contributing drainage area has been stabilized and perimeter erosion and sediment (E&S) controls have been removed and cleaned out.
- Filter strips require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction. Topsoil and or compost amendments should be incorporated evenly across the filter strip area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.

- Stormwater should not be diverted into the filter strip until the turf cover is dense and well established.
- For afforested filter strips, refer to *Specification 17. Afforestation*.

Construction Sequence for Vegetated Open Space. It is preferred that Vegetated Open Space be preserved in its existing undisturbed condition whenever possible. **No clearing or grading shall take place in Vegetated Open Space except temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation. The Vegetated Open Space area shall not be stripped of topsoil.** Some light grading may be needed at the boundary using tracked vehicles to prevent compaction.

The Vegetated Open Space should be fully protected during the construction stage of development.

- The perimeter of the Vegetated Open Space should be protected by super silt fence, orange safety fence, or other measures to prevent compaction and sediment discharge.
- The limits of disturbance should be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, silt fence, safety fence or other protective barrier.
- Construction of the gravel diaphragm or engineered level spreader should not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out.
- Stormwater should not be diverted into the vegetated open space until the gravel diaphragm and/or level spreader are installed and stabilized.
- For afforested open space, refer to *Specification 17. Afforestation*.

Construction Review. Construction review is critical to ensure compliance with design standards. Construction reviewers should evaluate the performance of the filter strip or open space after the first big storm to look for evidence of gullies, outflanking, undercutting or sparse vegetative cover. Spot repairs should be made, as needed.

Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls and sensitive area protection surrounding vegetated filter strip locations**
- **Excavation and grading including interim and final elevations**
- **Implementation of required stabilization and planting plan**
- **Final construction review including development of a punch list for facility acceptance**

Post Construction Verification Documentation. Upon facility completion, the owner shall submit Post Construction Verification Documents at the discretion of the Department or

Delegated Agency as follows to demonstrate that the Vegetated Filter Strip or Vegetated Open Space has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. The following items, as applicable, shall be included in the Post Construction Verification Documentation for Sheet Flow Practices:

- **Dimensions of Vegetated Filter Strips (length and width).**
- **Area of Vegetated Open Space.**
- **Cross-slope.**
- **Elevations of any structural components, such as gravel diaphragms or engineered level spreaders.**
- **Photo documentation of the grassed filter strip or grassed open space providing verification of achievement of the required 90% vegetated cover.**

Constructed allowable tolerances for vegetated filter strips and vegetated open spaces, if disturbed, shall be within the tolerances of design geometrics for the following parameters:

- **Slope shall be no greater than 2% steeper than design slope**
- **Length shall be no less than 90% of design length**
- **Width shall be no less than 90% of design width**
- **Elevations of any structural components shall be within 0.15 feet of design elevation**

In the event that the constructed allowable tolerances are exceeded for the vegetated filter strip, supplemental calculations shall be submitted to determine if the vegetated filter strip, as constructed, meets the minimum residence time. The computed residence time rounded to the nearest minute shall be no less than the minimum design residence time.

Performance of a vegetated filter strip shall be evaluated by the Department or Delegated Agency if requested in writing to determine if reconstruction of a vegetated filter strip that exceeds allowable tolerances is necessary.

9.9 Sheet Flow Maintenance Criteria

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan should specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Operation and Maintenance Plans should clearly outline how vegetation in the Sheet Flow Practice will be managed or harvested in the future. Maintenance of Sheet Flow Practices is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 9.6. Sheet Flow to Filter Strip or Open Space Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas • Water trees and shrubs during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Repair-eroded, and/or bare soil areas
Twice a year	• Mowing of the grassed filter strip or grassed open space • Inspect and treat for invasive species as needed
Annually	• Remove trash and debris • A full maintenance review

9.10 References

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10.0 Detention Practices

Definition: **Detention Practices are storage practices that are explicitly designed to provide stormwater detention for the Conveyance Event, Cv (10-year) and Flooding Event, Fv (100-year).**

Design variants include:

- 10-A **Dry Detention Pond**
- 10-B **Dry Extended Detention (ED) Basin**
- 10-C **Underground Detention Facilities**

Dry Detention Ponds and Dry ED Basins are widely applicable for most land uses and are best suited for larger drainage areas. An outlet structure restricts stormwater flow, so it backs up and is stored within the basin. The temporary ponding reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on the bed and banks of the receiving stream. Dry Detention Ponds receive some credit for pollutant removal, while Dry ED Basins receive both runoff reduction and pollutant removal credits.

The key difference between Dry Detention Ponds and Dry ED Basins is that, in addition to management of the Cv and Fv, a Dry ED Basin provides 48-hour detention of the Resource Protection Volume (RPv). An under-sized outlet structure restricts stormwater flow so it backs up, is stored within the basin, and released at a slower rate. The temporary ponding enables particulate pollutants to settle out and reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of the receiving stream. Unlike the Dry Detention Pond's stormwater detention, extended detention is designed to achieve a minimum drawdown time, rather than a maximum peak rate of flow. Dry Detention Ponds, which are designed only to manage the larger Cv and Fv will often detain smaller storm events for only a few minutes or hours.

Underground Detention Facilities include vaults and tanks. Underground Detention Vaults are box-shaped underground stormwater storage facilities typically constructed with reinforced concrete. Underground Detention Tanks are underground storage facilities typically constructed with large diameter metal or plastic pipe. Both serve as an alternative to surface dry detention for stormwater quantity control, particularly for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area. Prefabricated concrete vaults are available from commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems. Unless they provide 48-hour extended detention, underground detention vaults do not receive any runoff reduction or pollutant removal credit and should be considered only for management of larger storm events.

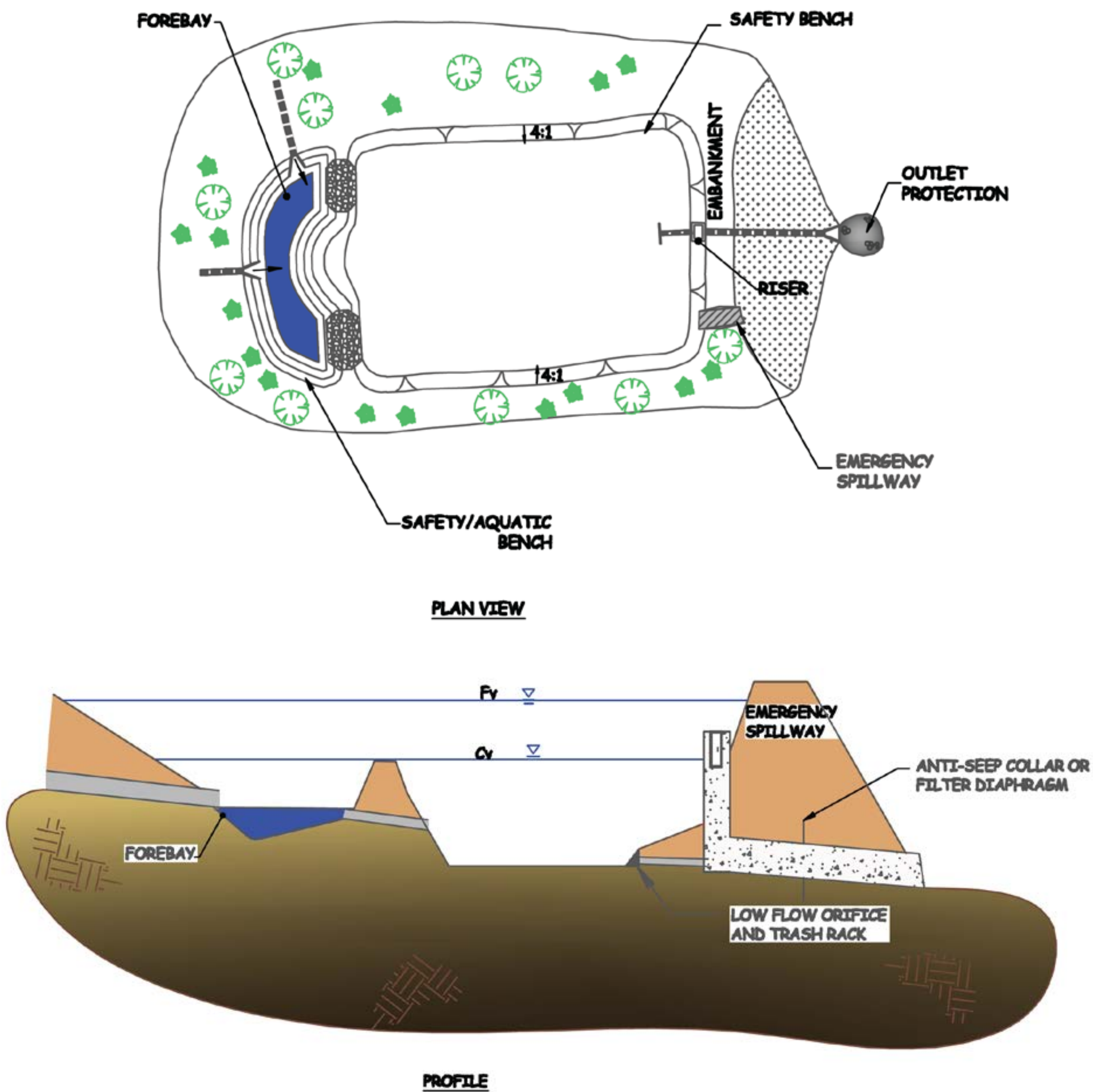

Figure 10.1. Example of a Dry Detention Pond (10-A)

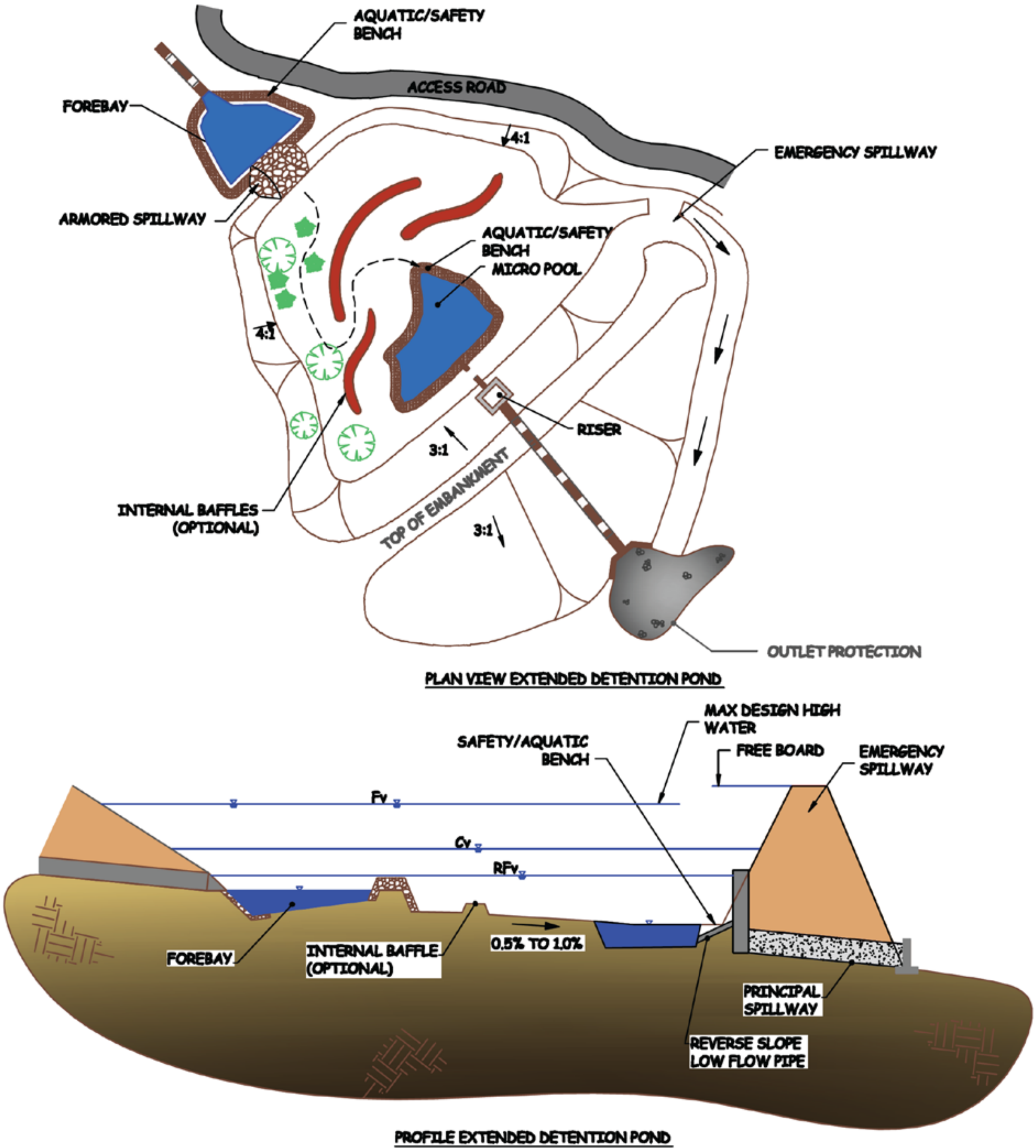

Figure 10.2. Example of a Dry Extended Detention Basin (10-B)

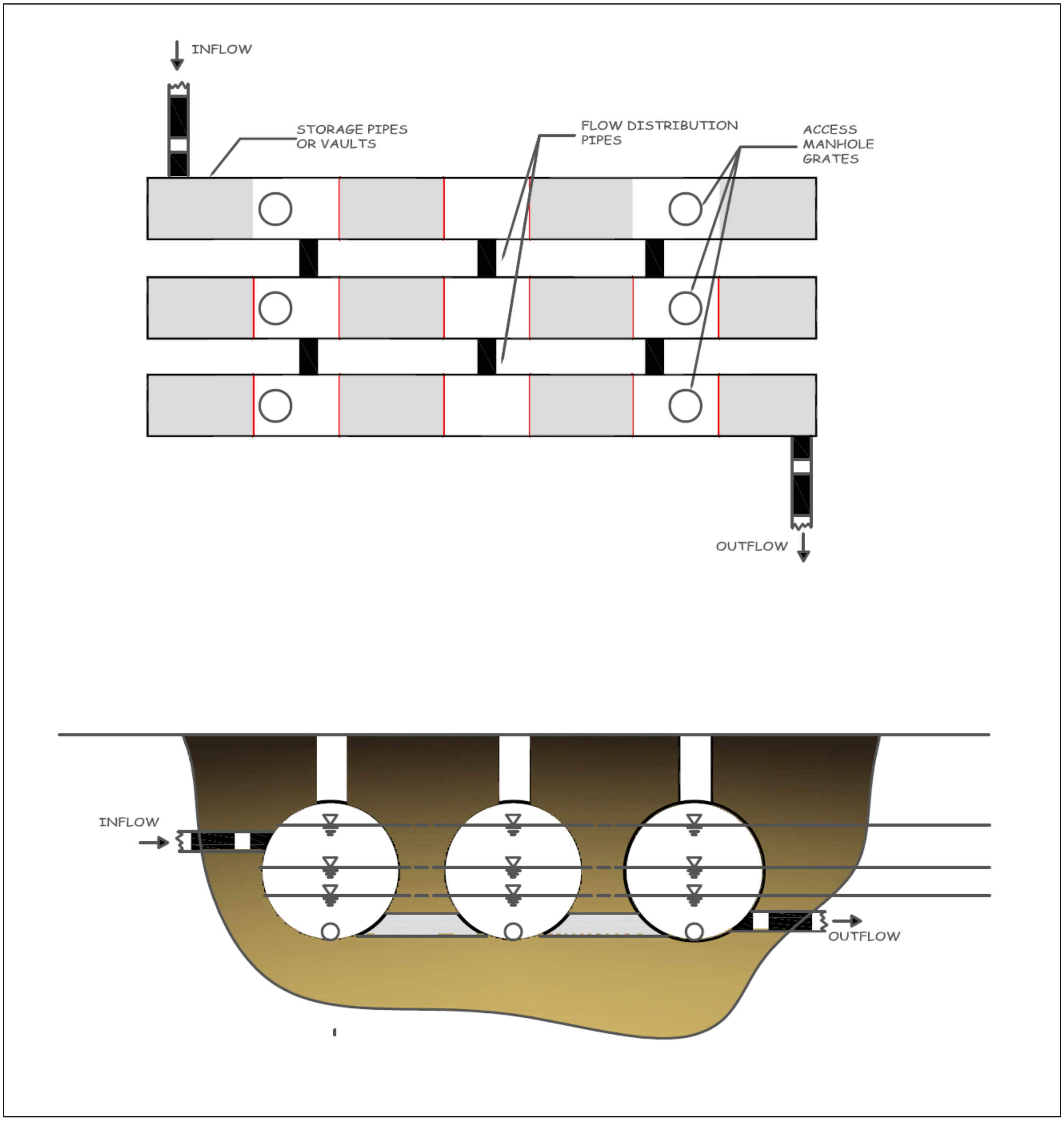

Figure 10.3. Example of an Underground Detention Facility (10-C)

10.1 Detention Practices Stormwater Credit

Dry Detention Ponds and Dry ED Basins constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Delaware Pond Code 378 as amended. Dry Detention Ponds and Dry ED Basins receive pollutant removal credits as follows in Table 10.1 and 10.2. **Full runoff reduction credit is given for detention practices that provide 48-hour extended detention of the full RPv.**

Table 10.1 Dry Detention Pond and Underground Detention Facilities Performance Credits

Runoff Reduction	
Retention Allowance	**0%**
RPv -A/B Soil	**0%**
RPv - C/D Soil	**0%**
Cv	**0%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**Not less than 5%**
TP Reduction	**Not less than 10%**
TSS Reduction	**Not less than 10%**

Table 10.2 Dry 48-hour ED Basin and Underground Detention Facilities with 48-hour ED Performance Credits

Runoff Reduction	
RPv – Detention Allowance	**100%**
Cv	**1%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**Not less than 20%**
TP Reduction	**Not less than 20%**
TSS Reduction	**Not less than 60%**

Because Detention Practices are designed for larger storm events, rather than the RPv, the credits above are “fixed” credits. They are not based on the relative size of the practice.

10.2 Detention Practices Summary

Table 10.3 summarizes feasibility, design, construction and maintenance criteria for Detention Practices. For more detail, consult Sections 10.3 through 10.97.

Table 10.3 Detention Practices Summary

Feasibility Criteria (Section 10.3)	• 1%-3% of CDA for footprint • Recommended minimum CDA = 10 acres • Refer to Appendix A-8 for setback requirements. • **Dry Detention Ponds or Dry ED Basins shall not be allowed if the seasonal high water table or bedrock will be within 1 foot of the floor of the pond.** • **Non-watertight Underground Detention Facilities shall be no lower than the seasonal high water table and 2 feet above bedrock.** • **For watertight Underground Detention Facilities, an anti-flotation analysis is required to check for buoyancy problems in seasonal high water table areas** • **Soil Investigation Procedures shall be followed for testing.** • **Underground Detention Facilities must meet structural requirements for bearing capacity, overburden support, and traffic loading as determined by a licensed design professional, and based upon manufacturer's recommendations where applicable.**
Conveyance Criteria (Section 10.4)	• **The principal spillway must be accessible from dry land.** • **A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure.** • **A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure.** • **A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure.** • **When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced with riprap or other acceptable material to prevent scour.** • **For Dry ED Basins, the control structure must include an outlet that will slowly release the RPv over a 48-hour period.** • **When a low flow orifice is specified, it must be adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection. Orifice diameters shall not be less than 3 inches unless internal orifice control is provided.** • **Dry Detention Ponds and Dry ED Basins must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the Dry Detention Ponds and Dry ED Basins rather than bypassing.** • **Inflow points into the Dry Detention Ponds and Dry ED Basins must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance event (Cv).** • **A forebay shall be provided at each inflow location that provides 10% or greater of the total RPv inflow to the Dry Detention Ponds and Dry ED Basins.**

Conveyance Criteria (Section 10.4) *cont.*	• **In the event that the embankment is a regulated dam, the designer must verify that the appropriate Dam Safety Permit has been approved by the Department's Dam Safety Program.** • **For Underground Detention Facilities, an internal or external high flow bypass or overflow shall be included in the design to safely pass the Fv.**
Pretreatment Criteria (Section 10.5)	• Forebays maintain the longevity of all Dry Detention Ponds and Dry ED Basins • **A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell.** • **The following criteria apply to forebay design:** o **A major inlet is defined as an individual storm drain inlet pipe or open channel conveying at least 10% of the Dry Detention Pond's and Dry ED Basin's contributing RPv runoff volume.** o **The forebay shall be no deeper than 3 feet.** o **The forebay must be sized to contain 10% of the volume of runoff from the contributing drainage area for the Resource Protection event.** o **Discharge from the forebay shall be non-erosive.** • **Every underground detention practice shall have pretreatment mechanisms to protect the long term integrity of the practice.**
Design Criteria (Section 10.6)	• **Dry Detention Ponds and Dry ED Basins constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Delaware Pond Code 378 as amended.** • **In order to simulate a baseflow condition to the extent practicable, the peak discharge for the outflow hydrograph shall not exceed five times the average discharge rate.** • **Earthen side slopes shall be designed and constructed no steeper than 3H:1V.** • **Retaining walls around Dry Detention Ponds and Dry ED Basins shall be limited to no more than 50% of the pond perimeter based upon the peak elevation of the Cv. In order to maintain the safety requirements, retaining walls shall be configured as follows:** o **The retaining wall shall have a maximum height of 3 feet.** o **Any additional retaining walls shall have a maximum height of 2 feet and provide a minimum 10-foot level terrace from a lower retaining wall.** • **Any opening 12 inches or greater discharging to a closed drainage system shall include safety grates.** • **The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.** • **The emergency spillway exit channel must be designed to direct runoff to a point of discharge without impact to downstream structures.** • **Maintenance access must meet the following criteria:** o **Minimum width of 15 feet.** o **Profile grade that does not exceed 10H:1V.** o **Minimum 10H:1V cross slope** • **Maintenance Set-Aside Area:** o **The maintenance set-aside area shall accommodate the volume of 50% of the collective forebay volume.** o **The maximum depth of the set aside volume shall be one foot.** o **The slope of the set aside area shall not exceed 5%.**

Design Criteria
(Section 10.6)
cont.
	• **Detention Vault and Tank Materials:**
	  o **All construction joints and pipe joints shall be water tight.**
	  o **Cast-in-place wall sections must be designed as retaining walls.**
	• **For watertight Underground Detention Facilities, anti-flotation analysis is required to check for buoyancy problems in the high water table areas. Anchors shall be designed to counter the pipe and structure buoyancy by at least a 1.2 factor of safety.**

Landscaping Criteria (Section 10.7)	• **Woody vegetation shall not be planted or allowed to grow within 15 feet of the embankment and 10 feet on either side of principal spillway or inflow pipes.** • **For Dry Detention Ponds and Dry ED Basins, a planting plan shall be provided that indicates the methods used to establish and maintain vegetative coverage within the Detention Practice and its vegetated perimeter area.** • **Minimum elements of a plan include seed mixes by botanical and common names as well as percentages by weight or volume.**

Construction Criteria
(Section 10.8)
	• **Construction of proprietary Underground Detention Facilities must be in accordance with manufacturer's specifications.**
	• **Underground Detention Facilities must be inspected and cleaned of sediment after the site is stabilized.**
	• **Approval from the Department or the appropriate Delegated Agency must be obtained before any planned Dry Detention Ponds and Dry ED Basins can be used as a sediment basin. If a Dry Detention Pond or Dry ED Basin serves as a sediment basin during project construction, the volume of the sediment basin must be based on the more stringent sizing rule.**
	• **When the sediment basin is being converted into a Dry Detention Pond or Dry ED Basin, the sediment basin shall be dewatered in accordance with the approved plan and appropriate details from the Delaware Erosion and Sediment Control Handbook prior to removing accumulated sediment and regrading the pond bottom.**
	• **The Sediment and Stormwater Plan must include conversion steps from sediment basin to permanent Dry Detention Ponds and Dry ED Basins in the construction sequence. The Department or Delegated Agency must be notified and provide approval prior to conversion from sediment basin to the final configuration of the Dry Detention Pond or Dry ED Basin.**
	• **Appropriate procedures must be implemented to prevent discharge of turbid waters when the sediment basin is being converted into a Dry Detention Pond or Dry ED Basin.**
	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**
	  o **Pre-construction meeting**
	  o **Initial site preparation including installation of erosion and sediment controls**
	  o **Construction of the embankment, including installation of the principal spillway and the outlet structure**
	  o **For Dry Detention Pond and Dry ED Basin – excavation and grading including interim and final elevations**
	  o **For Underground Detention – subgrade, placement of stone, system components in accordance with manufacturer's recommendations and backfill**
	  o **Implementation of the planting plan and vegetative stabilization**
	  o **Final inspection including development of a punch list for facility acceptance**

Construction Criteria (Section 10.8) *cont.*	• **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the Detention Practice has been constructed within allowable tolerances and in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.** • **Allowable tolerances for Dry Detention Pond and Dry ED Basin are as follows:** o **The constructed top of bank elevation may be no lower than the design elevation for top of bank.** o **The constructed volume of the dry pond surface storage shall be no less than 90% of the design volume.** o **The constructed elevation of any structure shall be within 0.15 foot of the design.** • **Allowable tolerances for Underground Detention Facilities are as follows:** o **Grate and invert elevations of all structures, including weirs shall be within 0.15 foot of the design.** o **Diameter of all pipes or dimensions of chambers within underground detention facility shall be as shown on the plan.** o **Dimension of any weirs shall be within 10% of the design.** • **When the allowable tolerances are exceeded for volume or structure elevations, supplemental calculations must be submitted to the approval agency to demonstrate that the Detention Practice, as constructed, meets the design requirements.**
Maintenance Criteria (Section 10.9)	• **Repair of critical structural features such as embankments and risers shall be performed by responsible personnel that have successfully completed the Department Contractor Training Program.** • **Sediment removal in the Dry Detention Pond or Dry ED Basin pretreatment practice must occur when 50% of total forebay capacity has been lost.** • **Before project completion, the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

10.3 Detention Practices Feasibility Criteria

The following feasibility issues need to be evaluated when Detention Practices are considered:

EPA Requirements for Class V Injection Wells. Certain types of practices in this category, particularly Underground Detention Facilities, may be classified as Class V Injection Wells, which are subject to regulations under the Federal Underground Injection Control (UIC) program. In general, if the facility allows stormwater runoff to come in direct contact with groundwater it would meet this criterion. Facilities with a minimum 2-foot vadose zone separation from the groundwater table would not meet the criterion. Designers are advised to contact the DNREC Groundwater Discharges Section for additional information regarding UIC regulations and possible permitting requirements.

Space Required. A typical Detention Practice requires a footprint of 1% to 3% of its contributing drainage area, depending on the depth of the Dry Detention Pond, Dry Extended Detention Basin, or Underground Detention Facility (i.e., the deeper the practice, the smaller footprint needed).

Dry Detention Ponds and Dry ED Basins can function with drainage areas less than 10 acres, but designers should be aware that these “pocket” ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions. When the contributing drainage area of the Dry Detention Ponds and Dry ED Basins is less than 10 acres, alternative outlet configurations should be used to eliminate the possibility of clogging of the outlet.

Underground Detention Systems can be located downstream of other structural stormwater controls providing treatment of the design storm. For treatment train designs where upland practices are used for treatment of the RPv, designers can use a site-adjusted curve number (CN) that reflects the volume reduction of upland practices and likely reduce the size and cost of detention (see *Section 10.6. Detention Practice Design Criteria*).

Minimum Setbacks. Refer to Appendix A-8.

Depth-to-Water Table and Bedrock. Dry Detention Ponds or Dry ED Basins shall not be allowed if the seasonal high water table or bedrock will be within 1 foot of the floor of the pond. Non-watertight Underground Detention Facilities shall be no lower than the seasonal high water table and 2 feet above bedrock. For watertight Underground Detention Facilities, an anti-flotation analysis is required to check for buoyancy problems in seasonal high water table areas. Soil Investigation Procedures shall be followed for testing.

Structural Stability. **Underground Detention Facilities must meet structural requirements for bearing capacity, overburden support, and traffic loading as determined by a licensed design professional, and based upon manufacturer’s recommendations where applicable**.

10.4 **Detention Practice Conveyance Criteria**

Principal Spillway. The principal spillway may be composed of a structure-pipe configuration or a weir-channel configuration. **The principal spillway must be accessible from dry land. A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure. The outfall pipe and all connections to the outfall structure shall be made watertight. Soil tight only joints are not acceptable. Anti-seep collars shall be used in accordance with USDA NRCS Delaware Pond Code 378, as amended. When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced with riprap or other acceptable material to prevent scour.**

Non-Clogging Outlet. F**or Dry ED Basins, the control structure must include an outlet that will slowly release the RPv over a 48-hour period. When a low flow orifice is specified, it must be adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection. Orifice diameters shall not be less than 3 inches unless internal orifice control is provided.**

Outfall Protection. **The design shall specify an outfall that can discharge the maximum design storm event in a non-erosive manner at the project point of discharge.** If necessary, the channel immediately below the Dry Detention Pond and Dry ED Basin outfall may be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This can be accomplished by placing appropriately sized riprap over stabilization geotextile in accordance with HEC-14 Hydraulic Design of Energy Dissipators for Culverts and Channels and Delaware Erosion and Sediment Control Handbook Specification 3.3.10 Riprap Outlet Protection or 3.3.11 Riprap Stilling Basin, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps) based upon the channel lining material. Flared pipe sections, which discharge at or near the stream invert or into a step pool arrangement, should be used at the spillway outlet.

When the discharge is to a manmade pipe or channel system, the system should be adequate to convey the required design storm peak discharge in a non-erosive manner. Care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided. The final release rate of the facility should be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow unless downstream improvements are made to accommodate the increase.

Emergency Spillway. Dry Detention Ponds and Dry ED Basins must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the Dry Detention Ponds and Dry ED Basins rather than bypassing. An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.

Inflow Points. **Inflow points into the Dry Detention Ponds and Dry ED Basins must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance event (Cv).** Inlet pipe inverts should generally be located at the permanent pool elevation. **A forebay shall be provided at each inflow location that provides 10% or greater of the total RPv inflow to the Dry Detention Ponds and Dry ED Basins.** Additional information on forebays may be found in 10.5 Detention Practices Pretreatment Criteria.

Dam Safety Permits. The designer should determine whether or not the embankment meets the criteria to be regulated as a dam by the Delaware Dam Safety Regulations. **In the event that the**

embankment is a regulated dam, the designer must verify that the appropriate Dam Safety Permit has been approved by the Department's Dam Safety Program.

Bypass. **For Underground Detention Facilities, an internal or external high flow bypass or overflow shall be included in the design to safely pass the Fv.**

10.5 Detention Practices Pretreatment Criteria

Pretreatment Forebay.

Sediment forebays are considered to be an integral design feature to maintain the longevity of all Dry Detention Ponds and Dry ED Basins. **A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:**

- **A major inlet is defined as an individual storm drain inlet pipe or open channel conveying at least 10% of the Dry Detention Pond's and Dry ED Basin's contributing RPv runoff volume.**
- The preferred forebay configuration consists of a separate cell, formed by an acceptable barrier such as a concrete weir, riprap berm, gabion baskets, etc. Riprap berms are the preferred barrier material.
- **The forebay shall be no deeper than 3 feet.**
- **The forebay must be sized to contain 10% of the volume of runoff from the contributing drainage area for the Resource Protection event.** The relative size of individual forebays should be proportional to the percentage of the total inflow to the Dry Detention Pond and Dry ED Basin. The storage volume within the forebay may be included in the calculated required storage volume for the Dry Detention Pond and Dry ED Basin.
- The recommended minimum length of the forebay is 10 feet. The forebay should have a length to width ratio of 2:1 or greater. Length is measured with the direction of flow into the Dry Detention Pond and Dry ED Basin.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation. Metered wooden stakes may need to be replaced frequently in Dry Detention Pond and Dry ED Basin forebays; alternative materials should be considered for longevity.
- Vegetation may be included within forebays to increase sedimentation and reduce resuspension and erosion of previously trapped sediment.
- **Discharge from the forebay shall be non-erosive.**

Underground Detention Pretreatment. **Every underground detention practice shall have pretreatment mechanisms to protect the long term integrity of the practice.** Recommended techniques to pretreat 100% of the inflow in every practice include but are not limited to:

- Practices capable of removing floatables such as oils and greases
- Practices capable of removing gross pollutants such as trash and debris
- Proprietary Practices that can achieve a 50% reduction in suspended solids (see Specification 15. Proprietary Practices)
- Catch Basin Sumps (applicable for perforated pipe systems for residential streets and site drainage only, minimum 2')

10.6 Detention Practices Design Criteria

Dry Detention Ponds and Dry ED Basins constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Delaware Pond Code 378 as amended.

Detention Practice Sizing. In order to receive the credits outlined in Tables 10.1 and 10.2, **for RPv compliance, a Dry ED Basin or Underground Detention Facility must provide 48 hours extended detention for the RPv runoff volume. Detention time shall be based on the time of initial inflow to time of final outflow from the facility. In order to simulate a baseflow condition to the extent practicable, the peak discharge for the outflow hydrograph shall not exceed five times the average discharge rate.**

Detention Practices can be designed to capture and treat the remaining stormwater discharged from upstream practices to improve water quality. Detention Practices should be sized to control peak flow rates from the Conveyance Event and Flooding Event as required in accordance with the Delaware Sediment and Stormwater Regulations and accompanying Technical Specifications.

For treatment train designs where upland practices are used for treatment of the RPv, designers can use a site-adjusted CN that reflects the volume reduction of upland practices to compute the Cv and Fv that must be treated by the Detention Practice.

Dry Detention Pond and Dry ED Basin Internal Design Features. The following apply to Dry Detention Pond and Dry ED Basin design:

- *Flow Distribution.* Dry Detention Ponds and Dry ED Basin should be constructed in a manner whereby flows are evenly distributed across the pond bottom, to avoid scour, promote attenuation, filtering, and, where possible, infiltration.
- *Internal Slope.* The minimum recommended longitudinal slope through a pond should be 1%.
- *Side Slopes.* Side slopes within the Dry Detention Pond or Dry ED Basin should have a

gradient of 3H:1V to 4H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. **Earthen side slopes shall be designed and constructed no steeper than 3H:1V.**

- *Long Flow Path.* Dry Detention Pond and Dry ED Basin designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time, treatment pathways, and pond performance and to eliminate short-cutting. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond and (2) the length of the shortest flow path (Hirschman et al., 2009):
    - The *overall flow path* can be represented as the length-to-width ratio *OR* the flow path ratio. These ratios should be at least 2L:1W (3L:1W preferred). Internal berms, baffles, or topography can be used to extend flow paths and/or create multiple pond cells.
    - The *shortest flow path* represents the distance from the closest inlet to the outlet. The ratio of the shortest flow to the overall length should be at least 0.4. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these "closer" inlets should constitute no more than 20% of the total contributing drainage area.

Retaining Walls: **Retaining walls around Dry Detention Ponds and Dry ED Basins shall be limited to no more than 50% of the pond perimeter based upon the peak elevation of the Cv. In order to maintain the safety requirements, retaining walls shall be configured as follows:**

- **The retaining wall shall have a maximum height of 3 feet.**
- **Any additional retaining walls shall have a maximum height of 2 feet and provide a minimum 10-foot level terrace from a lower retaining wall.**

Safety Features. The following safety features apply to Detention Practices:

- **Any inflow opening 12 inches or greater discharging to a closed drainage system shall include safety grates.**
- **The emergency spillway must be located so that downstream structures will not be adversely impacted by spillway discharges.**
- **The emergency spillway exit channel must be designed to direct runoff to a point of discharge without adverse impact to downstream structures.**
- Fencing of the perimeter of Dry Detention Ponds and Dry ED Basins is discouraged. The preferred method to reduce risk is to manage the contours of the pond to eliminate drop-offs or other safety hazards.

- Maintenance access to Underground Detention Facilities should be locked at all times. The Operation and Maintenance Plan should specify how access to the Underground Detention Facility will be accomplished.

Maintenance Access. **All Detention Practices shall be designed so as to be accessible for maintenance. Adequate maintenance access must extend to the pretreatment, riser, and outlet structure. Adequate maintenance access must also be provided for all Underground Detention Facilities. A maintenance right-of-way or easement must extend to the Detention Practice from a public or private road.**
Maintenance access must meet the following criteria:

- **Minimum width of 15 feet.**
- **Profile grade that does not exceed 10H:1V.**
- **Minimum 10H:1V cross slope.**

Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines. When not specified in local code, the top of bank of Dry Detention Ponds and Dry ED Basins Ponds should be set back at least 15 feet from property lines to ensure maintenance access.

Maintenance Set-Aside Area. Adequate land area adjacent to the Dry Detention Pond or Dry ED Basin should be provided for in the Operation and Maintenance Plan as a location for disposal of sediment removed from the pond when maintenance is performed

- **The maintenance set-aside area shall accommodate the volume of 50% of the collective forebay volume.**
- **The maximum depth of the set aside volume shall be one foot.**
- **The slope of the set aside area shall not exceed 5%.**
- The area and slope of the set aside area may be modified if an alternative area or method of disposal is approved by the Department or Delegated Agency.

Detention Vault and Tank Materials: Designers should consider longevity in selecting materials for construction of Underground Detention Facilities. **All construction joints and pipe joints shall be water tight. Cast-in-place wall sections must be designed as retaining walls.** The maximum depth from finished grade to the vault invert should be 20 feet. Manufacturer's specifications should be consulted for proprietary Underground Detention Facilities.

Anti-floatation Analysis for Underground Detention: **For watertight Underground Detention Facilities, anti-flotation analysis is required to check for buoyancy problems in the high water table areas. Anchors shall be designed to counter the pipe and structure buoyancy by at least a 1.2 factor of safety.**

10.7 Detention Practices Landscaping Criteria

No landscaping criteria apply to Underground Detention Facilities.

Woody Vegetation. **Woody vegetation shall not be planted or allowed to grow within 15 feet of the embankment and 10 feet on either side of principal spillway or inflow pipes.** These recommendations may be relaxed in situations where Dry Detention Ponds and Dry ED Basins are constructed adjacent to existing forested areas.

Planting Plan. **For Dry Detention Ponds and Dry ED Basins, a planting plan shall be provided that indicates the methods used to establish and maintain vegetative coverage within the Detention Practice and its vegetated perimeter area.** The planting plan should allow the pond to mature into a native forest in the right places, but yet keep mowable turf along the embankment and all access areas. Avoid plant species that require full shade, or are prone to wind damage. **Minimum elements of a plan include seed mixes by botanical and common names as well as percentages by weight or volume.**

10.8 Detention Practices Construction

Underground Detention Facilities. **Construction of proprietary Underground Detention Facilities must be in accordance with manufacturer's specifications.** All runoff into the system should be blocked until the site is stabilized. **Underground Detention Facilities must be inspected and cleaned of sediment after the site is stabilized.**

Use of Dry Detention Pond or Dry ED Basin for Erosion and Sediment Control. A Dry Detention Pond may serve as a sediment basin during project construction. **Approval from the Department or the appropriate Delegated Agency must be obtained before any planned Dry Detention Ponds and Dry ED Basins can be used as a sediment basin. If a Dry Detention Pond or Dry ED Basin serves as a sediment basin during project construction, the volume of the sediment basin must be based on the more stringent sizing rule.** Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction Dry Detention Pond or Dry ED Basin in mind. The bottom elevation of the temporary sediment basin should be a minimum of 6 inches higher than the proposed bottom elevation of the Dry Detention Pond or Dry ED Basin to allow for accumulated sediment to be removed with the remaining material during conversion from sediment basin to permanent pond. **When the sediment basin is being converted into a Dry Detention Pond or Dry ED Basin, the sediment basin shall be dewatered in accordance with the approved plan and appropriate details from the Delaware Erosion and**

Sediment Control Handbook prior to removing accumulated sediment and regrading the pond bottom.

The Sediment and Stormwater Plan must include conversion steps from sediment basin to permanent Dry Detention Ponds and Dry ED Basins in the construction sequence. The Department or Delegated Agency must be notified and provide approval prior to conversion from sediment basin to the final configuration of the Dry Detention Pond or Dry ED Basin. Appropriate procedures must be implemented to prevent discharge of turbid waters when the sediment basin is being converted into a Dry Detention Pond or Dry ED Basin.

Dry Detention Pond, Dry ED Basin, and Underground Detention Construction Review. Multiple construction reviews are critical to ensure that Dry Detention Ponds and Dry ED Basins are properly constructed. **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls**
- **Construction of the embankment, including installation of the principal spillway and the outlet structure**
- **For Dry Detention Pond and Dry ED Basin – excavation and grading including interim and final elevations**
- **For Underground Detention – subgrade, placement of stone, system components in accordance with manufacturer's recommendations and backfill**
- **Implementation of the planting plan and vegetative stabilization**
- **Final inspection including development of a punch list for facility acceptance**

The following is a typical construction sequence to properly install a Dry Detention Pond or Dry ED Basin. The steps may be modified to reflect different designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: Stabilize the Drainage Area. Dry Detention Ponds or Dry ED Basins should be constructed after the contributing drainage area is stabilized. If the proposed Dry Detention Pond or Dry ED Basin site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be dewatered, dredged, and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas. Ensure that appropriate compaction and dewatering equipment is available. Locate the project benchmark and if necessary transfer a benchmark nearer to the Dry Detention Ponds and Dry ED Basins location for use during construction.

Step 3: Install Erosion and Sediment Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond or basin that are graded or denuded during construction should be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 4: Clear and Strip the embankment area to the desired sub-grade.

Step 5: Excavate the Core Trench and Install the Principal Spillway Pipe in accordance with construction specification of NRCS Small Pond Code 378.

Step 6: Install the Riser or Outflow Structure and ensure that the top invert of the overflow weir is constructed level at the design elevation.

Step 7: Construct the Embankment and any Internal Berms using acceptable material in 8 to 12-inch lifts and compact the lifts with appropriate equipment. Construct the embankment to allow for 10% settlement of the embankment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the Dry Detention Pond or Dry ED Basin. Construct forebays at the proposed inflow points.

Step 9: Construct the Emergency Spillway in cut or structurally stabilized soils.

*Step 10: Install Outlet Pipe*s, including any flared end sections, headwalls, and downstream rip-rap apron protection underlain by stabilization geotextile.

Step 11: Stabilize Exposed Soils with the approved seed mixtures in accordance with the vegetative stabilization specifications on the approved Sediment and Stormwater Management Plan.

Step 12: Plant the Dry Detention Pond or Dry ED Basin.

Post Construction Verification.

Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the Detention Practice has been constructed within allowable tolerances and in accordance with the approved Sediment and Stormwater Management Plan and

accepted by the approving agency.

Allowable tolerances for Dry Detention Pond and Dry ED Basin are as follows:

- **The constructed top of bank elevation may be no lower than the design elevation for top of bank.**
- **The constructed volume of the dry pond surface storage shall be no less than 90% of the design volume.**
- **The constructed elevation of any structure shall be within 0.15 foot of the design.**

Allowable tolerances for Underground Detention Facilities are as follows:

- **Grate and invert elevations of all structures, including weirs shall be within 0.15 foot of the design.**
- **Diameter of all pipes or dimensions of chambers within underground detention facility shall be as shown on the plan.**
- **Dimension of any weirs shall be within 10% of the design.**

When the allowable tolerances are exceeded for volume or structure elevations, supplemental calculations must be submitted to the approval agency to demonstrate that the Detention Practice, as constructed, meets the design requirements.

10.9 Detention Practices Maintenance Criteria

Repair of critical structural features such as embankments and risers shall be performed by responsible personnel that have successfully completed the Department Contractor Training Program.

Sediment removal in the Dry Detention Pond or Dry ED Basin pretreatment practice must occur when 50% of total forebay capacity has been lost. The owner can plan for this maintenance activity to occur every 5 to 7 years.

Before project completion, the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper

maintenance is not performed.

Typical maintenance activities for Detention Practices are outlined in Table 10.5. Maintenance requirements for Underground Storage Facilities should include quarterly visual inspections from the manhole access points to verify that there is no standing water or excessive sediment buildup. Entry into the system for a full inspection of the system components (pipe or vault joints, general structural soundness, etc.) should be conducted annually. Confined space entry credentials may be required for this inspection.

Table 10.5 Typical maintenance items for Detention Practices

Frequency	Maintenance Items
During establishment, as needed (first year)	• Water Dry Detention Pond and Dry ED Basin side slopes and bottom area to promote vegetation growth and survival
Quarterly or after major storms (>1 inch of rainfall)	• Remove sediment and oil/grease from inlets, pre-treatment devices, flow diversion structures, storage practices and overflow structures. • Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. • Ensure that the contributing drainage area is stabilized. Perform spot-reseeding where needed. • Repair undercut and eroded areas at inflow and outflow structures.
Annually	• Measure sediment accumulation levels in forebay. Remove sediment when 50% of the forebay capacity has been lost. • Inspect the condition of stormwater inlets for material damage, erosion or undercutting. Repair as necessary. • Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine pond embankment integrity. • Inspect outfall channels for erosion, undercutting, rip-rap displacement, woody growth, etc. • Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc. • Inspect condition of all trash racks, flashboard risers, and other appurtenances for evidence of clogging, leakage, debris accumulation, etc. • Inspect maintenance access to ensure it is free of debris or woody vegetation, and check to see whether valves, manholes and locks can be opened and operated. • Inspect internal and external side slopes of Dry Detention Ponds for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately. • Monitor the growth of trees and shrubs planted in Dry Detention Ponds. Remove invasive species and replant vegetation where necessary to ensure dense coverage.

Operation and Maintenance Plans should clearly outline how vegetation in the Dry Detention Pond or Dry ED Basin and its vegetated perimeter will be managed or harvested in the future. Periodic mowing of the vegetated perimeter area is only required within the maintenance access and the embankment. The remaining perimeter can be managed as a meadow (mowing every other year) or forest. The Operation and Maintenance Plan should schedule a shoreline cleanup at least once a year to remove trash and debris. Maintenance of Detention Practices is driven by annual maintenance reviews that evaluate the condition and performance of the Detention Practice. Based on maintenance review results, specific maintenance tasks may be required.

10.10 References

Cappiella, K., Schueler, T., and T. Wright. 2005. *Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed*. NA-TP-04-05. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs*. Center for Watershed Protection. Ellicott City, MD.

11.0 Stormwater Filtering Systems

Definition: **Stormwater Filter Systems are practices that capture and temporarily store the design storm volume and pass it through a filter media or material. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially infiltrate into the soil.**

Design variants include:

- 11-A **Non-Structural Sand Filter**
- 11-B **Surface Sand Filter**
- 11-C **Three-Chamber Underground Sand Filter**
- 11-D **Perimeter Sand Filter** (including “Delaware” Modular Sand Filter)

Bioretention also functions as a Stormwater Filtering System; however, since it also requires a vegetative component, Bioretention is included as in a separate specification (see Specification 2.0, Bioretention).

Stormwater Filtering Systems are a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater Filtering Systems capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system. The filter consists of two chambers: the first is devoted to settling, and the second serves as a filter bed consisting of a sand filter media.

Stormwater Filtering Systems are a versatile option because they consume very little surface land and have few site restrictions. They provide moderate pollutant removal performance at small sites where space is limited. However, filters have limited or no runoff volume reduction capability, so designers should consider using up-gradient runoff reduction practices, which have the effect of decreasing the design storm volume (and size) of the filtering practices. Filtering practices are also suitable to provide special treatment at designated stormwater hotspots. A list of potential stormwater hotspots applications can be found in Appendix 4, Stormwater Hotspots Guidelines. Stormwater Filtering Systems are typically not to be designed to provide stormwater detention (Cv and Fv), but they may in some circumstances. However, the Three-Chamber Underground Sand Filter can be modified by expanding the first or settling chamber, or adding an extra chamber between the filter chamber and the clear well chamber to handle the detention volume, which is subsequently discharged at a pre-determined rate through an orifice and weir combination.

While proprietary filters are discussed in this document, they are highly variable in design, and consequently are not included in this table. Specification 15.0 outlines a process for acceptance of proprietary practices.

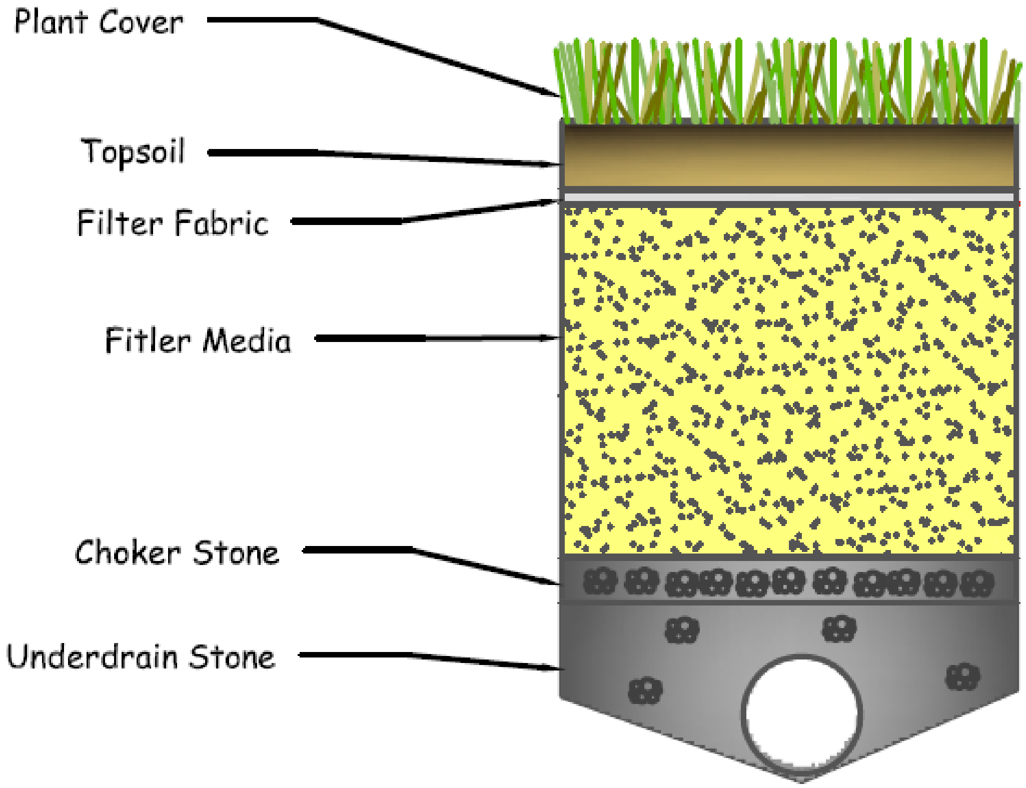

Figure 11.1 Non-Structural Sand Filter

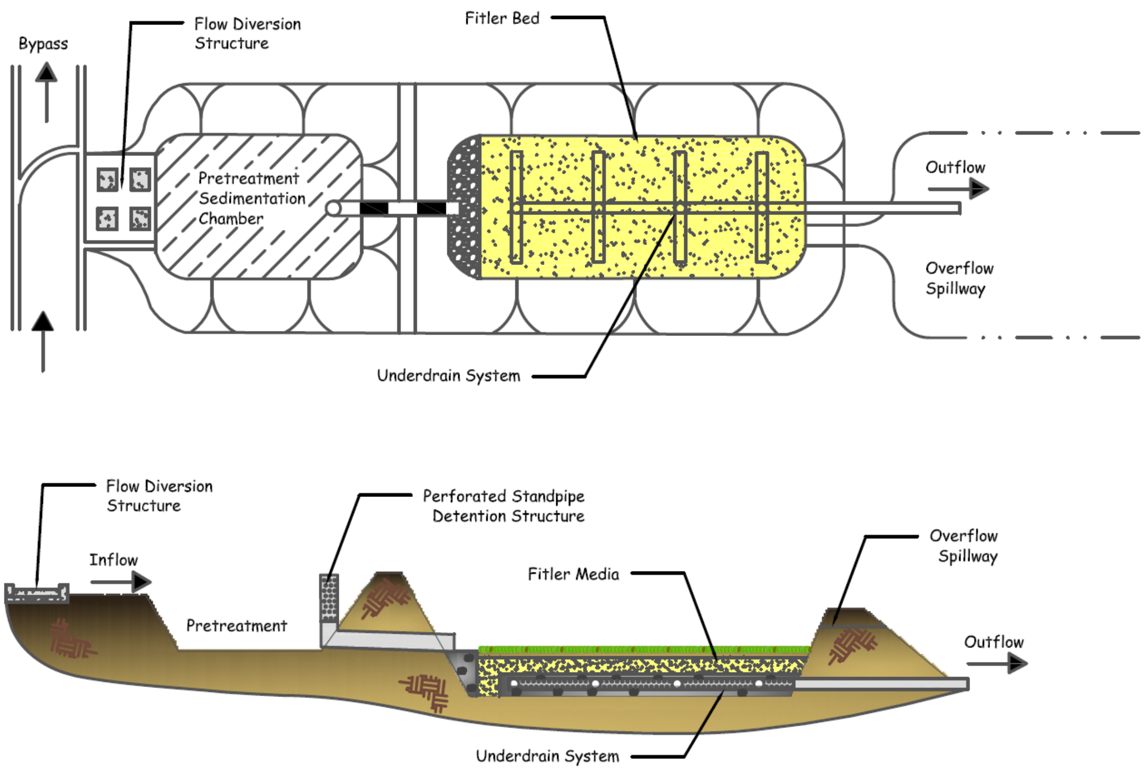

Figure 11.2 Surface Sand Filter

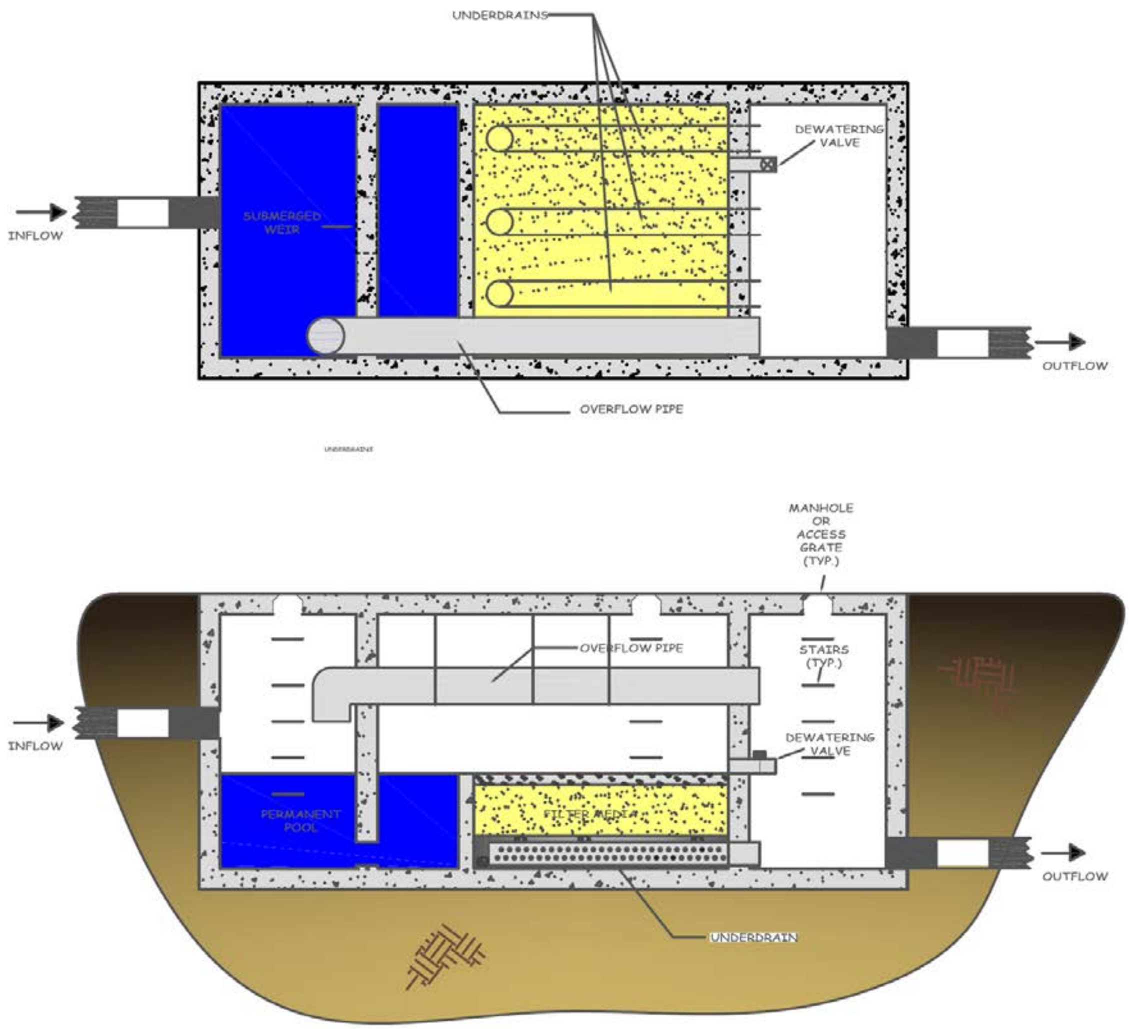

Figure 11.3 Three Chamber Underground Sand Filter

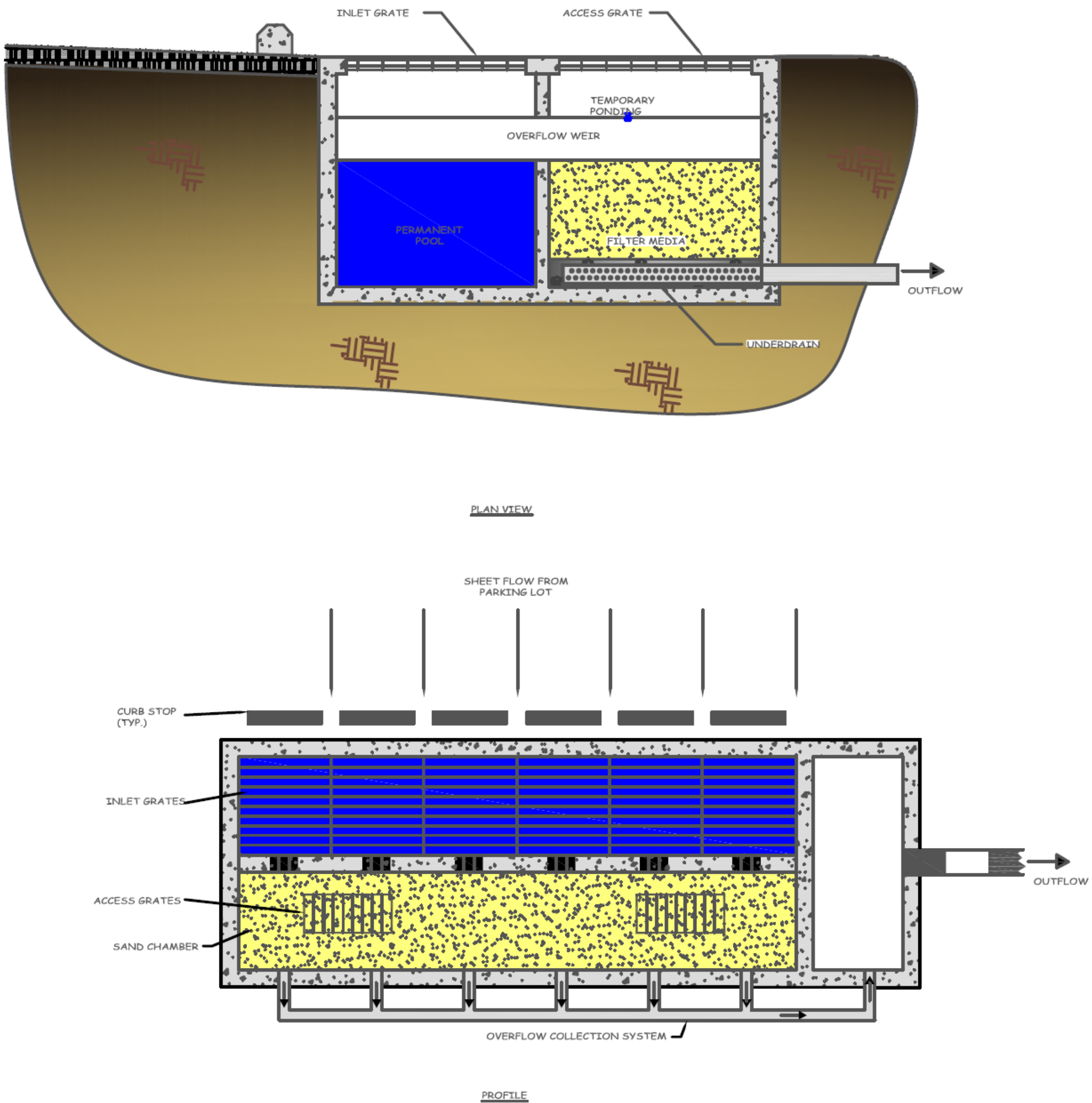

Figure 11.4. Perimeter Sand Filter

11.1. Stormwater Filtering Systems Stormwater Credits

Stormwater Filtering Systems receive no runoff reduction performance credit, but are credited for pollutant filtering (see Table 11.1). **Stormwater Filtering Systems sized in accordance with the design criteria shall receive the following pollutant reduction performance credits:**

11.1 Filtering Practices Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	**Not less than 40%**
TP Reduction	**Not less than 60%**
TSS Reduction	**Not less than 80%**

11.2 Stormwater Filtering Systems Practice Summary

Table 11.2 summarizes various criteria for Stormwater Filtering Systems, and Table 11.3 summarizes the materials specifications for these practices. For more detail, consult Sections 11.3 through 11.7. Sections 11.8 and 11.9 describe practice construction and maintenance criteria.

Table 11.2 Stormwater Filtering Systems Practice Summary

	Surface and Non-Structural Filters (11-A and 11-B)	Underground and Perimeter Filters (11-C and 11-D)
Feasibility Criteria (Section 11.3)	• **Min 2' separation to SHWT or bedrock unless mounding analysis or piezometer testing provided** • Typically consume 2%-3% of CDA	• **No min. separation to SHWT or bedrock** • Typically consume <1% of CDA
	• 10" to 10' head requirement, with lowest requirement for Perimeter Filters (F-4) • Ideally suited to treat stormwater hotspots and parking lots. • <5 Acre CDA, near 100% impervious • **Slopes <6%** • Not hydraulically connected to structure foundations • **Must be accessible for maintenance**	
Conveyance Criteria (Section 11.4)	• Typically designed as off-line systems • **On-line systems shall safely pass the largest design storm event** • **Drain or dewater within 48 hours**	
Pretreatment Criteria (Section 11.5)	• **Every inlet shall have a pretreatment mechanism** • Sediment chamber or a series of options including grassed channels, filter strip, check dam, and gravel diaphragm. • Sediment Chamber designed to capture 25% of the design volume.	
Design Criteria (Section 11.6)	• **Designed to drain the design storm volume within 48 hours** • **Filter media: clean washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter** • **Min. filter bed depth of 12"** • **When an underdrain is specified a needled, non-woven, polypropylene geotextile having a flow rate (ASTM D4491) ≥110 gpm/sq. ft. and an apparent opening size (ASTM D4751) of US #70 or #80 sieve shall be placed beneath the filter media and above the underdrain gravel layer.** • **Sized to contain a minimum of 75% of the RPv prior to filtration**	
Sizing: Filter Area (Section 11.6)	$SA_{filter} = (DesignVolume)(d_f)/\left[(k)(h_{avg}+d_f)(t_f)\right]$ *Design Volume* = design storm volume, typically the water quality storm (cu. ft.) d_f = Filter media depth (thickness) = minimum 1 ft. (ft.) k = Coefficient of permeability – partially clogged sand (ft./day) = 3.5 ft./day h_f = Average height of water above the filter bed (ft.), with a maximum of 5ft./2 t_f = Allowable drawdown time = 1.67 day	
Safety/ Maintenance Features (Section 11.6)	• Observation wells and clean-outs • Clearly visible (signs or markings for underground practices)	• **Minimum 30" diameter manholes (for 11-C) with steps** • Confined space considerations for 11-C may apply with minimum 5' headroom for 11-C

Safety/ Maintenance Features (Section 11.6)	• **Designed to be accessible for maintenance**
	  o **Maintenance ROW or easement to filter from public or private road**
	  o **Extend to pretreatment and filter bed**
	  o **Maintenance access**
	    ▪ **Min width 15'**
	    ▪ **Profile grade does not exceed 10H:1V**
	    ▪ **Min 10H:1V cross slope**

Landscaping Criteria (Section 11.7)	• **Vegetative cover shall be established over the CDA before runoff can be accepted into the filtering system**

Construction Criteria (Section 11.8)	• **No runoff shall be allowed to enter the Stormwater Filtering System prior to completion of all construction activities, including revegetation and final site stabilization.**
	• **Construction runoff shall be treated in separate sedimentation basins and routed to bypass the filter system.**
	• **Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials shall be removed and replaced with new clean filter materials before a regulatory inspector approves its completion.**
	• **The approved Sediment & Stormwater Plan shall include specific measures to provide for the protection of the filter system before the final stabilization of the site.**
	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**
	  o **Pre-construction meeting.**
	  o **Initial site preparation including installation of erosion and sediment controls, sensitive area protection, and blockage of inlets to stormwater filtering system locations.**
	  o **Excavation and grading to design dimensions and elevations.**
	  o **Installation of the filter structure, including the water tightness test as applicable.**
	  o **Installation of the underdrain and filter bed.**
	  o **Check that stabilization in contributing area is adequate to bring the stormwater filtering system online.**
	  o **Final construction review after a rainfall event to ensure that it drains properly and all pipe connections are watertight. Develop a punch list for facility acceptance.**
	• **Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the stormwater filtering system has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.**
	• **Allowable tolerances for stormwater filtering systems are as follows:**
	  o **The constructed surface area of the filter bed shall be no less than 90% of the design surface area.**
	  o **The constructed volume of the surface storage shall be no less than 90% of the design volume.**
	  o **Depth of filter media shall be no less than 12 inches.**
	  o **The constructed elevation of any structure shall be within 0.15 foot of the design.**

Maintenance Criteria (Section 11.9)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

Table 11.3. Stormwater Filtering Systems Material Specifications

Material	Specification
Sand	**The filter media shall consist of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter.**
Underdrain	**The underdrain shall be a minimum of 4-inch perforated corrugated polyethylene pipe (CPP).**
Non-woven Geotextile	**When an underdrain is specified a needled, non-woven, polypropylene geotextile having a flow rate (ASTM D4491) ≥110 gpm/sq. ft. and an apparent opening size (ASTM D4751) of US #70 or #80 sieve shall be placed beneath the filter media and above the underdrain gravel layer.**
Underdrain Stone	**The underdrain shall be encased in a layer of clean, washed nominal 1/4" gravel with a maximum of 2.0 percent passing the #200 sieve with a minimum of 3" of cover.**
Impermeable Liner	Thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

11.3 Stormwater Filtering Systems Feasibility Criteria

Stormwater Filtering Systems can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served, but there are situations where they may clearly be the best option for stormwater treatment (e.g., hotspot runoff treatment, small parking lots, ultra-urban areas etc.). The following criteria apply to filtering practices:

Available Hydraulic Head. The principal design constraint for Stormwater Filtering Systems is available hydraulic head, which is defined as the vertical distance between the top elevation of the filter and the bottom elevation of the discharge pipe. The head needed for Stormwater Filtering Systems ranges up to 10 feet, depending on the design variant. It is difficult to employ filters in extremely flat terrain, since they require gravity flow through the filter. The only exception is the Perimeter Sand Filter, which can be applied at sites with as little as 10 inches of head.

Depth to Water Table and Bedrock. Non-structural sand filter and surface sand filter should always be separated from the water table to ensure that groundwater does not intersect the invert. This could otherwise lead to possible groundwater contamination or failure of the filtering facility. **A minimum vertical distance of 2 feet must be provided between the bottom of the non-structural sand filter or surface sand filter and the seasonal high water table as determined by the soil investigation procedures or bedrock layer. The minimum vertical distance of 2 feet may be relaxed if a groundwater mounding analysis or piezometer testing has been performed by a qualified professional. Three-chamber underground sand filter and perimeter sand filter require no minimum separation to seasonal high water table or bedrock.**

Contributing Drainage Area. Stormwater Filtering Systems are best applied on small sites where the contributing drainage (CDA) area is as close to 100% impervious as possible in order to reduce the risk that eroded sediments will clog the filter. A maximum CDA of 5 acres is recommended for surface sand filters, and a maximum CDA of 2 acres is recommended for non-structural, perimeter or underground filters. Stormwater Filtering Systems have been used on larger drainage areas in the past, but greater clogging problems have typically resulted.

Space Needed. The amount of space needed for a Stormwater Filtering System depends on the design variant selected. Surface Sand Filters typically consume about 2% to 3% of the CDA, while Perimeter Sand Filters typically consume less than 1%. Underground Stormwater Filters generally consume no surface area except their manholes.

Land Use. As noted above, Stormwater Filtering Systems are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other applications include redevelopment of commercial sites or when existing parking lots are renovated or expanded. Stormwater Filtering Systems can work on most commercial, industrial, institutional or municipal sites and can be located underground if surface area is not available.

Site Topography. **Stormwater Filtering Systems shall not be located on slopes greater than 6%.**
Setbacks. To avoid the risk of seepage, non-structural Stormwater Filtering Systems should not be hydraulically connected to structure foundations. The designer should check to ensure footings and foundations of adjacent buildings do not encroach within an assumed 4:1 phreatic zone drawn from the maximum design water elevation in the non-structural stormwater filtering system. See Appendix 8 Stormwater Facility Setbacks for recommended setbacks.

Proximity to Utilities. Stormwater Filtering Systems should be sited to account for future maintenance of underground utilities in accordance with the utility owner's requirements. See Appendix 8 Stormwater Facility Setbacks for recommended separation distances for utilities.

Facility Access. **All Stormwater Filtering Systems must be designed so as to be accessible for maintenance** (by vacuum trucks).

11.4 Stormwater Filtering Systems Conveyance Criteria

Most Stormwater Filtering Systems are designed as off-line systems so that all flows enter the filter storage chamber until it reaches capacity, at which point larger flows are then diverted or bypassed around the filter to an outlet chamber and are not treated. Runoff from larger storm events should be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for filtering practices.

Some underground filters can be designed and constructed as on-line BMPs. **On-line stormwater filtering systems' designs, shall demonstrate that the filter will safely pass the largest design storm event** (e.g., the 10-year event) **to a stabilized water course without resuspending or flushing previously trapped material.**

All Stormwater Filtering Systems shall be designed to drain or dewater within 48 hours after

a storm event to reduce the potential for nuisance conditions.

11.5 Stormwater Filtering Systems Pretreatment Criteria

Every inlet into a Stormwater Filtering System shall have a pretreatment mechanism to trap sediment, preserve the capacity of the main treatment area, and protect the long term integrity of the practice. Pre-treatment devices are subject to the following recommended design criteria:

- Sedimentation chambers are typically used for pre-treatment to capture coarse sediment particles before they reach the filter bed.
- Sedimentation chambers may be wet or dry but should be sized to accommodate at least 25% of the total design storm volume (inclusive).
- Sediment chambers should be designed as level spreaders such that inflows to the filter bed have near zero velocity and spread runoff evenly across the bed.
- Non-Structural and Surface Sand Filters may use alternative pre-treatment measures, such as a grass filter strip, forebay, gravel diaphragm, check dam, level spreader, or combination. Grass filter strips that are perpendicular to incoming sheet flow extend from the edge of pavement (with a slight drop at the pavement edge) to the bottom of the stormwater filtering system at a 5:1 slope or flatter. Alternatively, if the stormwater filtering system has side slopes that are 3:1 or flatter, a 5 foot grass filter strip at a maximum 5% (20:1) slope can be used. The check dam may be wooden or concrete and should be installed so that it extends only 2 inches above the filter strip and has lateral slots to allow runoff to be evenly distributed across the filter surface. Alternative pre-treatment measures should contain a non-erosive flow path that distributes the flow evenly over the filter surface. If a forebay is used it should be designed to accommodate at least 25% of the total design storm volume (inclusive).

11.6 **Stormwater Filtering Systems Design Criteria**

Detention time. **Stormwater Filtering Systems shall be designed to drain the design storm volume from the filter chamber within 48 hours after each rainfall event.**

Structural Design.: If a filter will be located underground or experience traffic loads, a professional structural engineer should certify the structural integrity of the design.

Geometry. Stormwater Filtering Systems are gravity flow systems that normally need 2 to 10 feet of driving head to push the water through the filter media through the entire maintenance cycle; therefore, sufficient vertical clearance between the inverts of the inflow and outflow pipes is needed.

Filter. The filter media shall consist of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter. The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. The recommended filter bed depth is 18 inches. **A minimum**

filter bed depth of 12" is required. Designers should note that specifying the minimum depth of 12" will incur a more intensive maintenance schedule and possibly result in more costly maintenance.

Underdrain. Stormwater Filtering Systems are normally designed with an underdrain system. **The underdrain shall be a minimum of 4-inch perforated corrugated polyethylene pipe (CPP). The underdrain shall be encased in a layer of clean, washed nominal 1/4" gravel with a maximum of 2.0 percent passing the #200 sieve with a minimum of 3" of cover. When an underdrain is specified a needled, non-woven, polypropylene geotextile having a flow rate (ASTM D4491) ≥110 gpm/sq. ft. and an apparent opening size (ASTM D4751) of US #70 or #80 sieve shall be placed beneath the filter media and above the underdrain gravel layer.**

Liner. Impermeable liners included in Stormwater Filtering Systems designs are recommended to be thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

Type of Filter. There are several design variations of the basic filter that enable designers to use Stormwater Filtering Systems at challenging sites or to improve pollutant removal rates. The choice of which filter design to apply depends on available space and hydraulic head and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, Underground Sand Filters are often the only design that can be used. Surface and Perimeter Sand Filters are often a more economical choice when adequate surface area is available. The most common design variants include the following:

- Non-Structural Sand Filter (11-A). The Non-Structural Sand Filter is applicable to sites less than 2 acres in size, and is very similar to a Bioretention practice (see *Specification 2. Bioretention*), with the following exceptions:
    - The bottom is lined with an impermeable liner and always has an underdrain.
    - The surface cover is sand, turf or pea gravel.
    - The filter media is 100% sand.
    - The filter surface is not planted with trees, shrubs or herbaceous materials.
    - The filter has two cells, with a dry or wet sedimentation chamber preceding the sand filter bed.

  The Non-Structural Sand Filter is the least expensive filter option for treating hotspot runoff. The use of Bioretention areas is generally preferred at most other sites.

- Surface Sand Filter (11-B). The Surface Sand Filter is designed with both the filter bed and sediment chamber located at ground level. The most common filter media is sand; however, a peat/sand mixture may be used to increase the removal efficiency of the system. In most cases, the filter chambers are created using pre-cast or cast-in-place concrete. Surface Sand Filters are normally designed to be off-line facilities, so that only the desired water quality or runoff reduction volume is directed to the filter for treatment. However, in some cases they can be installed on the bottom of a Dry Extended Detention (ED) Pond (see *Specification 10. Detention Practices*).

- Three-Chamber Underground Sand Filter (11-C). The Three-Chamber Underground Sand Filter is a gravity flow system. The facility may be precast or cast-in-place. The first chamber acts as a pretreatment facility removing any floating organic material such as oil, grease, and tree leaves. It should have a submerged orifice leading to a second chamber and it should be designed to minimize the energy of incoming stormwater before the flow enters the second chamber (filtering or processing chamber).

  The second chamber is the filter chamber. It should contain at the filter material consisting of gravel, geotextile fabric, and sand, and should be situated behind a weir. Along the bottom of the structure should be a subsurface drainage system consisting of a parallel PVC pipe system in a gravel bed. A dewatering valve should be installed at the top of the filter layer for safety release in cases of emergency. A by-pass pipe crossing the second chamber to carry overflow from the first chamber to the third chamber is recommended.

  The third chamber is the discharge chamber. It should also receive the overflow from the first chamber through the bypass pipe when the storage volume is exceeded.

  Water enters the first chamber of the system by gravity or by pumping. This chamber removes most of the heavy solid particles, floatable trash, leaves, and hydrocarbons. Then the water flows to the second chamber and enters the filter layer by overtopping a weir. The filtered stormwater is then picked up by the subsurface drainage system that empties it into the third chamber.

  Whenever there is insufficient hydraulic head for a Three-Chamber Underground Sand Filter, a well pump may be used to discharge the effluent from the third chamber into the receiving storm or combined sewer. For Three-Chamber Underground Sand Filters in combined-sewer areas, a water trap should be provided in the third chamber to prevent the back flow of odorous gas.

- Perimeter Sand Filter (11-D). The Perimeter Sand Filter also includes the basic design elements of a sediment chamber and a filter bed. The Perimeter Sand Filter typically consists of two parallel trenches connected by a series of overflow weir notches at the top of the partitioning wall, which allows water to enter the second trench as sheet flow. The first trench is a pretreatment chamber removing heavy sediment particles and debris. The second trench consists of the sand filter layer. A subsurface drainage pipe should be installed at the bottom of the second chamber to facilitate the filtering process and convey filter water into a receiving system.

  In this design, flow enters the system through grates, usually at the edge of a parking lot. The Perimeter Sand Filter is usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by entering an overflow chamber. One major advantage of the Perimeter Sand Filter design is that it needs little hydraulic head and is therefore a good option for sites with low topographic relief.

The Delaware Modular Sand Filter was specifically developed to meet these conditions using a pre-cast structure. The Standard Detail & Specifications for the Delaware Modular Sand Filter are included as *Appendix 11-1* of this document.

Surface Cover. The surface cover for Non-Structural and Surface Sand Filters should consist of a 3-inch layer of topsoil on top of a non-woven filter fabric laid above the sand layer. The surface may also have pea gravel inlets in the topsoil layer to promote filtration. The pea gravel may be located where sheet flow enters the filter, around the margins of the filter bed, or at locations in the middle of the filter bed.

Underground Sand Filters should have a pea gravel layer on top of a coarse non-woven fabric laid over the sand layer. The pea-gravel helps to prevent bio-fouling or blinding of the sand surface. The fabric serves to facilitate removing the gravel during maintenance operations.

Maintenance Reduction Features. The following maintenance issues should be addressed during filter design to reduce future maintenance problems:

- *Observation Wells and Cleanouts.* Non-Structural and Surface Sand Filters should include an observation well consisting of a 6-inch diameter non-perforated PVC pipe fitted with a lockable cap. It should be installed flush with the ground surface to facilitate periodic inspection and maintenance. In most cases, a cleanout pipe will be tied into the end of all underdrain pipe runs. The portion of the cleanout pipe/observation well in the underdrain layer should be perforated. At least one cleanout pipe should be provided for every 2000 square feet of filter surface area.
- *Access.* **All Stormwater Filtering Systems must be designed so as to be accessible for maintenance.**
    - **A maintenance right-of-way or easement must extend to the Stormwater Filtering System from a public or private road.**
    - **Adequate maintenance access must extend to the perimeter of the Stormwater Filtering System pretreatment area and the filter bed.**
    - **Maintenance access must meet the following criteria:**
        - **Minimum width of fifteen feet.**
        - **Profile grade that does not exceed 10H:1V.**
        - **Minimum 10H:1V cross slope.**
- Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. "Sufficient access" is operationally defined as the ability to get a vacuum truck or similar equipment close enough to the sedimentation chamber and filter to enable cleanouts. For underground structures, sufficient headroom for maintenance should be provided. A minimum head space of 5 feet above the filter is recommended for maintenance of the structure. However, if 5 feet headroom is not available, manhole access should be installed.
- *Manhole Access (for Underground Sand Filters).* **Access to Underground Sand Filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur.**

- *Visibility.* Stormwater filters should be clearly visible at the site so inspectors and maintenance crews can easily find them. Adequate signs or markings should be provided at manhole access points for Underground Sand Filters.
- *Confined Space Issues.* Underground Sand Filters are often classified as a *confined space*. Consequently, special OSHA rules may apply, and training may be needed to protect the workers that access them. These procedures often involve training about confined space entry, venting, and the use of gas probes.

Filter Material Specifications. The basic material specifications for filtering practices that utilize sand as a filter media are outlined in Table 11.3. Proprietary filters, including those being utilized for pre-treatment for rainwater harvesting systems, infiltration, and other applications that utilize alternative media should be evaluated as noted in Specification 15.

Filter Sizing . The volume to be treated by the device is a function of the storage depth above the filter and the surface area of the filter. The storage volume is the volume of ponding above the filter. For a given design volume, Equation 11.1 may be used to determine the filter surface area:

Equation 11.1. Minimum Filter Surface Area for Filtering Practices

$$SA_{filter} = (DesignVolume)(d_f)/\left[(k)(h_{avg} + d_f)(t_f)\right]$$

Where:

SA_{filter} = area of the filter surface (sq. ft.)

$DesignVolume$ = design storm volume, RPv (cu. ft.)*

d_f = Filter media depth (thickness) = minimum 1 ft. (ft.)

k = Coefficient of permeability – partially clogged sand (ft./day) = 3.5 ft./day

h_f = Average height of water above the filter bed (ft.), with a maximum of 5 ft./2

t_f = Allowable drawdown time = 1.67 day

The coefficient of permeability (ft./day) is intended to reflect the worst case situation (i.e., the condition of the sand media at the point in its operational life where it is in need of replacement or maintenance). Stormwater Filtering Systems are therefore sized to function within the desired constraints at the end of the media's operational life cycle.

The Stormwater Filtering System including pretreatment shall be sized to contain a minimum of 75% of the RPv prior to filtration (Equation 11.2). This reduced volume takes into account the varying filtration rate of the water through the media, as a function of a gradually declining hydraulic head.

Equation 11.2. Required Volume of Storage for Filtering Practices

$$V_{ponding} = 0.75(DesignVolume)$$

Where:

$V_{ponding}$ = storage volume required prior to filtration (cu. ft.)

11.7 Stormwater Filtering Systems Landscaping Criteria

Vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the Stormwater Filtering System. Native plants should be used where possible. Stormwater Filtering Systems should be incorporated into site landscaping to increase their aesthetics and public appeal.

Surface and Non-Structural Sand Filters may have a grass cover to aid in the pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

11.8 **Stormwater Filtering Systems Construction Criteria**

Erosion and Sediment Control. No runoff shall be allowed to enter the Stormwater Filtering System prior to completion of all construction activities, including revegetation and final site stabilization. Construction runoff shall be treated in separate sedimentation basins and routed to bypass the filter system. Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials shall be removed and replaced with new clean filter materials before a regulatory inspector approves its completion. The approved Sediment & Stormwater Plan shall include specific measures to provide for the protection of the filter system before the final stabilization of the site.

Filter Installation. The following is the typical construction sequence to properly install a Stormwater Filtering System. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity and configuration of the proposed filtering application.

Step 1: Stabilize Drainage Area. Filtering practices should only be constructed after the contributing drainage area to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed filtering area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is complete, the sediment control facility will be dewatered, dredged and regraded to design dimensions for the post-construction filter.

Step 2: Install E&S Controls for the Filtering Practice. Stormwater should be diverted around filtering practices as they are being constructed. This is usually not difficult to accomplish for off-line filtering practices. It is recommended to keep runoff and eroded sediments away from the filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the filter, and erosion control fabric may be needed during construction on exposed side-slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the filtering practice should be rapidly stabilized by hydro-seed, sod, mulch, or other method.

Step 3: Assemble Construction Materials on-site, assuring they meet design specifications, and prepare any staging areas.

Step 4: Clear and Strip the project area to the desired subgrade.

Step 5: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the filtering practice.

Step 6: Install the Filter Structure and check all design elevations (concrete vaults for surface, underground and perimeter sand filters). Upon completion of the filter structure shell, inlets and outlets should be temporarily plugged and the structure filled with water to the brim to demonstrate water tightness. Maximum allowable leakage is 5% of the water volume in a 24-hour period. If the structure fails the test, repairs should be performed to make the structure watertight before any sand is placed into it.

Step 7: Install the gravel, underdrains, and geotextile layer of the filter.

Step 8: Spread Sand Across the Filter Bed in 1 foot lifts up to the design elevation. Backhoes or other equipment can deliver the sand from outside the filter structure. Sand should be manually raked. Clean water is then added until the sedimentation chamber and filter bed are completely full. The facility is then allowed to drain, hydraulically compacting the sand layers. After 48 hours of drying, refill the structure to the final top elevation of the filter bed.

Step 9 (Surface Sand Filters Only): Install the Permeable Filter Fabric over the sand, add a 3-inch topsoil layer and pea gravel inlets, and immediately seed with the permanent grass species. The grass should be watered, and the facility should not be switched on-line until a vigorous grass cover has become established.

Step 10: Stabilize Exposed Soils on the perimeter of the structure with temporary seed mixtures appropriate for a buffer. All areas above the normal pool should be permanently stabilized by hydroseed, sod, or seeding and mulch.

Step 11: *Conduct the final construction inspection.*

Construction Review. **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**

- **Pre-construction meeting.**
- **Initial site preparation including installation of erosion and sediment controls, sensitive area protection, and blockage of inlets to stormwater filtering system locations.**
- **Excavation and grading to design dimensions and elevations.**
- **Installation of the filter structure, including the water tightness test as applicable.**
- **Installation of the underdrain and filter bed.**

- **Check that stabilization in contributing area is adequate to bring the stormwater filtering system online.**
- **Final construction review after a rainfall event to ensure that it drains properly and all pipe connections are watertight. Develop a punch list for facility acceptance.**

Post Construction Verification Documentation.
Upon facility completion, the owner shall submit post construction verification documents to demonstrate that the stormwater filtering system has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for stormwater filtering systems are as follows:

- **The constructed surface area of the filter bed shall be no less than 90% of the design surface area.**
- **The constructed volume of the surface storage shall be no less than 90% of the design volume.**
- **Depth of filter media shall be no less than 12 inches.**
- **The constructed elevation of any structure shall be within 0.15 foot of the design.**

11.9 Stormwater Filtering Systems Maintenance Criteria

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.
Operation and Maintenance Plans should clearly outline how vegetation in the Filtering Practice will be managed or harvested in the future. The Operation and Maintenance Plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of Stormwater Filtering Systems is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 11.4. Typical Stormwater Filtering System Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the Stormwater Filtering System perimeter area
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris and blockages • Repair undercut, eroded, and bare soil area
Twice a year	• Mowing of the Stormwater Filtering System vegetated perimeter area as applicable
Annually	• Cleanup to remove trash, debris and floatables • A full maintenance review • Review condition of structural components • Repair broken mechanical components, if needed
Every 5 to 7 years	• Forebay sediment removal (as applicable) • Flush underdrain system (as applicable)
From 5 to 25 years	• Repair pipes and structural components as needed • Remove any accumulated sediment within facility, as needed

11.10 References

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual, First Edition*. Available online at: http://www.georgiastormwater.com

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. http://www.cwp.org/PublicationStore/special.htm

Shaver, E and R. Baldwin, *Sand Filter Design for Water Quality Treatment*, Delaware DNREC, 1991.

APPENDIX 11-1

STANDARD DETAIL & SPECIFICATIONS FOR DELAWARE MODULAR SAND FILTER

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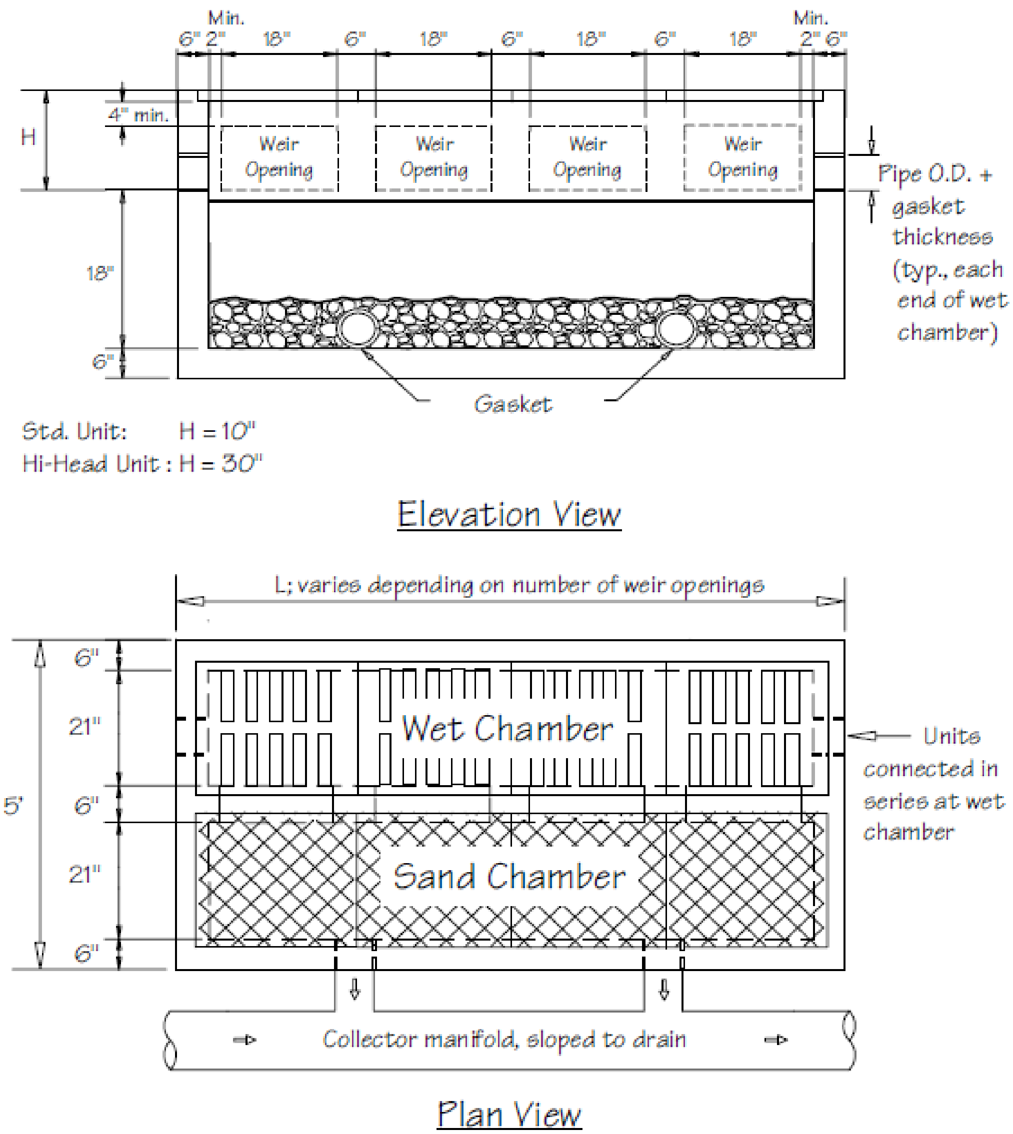
Standard Detail & Specifications

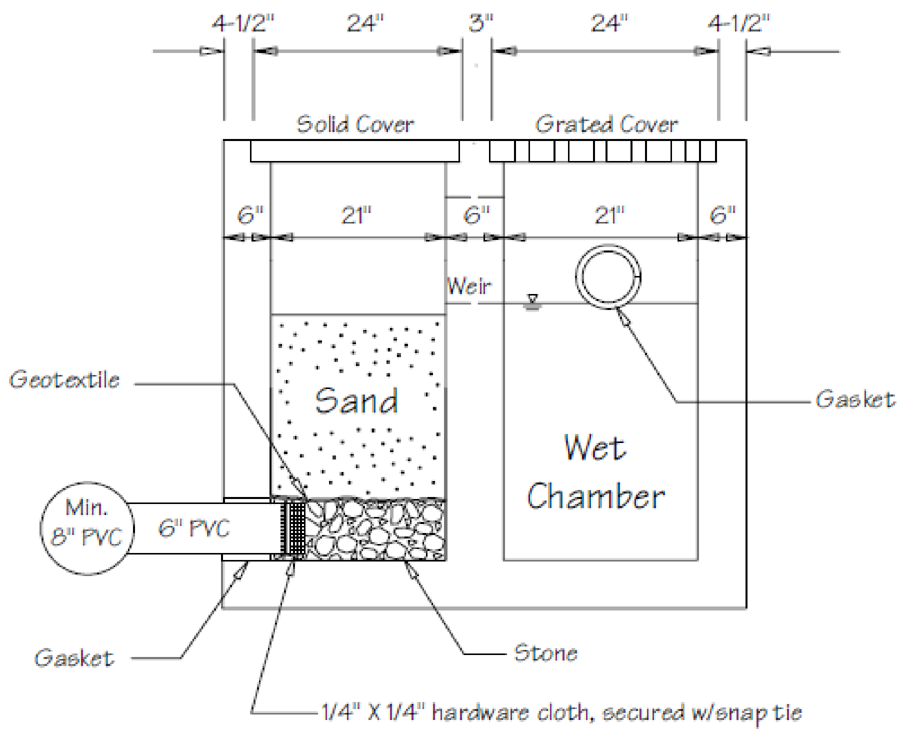
Delaware Modular Sand Filter



Source:	Symbol:	Detail No.
Design: Shaver/Baldwin Modifications: Carey/Greer Drawing: Modified from Vandemark & Lynch	**Sand Filter**	**DE-SWM-1.0** Sheet 1 of 2 Date: 3/98

Standard Detail & Specifications

Delaware Modular Sand Filter



Section View

Materials

1. Sand - Concrete sand (AASHTO M6 or equiv.)
2. Stone - ¾" washed (DE No. 57 or equiv.)
3. Geotextile - Woven drainage fabric (Amoco 1198, Mirafi-700XG or equiv.)
4. Piping - PVC (Min. SDR 35)
5. Gaskets - Compatible w/ PVC schedule (A-LOK, Star Seal or equiv.)
6. Grates - Cast iron storm drain (East Jordan 6957 Type "M-2" or equiv.)
7. Solid covers - Cast iron storm drain (East Jordan 6957 Type "A" or equiv.)
8. Frames - ¼" steel angle
9. Concrete - 4500 psi at 28 days
10. Min. Reinforcing - 2 mats of 6" X 6" W4/W4 wire mesh

Source:	Symbol:	Detail No.
Design: Shaver/Baldwin Modifications: Carey/Greer Drawing: Modified from Vandemark & Lynch	**Sand Filter**	**DE-SWM-1.0** Sheet 2 of 2 Date: 3/98

12.0 Constructed Wetlands

Definition: **Practices that mimic natural wetland areas to treat urban stormwater by incorporating permanent pools with shallow storage areas. Constructed Wetlands may provide stormwater detention for larger storms (Cv and Fv) above the RPv storage.**

Design variants include:

- 12-A **Traditional Constructed Wetlands**
- 12-B **Wetland Swales**
- 12-C **Ephemeral Constructed Wetlands**
- 12-D **Submerged Gravel Wetlands**
- 12-E Floating Wetlands (to be added at a later date)

Constructed Wetlands are shallow depressions that receive stormwater inputs for water quality treatment. The majority of the wetland surface area is covered by shallow (<1-foot deep) wetland area, with greater depths in the forebay and pools within the wetland. Wetlands possess variable microtopography to promote dense and diverse wetland cover. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity.

Submerged Gravel Wetlands (SGW) treat stormwater runoff primarily through filtration, sedimentation, physical and chemical sorption, microbially mediated transformation, uptake, and attenuation. Sedimentation occurs in the pretreatment forebay as well as above the wetland surface. Filtration, sorption, and transformation occur as the stormwater passes through the gravel substrate via microbe rich environment. While uptake occurs from the wetland vegetation most of the treatment is within the gravel substrate in a "plug flow" type system.

The Constructed Wetlands design variants all share commonalities but are also unique in their performance credits.

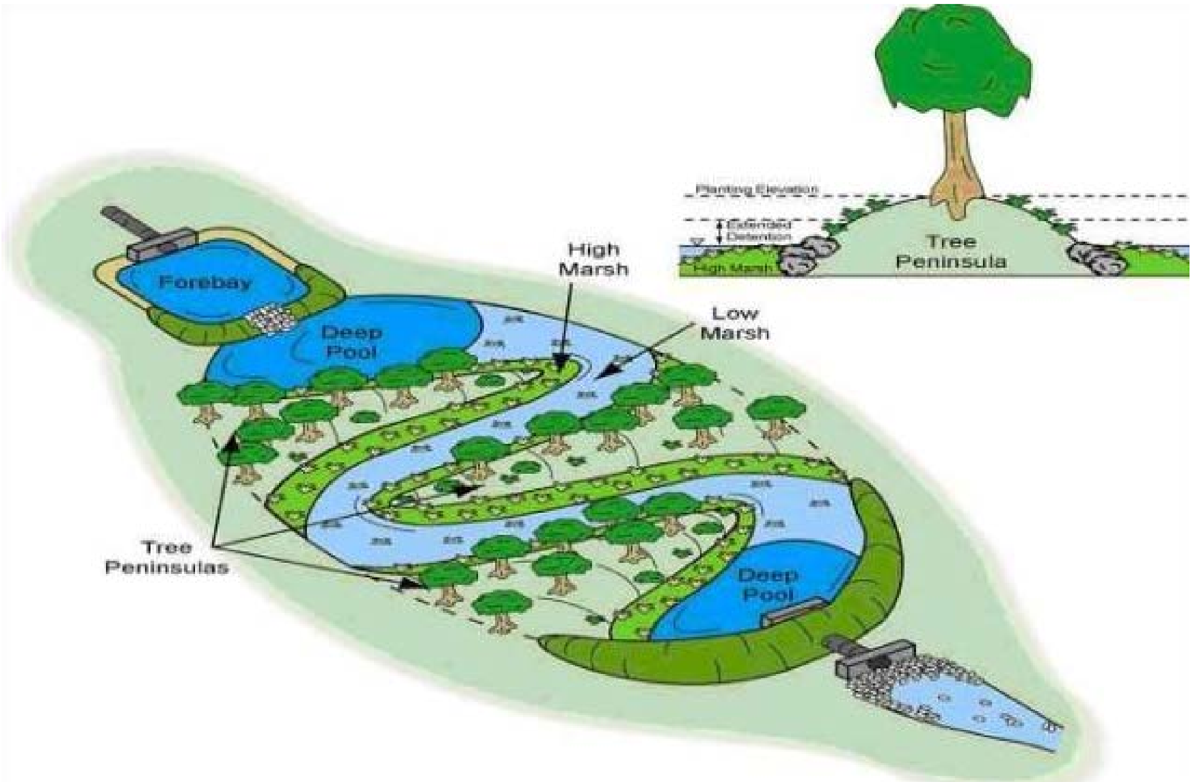


Figure 12.1 Typical Traditional Constructed Wetland

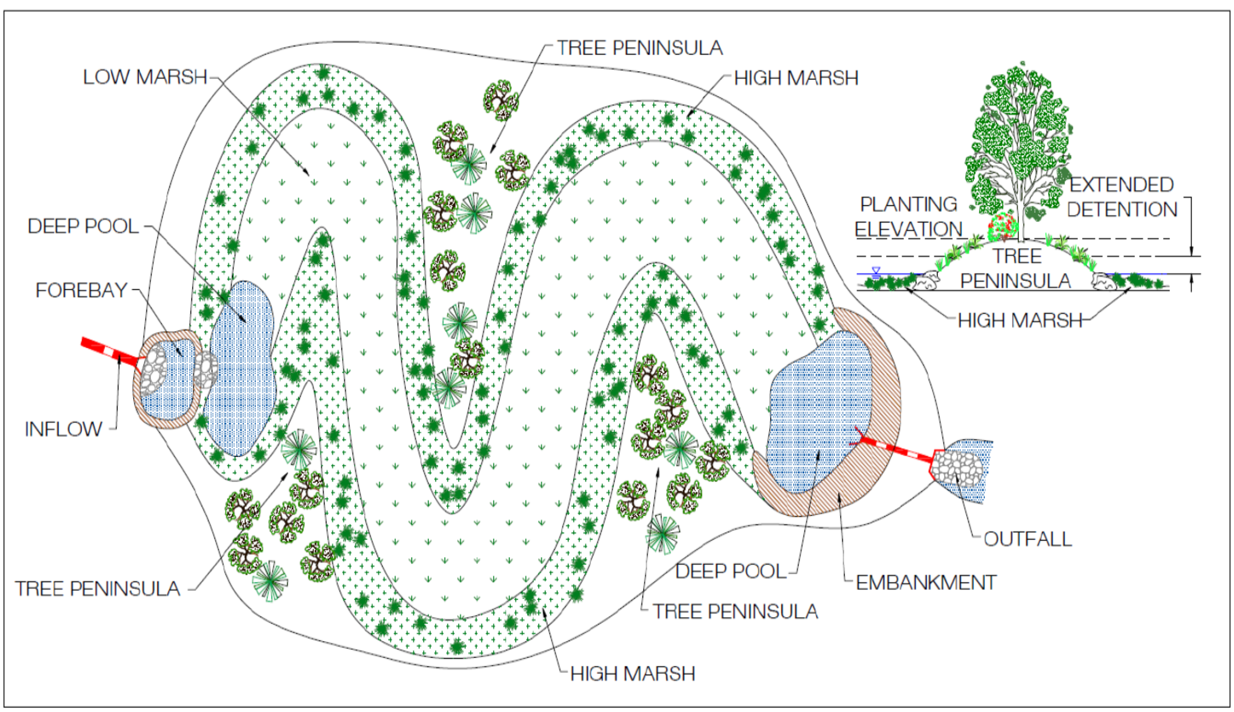


Figure 12.2 Typical Traditional Constructed Wetland Plan View

12.3 Typical Wetland Swale Section View

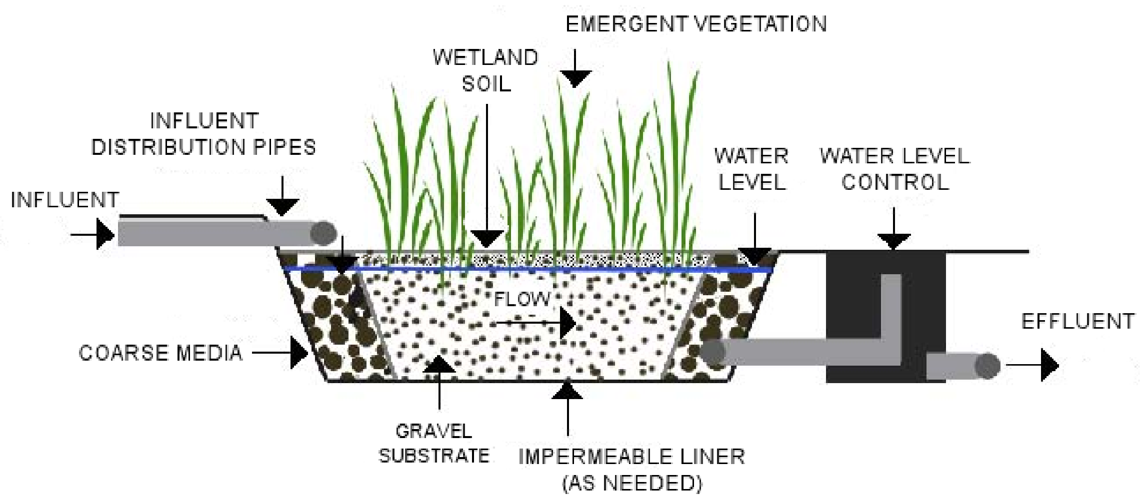


Figure 12.4 Typical Submerged Gravel Wetland Profile View

12.1 Constructed Wetland Stormwater Credits

Constructed wetlands receive 0% retention credit (R_v) and pollutant removals are outlined in Table 12.1.

Table 12.1-A
Traditional Constructed Wetlands Performance Credits

Runoff Reduction	
RPv	**100%**
Cv	**Not Less Than 1%**
Fv	**Not Less Than 0%**
Pollutant Reduction	
TN Reduction	**Not less than 30% Removal Efficiency**
TP Reduction	**Not less than 40% Removal Efficiency**
TSS Reduction	**Not less than 80% Removal Efficiency**

Table 12.1-B
Wetland Swale Performance Credits

Runoff Reduction	
RPv -A/B Soil	**15% Annual Runoff Reduction**
RPv - C/D Soil	**10% Annual Runoff Reduction**
Cv	**Not Less Than 1% of RPv Allowance**
Fv	**Not Less Than 0%**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction + Not less than 20% Removal Efficiency**
TP Reduction	**100% of Load Reduction + Not less than 30% Removal Efficiency**
TSS Reduction	**100% of Load Reduction + Not less than 60% Removal Efficiency**

Table 12.1-C

Ephemeral Constructed Wetland Performance Credits

Runoff Reduction* **	
RPv -A/B Soil	**40% Annual Runoff Reduction**
RPv - C/D Soil	**10% Annual Runoff Reduction**
Cv	**Not Less Than 1% of RPv Allowance**
Fv	**Not Less Than 0%**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction + Not less than 20% Removal Efficiency**
TP Reduction	**100% of Load Reduction + Not less than 30% Removal Efficiency**
TSS Reduction	**100% of Load Reduction + Not less than 60% Removal Efficiency**

***NOTE: An Ephemeral Constructed Wetland constructed in accordance with the Sediment and Stormwater Plan Review Policy and Procedures for Poultry House Projects as a forebay having a volume equivalent to the full RPv shortfall volume is given full volume reduction credit. The Department will monitor the performance of the ephemeral constructed wetland forebays at these poultry house projects and may adjust the volume reduction credit as necessary.

Table 12.1-D
Submerged Gravel Wetland Performance Credits

Runoff Reduction	
Retention Allowance	**0%**
RPv	**100% of Detention Storage**
Cv	**100% of Detention Storage**
Fv	**100% of Detention Storage**
Pollutant Reduction	
TN Reduction	**Not less than 30% Removal Efficiency**
TP Reduction	**Not less than 40% Removal Efficiency**
TSS Reduction	**Not less than 80% Removal Efficiency**

12.2 Constructed Wetlands Practice Summary

Table 12.2 summarizes the various criteria for Constructed Wetlands.

Table 12.2 Constructed Wetlands Practice Summary

Feasibility Criteria (Section 12.3)	• **Constructed Wetlands shall not be located within existing jurisdictional wetlands.**
Conveyance Criteria (Section 12.4)	• **The principal spillway must be accessible from dry land.** • **A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure.** • **The outfall pipe and all connections to the outfall structure shall be made watertight. Soil tight only joints are not acceptable.** • **Anti-seep collars shall be used in accordance with Pond Code 378, as amended.** • **When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced with riprap or other acceptable material to prevent scour.** • **When a low flow orifice is specified, it must be adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection. Orifice diameters shall not be less than 3 inches.** • **The design shall specify an outfall that can discharge the maximum design storm event in a non-erosive manner at the project point of discharge.** • **Constructed Wetlands must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the Constructed Wetland rather than bypassing.** • **An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.** • **Inflow points into the Constructed Wetland must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance event (Cv).** • **For Submerged Gravel Wetlands, the inflow volume shall enter the gravel substrate directly via a pipe manifold or inflow chimneys or as sheet flow through connected gravel layer.**

Pretreatment Criteria (Section 12.5)	• **Every inlet into a Constructed Wetland shall have pretreatment.**
	• **Exit velocities from the pretreatment shall be non-erosive during the largest design storm that is routed through the Constructed Wetland.**
	• **A forebay shall be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell.**
	• **The following criteria apply to forebay design:**
	  o **A major inlet is defined as an individual storm drain inlet pipe or open channel conveying at least 10% of the Constructed Wetland's contributing RPv runoff volume.**
	  o **The forebay must be sized to contain 10% of the volume of runoff from the contributing drainage area for the Resource Protection event.**
	• **Discharge from the forebay shall be non-erosive.**

Design Criteria (Section 12.6)	• **Constructed Wetlands constructed to meet regulatory stormwater management requirements shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended.** • **Constructed Wetlands shall be designed so that they will dewater the Fv within 72 hours, or manage the Fv on site with no adverse impact. The extents of the Fv shall be clearly delineated.**

Design Criteria (Section 12.6) *cont.*	**• The lowest discharge elevation on the outlet device shall be located no lower than the seasonal high groundwater table as determined by the Soil Investigation Procedures.
	• All Traditional Constructed Wetlands shall be evaluated for feasibility and ability to maintain permanent pool, including the need for a liner, by a qualified, licensed geotechnical engineer or geologist. If the design professional chooses not to follow the recommendations of the geotechnical professional, a signed, sealed and dated letter from the design professional providing justification for removal of the liner from the design shall be provided to DNREC or their delegated Agency.
	• When the geotechnical engineer recommends a liner, acceptable options include the following:
	  o A clay liner having a minimum compacted thickness of six inches with an additional six inch layer of engineered wetland soil mix containing a minimum of 35% organic material above it. Clay used as a liner must meet the following specifications:
	    ▪ Permeability of 1x10-6 cm/sec using ASTM D-2434 procedure.
	    ▪ Plasticity index of not less than 15% using ASTM D-423/424 procedures.
	    ▪ Liquid limit of not less than 30% using ASTM D-2216 procedure.
	    ▪ Clay particles passing not less than 30% using ASTM D-422 procedure.
	    ▪ Compaction of 95% of standard proctor density using ASTM D-2216 procedure.
	  o Other acceptable measures as recommended by a qualified geotechnical professional.
	• Trash racks shall be provided for low-flow pipes and for all riser structure openings.
	• All metal trash racks shall be coated with a rust inhibitor to increase longevity of the device.
	• When a riser is used, it must be located such that it is accessible from the side slope for the purposes of inspection and maintenance.
	• Safety features:
	  o Any opening 12 inches or greater discharging to a closed drainage system shall include safety grates.
	  o The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
	  o The emergency spillway exit channel must be designed to direct runoff to a point of discharge without impact to downstream structures.
	• All Constructed Wetlands must be designed so as to be accessible for maintenance.
	• Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure.
	• A maintenance right-of-way or easement must extend to the Constructed Wetland from a public or private road.
	• Maintenance access must meet the following criteria:
	  o Minimum width of 15 feet.
	  o Profile grade that does not exceed 10H:1V.
	  o Minimum 10H:1V cross slope.
	• Maintenance set-aside area:
	  o The maintenance set-aside area shall accommodate the volume of 50% of the collective forebay volume.
	  o The maximum depth of the set aside area shall be 1 foot.
	  o The slope of the set aside area shall not exceed 5%.**

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<td>Variant Specific Design Criteria (Section 12.6)</td>
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Traditional Constructed Wetland (12-A)

The permanent pool volume, or the volume below the normal water surface elevation, shall be equivalent to a minimum of 50% of theRPv volume.
Traditional Constructed Wetlands shall be sized so that the RPv has a maximum ponding depth of 12 inches above the normal water surface elevation. The RPv shall dewater within 48 hours.
The Cv maximum ponding depth shall not exceed 12 inches above the normal water surface elevation for more than 12 hours.
he total length of the flow path compared to the linear length through the Traditional Constructed Wetland shall be a minimum ratio of 2:1.
When an inlet is located near the outlet, the ratio of the shortest flow path through the system to the overall length shall be a minimum of 0.5:1.
The drainage area served by any inlets located less than a 0.5:1 ratio shall constitute no more than 20% of the total contributing drainage area.
Traditional Constructed Wetlands shall be composed of the following zones:

Zone 1: Deep Pools

The volume of water stored in the deep pools, also referred to as micropools, shall be at least 20% of the RPv volume.
A minimum of two deep pools in addition to the forebay shall be provided, one of which shall be located prior to the outlet location to provide for additional sediment deposition.
The deep pools shall be hydraulically connected within the water flow path.
The deep pools shall be designed with a side slope not steeper than 3:1.
A safety bench is required for deep pool depths greater than four feet.

Zone 2: Transition Zone

Zone 2 is a short transition zone between the deeper pools and the low marsh zone, and ranges from a minimum of 6 inches to a maximum of 30 inches below the normal pool elevation.
The volume of water stored in the transition zone shall be a minimum of 20% of the RPv volume.
The transition zone shall have a maximum side slope of 3:1from the deep pool to the low marsh zone.

Zone 3: Low Marsh Zone

The low marsh zone ranges from a maximum of 6 inches below the normal pool elevation to the normal pool elevation.
The volume of water stored in the low marsh zone shall be a minimum of 10% of the RPv volume.
The side slope within the low marsh zone shall not be steeper than 4:1.

Zone 4: High Marsh Zone

The upper end of the marsh zone is the high marsh zone, which ranges from the normal pool elevation to a maximum of 12 inches above the normal pool elevation, allowing the RPv to inundate to the top of the high marsh zone.
The side slope within the high marsh zone shall not be steeper than 4:1.

Zone 5: Floodplain

A low floodplain shall range between a minimum of 12 inches and a maximum of 18 inches above the normal water surface elevation and be planted with plants suited for infrequent to

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Variant Specific Design Criteria (Section 12.6) *cont.*	**temporary saturations.** ▪ **The side slope within the floodplain shall not be steeper than 4:1.** • **A minimum 10-foot-wide vegetated perimeter around the wetland area shall be planted with appropriate grasses, trees, and shrubs.** • **A simple water balance calculation shall be performed, using Equation 12.2 (Hunt et al., 2007), to ensure that the deep pools will not go completely dry during a 30-day summer drought.** *Wetland Swale (12-B):* • **Wetland swales shall contain the Cv event.** • **If the Fv event is not contained within the Wetland swale top of bank, then the area of inundation and discharge route shall be delineated.** • **The maximum RPv water surface elevation shall be no greater than 6 inches above the normal water surface elevation.** • **The average groundwater elevation shall be below the bottom of the Wetland Swale. Only the seasonal high groundwater may intersect the bottom of the Wetland Swale.** • **Wetland Swales shall not have side slopes steeper than 3:1.** • **The maximum longitudinal slope shall be an average of 1%.** • **A minimum 10-foot-wide vegetated perimeter on both sides of the wetland swale shall be planted with appropriate grasses, trees and shrubs.** *Ephemeral Constructed Wetland (12-C)* • **The RPv event shall pond a minimum of 6 inches and a maximum of 12 inches of water above the ground surface of the Ephemeral Constructed Wetland.** • **The Fv water surface shall be a maximum of 30 inches above the ground surface of the Ephemeral Constructed Wetland.** • **The average groundwater elevation as determined by the Soil Investigation Procedures shall be below the wetland bottom of the Ephemeral Constructed Wetland.** • **Only the seasonal high groundwater as determined by the Soil Investigation Procedures may intersect the bottom of the Ephemeral Constructed Wetland.** • **If the seasonal high groundwater intersects the bottom of the Ephemeral Constructed Wetland, the wetland shall be modeled considering the elevation of the seasonal high groundwater.** • **The side slopes of the buffer area and within the wetland shall be 4:1 or flatter.** • **A minimum 10-foot-wide vegetated perimeter around the wetland area shall be planted with appropriate grasses, trees, and shrubs.** *Submerged Gravel Wetland (12-D)* • **The maximum surface ponding depth for the RPv shall not be greater than the tolerance depths of the wetland plantings selected, or two feet, whichever is less.** • **The Submerged Gravel Wetland shall store the RPv volume within the stone substrate and wetland soils and above the soils in surface ponding.** • **Submerged Gravel Wetlands shall have no minimum detention time.** • **The gravel substrate shall be a minimum of 2 feet and a maximum of 4 feet in depth.** • **The gravel substrate shall be sized to contain a minimum of 25% of the RPv volume considering 40% void ratio.** • **The gravel substrate shall be composed of clean washed gravel, with a maximum of 2.0% passing the #200 sieve.** • **Gravel shall have a maximum diameter of 2.5 inches and a minimum diameter of 0.5 inches.** • **A porosity value of 0.4 shall be used for areas of stone in the design of gravel substrate.** • **Sand shall not be an acceptable substitute for gravel.** • **An engineered wetland soil layer containing a minimum of 15% organic material and a**

Variant Specific Design Criteria (Section 12.6) *cont.*	**maximum of 15% clay content shall be included on the surface of the Submerged Gravel Wetland. The wetland soil layer shall be a minimum of 8 inches thick.** • **A minimum 4 inch thick layer of clean, washed nominal ¼" gravel with a maximum of 2.0% passing the #200 sieve shall be installed between the gravel substrate and the wetland soil layer.** • **An underdrain shall be provided at an elevation 3 inches above the invert of the gravel substrate. The underdrain shall be a minimum of 4-inch perforated high density polyethylene pipe (HDPE) or polyvinyl chloride pipe (PVC).** • **The underdrain shall connect to the outlet structure. The discharge elevation shall be 4 inches below the wetland soil surface.** • **There shall be a minimum of 15 feet separation distance between all gravel substrate inflow points and all underdrain outlet points.** • **Side slopes above the gravel substrate shall not be steeper than 3:1.**
Landscaping Criteria (Section 12.7)	• **A planting plan is required for all Constructed Wetlands.** • **Invasive species shall not be specified within Constructed Wetlands.** • **The planting plan shall be certified by a qualified professional with demonstrated knowledge in wetland species.** • **Plants used in Constructed Wetlands shall be supplied by a certified wetland nursery using plants selected for the region.**

Construction Criteria (Section 12.8)	• **Approval from the Department or the appropriate Delegated Agency must be obtained before any planned Constructed Wetlands can be used as a sediment basin.**
	• **If a Constructed Wetlands serves as a sediment basin during project construction, the volume of the sediment basin must be based on the more stringent sizing rule.**
	• **The Sediment and Stormwater Plan must include conversion steps from sediment basin to permanent Constructed Wetlands in the construction sequence.**
	• **The Department or Delegated Agency must be notified and provide approval prior to conversion from sediment basin to the final configuration of the Constructed Wetlands.**
	• **Appropriate procedures must be implemented to prevent discharge of turbid waters when the sediment basin is being converted into a Constructed Wetlands.**
	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**
	  o **Pre-construction meeting**
	  o **Initial site preparation including installation of erosion and sediment controls**
	  o **Construction of the embankment, including installation of the principal spillway and the outlet structure as applicable**
	  o **Excavation and grading including interim and final elevations**
	  o **Construction of wetland features including grading of microtopography, introduction of soil amendments and staking of planting zones**
	  o **Construction of the underdrain, installation of gravel substrate and wetland soils as applicable**
	  o **Implementation of the planting plan and vegetative stabilization**
	  o **Final inspection including development of a punch list for facility acceptance**
	• **All areas surrounding the Constructed Wetlands that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.**
	• **Temporary seed, such as annual rye or winter wheat, may be used to stabilize the soil within the Constructed Wetland, but permanent species shall then be planted or seeded at next optimum planting date.**
	• **Stabilization matting shall be utilized in Wetland Swales and in all areas of concentrated flow or slopes 3:1 or steeper.**

Construction Criteria (Section 12.8) *cont.*	• **Upon facility completion, the owner shall submit Post Construction verification documents to demonstrate that the Constructed Wetlands has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for Constructed Wetlands practices are as follows:** o **The constructed top of bank elevation may be no lower than the design elevation for top of bank.** o **The constructed volume of the Constructed Wetlands surface storage shall be no less than 90% of the design volume.** o **The constructed volume of the gravel substrate storage for Submerged Gravel Wetlands shall be no less than 90% of the design volume.** o **The constructed elevation of any structure shall be within 0.15 foot of the design.**
Maintenance Criteria (Section 12.9)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system.** • **Operation and Maintenance Plans remain valid for the life of the stormwater management system.** • **During the first two years following construction, the Constructed Wetland shall be reviewed twice each year by a qualified professional with demonstrated knowledge of wetland species, once in the spring and once in the fall after a storm event that exceeds 1/2 inch of rainfall.** • **The Operation and Maintenance Plan shall outline a detailed schedule for the monitoring and possible reinstallation of vegetation in the wetland and its buffer for the first two years of establishment.** • **Repair of critical structural features such as embankments and risers shall be performed by responsible personnel that have successfully completed the Department Contractor Training Program.** • **Project closeout shall not occur until a minimum of 70% of the wetland area is permanently vegetated.** • **Sediment removal in the pretreatment forebay shall occur when 50% of total forebay capacity has been lost.** • **The Department or the Delegated Agency shall be notified before a Constructed Wetland is drained.**

12.3 Wetland Feasibility Criteria

Constructed wetland designs are subject to the following site constraints:

Adequate Water Balance. Traditional Constructed Wetlands (12-A) should have enough water supplied from groundwater, runoff or baseflow so that the permanent pools are designed to remain moist after a 30-day summer drought. See *Section 12.6. Water Balance Testing* for deep pool design criteria.

Contributing Drainage Area (CDA). The contributing drainage area should be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then typically more than 2 to 3 acres of drainage area is needed to maintain constant water elevations. Smaller drainage areas are acceptable if the bottom of the wetland intercepts the groundwater table or if the designer and the landowner are willing to accept periods of relative dryness (i.e., Ephemeral Constructed Wetlands, 12-C), and the plant species are chosen to accommodate this design variable. The minimum recommended drainage area for Submerged Gravel Wetlands, 12-D, is one acre.

Space Requirements. Constructed Wetlands normally require a footprint that takes up about 10% of the contributing drainage area, depending on the average depth of the wetland.

Site Topography. Wetlands are best applied when the grade of contributing slopes is less than 8%. Reference *Specification 6.0. Restoration Practices* for additional information on a step pool approach to Constructed Wetlands that can be applied on steep sloped areas.

Available Hydraulic Head. The permanent pool elevation is typically fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because the storage needed for storm events in Constructed Wetlands is shallow, the amount of head needed is typically less than for Wet Ponds, usually a minimum of 2 to 4 feet.

Minimum Setbacks. See Appendix 8 Stormwater Facility Setbacks for recommended setbacks.

Proximity to Utilities. See Appendix 8 Stormwater Facility Setbacks for recommended siting with respect to utilities.

Depth to Water Table. The depth to the groundwater table is not a major constraint for Constructed Wetlands because a high water table can help maintain the permanent pool elevation. However, designers should keep in mind that high groundwater inputs may reduce pollutant removal rates, increase excavation costs, and reduce the storage volume. For Ephemeral Constructed Wetlands, 12-C, the normal groundwater elevation should be below the bottom of the wetland although the seasonal high groundwater may fluctuate within the storage area.

Soils. Soil tests should be conducted in accordance with Soil Investigation Procedures to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of HSG C or D should be adequate to maintain a permanent pool. Most HSG A soils and HSG B soils are only suitable for variants 12-B or 12-C.

Use of, or Discharges to, Natural Wetlands. **Constructed Wetlands shall not be located within existing jurisdictional wetlands**. Constructed wetland should be constructed off-line from and designed to avoid impacts to federal or state jurisdictional waters, including perennial and intermittent streams and ditches, and tidal and non-tidal wetlands. Designers should request a jurisdictional determination from the federal regulatory agency (U.S. Army Corps of Engineers, Philadelphia District, 215-656-6728) and the state regulatory agency (Delaware Department of Natural Resources and Environmental Control, Wetland and Subaqueous Lands Section, 302-739-9943) to ensure that all federal and state jurisdictional areas are identified. An environmental consultant can be hired to assist with the determination.

Wetlands swales are discouraged in residential subdivisions. Wetland swales will periodically contain standing water which can been viewed as an impediment to regular maintenance, including mowing and become a cause for concern of the residence with respect to mosquitos and odors.

12.4 Constructed Wetland Conveyance Criteria

The longitudinal slope profile within individual wetland cells should generally be flat from inlet to outlet, at 1% maximum. The recommended maximum elevation drop between wetland cells should be 1 foot or less.

While many different options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used, given their greater operational flexibility to adjust water levels following construction (see Hunt et al, 2007). A weir or spillway can also be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

Principal Spillway. The principal spillway may be composed of a structure-pipe configuration or a weir-channel configuration. **The principal spillway must be accessible from dry land. A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure. The outfall pipe and all connections to the outfall structure shall be made watertight. Soil tight only joints are not acceptable. Anti-seep collars shall be used in accordance with Pond Code 378, as amended. When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced with riprap or other acceptable material to prevent scour.**

Non-Clogging Low Flow Orifice. **When a low flow orifice is specified, it must be adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection. Orifice diameters shall not be less than 3 inches.**

Outfall Protection. **The design shall specify an outfall that can discharge the maximum design storm event in a non-erosive manner at the project point of discharge.** If necessary, the channel immediately below the Constructed Wetland outfall may be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This can be accomplished by placing appropriately sized riprap over stabilization geotextile in accordance with HEC-14 Hydraulic Design of Energy Dissipators for Culverts and Channels and Delaware Erosion and Sediment Control Handbook Specification 3.3.10 Riprap Outlet Protection or 3.3.11 Riprap Stilling Basin, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps) based upon the channel lining material. Flared pipe sections, which discharge at or near the stream invert or into a step pool arrangement, should be used at the spillway outlet.

When the discharge is to a manmade pipe or channel system, the system should be adequate to convey the required design storm peak discharge in a non-erosive manner. Care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided. The final release rate of the facility should be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow unless downstream improvements are made to accommodate the increase.

Emergency Spillway. Constructed Wetlands must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the Constructed Wetland rather than bypassing. An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.

Inflow Points. **Inflow points into the Constructed Wetland must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance event (Cv).** Inlet pipe inverts should generally be located at the permanent pool elevation. **For Submerged Gravel Wetlands, the inflow volume shall enter the gravel substrate directly via a pipe manifold or inflow chimneys or as sheet flow through connected gravel layer.**

12.5 Constructed Wetland Pretreatment Criteria

Sediment regulation is critical to sustain Constructed Wetlands. **Every inlet into a Constructed Wetland shall have pretreatment. Exit velocities from the pretreatment shall be non-erosive during the largest design storm that is routed through the Constructed Wetland. A forebay shall be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:**

- **A major inlet is defined as an individual storm drain inlet pipe or open channel conveying at least 10% of the Constructed Wetland's contributing RPv runoff volume.**
- The preferred forebay configuration consists of a separate cell, formed by an acceptable barrier such as a concrete weir, riprap berm, gabion baskets, etc. Riprap berms are the preferred barrier material.
- The forebay should be 3 to 4 feet deep. **The forebay must be sized to contain 10% of the volume of runoff from the contributing drainage area for the Resource Protection event.** The relative size of individual forebays should be proportional to the percentage of the total inflow to the Constructed Wetland. The storage volume within the forebay may be included in the calculated required storage volume for the Constructed Wetland.
- The recommended minimum length of the forebay is 10 feet. The forebay should have a length to width ratio of 2:1 or greater. Length is measured with the direction of flow into the Constructed Wetland.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation. Metered wooden stakes may need to be replaced frequently in Constructed Wetland forebays; alternative materials should be considered for longevity.
- Vegetation may be included within forebays to increase sedimentation and reduce resuspension and erosion of previously trapped sediment.
- **Discharge from the forebay shall be non-erosive.**

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2.6 Constructed Wetland Design Criteria

Constructed Wetlands constructed to meet regulatory stormwater management requirements shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended. Constructed Wetlands shall be designed so that they will dewater the Fv within 72 hours, or manage the Fv on site with no adverse impact. The extents of the Fv shall be clearly delineated. The lowest discharge elevation on the outlet device shall be located no lower than the seasonal high groundwater table as determined by the Soil Investigation Procedures.

Liners. All Traditional Constructed Wetlands shall be evaluated for feasibility and ability to maintain permanent pool, including the need for a liner, by a qualified, licensed geotechnical engineer or geologist. If the design professional chooses not to follow the recommendations of the geotechnical professional, a signed, sealed and dated letter from the design professional providing justification for removal of the liner from the design shall be provided to DNREC or their delegated Agency. When the geotechnical engineer recommends a liner, acceptable options include the following:

- **A clay liner having a minimum compacted thickness of six inches with an additional six inch layer of engineered wetland soil mix containing a minimum of 35% organic material above it. Clay used as a liner must meet the following specifications:**
    - **Permeability of 1x10-6 cm/sec using ASTM D-2434 procedure.**
    - **Plasticity index of not less than 15% using ASTM D-423/424 procedures.**
    - **Liquid limit of not less than 30% using ASTM D-2216 procedure.**
    - **Clay particles passing not less than 30% using ASTM D-422 procedure.**
    - **Compaction of 95% of standard proctor density using ASTM D-2216 procedure.**
- **Other acceptable measures as recommended by a qualified geotechnical professional.**

Trash Racks. Trash racks shall be provided for low-flow pipes and for all riser structure openings. Open weirs that discharge to an open channel will not require trash racks. Synthetic trash rack materials options are available and should be considered. **All metal trash racks shall be coated with a rust inhibitor to increase longevity of the device.**

Non-clogging Low Flow (Extended Detention) Orifice: The low flow extended detention orifice should be protected from clogging by an external trash rack. The preferred method is a hood apparatus over the orifice that reduces gross pollutants such as floatables and trash, as well as oil and grease and sediment.

Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging. As an alternative, internal orifice protection may be used (i.e., an orifice internal to a perforated vertical stand pipe with 0.5-inch perforations or slots that are protected by wirecloth and a stone filtering jacket). Floating skimmers, seepage berms, French drains or other similar measures may be a better alternative to provide the 48-hour detention required for Wet ED Ponds if the orifice diameter is too small.

Riser: **When a riser is used, it must be located such that it is accessible from the side slope for the purposes of inspection and maintenance.** The riser may be located within the embankment for maintenance access, safety, and aesthetics. Where appropriate, access to the riser may be provided by manhole covers and manhole steps within easy reach of valves and other controls.

Pond Drain: Constructed Wetlands should have a drain pipe that can completely or partially drain the permanent pool. In cases where a low level drain is not feasible (such as in an excavated Constructed Wetland), the Operation and Maintenance Plan should include requirements for dewatering the Constructed Wetland.

- The drain pipe should have an upturned elbow or protected intake within the Constructed Wetland to help keep it clear of sediment deposition, and a diameter capable of draining the Constructed Wetland within 24 hours.
- The Constructed Wetland drain should be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

Care should be exercised during Constructed Wetland drawdowns to prevent downstream discharge of sediments or anoxic water and rapid drawdown. The Department or the Delegated Agency should be notified before a Constructed Wetland is drained.

Adjustable Gate Valve: If desired to adjust the pond permanent pool elevation, both the outlet pipe and the Constructed Wetland drain should be equipped with an adjustable gate valve (typically a hand wheel activated knife gate valve) or pump well and be sized one pipe size greater than the calculated design diameter. Valves should be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner. To prevent vandalism, the hand wheel should be chained to a ringbolt, manhole step or other fixed object.

Safety Features:

- **Any opening 12 inches or greater discharging to a closed drainage system shall include safety grates.**
- **The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.**
- **The emergency spillway exit channel must be designed to direct runoff to a point of discharge without impact to downstream structures.**
- Fencing of the perimeter of Constructed Wetland is discouraged. The preferred method to reduce risk is to manage the contours of the Constructed Wetland to eliminate drop-offs or other safety hazards.
- Warning signs may be posted.

Maintenance Reduction Features: The following Constructed Wetland maintenance issues can be addressed during the design, in order to make on-going maintenance easier:

Maintenance Access. **All Constructed Wetlands must be designed so as to be accessible for maintenance.** Good access is needed so crews can remove sediments, make repairs and preserve Constructed Wetland treatment capacity.

- **Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure.**
- **A maintenance right-of-way or easement must extend to the Constructed Wetland from a public or private road.**
- **Maintenance access must meet the following criteria:**
  - **Minimum width of 15 feet.**
  - **Profile grade that does not exceed 10H:1V.**
  - **Minimum 10H:1V cross slope.**
- Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines. When not specified in local code, the top of bank of Constructed Wetlands should be set back at least 15 feet from property lines to ensure maintenance access.

- **Maintenance Set-Aside Area**: Adequate land area adjacent to the Constructed Wetland should be provided for in the Operation and Maintenance Plan as a location for disposal of sediment removed from the Constructed Wetland when maintenance is performed. The maintenance set-aside area is necessary on all sites adjacent to the Constructed Wetland to adequately dewater sediment removed from the pond prior to spreading and seeding or transporting from the site.
  - **The maintenance set-aside area shall accommodate the volume of 50% of the collective forebay volume.**
  - **The maximum depth of the set aside area shall be 1 foot.**
  - **The slope of the set aside area shall not exceed 5%**.

The area and slope of the set aside area may be modified if an alternative area or method of disposal is approved by the Department or Delegated Agency.

Variant 12-A, **Traditional Constructed Wetlands:**

Wetland Sizing. Traditional Constructed Wetlands provide water quality enhancement for stormwater volumes remaining after upstream practices have provided runoff reduction. Additionally, stormwater wetlands can be sized to control flows from the Cv and Fv storms. The available storage volume of storm events in Constructed Wetlands is equal to the volume provided above the permanent pool, or the normal water surface elevation. **The permanent pool volume, or the volume below the normal water surface elevation, shall be equivalent to a minimum of 50% of theRPv volume** to maintain a healthy system.

To reduce impact on the aquatic plantings, **Traditional Constructed Wetlands shall be sized so that the RPv has a maximum ponding depth of 12 inches above the normal water surface elevation. The RPv shall dewater within 48 hours**. **The Cv maximum ponding depth shall not exceed 12 inches above the normal water surface elevation for more than 12 hours.**

Internal Design Geometry. Traditional Constructed Wetlands can be designed in several ways, all of which promote diverse emergent and aquatic vegetation, as well as anaerobic and aerobic conditions within the water to promote pollutant removal. In all cases, varied topography within each component of the wetland is encouraged to provide diverse ecology (e.g., hummocks, forested peninsulas, horizontal tree stumps, boulders, etc). Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of stormwater wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume.

Flow Path. Whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. **The total length of the flow path compared to the linear length through the Traditional Constructed Wetland shall be a minimum ratio of 2:1. When an inlet is located near the outlet, the ratio of the shortest flow path through the system to the overall length shall be a minimum of 0.5:1. The drainage area served by any inlets located less than a 0.5:1 ratio shall constitute no more than 20% of the total contributing drainage area.**

One continuous winding system can be designed that distributes the runoff through wetland areas and deeper permanent pools. The flow through the Traditional Constructed Wetland should be limited to maximum of 1% average slope excluding any drops or riffles. See below for more detailed information on the various components.

If a more varied range in elevation is desired, a more step-pool approach can be taken, where the different cells can be separated in elevation by bio or compost logs, sand berms anchored with rocks/boulders, or other stabilized protection. Forested peninsulas can also be extended across 95% of the width of the wetland, creating two separate zones. Riffles, or rock lined slopes of a maximum of 8%, can also be used to adjust the grades. The elevation difference between the wetland cells should not exceed 1 foot.

Inundation Zones.

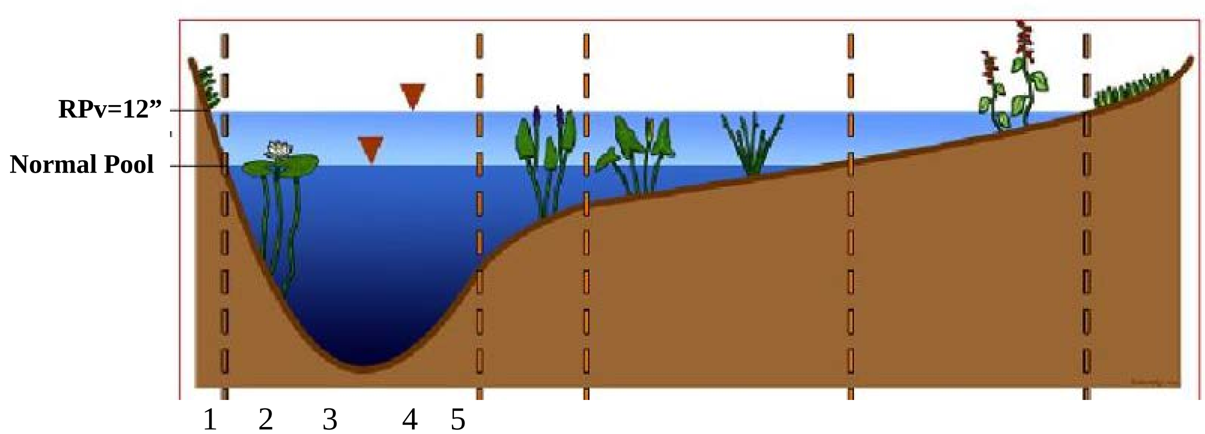

Figure 12.4. Traditional Constructed Wetland Inundation Zones: (1) Deep Pool (depth -36 to -18 inches), (2) Transition Zone (depth -18 to -6 inches), (3) Low Marsh Zone (depth -6 inches to

normal pool), (4) High Marsh Zone (normal pool to +12 inches), and (5) Floodplain (+12 to +30 inches) (adapted from Hunt et al,. 2007).

Traditional Constructed Wetlands shall be composed of the following zones:

***Zone 1: Deep Pools*. The volume of water stored in the deep pools, also referred to as micropools, shall be at least 20% of the RPv volume. A minimum of two deep pools in addition to the forebay shall be provided, one of which shall be located prior to the outlet location to provide for additional sediment deposition.** Deep pools can help to provide fish habitat, cooler water temperatures, energy dissipation, and sedimentation. **Deep pools shall range from a minimum of 30 inches to a maximum of 6 feet in depth below the normal pool elevation and shall be designed to remain permanently saturated.** If groundwater will not support the permanent pool elevation in the summer months, then the minimum deep pool elevation should be lowered to 22 inches. **The deep pools shall be hydraulically connected within the water flow path. The deep pools shall be designed with a side slope not steeper than 3:1. A safety bench is required for deep pool depths greater than four feet.**

***Zone 2: Transition Zone.* Zone 2 is a short transition zone between the deeper pools and the low marsh zone, and ranges from a minimum of 6 inches to a maximum of 30 inches below the normal pool elevation. The volume of water stored in the transition zone shall be a minimum of 20% of the RPv volume. The transition zone shall have a maximum side slope of 3:1from the deep pool to the low marsh zone.** It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

Zone 3: Low Marsh Zone. Most of the wetland surface area will exist between the two marsh zones, zones 3 and 4. **The low marsh zone ranges from a maximum of 6 inches below the normal pool elevation to the normal pool elevation.** Therefore, it should normally be saturated and planted with species that thrive in this wet condition. **The volume of water stored in the low marsh zone shall be a minimum of 10% of the RPv volume. The side slope within the low marsh zone shall not be steeper than 4:1.** Because this zone provides essential wetland function in between storm events, it should have a surface area between 75 and 125% of the high marsh zone surface area.

***Zone 4: High Marsh Zone*. The upper end of the marsh zone is the high marsh zone, which ranges from the normal pool elevation to a maximum of 12 inches above the normal pool elevation, allowing the RPv to inundate to the top of the high marsh zone.** Where conditions allow, the RPv ponding depth should be reduced to be closer to 6 inches, which will increase the plant survivability. **The side slope within the high marsh zone shall not be steeper than 4:1,** and typically much flatter marsh zones are designed to increase storage**.**

Zone 5: Floodplain. Any storm events above the RPv event should inundate into the floodplain area. **A low floodplain shall range between a minimum of 12 inches and a maximum of 18 inches above the normal water surface elevation and be planted with plants suited for**

infrequent to temporary saturations, depending on weather patterns. An upper floodplain of elevations ranges +18 to +30 inches provides storage for the higher storm events, including the Fv. The two floodplains areas can be combined for smaller drainage areas less than 10 acres. Also, if the Constructed Wetland is connected to a Wet Pond, then the Wet Pond can be used for the storage of the higher storm events, and the floodplain storage within the Constructed Wetland can be reduced. **The side slope within the floodplain shall not be steeper than 4:1,** and typically much flatter floodplains are designed to increase storage**.**

Vegetated Perimeter. **A minimum 10-foot-wide vegetated perimeter around the wetland area shall be planted with appropriate grasses, trees, and shrubs.** The emergency spillway should either be grass or riprap. Existing vegetation can and should remain in the perimeter area, so long as noxious species are eradicated and invasive species are controlled.

Water Balance Testing. Traditional Constructed Wetlands can be scaled to accommodate small drainage areas, although a water balance calculation shall be provided when the contributing drainage area is less than 5 acres.

A simple water balance calculation shall be performed, using Equation 12.2 (Hunt et al., 2007), **to ensure that the deep pools will not go completely dry during a 30-day summer drought.**

Equation 12.2. The Hunt Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland

$$DP = RF_m * EF * WS/WL - ET - INF - RES$$

Where: DP = Depth of pool, inches

RF_m = Monthly rainfall during drought, inches (assume 1 inch, or use historically data)

EF = Fraction of rainfall that enters the stormwater wetland (Rational runoff coefficient)

WS/WL = Ratio of contributing drainage area to the normal pool wetland surface area

ET = Summer evapotranspiration rate, inches (assume 7 inches)

INF = Monthly infiltration loss (assume 7.2 inches, or 0.01 inch/hour for 30 days, unless a higher infiltration rate is known)

RES = Reservoir of water for a factor of safety, inches (assume 6 inches)

Variant 12-B, **Wetland Swales:**

Wetland Swale Sizing. Wetland swales are designed similar to traditional vegetated swales in that they should convey the Cv and Fv events with non-erosive velocities. **Wetland swales shall contain the Cv event** (no freeboard required). **If the Fv event is not contained within the Wetland swale top of bank, then the area of inundation and discharge route shall be delineated. The maximum RPv water surface elevation shall be no greater than 6 inches**

above the normal water surface elevation. There is no minimum or maximum drainage area, though typically swales are designed for less than 5 acres of contributing area.

Internal Geometry. Wetland swales should be designed as a two-stage system. The low-flow channel requires a minimum width of 1 foot, and should be designed with a permanent to semi-permanent water elevation of 4 to 6 inches. This can be accomplished through inception with the seasonal high groundwater or through the use of check dams or other control structures that back the water up to that level during wet conditions. The low-flow channel should support plants that tolerate mostly wet conditions. The width of the low-flow channel should be maximum 6 feet to prevent additional low-flow channels from forming within (or braiding); very large drainage areas may require increased widths, but typically the low-flow channel will fall in the 2 to 4-foot-width range. To increase functionality, the low-flow channel should be meandered within the total confines of the Wetland Swale (i.e., the top of bank does not need to meander, but the low-flow channel should).

At the water surface elevation of the RPv event (within +/- 0.1'), a shallow floodplain bench shall be provided, which alleviates shear stress on the sides of the banks. The total bench width should be minimum 4 feet and is generally split on either side of the low-flow channel, though the dimensions can alter as the low-flow channel meanders through the swale section, with increased bench widths on the inside of a curve. Vegetation planted on the benches should also support wet periods, though will be inundated less frequently then the plants in the low-flow channel.

Deep pools should not be incorporated into the Wetland Swales for safety purposes as most people assume swales are traversable and would not suspect a deep portion. **The average groundwater elevation shall be below the bottom of the Wetland Swale. Only the seasonal high groundwater may intersect the bottom of the Wetland Swale.**

Side Slopes. **Wetland Swales shall not have side slopes steeper than 3:1.**

Longitudinal Slope: **The maximum longitudinal slope shall be an average of 1%.** Grade breaks similar to variant 12-A can be used as necessary.

Vegetated Perimeter. **A minimum 10-foot-wide vegetated perimeter on both sides of the wetland swale shall be planted with appropriate grasses, trees and shrubs.** Existing vegetation can and should remain in the perimeter area, so long as invasive species are eradicated and invasive species are controlled.

Variant 12-C, **Ephemeral Constructed Wetlands:**

Ephemeral Constructed Wetland Sizing. Ephemeral Constructed Wetlands are designed without a permanent pool because the intent is for them to be wet only in the spring and fall months. **The RPv event shall pond a minimum of 6 inches and a maximum of 12 inches of water above the ground surface of the Ephemeral Constructed Wetland. The Fv water surface shall be a maximum of 30 inches above the ground surface of the Ephemeral Constructed Wetland.**

An emergency spillway may be necessary for the 100-year and larger events, but traditionally no other outlets are provided. If freezing in the winter is a concern, or for maintenance purposes, a drain pipe can be provided, but the Ephemeral Constructed Wetland should only be drained in late November after amphibian breeding seasons. The wetland can be modeled with the design infiltration rate and are allowed to hold the RPv event for greater than 48 hours.

Ephemeral Constructed Wetlands should mimic those found naturally, which typically are ponded low areas. These shallow areas fill up with runoff during wet conditions and will dry up during periods of little to no rain. These fluctuations typically provide more diversity in vegetation and animals. The shallow ponded area should be planted with a variety of vegetation that can tolerate both wet and dry conditions.

The seasonal high groundwater may fluctuate into the bottom of the Ephemeral Constructed Wetland**,** but **the average groundwater elevation as determined by the Soil Investigation Procedures shall be below the wetland bottom of the Ephemeral Constructed Wetland. Only the seasonal high groundwater as determined by the Soil Investigation Procedures may intersect the bottom of the Ephemeral Constructed Wetland. If the seasonal high groundwater intersects the bottom of the Ephemeral Constructed Wetland, the wetland shall be modeled considering the elevation of the seasonal high groundwater.**

Depending on the existing grades, an embankment may be required to contain the wetland pool. **Constructed Wetlands constructed to meet regulatory stormwater management requirements shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended.** A core trench should extend down to a limiting layer or minimum 4 feet below ground surface, which will help prevent lateral migration of water through the embankment, compromising the construction.

For Ephemeral Constructed Wetlands functioning as forebays on poultry house projects, forebays located in HSG C/D should be no deeper than 1 foot as measured from the invert of the overflow weir to the bottom of the forebay. Forebays located in HSG A/B should be no deeper than 2 feet as measured from the invert of the overflow weir to the bottom of the forebay.

Side Slopes. **The side slopes of the buffer area and within the wetland shall be 4:1 or flatter.**

Vegetated Perimeter. **A minimum 10-foot-wide vegetated perimeter around the wetland area shall be planted with appropriate grasses, trees, and shrubs** (the emergency spillway should either be grass or riprap). Existing vegetation can and should remain in the perimeter area, so long as noxious species are eradicated and invasive species are controlled.

Variant 12-D, **Submerged Gravel Wetlands**

Submerged Gravel Wetland Sizing. The maximum surface ponding depth for the RPv shall not be greater than the tolerance depths of the wetland plantings selected, or two feet, whichever is less. The Submerged Gravel Wetland shall store the RPv volume within the

stone substrate and wetland soils and above the soils in surface ponding. Submerged Gravel Wetlands shall have no minimum detention time.

Gravel substrate. The gravel substrate shall be a minimum of 2 feet and a maximum of 4 feet in depth. The gravel substrate shall be sized to contain a minimum of 25% of the RPv volume considering 40% void ratio. The gravel substrate shall be composed of clean washed gravel, with a maximum of 2.0% passing the #200 sieve. Gravel shall have a maximum diameter of 2.5 inches and a minimum diameter of 0.5 inches. A porosity value of 0.4 shall be used for areas of stone in the design of gravel substrate. Sand shall not be an acceptable substitute for gravel.

Wetland soil. **An engineered wetland soil layer containing a minimum of 15% organic material and a maximum of 15% clay contentshall be included on the surface of the Submerged Gravel Wetland. The wetland soil layer shall be a minimum of 8 inches thick.** The wetland soil layer should not be included in the storage volume computations.
A minimum 4 inch thick layer of clean, washed nominal ¼" gravel with a maximum of 2.0% passing the #200 sieve shall be installed between the gravel substrate and the wetland soil layer.

Underdrain. An underdrain shall be provided at an elevation 3 inches above the invert of the gravel substrate. The underdrain shall be a minimum of 4-inch perforated high density polyethylene pipe (HDPE) or polyvinyl chloride pipe (PVC). The underdrain shall connect to the outlet structure. The discharge elevation shall be 4 inches below the wetland soil surface.

Flow Path. **There shall be a minimum of 15 feet separation distance between all gravel substrate inflow points and all underdrain outlet points.**

Side Slopes. **Side slopes above the gravel substrate shall not be steeper than 3:1.**
Constructed Wetland Material Specifications:
Wetlands are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and stabilization fabric for lining banks or berms. In some instances, clay may need to be imported to provide a permanent pool elevation in certain areas of the constructed wetland that may not otherwise support a permanent pool. Plant stock should be nursery grown, unless otherwise approved by the local regulatory authority, and should be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined by the local regulatory authority.

12.7 Constructed Wetland Landscaping Criteria

A planting plan is required for all Constructed Wetlands. Natives species are recommended and **invasive species shall not be specified within Constructed Wetlands. The planting plan shall be certified by a qualified professional with demonstrated knowledge in wetland**

species. Plants used in Constructed Wetlands shall be supplied by a certified wetland nursery using plants selected for the region. The planting plan should outline a detailed schedule for the care, maintenance and possible reinstallation of vegetation in the wetland and its buffer for the first 10 years of establishment.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. Reference the Landscaping Criteria Appendix for additional Constructed Wetland landscaping specifications.

For Ephemeral Constructed Wetlands functioning as forebays on poultry house projects, since the forebay is likely to be subjected to prolonged periods of saturation especially on HSG C/D soils, the recommendations for Zone 4, High Marsh may be used to select plant materials for the forebay area under those soil conditions.

12.8. **Constructed Wetland Construction**

The construction sequence for the wetland variants depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing a wetland facility and establishing vigorous plant cover.

Approval from the Department or the appropriate Delegated Agency must be obtained before any planned Constructed Wetlands can be used as a sediment basin. If a Constructed Wetlands serves as a sediment basin during project construction, the volume of the sediment basin must be based on the more stringent sizing rule.

The Sediment and Stormwater Plan must include conversion steps from sediment basin to permanent Constructed Wetlands in the construction sequence. The Department or Delegated Agency must be notified and provide approval prior to conversion from sediment basin to the final configuration of the Constructed Wetlands. Appropriate procedures must be implemented to prevent discharge of turbid waters when the sediment basin is being converted into a Constructed Wetlands.

Construction Review. Multiple construction reviews are critical to ensure that Constructed Wetlands are properly constructed. **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls**
- **Construction of the embankment, including installation of the principal spillway and the outlet structure as applicable**
- **Excavation and grading including interim and final elevations**
- **Construction of wetland features including grading of microtopography, introduction of soil amendments and staking of planting zones**

- **Construction of the underdrain, installation of gravel substrate and wetland soils as applicable**
- **Implementation of the planting plan and vegetative stabilization**
- **Final inspection including development of a punch list for facility acceptance**

Stage 1 Construction Sequence: Wetland Facility Construction.
Step 1: Stabilize Drainage Area. Constructed wetlands should only be constructed after the contributing drainage area to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.
Step 2: Assemble Construction Materials on-site, make sure that they meet design specifications, and prepare any staging areas.

Step 3: Install Erosion and Sediment (E&S) Controls prior to construction, including temporary dewatering devices, sediment basins, and stormwater diversion practices. **All areas surrounding the Constructed Wetlands that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.** In some cases, a phased or staged E&S Control plan may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

Step 4: Excavate the Core Trench for the Embankment and Construct the Embankment (if required). Install the Outlet Pipe and Emergency Spillway.

Step 5: Install the Riser or Outflow Structure and ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al, 2007).
Step 6: Clear and Strip the wetland project area to the desired sub-grade.

Step 7: Construct any Internal Berms in 8 to 12-inch lifts and compact with appropriate equipment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the wetland. This is normally done by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

Step 9: Install Micro-Topographic Features and Soil Amendments within wetland area. Because most stormwater wetlands are excavated to sub-soil, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. Therefore, it is strongly recommended to add compost, topsoil, or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor plant survival and sparse wetland plant coverage are likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand.

Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped, but it should not be overly compacted.

Step 10: Stabilize Exposed Soils above the normal pool elevation with permanent seed mixtures appropriate for a wetland environment by hydro-seeding or seeding under straw per the Landscape Plan. Outside of optimum seeding and planting dates,**temporary seed, such as annual rye or winter wheat, may be used to stabilize the soil within the Constructed Wetland, but permanent species shall then be planted or seeded at next optimum planting date. Stabilization matting shall be utilized in Wetland Swales and in all areas of concentrated flow or slopes 3:1 or steeper.**

Step 11: Post Construction Verification Documentation. **Upon facility completion, the owner shall submit Post Construction verification documents to demonstrate that the Constructed Wetlands has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency. Allowable tolerances for Constructed Wetlands practices are as follows:**

- **The constructed top of bank elevation may be no lower than the design elevation for top of bank.**
- **The constructed volume of the Constructed Wetlands surface storage shall be no less than 90% of the design volume.**
- **The constructed volume of the gravel substrate storage for Submerged Gravel Wetlands shall be no less than 90% of the design volume.**
- **The constructed elevation of any structure shall be within 0.15 foot of the design.**

When the allowable tolerances are exceeded for Constructed Wetlands surface area or volume or structure elevations, supplemental calculations must be submitted to the approval agency to determine if the Constructed Wetlands, as constructed, meets the design requirements.

Stage 2 Construction Sequence: Establishing the Wetland Vegetation.

Step 12: Open Up the Wetland Connection (if desired). Once the final grades are attained, the pond and/or contributing drainage area connection can be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the wetland to minimize erosion of unplanted features. If the wetland area is connected, then it will need to be dewatered to the lowest planting elevation (i.e., the low marsh zone) prior to planting.

Step 13: Finalize the Wetland Landscaping Plan (if needed). At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan *after* the Constructed Wetland has been constructed and the normal pool elevation has been established if there have been any changes to the planting zones from the initial design. This can allow the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland,

and also confirm plant availability

Step 14: Measure and Stake Planting Depths at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. Surveyed planting zones should be marked on the post construction verification, and their locations should also be identified in the field, using stakes or flags. If necessary, dewater to the bottom of the low marsh zone prior to staking and planting.

Step 15: Propagate the Constructed Wetland. Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. *Initial Planting of Container-Grown Wetland Plant Stock.* The transplanting window extends from early April to mid-June. Planting after these dates is quite chancy because emergent wetland plants need a full growing season to build the root reserves needed to get through the winter. If at all possible, the plants should be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.
2. *Broadcasting Wetland Seed Mixes*. The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
3. *Allowing "Volunteer Wetland Plants to Establish*. The establishment of volunteer species should be encouraged with the exception of noxious weeds and invasive species. Typically, if properly managed, the constructed wetland will fill out with volunteer species and establishment of the planted and seeded species within 3 to 5 years.

Step 16: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergent and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a crisscross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 17: Plant the Wetland Floodplain and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation. Consequently, plants in this zone are less frequently inundated but still should be able to tolerate periods of flooding and soil saturation. The buffer area can be planted with species that do not need wet conditions, and can be planted in the spring or fall.

12.9 Constructed Wetland Maintenance Criteria

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Operation and Maintenance Plans should clearly outline how vegetation in the Constructed Wetland and its buffer will be managed or harvested in the future. Periodic mowing of the Constructed Wetland buffer is only required along the maintenance access and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

Maintenance of a Constructed Wetland is driven by annual maintenance reviews that evaluate the condition and performance of the Constructed Wetland. Based on maintenance review results, specific maintenance tasks may be required. Additional reviews are required during the first two years of establishment.

During the first two years following construction, the Constructed Wetland shall be reviewed twice each year by a qualified professional with demonstrated knowledge of wetland species, once in the spring and once in the fall after a storm event that exceeds 1/2 inch of rainfall. The Operation and Maintenance Plan shall outline a detailed schedule for the monitoring and possible reinstallation of vegetation in the wetland and its buffer for the first two years of establishment.

Repair of critical structural features such as embankments and risers shall be performed by responsible personnel that have successfully completed the Department Contractor Training Program.

Additional trips to the project site are recommended for watering, maintenance, etc, which is described below.

- Spot Reseeding. Maintenance personnel should look for bare or eroding areas in the contributing drainage area, around the wetland buffer, and in the wetland cells, to ensure that they are immediately stabilized with grass cover.

- Watering. Trees and shrubs planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every three days for first month, and then weekly during the first growing season (April - October), depending on rainfall. In the summer months, and times of prolonged drought, all of the plantings may need watering to ensure survival.

- Reinforcement Plantings. Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain non-vegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, and drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting, to selectively replant portions of the wetland that fail to fill in or survive. **Project closeout shall not occur until a minimum of 70% of the wetland area is permanently vegetated**, which may take several growing seasons and additional plantings.

- Invasive Species. Designers should expect significant changes in wetland species composition to occur over time. Reviews should carefully track changes in wetland plant species distribution over time. Noxious plants and undesired invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of noxious weeds and undesirable invasive species (e.g., cattails and Phragmites) should commence as soon as they are spotted and before their coverage exceeds more than 5% of a wetland cell area. Herbicides must be applied by a Certified aquatic pesticide applicator through the Department of Agriculture and be aquatic safe (i.e., Glyphosate-based products). Extended periods of dewatering may also work because early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

Annual, On-going Maintenance: Managing vegetation is an important ongoing maintenance task at every Constructed Wetland and for each inundation zone.

- Vegetation Management. Thinning or harvesting of excess forest growth will be needed periodically to guide the forested wetland into a more mature state and prevent it from becoming overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Removal of woody species on or near the embankment, structural components such as inflow and outflow pipes, and maintenance access areas should be conducted every 2 years.

- Mowing. Regular mowing operations only need to occur along maintenance accessways and should occur at minimum twice a year. Reference the Landscape Plan for additional requirements; some upland meadow areas may also require occasional mowing.

- Sediment Removal. **Sediment removal in the pretreatment forebay shall occur when 50% of total forebay capacity has been lost.** The owner can plan for this maintenance activity to occur every 5 to 7 years.

- Sediment Deposits. Sediment removed from the forebay should be deposited in the designated maintenance set aside area for dewatering, prior to leveling and stabilization or removal from the site. Sediments excavated from Constructed Wetlands are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the contributing area serves a hotspot land use.
- Care should be exercised during Constructed Wetland drawdowns to prevent downstream discharge of sediments or anoxic water and rapid drawdown. **The Department or the Delegated Agency shall be notified before a Constructed Wetland is drained.**

12.10 References

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13.0 Wet Ponds

Definition: **Wet Ponds are stormwater storage practices that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake and microbial activity. Wet Ponds are widely applicable for most land uses and are best suited for larger drainage areas. Runoff from each new storm enters the wet pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, Wet Ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Wet Ponds can also provide storage above the permanent pool to help meet stormwater management requirements for larger storms. Design variants include:**

- 13-A **Wet Quantity Management Pond**
- 13-B **Wet Extended Detention (ED) Pond**

A Wet ED Pond differs from a typical Wet Quantity Management Pond in that a Wet ED Pond provides 48-hour detention of all or a portion of the Resource Protection Volume (RPv). Optional internal baffles in the Wet ED Pond extend the flow path through the pond from the inflow point to the outlet. In addition, an undersized outlet structure restricts stormwater flow so it backs up and is stored within the Wet ED Pond. The temporary ponding enhances the ability of particulate pollutants to settle out and reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of the receiving stream.

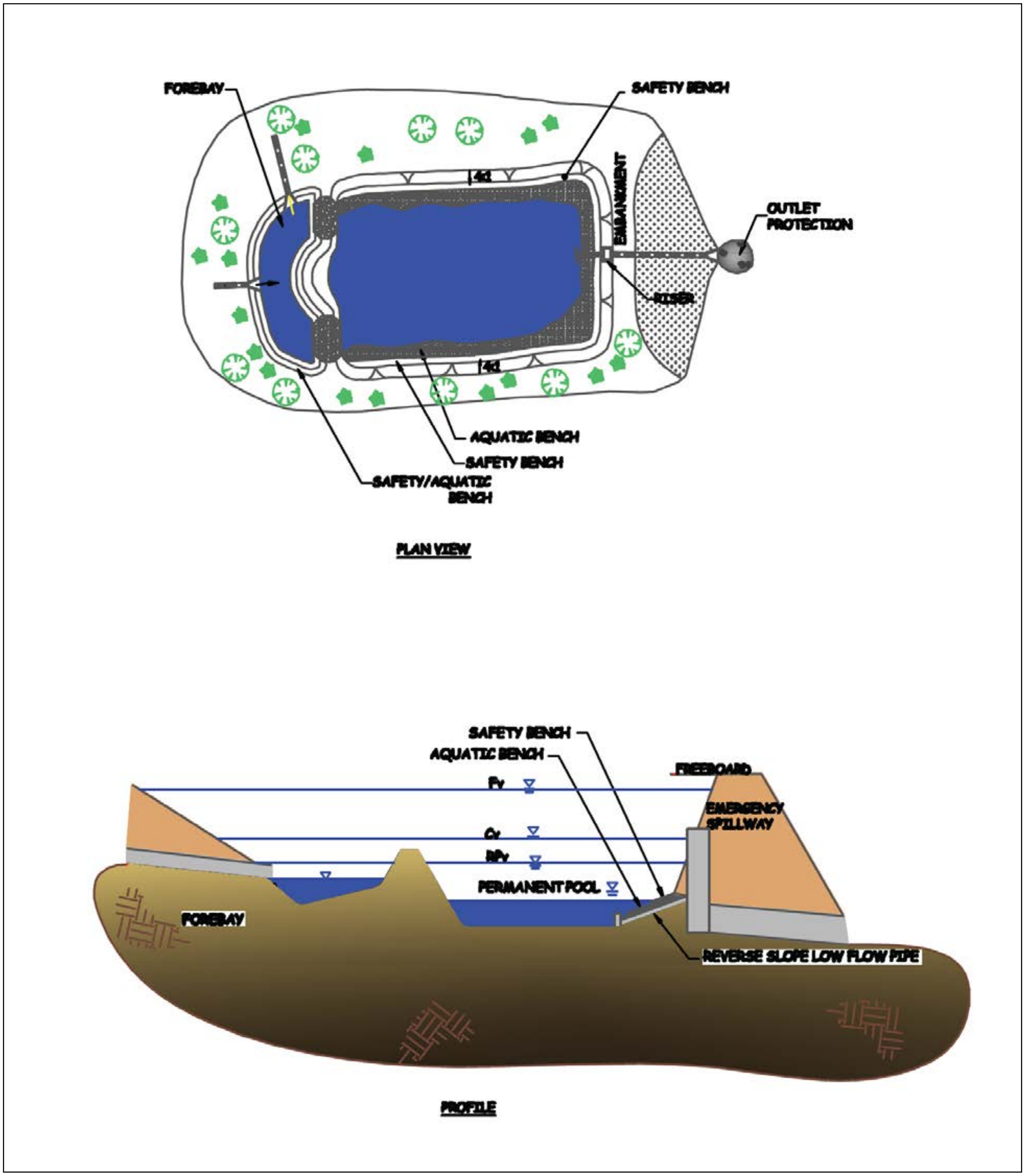

Figure 13.1. Wet Quantity Management Pond (13-A) and Wet ED Pond (13-B) Design Schematics.

13.1 Wet Pond Credit Calculations

Wet Quantity Management Ponds used solely for quantity management receive 0% retention credit (RPv) and 0% pollutant removal credit as outlined in Table 13.1a. Wet ED Ponds that provide 48-hour detention receive full credit for the portion of the RPv managed and pollutant reductions as outlined in Table 13.1b.

Table 13.1a Wet Quantity Management Pond Performance Credits

Runoff Reduction	
Retention Allowance	**0%**
RPv	**0%**
Cv	**0%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**Not less than 0%**
TP Reduction	**Not less than 0%**
TSS Reduction	**Not less than 0%**

Table 13.1b Wet ED Pond Performance Credits

Runoff Reduction	
RPv – 48-HR Detention Allowance	**100%**
Cv	**1%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**Not less than 30%**
TP Reduction	**Not less than 55%**
TSS Reduction	**Not less than 60%**

13.2 Wet Pond Practice Summary

Wet Ponds constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended. Table 13.2 summarizes the various criteria for Wet Ponds. For more detail on design criteria, consult Sections 13.3 through 13.7. Sections 13.8 describes practice construction and and Section 13.9 describes maintenance criteria.

Table 13.2 Wet Pond Practice Summary

Feasibility Criteria (Section 13.3)	• Adequate groundwater, runoff or baseflow to support permanent pool • Recommended minimum contributory drainage area (CDA) of 10 to 25 acres • Wet Pond surface area size allowance of 1% to 3% of CDA • Contributing slopes <15% • Wet Pond discharge point allows for gravity discharge • Setbacks in accordance with local codes and Appendix 8 • Utilities should not cross the embankment • Seasonal high water table < design permanent pool elevation • HSG C and D soils; HSG A and some HSG B soils may require a liner • **Soil investigations must be conducted to determine suitability of the soils to meet recommended embankment and permanent pool criteria.** • **Locating Wet Ponds within perennial streams will require all appropriate state and federal permits.**
Conveyance Criteria (Section 13.4)	• **Designed and constructed in accordance with USDA NRCS Pond Code 378 as amended** • **Principal spillway must be accessible from dry land.** • **A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure.** • **The outfall pipe and all connections to the outfall structure shall be made watertight. Soil tight only joints are not acceptable.** • **Anti-seep collars shall be used in accordance with Pond Code 378, as amended.** • **When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced with riprap or other acceptable material to prevent scour.** • **When a low flow orifice is specified, it must be adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection. Orifice diameters shall not be less than 3 inches unless internal orifice control is provided.** • **The design shall specify an outfall that can discharge the maximum design storm event in a non-erosive manner at the project point of discharge.** • **Wet Ponds must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the Wet Pond rather than bypassing.** • **An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.** • **Inflow points into the Wet Pond must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance event (Cv).** • **A forebay shall be provided at each inflow location that provides 10% or greater of the total RPv inflow to the Wet Pond.** • **In the event that the embankment is a regulated dam, the designer must verify that the appropriate Dam Safety Permit has been approved by the Department's Dam Safety Program.**
Pretreatment Criteria	• **A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell.**

(Section 13.5)	• **The following criteria apply to forebay design:**
	  o **A major inlet is defined as an individual storm drain inlet pipe or open channel conveying at least 10% of the Wet Pond's contributing RPv runoff volume.**
	  o **A safety bench is required at the pond shoreline for forebay depths greater than 3 feet.**
	  o **The forebay must be sized to contain 10% of the volume of runoff from the contributing drainage area for the Resource Protection event.**
	  o **Discharge from the forebay shall be non-erosive.**

Design Criteria Storage (Section 13.6)	• **For RPv compliance, a Wet ED Pond must provide 48 hours extended detention for the RPv runoff volume.** • **Detention time shall be based on the time of initial inflow to time of final outflow from the facility.** • **In order to simulate a base flow condition to the extent practicable, the peak discharge for the outflow hydrograph shall not exceed five times the average discharge rate.**

Design Criteria Geometry (Section 13.6)	• **Minimum depth = 4'; maximum depth = 8'**
	• **Side slopes no steeper than 3H:1V for earthen side slopes**
	• **Ten foot wide safety bench constructed 1' above permanent pool when side slopes are steeper than 4:1 excluding areas containing retaining walls**
	• **Maximum safety bench slope = 5%**
	• **Ten foot wide aquatic bench constructed 1' below permanent pool**
	• **Retaining walls limited to 50% of perimeter based on the Cv pool elevation and configured as follows:**
	  o **Maximum 3' height above the aquatic bench for a wall at the permanent pool**
	  o **Maximum 2' height for any additional wall and minimum 10' wide terrace from lower wall**

Design Criteria Appurtenances (Section 13.6)	• **A pond liner shall be required when recommended by a licensed, professional geotechnical engineer or geologist.**
	• **When the geotechnical engineer recommends a liner, acceptable options include the following:**
	  o **a clay liner having a minimum compacted thickness of 12 inches with an additional 12 inch layer of compacted soil above it. Clay used as a pond liner must meet the following specifications:**
	    ▪ **Permeability of $1x10^{-6}$ cm/sec using ASTM D-2434 procedure**
	    ▪ **Plasticity index of not less than 15% using ASTM D-423/424 procedures**
	    ▪ **Liquid limit of not less than 30% using ASTM D-2216 procedure**
	    ▪ **Clay particles passing not less than 30% using ASTM D-422 procedure**
	    ▪ **Compaction of 95% of standard proctor density using ASTM D-2216 procedure**
	  o **A 30 mil poly-liner; or**
	  o **Other acceptable measures as recommended by a qualified geotechnical professional.**
	• **Trash racks shall be provided for low-flow pipes and for all riser structure openings.**
	• **All metal trash racks shall be coated with a rust inhibitor to increase longevity of the device.**
	• **The low flow extended detention orifice shall be protected from clogging by an external trash rack.**
	• **Riser structure must be accessible for maintenance**
	• **The Department or the Delegated Agency shall be notified before a Wet Pond is drained.**
	• **Materials meet Pond Code 378 specifications**

Design Criteria Safety (Section 13.6)	• **Safety grates on openings 12” or greater** • **The emergency spillway and exit channel must be designed to direct runoff to a point of discharge without adversely impacting downstream structures** • Fencing of the pond perimeter is discouraged
Design Criteria Maintenance Access (Section 13.6)	• **Provide access to forebays, safety bench, riser and outlet structure** • **Maintenance ROW or easement to the Wet Pond from a public or private road** • **Minimum width of access roads = 15’, profile grade < 10H:1V with 10H:1V cross slope** • Top of bank should be set back at least 15 feet from property lines • **Maintenance set aside area provided to accommodate 50% of the collective forebay volume** • **Set aside area depth max.1 foot and slope not to exceed 5%**

Landscaping Criteria (Section 13.7)	• **No woody vegetation within 15’ of the embankment and 10’ on either side of principal spillway or inflow pipes**
	• **A planting plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the Wet Pond and its vegetated perimeter.**
	• **Minimum elements of a planting plan include the following:**
	  o **Delineation of zones within both the Wet Pond and vegetated perimeter area**
	  o **Selection of corresponding plant species**
	  o **Size and spacing of plant material and/or application rate of seed mixes**
	    ▪ **Native plant material shall be specified by botanical and common name**
	    ▪ **Seed mixes shall be specified by botanical and common names as well as percentages by weight or volume**

Construction Criteria (Section 13.8)	• **Approval from the Department or the appropriate Delegated Agency must be obtained before any planned Wet Quantity Management Pond or Wet ED Pond can be used as a sediment basin.**
	• **If a Wet Pond serves as a sediment basin during project construction, the volume of the sediment basin must be based on the more stringent sizing rule**
	• **The Sediment and Stormwater Plan must include conversion steps from sediment basin to permanent Wet Pond in the construction sequence.**
	• **The Department or Delegated Agency must be notified and provide approval prior to conversion from sediment basin to the final configuration of the Wet Quantity Management Pond or Wet ED Pond.**
	• **Appropriate procedures must be implemented to prevent discharge of turbid waters when the sediment basin is being converted into a Wet Pond**
	• **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**
	  o **Pre-construction meeting**
	  o **Initial site preparation including installation of erosion and sediment controls**
	  o **Construction of the embankment, including installation of the principal spillway and the outlet structure**
	  o **Excavation and grading including interim and final elevations**
	  o **Implementation of the planting plan and vegetative stabilization**
	  o **Final inspection including development of a punch list for facility acceptance**
	• **All areas surrounding the Wet Pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization**
	• **Upon project completion, the owner shall submit Post Construction verification documents to demonstrate that the wet pond has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.**
	• **Allowable tolerances for wet pond practices are as follows:**

	o **The constructed top of bank elevation may be no lower than the design elevation for top of bank.** o **The constructed volume of the wet pond surface storage shall be no less than 90% of the design volume.** o **The constructed elevation of any structure shall be within 0.15 foot of the design.** • **When the allowable tolerances are exceeded for wet pond surface area or volume or structure elevations, supplemental calculations must be submitted to the approval agency to determine if the wet pond, as constructed, meets the design requirements.**
Maintenance Criteria (Section 1.9)	• **Repair of critical structural features such as embankments and risers shall be performed by responsible personnel that have successfully completed the Department Contractor Training Program** • **The Department or the Delegated Agency shall be notified before a Wet Pond is drained** • **Sediment removal in the Wet Pond pretreatment forebay must occur when 50% of total forebay capacity has been lost** • **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

13.3 Wet Pond Feasibility Criteria

The following feasibility issues need to be considered when Wet Ponds are considered a final storm water management practice of the treatment train.

Adequate Water Balance. Wet Ponds should have enough water supplied from groundwater, runoff or baseflow to provide a permanent pool. A simple water balance calculation using the Equations 13.1 and 13.2 provided in Water Balance Testing can help determine the feasibility of the site to support a wet pond.

Contributing Drainage Area. A contributing drainage area of 10 to 25 acres is typically recommended for Wet Ponds to provide a permanent pool. Wet Ponds can still function with drainage areas less than 10 acres, but designers should be aware that these “pocket” ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions. When the contributing drainage area of the Wet Pond is less than 10 acres, alternative outlet configurations should be used to eliminate the possibility of clogging of the outlet.

Space Requirements. The surface area of a Wet Pond will normally be at least 1% to 3% of its contributing drainage area, depending on the pond’s depth.

Site Topography. Wet Ponds are best applied when the grade of contributing slopes is less than 15%.

Available Hydraulic Head. The ultimate discharge point from the Wet Pond should be used to determine the minimum elevation of the permanent pool. The permanent pool elevation will be higher than the outlet elevation in order to have a gravity discharge. In situations where there is little relief on the parcel and the head differential between the permanent pool elevation and the discharge elevation is small, an option for the Wet Pond outlet is a weir and outlet channel configuration.

Minimum Setbacks. See Appendix 8 Stormwater Facility Setbacks for recommended setbacks.

Proximity to Utilities. Wet Ponds should not be sited such that utility lines would cross any part of the embankment.

Depth-to-Water Table. The depth to the seasonal high water table is an important consideration in planning of a Wet Pond. When the seasonal high water table elevation exceeds the proposed permanent pool elevation of the Wet Pond, the capacity planned for management of the Cv and Fv in the Wet Pond may be taken up by groundwater. Further, if the water table is close to the surface, it may make excavation difficult and expensive.

Soils. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A and B soils will not support a permanent pool without the use of a liner (Refer to Liners in 13.6 Wet Pond Design Criteria and Table 13.3). **Soil investigations must be conducted in accordance with Soil Investigation Procedures to determine the suitability of the soils to meet recommended embankment and permanent pool criteria.** When soil borings confirm HSG A/B soils, an infiltration test should be conducted. If the infiltration test results in an infiltration rate greater than 1.0 inch/hour at the proposed Wet Pond invert, and the seasonal high groundwater table is two feet or more below the proposed Wet Pond invert, a stormwater management BMP other than a Wet Pond or Wet ED Pond should be designed.

Use of or Discharges to Natural Wetlands. Wet Ponds may not be located within jurisdictional waters, including wetlands, without obtaining all appropriate state or federal permits. In addition, the designer should investigate the wetland status of adjacent areas to determine if the discharge from the Wet Pond will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006, for guidance on minimizing stormwater discharges to existing wetlands).

Perennial Streams. **Locating Wet Ponds within perennial streams will require all appropriate state or federal permits.**

13.4 Wet Pond Conveyance Criteria

Wet Ponds constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Pond Code 378 as amended.

Internal Slope. The longitudinal slope of the Wet Pond bottom should be at least 0.5% to facilitate maintenance.

Principal Spillway. The principal spillway may be composed of a structure-pipe configuration or a weir-channel configuration. **The principal spillway must be accessible from dry land. A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure. The outfall pipe and all connections to the outfall structure shall be made watertight. Soil tight only joints are not acceptable. Anti-seep collars shall be used in accordance with Pond Code 378, as amended. When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced with riprap or other acceptable material to prevent scour.**

Non-Clogging Low Flow Orifice. **When a low flow orifice is specified, it must be adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection. Orifice diameters shall not be less than 3 inches unless internal orifice control is provided.**

Outfall Protection. **The design shall specify an outfall that can discharge the maximum design storm event in a non-erosive manner at the project point of discharge.** If necessary, the channel immediately below the Wet Pond outfall may be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This can be accomplished by placing appropriately sized riprap over stabilization geotextile in accordance with HEC-14 Hydraulic Design of Energy Dissipators for Culverts and Channels and Delaware Erosion and Sediment Control Handbook Specification 3.3.10 Riprap Outlet Protection or 3.3.11 Riprap Stilling Basin, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps) based upon the channel lining material. Flared pipe sections, which discharge at or near the stream invert or into a step pool arrangement, should be used at the spillway outlet.

When the discharge is to a manmade pipe or channel system, the system should be adequate to convey the required design storm peak discharge in a non-erosive manner. Care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided. The final release rate of the facility should be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow unless downstream improvements are made to accommodate the increase.

Emergency Spillway. **Wet Ponds must be designed to pass the maximum design storm event (Fv) if the Fv is being routed through the Wet Pond rather than bypassing. An earthen emergency spillway designed to convey the Fv shall be cut in natural ground or, if cut in fill, shall be constructed and stabilized with methods to prevent erosion and structural failure.**

Inflow Points. **Inflow points into the Wet Pond must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance event (Cv).** Inlet pipe inverts should generally be located at the permanent pool elevation. **A forebay shall be provided at each inflow location that provides 10% or greater of the total RPv inflow to the Wet Pond.** Additional information on forebays may be found in 13.5 Wet Pond Pretreatment Criteria.

Dam Safety Permits. The designer should determine whether or not the embankment meets the criteria to be regulated as a dam by the Delaware Dam Safety Regulations. **In the event that the embankment is a regulated dam, the designer must verify that the appropriate Dam Safety Permit has been approved by the Department's Dam Safety Program.**

13.5 **Wet Pond Pretreatment Criteria**

Sediment forebays are considered to be an integral design feature to maintain the longevity of all Wet Ponds. **A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:**

- **A major inlet is defined as an individual storm drain inlet pipe or open channel conveying at least 10% of the Wet Pond's contributing RPv runoff volume.**
- The preferred forebay configuration consists of a separate cell, formed by an acceptable barrier such as a concrete weir, riprap berm, gabion baskets, etc. Riprap berms are the preferred barrier material.
- The forebay should be 3 to 4 feet deep. **A safety bench is required at the pond shoreline for forebay depths greater than 3 feet.** The safety bench need not continue around the entire forebay.
- **The forebay must be sized to contain 10% of the volume of runoff from the contributing drainage area for the Resource Protection event.** The relative size of individual forebays should be proportional to the percentage of the total inflow to the Wet Pond. The storage volume within the forebay may be included in the calculated required storage volume for the Wet Pond.
- The recommended minimum length of the forebay is 10 feet. The forebay should have a length to width ratio of 2:1 or greater. Length is measured with the direction of flow into the Wet Pond.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation. Metered wooden stakes may need to be replaced frequently in Wet Pond forebays; alternative materials should be considered for longevity.
- Vegetation may be included within forebays to increase sedimentation and reduce resuspension and erosion of previously trapped sediment.
- **Discharge from the forebay shall be non-erosive.**

13.6 Wet Pond Design Criteria

Wet Pond Sizing: In order to receive the credits outlined in Table 13.1b, **for RPv compliance, a Wet ED Pond must provide 48 hours extended detention for the RPv runoff volume. Detention time shall be based on the time of initial inflow to time of final outflow from the facility. In order to simulate a base flow condition to the extent practicable, the peak discharge for the outflow hydrograph shall not exceed five times the average discharge rate.**

Additionally, Wet Quantity Management Ponds and Wet ED Ponds should be sized to manage the Conveyance Event and Flooding Event as required in accordance with the Delaware Sediment and Stormwater Regulations.

For treatment train designs where upland practices are utilized for treatment of the resource protection storm (RPv), designers can use a site-adjusted runoff curve number (RCN) that reflects the volume reduction of upland practices to compute the Cv and Fv that will be treated by the Wet Pond.

Water Balance Testing: A water balance calculation may be required to document that sufficient inflows to Wet Quantity Management Ponds and Wet ED Ponds exist to compensate for combined infiltration and evapo-transpiration losses during a 30-day summer drought without creating unacceptable drawdowns (see Equation 13.1, adapted from Hunt et al., 2007). The recommended minimum pool depth to avoid nuisance conditions may vary; however, it is generally recommended that the water balance maintain a minimum 24-inch reservoir.

Equation 13.1. Water Balance Equation for Acceptable Water Depth in a Wet Pond

$$DP > ET + INF + RES - MB$$

Where:

DP	=	Average design depth of the permanent pool (inches)
ET	=	Summer evapo-transpiration rate (inches) (assume 8 inches)
INF	=	Monthly infiltration loss (assume 7.2 @ 0.01 inch/hour)
RES	=	Reservoir of water for a factor of safety (assume 24 inches)
MB	=	Measured baseflow rate to the Wet Pond, if any (convert to inches)

Design factors that will alter this equation are the measurements of seasonal base flow and infiltration rate. The use of a liner could eliminate or greatly reduce the influence of infiltration. Similarly, land use changes in the upstream watershed could alter the base flow conditions over time (e.g., urbanization and increased impervious cover).

Translating the baseflow to inches refers to the depth within the Wet Pond. Therefore, Equation 13.2 can be used to convert the baseflow, measured in cubic feet per second (ft^3/s), to pond-inches:

Equation 13.2. Baseflow Conversion Equation

$$\text{Pond inches} = (\text{MB in } ft^3/s) * (2.592E6) * (12''/ft) / \text{SA of Pond } (ft^2)$$

Where:

2.592E6 = Conversion factor: ft^3/s to $ft^3/month$.

SA = surface area of Wet Pond in ft^2

Wet Pond Storage Design: Volume storage may be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, extended detention [ED], and marsh).

A minimum of 50% of the pond area should have the minimum depth of 4 feet in order to prevent the pond from being overgrown by aquatic vegetation, allowing for a more balanced ecosystem to manage pest species.

Maximum Extended Detention Levels: The maximum extended detention volume associated with the Resource Protection volume should occur within the storage for the Conveyance storm (Cv). The total storage, including any ponding for larger flooding events (100-year storm) should not extend more than 5 feet above the permanent pool unless specific design enhancements to ensure side slope stability, safety, and maintenance are identified and approved.

Wet Pond Geometry: Wet Pond designs should have an irregular shape and a long flow path from inlet to outlet, to increase water residence time and Wet Pond performance. Greater flow paths and irregular shapes are recommended. The total length of the flow path compared to the linear length through the Wet Pond from inlet to outlet, should be a minimum ratio of 2:1. Internal berms, baffles, or vegetated peninsulas can be used to extend flow paths and/or create multiple pond cells.

In addition, the ratio of the shortest flow path through the system (due to an inlet located near the outlet) to the overall length should be at least 0.5:1. The drainage area served by any inlets located less than a 0.5:1 ratio should constitute no more than 20% of the total contributing drainage area.

Permanent Pool Depth: **The minimum depth to prevent the permanent pool area from being overtaken by undesirable vegetation is 4 feet. The maximum depth of the permanent pool shall not exceed 8 feet for safety reasons.**

Earthen Side Slopes: **Earthen side slopes for Wet Ponds both above and below permanent pool shall be no steeper than 3H:1V.** Mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Wet Pond Benches:

- Safety Bench. **Excluding areas containing retaining walls, when Wet Pond side slopes above permanent pool are steeper than 4H:1V, a 10 foot wide safety bench shall be constructed 1 foot above the permanent pool.** The safety bench allows for maintenance access and reduces safety risks. **The maximum slope of the safety bench shall be 5%.**
- Aquatic Bench. An aquatic bench is a shallow area below the permanent pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces

shoreline erosion, and conceals floatable trash. **A 10 foot wide aquatic bench shall be provided 1 foot below permanent pool.**

Retaining Walls: Retaining walls around Wet Ponds shall be limited to no more than 50% of the pond perimeter based upon the peak elevation of the Cv. In order to maintain the safety requirements, retaining walls shall be configured as follows:

- **The retaining wall at the permanent pool shall have a maximum height of 3 feet above the aquatic bench.**
- **Any additional retaining walls shall have a maximum height of 2 feet and provide a minimum 10-foot level terrace from a lower retaining wall.**

Liners: Highly permeable soils will make it difficult to maintain a healthy permanent pool. **All wet ponds shall be evaluated for feasibility and ability to maintain permanent pool, including the need for a liner, by a qualified, licensed geotechnical engineer or geologist. If the pond designer chooses not to follow the recommendations of the geotechnical professional, a signed and sealed letter from the designer providing justification for the design shall be provided to DNREC or their delegated Agency.**

When the geotechnical engineer recommends a liner, acceptable options include the following:

(1) a clay liner having a minimum compacted thickness of 12 inches with an additional 12 inch layer of compacted soil above it. Clay used as a pond liner must meet the following specifications:

  a. Permeability of $1x10^{-6}$ cm/sec using ASTM D-2434 procedure
  b. Plasticity index of not less than 15% using ASTM D-423/424 procedures
  c. Liquid limit of not less than 30% using ASTM D-2216 procedure
  d. Clay particles passing not less than 30% using ASTM D-422 procedure
  e. Compaction of 95% of standard proctor density using ASTM D-2216 procedure

(2) A 30 mil poly-liner; or

(3) **Other acceptable measures as recommended by a qualified geotechnical professional.**

Trash Racks: **Trash racks shall be provided for low-flow pipes and for all riser structure openings.** Open weirs that discharge to an open channel will not require trash racks. Synthetic trash rack materials options are available and should be considered. **All metal trash racks shall be coated with a rust inhibitor to increase longevity of the device.**

Non-clogging Low Flow (Extended Detention) Orifice: **The low flow extended detention orifice shall be protected from clogging by an external trash rack.** The preferred method is a hood apparatus over the orifice that reduces gross pollutants such as floatables and trash, as well as oil and grease and sediment.

Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging. As an alternative, internal orifice protection may be used (i.e., an orifice internal to a perforated vertical stand pipe with 0.5-inch perforations or slots that are protected by wirecloth and a stone filtering jacket). Floating skimmers, seepage berms, French drains or other similar measures may be a better alternative to provide the 48-hour detention required for Wet ED Ponds if the orifice diameter is too small.

Riser: **When a riser is used, it must be located such that it is accessible from the pond side slope or safety bench for the purposes of inspection and maintenance.** The riser may be located within the embankment for maintenance access, safety, and aesthetics. Where appropriate, access to the riser may be provided by manhole covers and manhole steps within easy reach of valves and other controls.

Pond Drain: Wet Ponds should have a drain pipe that can completely or partially drain the permanent pool. In cases where a low level drain is not feasible (such as in an excavated Wet Pond), the Operation and Maintenance Plan should include requirements for dewatering the Wet Pond.

- The drain pipe should have an upturned elbow or protected intake within the Wet Pond to help keep it clear of sediment deposition, and a diameter capable of draining the Wet Pond within 24 hours.
- The Wet Pond drain should be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

Care should be exercised during Wet Pond drawdowns to prevent downstream discharge of sediments or anoxic water and rapid drawdown. **The Department or the Delegated Agency shall be notified before a Wet Pond is drained.**

Adjustable Gate Valve: If desired to adjust the pond permanent pool elevation, both the outlet pipe and the Wet Pond drain should be equipped with an adjustable gate valve (typically a hand wheel activated knife gate valve) or pump well and be sized one pipe size greater than the calculated design diameter. Valves should be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner. To prevent vandalism, the hand wheel should be chained to a ringbolt, manhole step or other fixed object.

Material Specifications: **All materials used in construction of a Wet Quantity Management Pond or Wet ED Pond shall meet the material specifications in USDA NRCS Pond Code 378 as amended.**

Safety Features:

- **Any opening 12 inches or greater discharging to a closed drainage system shall include safety grates.**
- **The emergency spillway and exit channel must be designed to direct runoff to a point of discharge without adversely impacting downstream structures.**
- Fencing of the perimeter of Wet Ponds is discouraged. The preferred method to reduce risk is to manage the contours of the Wet Pond to eliminate drop-offs or other safety hazards.
- Warning signs may be posted.

Maintenance Reduction Features: The following Wet Pond maintenance issues can be addressed during the design, in order to make on-going maintenance easier:

- Maintenance Access. **All Wet Ponds must be designed so as to be accessible for maintenance.** Good access is needed so crews can remove sediments, make repairs and preserve Wet Pond treatment capacity.
    - **Adequate maintenance access must extend to the pretreatment, safety bench, riser, and outlet structure.**
    - **A maintenance right-of-way or easement must extend to the Wet Pond from a public or private road.**
    - **Maintenance access must meet the following criteria:**
        - **Minimum width of 15 feet.**
        - **Profile grade that does not exceed 10H:1V.**
        - **Minimum 10H:1V cross slope.**
    - Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines. When not specified in local code, the top of bank of Wet Ponds should be set back at least 15 feet from property lines to ensure maintenance access.

- **Maintenance Set-Aside Area**: Adequate land area adjacent to the Wet Pond should be provided for in the Operation and Maintenance Plan as a location for disposal of sediment removed from the Wet Pond when maintenance is performed. The maintenance set-aside area is necessary on all sites adjacent to the Wet Pond to adequately dewater sediment removed from the pond prior to spreading and seeding or transporting from the site.
    - **The maintenance set-aside area shall accommodate the volume of 50% of the collective forebay volume.**
    - **The maximum depth of the set aside area shall be one foot.**
    - **The slope of the set aside area shall not exceed 5%**.
    - The area and slope of the set aside area may be modified if an alternative area or method of disposal is approved by the Department or Delegated Agency.

13.7 Wet Pond Landscaping Criteria

Woody Vegetation: **Woody vegetation shall not be planted or allowed to grow within 15 feet of the embankment and 10 feet on either side of principal spillway or inflow pipes.** These recommendations may be relaxed in situations where Wet Ponds are constructed adjacent to existing forested areas.

Planting Plan: **A planting plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the Wet Pond and its vegetated perimeter.** Avoid species that require full shade, or are prone to wind damage. Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds. See Appendix 2. Landscaping Guidelines for additional information.

Minimum elements of a planting plan include the following:

- **Delineation of zones within both the Wet Pond and vegetated perimeter area**
- **Selection of corresponding plant species**
- **Size and spacing of plant material or application rate of seed mixes, as applicable**
  - **Native plant material shall be specified by botanical and common name**
  - **Seed mixes shall be specified by botanical and common names as well as percentages by weight or volume**

13.8 Wet Pond Construction

Use of Wet Ponds for Erosion and Sediment Control. A Wet Pond may serve as a sediment basin during project construction. **Approval from the Department or the appropriate Delegated Agency must be obtained before any planned Wet Quantity Management Pond or Wet ED Pond can be used as a sediment basin. If a Wet Pond serves as a sediment basin during project construction, the volume of the sediment basin must be based on the more stringent sizing rule** (erosion and sediment control requirement vs. storage volume requirement)**.** Installation of the permanent principal spillway should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction Wet Pond in mind.

The Sediment and Stormwater Plan must include conversion steps from sediment basin to permanent Wet Pond in the construction sequence. The Department or Delegated Agency must be notified and provide approval prior to conversion from sediment basin to the final configuration of the Wet Quantity Management Pond or Wet ED Pond. Appropriate procedures must be implemented to prevent discharge of turbid waters when the sediment basin is being converted into a Wet Pond.

Construction Review. Multiple construction reviews are critical to ensure that Wet Ponds are properly constructed. **Construction reviews are required during the following stages of**

construction, and shall be noted on the plan in the sequence of construction:

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls**
- **Construction of the embankment, including installation of the principal spillway and the outlet structure**
- **Excavation and grading including interim and final elevations**
- **Implementation of the planting plan and vegetative stabilization**
- **Final inspection including development of a punch list for facility acceptance**

Construction Sequence. The following is a typical construction sequence to properly install a Wet Pond. The steps may be modified to reflect different Wet Pond designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: Stabilize the Drainage Area. If the proposed Wet Pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas. Ensure that appropriate compaction and dewatering equipment is available. Locate the project benchmark and if necessary transfer a benchmark nearer to the Wet Pond location for use during construction.

Step 3: Install Erosion and Sediment Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. **All areas surrounding the Wet Pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.**

Step 4: Clear and Strip the embankment area to the desired sub-grade.

Step 5: Excavate the Cutoff Trench and Install the Principal Spillway Pipe in accordance with construction specification of USDA NRCS Pond Code 378 as amended.

Step 6: Install the Riser or Outflow Structure, and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 7: Construct the Embankment and Any Internal Berms using acceptable material in 8- to 12-inch lifts, compact the lifts with appropriate equipment. Construct the embankment allowing for 10% settlement of the embankment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the Wet Pond. Construct forebays at the proposed inflow points.

Step 9: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 10: Install Outlet Pipes, including any flared end sections, headwalls, and downstream rip-rap outlet protection underlain by stabilization geotextile.

Step 11: Stabilize Exposed Soils with the approved seed mixtures appropriate for the Wet Pond perimeter area. All areas above the permanent pool elevation should be permanently stabilized in accordance with the vegetative stabilization specifications on the approved Sediment and Stormwater Management Plan.

Step 12: Plant the Wet Pond Benches and Vegetated Perimeter Area, following the planting plan (see Section 13.7 Wet Pond Landscaping Criteria).

Post Construction Verification Documentation. **Upon project completion, the owner shall submit Post Construction verification documents to demonstrate that the wet pond has been constructed within allowable tolerances in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.**
Allowable tolerances for wet pond practices are as follows:

- **The constructed top of bank elevation may be no lower than the design elevation for top of bank.**
- **The constructed volume of the wet pond surface storage shall be no less than 90% of the design volume.**
- **The constructed elevation of any structure shall be within 0.15 foot of the design.**

When the allowable tolerances are exceeded for wet pond surface area or volume or structure elevations, supplemental calculations must be submitted to the approval agency to determine if the wet pond, as constructed, meets the design requirements.

13.9 Wet Pond Maintenance Criteria

Maintenance is needed so Wet Ponds continue to operate as designed on a long-term basis. Wet Pond maintenance activities vary regarding the level of effort and expertise required to perform them. Routine Wet Pond maintenance, such as mowing and removing debris and trash, is needed several times each year (See Table 13.4).

More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Inspection of critical structural features such as embankments and risers should be performed by a Certified Construction Reviewer or licensed professional who has experience in the construction, inspection, and repair of these features**.** **Repair of critical structural features such as embankments and risers shall be performed by responsible personnel that have successfully completed the Department Contractor Training Program.**
The Department or the Delegated Agency shall be notified before a Wet Pond is drained.

Sediment removal in the Wet Pond pretreatment forebay must occur when 50% of total forebay capacity has been lost. The owner can plan for this maintenance activity to occur every 5 to 7 years.

Sediment removed from the Wet Pond should be deposited in the designated maintenance set aside area for dewatering, prior to leveling and stabilization or removal from the site. Sediments excavated from Wet Ponds are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the Wet Pond serves a hotspot land use.

Community awareness can contribute to a properly maintained Wet Pond. Signs describing the function and/or minimum maintenance requirements for the Wet Pond may be posted at the Wet Pond location to increase community awareness.

Table 13.4. Typical Wet Pond Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the Wet Pond perimeter area • Water trees and shrubs planted in the Wet Pond vegetated perimeter area during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris, trash and blockages • Repair undercut, eroded, and bare soil areas
Twice a year	• Mowing of the Wet Pond vegetated perimeter area and embankment
Annually	• Shoreline cleanup to remove trash, debris and floatables • A full maintenance review ▪ Open up the riser to access and test the valves ▪ Repair broken mechanical components, if needed
Every 5 to 7 years	• Forebay sediment removal
From 5 to 25 years	• Repair pipes, riser, spillway, and embankment as needed • Remove sediment from Wet Pond area outside of forebays

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper

maintenance is not performed.

Operation and Maintenance Plans should clearly outline how vegetation in the Wet Pond and its vegetated perimeter area will be managed or harvested in the future. Periodic mowing of the Wet Pond vegetated perimeter area is only required along the maintenance access and the embankment. The remaining Wet Pond perimeter can be managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

Maintenance of a Wet Pond is driven by annual maintenance reviews that evaluate the condition and performance of the Wet Pond. Based on maintenance review results, specific maintenance tasks may be required.

13.10 References

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14.0 Soil Amendments

Definition: **Soil Amendment, also called soil restoration, is a technique applied after construction to till compacted soils and restore their porosity by amending them with compost. Soil amendments reduce the generation of runoff from compacted urban lawns and may also enhance the performance of impervious cover disconnections and grass channels.**

14.1 Soil Amendment Stormwater Credit Calculations

Soil Amendment does not receive a retention allowance. However, the use of soil amendments in accordance with this specification allows disturbed areas to receive a reduction credit for the annual runoff. The adjustment varies depending on the soil's Hydrologic Soil Group. Pollutant loads are assumed to be reduced by the equivalent reduction in runoff. Table 14.1 summarizes the runoff and pollutant reduction credits for this practice. Soil amendments can also enhance the performance of other runoff reduction practices that rely on surface infiltration. Runoff and pollutant reduction credits for these types of applications are discussed in the respective specifications for those practices.

14.1 Soil Amendment Performance Credits

Runoff Reduction	
Retention Allowance	**0%**
RPv	**HSG A – 48% Annual Runoff Reduction** **HSG B – 50% Annual Runoff Reduction** **HSG C - 29% Annual Runoff Reduction** **HSG D – 13% Annual Runoff Reduction**
Cv	**10% of RPv Allowance**
Fv	**1% of RPv Allowance**
Pollutant Reduction	
TN Reduction	**100% of Load Reduction**
TP Reduction	**100% of Load Reduction**
TSS Reduction	**100% of Load Reduction**
NOTE: **Runoff reduction allowances are applied to the amendment area only.**	

14.2 Soil Amendments Practice Summary

Table 14.2 summarizes the various criteria for Soil Amendments.

Table 14.2 Soil Amendments Practice Summary

Feasibility Criteria (Section 4.3)	• **Soil Amendments shall not be applied where:** o **The water table or bedrock is located within 2.0 feet of the soil surface. Soil Investigation Procedures shall be followed for determination of depth to the limiting layer.** o **Slope of soil to be amended exceeds 10%.** o **Soil to be amended is saturated or seasonally wet.** • Soil Amendments can be applied to the entire disturbed pervious area of a development or be applied only to select areas of the site to enhance the performance of runoff reduction practices.
Design Criteria (Section 4.4)	• **Soil testing shall be conducted during two stages of the Soil Amendment process.** • **The first test shall be performed to determine soil properties to a depth 1 foot below the proposed soil amendment area, with respect to saturation, bulk density, pH, salts, and soil nutrients.** • **The initial test shall determine what soil amendments are needed.** • **The second soil test shall be conducted at least one week after compost has been incorporated into the soils to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth.** • **When Soil Amendments are used to either adjust the hydrologic soil group of the amended area to lower the curve number of the site, or receive the annual runoff reduction performance credits for the amendment area, the soil amendment area shall receive no impervious cover runoff and shall place 3 inches of compost into the soil amendment area to a minimum incorporation depth of 6 inches using a tiller.** • **When Soil Amendments are used within the footprint of a BMP such as sheet flow to filter strip, sheet flow to open space, or vegetated channels to adjust the hydrologic soil group of the amended area and receive the runoff reduction performance credits for those BMPs, the following criteria apply:** o **Soil amendment areas having a contributing impervious cover (square feet) to surface area of compost amendment (square feet) ratio of up to 0.5 shall place 4 inches of compost into the soil amendment area to a minimum incorporation depth of 8 inches using a tiller.** o **Soil amendment areas having a contributing impervious cover (square feet) to surface area of compost amendment (square feet) ratio of 0.51 to 0.75 shall place 6 inches of compost into the soil amendment area to a minimum incorporation depth of 15 inches using an excavation and mixing method.** o **Soil amendment areas having a contributing impervious cover (square feet) to surface area of compost amendment (square feet) ratio greater than 0.75 shall place 8 inches of compost into the soil amendment area to a minimum incorporation depth of 20 inches using an excavation and mixing method.** • **Compost incorporation depths greater than 12" require removal of the existing soil down to the incorporation depth and physically mixing existing soil with compost.**

<table>
<tr><td></td><td>Compost used for soil amendment shall be STA certified compost, meeting the requirements of Delaware Erosion and Sediment Control Handbook Appendix A-6 Compost Material Properties.</td></tr>
<tr><td>Landscaping Criteria (Section 4.5)</td><td>There are no specific landscaping criteria for Soil Amendments other than what would be necessary to provide adequate stabilization.</td></tr>
<tr><td>Construction Criteria (Section 4.6)</td><td>
For compost incorporation depths up to 12”:

The proposed incorporation area shall be deep tilled to a depth of 2 to 3 feet using a tractor and sub-soiler. This deep-tilling step may be omitted when soil amendment is used for filter strip widths of 20 feet or less in the direction of flow.
Existing soils shall be in dry condition prior to incorporating compost.
The compost layer shall be placed on surface of proposed amendment area to the depth specified and then incorporated into the soil using a roto-tiller or similar equipment.
Conduct soil test to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth.

For compost incorporation depths 12” or greater:

The proposed amendment area shall be excavated to the required incorporation depth, as follows:

Remove topsoil and stockpile for later use.
Excavate subsoil working in strips perpendicular to the slope/flowpath, using multiple lifts.
Separate and remove a minimum of 25% of the subsoil, taking the most densely compacted soils for removal. Stockpile remaining subsoil next to excavated area, separately from topsoil.
Scarify bottom of excavated area.

Amended soil shall be returned to the soil amendment area as follows. The number of lifts may vary depending on the capabilities of the equipment being used, but a minimum of 2 lifts is required.

Replace subsoils by loosening, aerating, and mixing subsoil.
Replace stockpiled topsoil.
ncorporate required layer of compost, such that compost is uniformly incorporated throughout. Existing soils shall be in dry condition prior to incorporating compost.
Repeat above steps for each lift.

Rake to level and remove surface woody debris and rocks larger than 1”.
The finished grade of the combination of replaced subsoil, topsoil and compost shall be a minimum of 4” above the existing grade to account for settlement, but must be adjusted to account for field conditions and soil texture, such that a final settled grade at three months post-installation matches the original grade.
Conduct soil test to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth.

Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:

Pre-construction meeting
Initial site preparation including installation of erosion and sediment controls.

</td></tr>
</table>

	o **Deep tillage using subsoiler or excavation of existing subsoil.** o **Incorporation of compost amendment into existing soil including verification of the depth of compost amendment.** o **Implementation of required stabilization and planting plan.** o **Final construction review including development of a punch list for facility acceptance.** • **Upon project completion, the owner shall submit Post Construction verification documents, including but not limited to compost delivery tickets and photo documentation of construction, to demonstrate that the soil amendment has been constructed within in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.**
Maintenance Criteria (Section 4.7)	• **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

14.3 Soil Amendment Feasibility Criteria

Amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. They are particularly well suited when existing soils have low infiltration rates (HSG C and D) and when the pervious area will be used to filter runoff (downspout disconnections and grass channels). The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system. Soil Amendment is particularly recommended for sites that will experience mass grading of more than a foot of cut and fill across the site.

Soil Amendments shall not be applied where:

- **The water table or bedrock is located within 2.0 feet of the soil surface. Soil Investigation Procedures shall be followed for determination of depth to the limiting layer.**
- **Slope of soil to be amended exceeds 10%.**
- **Soil to be amended is saturated or seasonally wet** (including some soils in HSG D).

Soil Amendments are not recommended where:

- They would harm roots of existing trees (keep amendments outside the tree drip line).
- The downhill slope runs toward an existing or proposed building foundation.
- The contributing impervious surface area exceeds the surface area of the amended soils.
- Soil amendment areas will be used for snow storage.

Soil Amendments can be applied to the entire disturbed pervious area of a development or be applied only to select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include:

- Reduce runoff from compacted lawns.
- Enhance performance of impervious cover disconnections on poor soils.
- Increase runoff reduction within a grass channel.

- Increase runoff reduction within a vegetated filter strip.
- Increase the runoff reduction function of a reforested area of the site.

14.4 Soil Amendment Design Criteria

Soil Testing. **Soil testing shall be conducted during two stages of the Soil Amendment process. The first test shall be performed to determine soil properties to a depth 1 foot below the proposed soil amendment area, with respect to saturation, bulk density, pH, salts, and soil nutrients.** These tests should be conducted every 5000 square feet and at sufficient density to accurately characterize the heterogeneity of the site. These testing results are then used to characterize potential drainage problems. **The initial test shall determine what soil amendments are needed.**

The second soil test shall be conducted at least one week after compost has been incorporated into the soils to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth. This soil analysis should be conducted by a reputable laboratory. This soil analysis should be done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths.

Determining Depth of Compost Incorporation. The depth of compost incorporation is based on the relationship of the surface area of the Soil Amendment to the contributing area of impervious cover that it receives. The criteria below presents some general guidance derived from soil modeling by Holman-Dodds (2004) that evaluates the required depth to which compost must be incorporated. Some adjustments to the recommended incorporation depth were made to reflect alternative recommendations of Roa-Espinosa (2006), Balousek (2003), Chollak and Rosenfeld (1998) and others.

When Soil Amendments are used to either adjust the hydrologic soil group of the amended area to lower the curve number of the site, or receive the annual runoff reduction performance credits for the amendment area, the soil amendment area shall receive no impervious cover runoff and shall place 3 inches of compost into the soil amendment area to a minimum incorporation depth of 6 inches using a tiller.

When Soil Amendments are used within the footprint of a BMP such as sheet flow to filter strip, sheet flow to open space, or vegetated channels to adjust the hydrologic soil group of the amended area and receive the runoff reduction performance credits for those BMPs, the following criteria apply:

> **Soil amendment areas having a contributing impervious cover (square feet) to surface area of compost amendment (square feet) ratio of up to 0.5 shall place 4 inches of compost into the soil amendment area to a minimum incorporation depth of 8 inches using a tiller.**
>
> **Soil amendment areas having a contributing impervious cover (square feet) to surface area of compost amendment (square feet) ratio of 0.51 to 0.75 shall place 6 inches of**

compost into the soil amendment area to a minimum incorporation depth of 15 inches using an excavation and mixing method.

Soil amendment areas having a contributing impervious cover (square feet) to surface area of compost amendment (square feet) ratio greater than 0.75 shall place 8 inches of compost into the soil amendment area to a minimum incorporation depth of 20 inches using an excavation and mixing method.

Compost Incorporation. Incorporation depths up to 12" can generally be achieved by placing the recommended depth of compost material over the proposed amendment area and tilling down to the specified incorporation depth using appropriate equipment. **Compost incorporation depths greater than 12" require removal of the existing soil down to the incorporation depth and physically mixing existing soil with compost.**

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed, using an estimator developed by The Composting Council (TCC), (1997):

$$C = A * D * 0.0031$$

Where: C = compost needed (cu. yds.)
A = area of soil amended (sq. ft.)
D = depth of compost added (in.)

Compost Specifications
Compost used for soil amendment shall be STA certified compost, meeting the requirements of Delaware Erosion and Sediment Control Handbook Appendix A-6 Compost Material Properties.

14.5 Soil Amendment Landscaping Criteria

There are no specific landscaping criteria for Soil Amendments other than what would be necessary to provide adequate stabilization.

14.6 **Soil Amendment Construction Criteria**

The construction sequence for Soil Amendments differs depending on whether the practice will be applied to a large area or a narrow area such as a filter strip or grass channel. Construction techniques also differ depending on the specified incorporation depth.

For compost incorporation depths up to 12":

1. **The proposed incorporation area shall be deep tilled to a depth of 2 to 3 feet using a tractor and sub-soiler** with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow. **This deep-tilling step may be omitted when soil amendment is used**

for filter strip widths of 20 feet or less in the direction of flow.

2. **Existing soils shall be in dry condition prior to incorporating compost.**
3. **The compost layer shall be placed on surface of proposed amendment area to the depth specified and then incorporated into the soil using a roto-tiller or similar equipment.**
4. **Conduct soil test to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth.**

For compost incorporation depths 12" or greater:

1. **The proposed amendment area shall be excavated to the required incorporation depth, as follows:**
   - 1.1. **Remove topsoil and stockpile for later use.**
   - 1.2. **Excavate subsoil** working in strips perpendicular to the slope/flowpath, **using multiple lifts.**
   - 1.3. **Separate and remove a minimum of 25% of the subsoil, taking the most densely compacted soils for removal. Stockpile remaining subsoil next to excavated area, separately from topsoil.**
   - 1.4. **Scarify bottom of excavated area.**
2. **Amended soil shall be returned to the soil amendment area as follows. The number of lifts may vary depending on the capabilities of the equipment being used, but a minimum of 2 lifts is required.**
   - 2.1. **Replace subsoils by loosening, aerating, and mixing subsoil.**
   - 2.2. **Replace stockpiled topsoil.**
   - 2.3. **Incorporate required layer of compost, such that compost is uniformly incorporated throughout. Existing soils shall be in dry condition prior to incorporating compost.**
   - 2.4. **Repeat above steps for each lift.**
3. **Rake to level and remove surface woody debris and rocks larger than 1"**
4. **The finished grade of the combination of replaced subsoil, topsoil and compost shall be a minimum of 4" above the existing grade to account for settlement, but must be adjusted to account for field conditions and soil texture, such that a final settled grade at three months post-installation matches the original grade.**
5. **Conduct soil test to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth.**

Once the compost has been incorporated, vegetative stabilization should be initiated immediately. Lime and irrigation may be necessary to ensure adequate germination and quick establishment of vegetation. The soil amendment area should be protected from re-compaction, particularly following the first 3 months of completion as settlement occurs**.** Areas of Soil Amendment exceeding 5000 square feet should employ simple erosion control measures, such as silt fence, to reduce the potential for erosion and trap sediment

Construction Reviews. **Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:**

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls,**
- **Deep tillage using subsoiler or excavation of existing subsoil.**
- **Incorporation of compost amendment into existing soil including verification of the depth of compost amendment.**
- **Implementation of required stabilization and planting plan.**
- **Final construction review including development of a punch list for facility acceptance**

Upon project completion, the owner shall submit Post Construction verification documents, including but not limited to compost delivery tickets and photo documentation of construction, to demonstrate that the soil amendment has been constructed within in accordance with the approved Sediment and Stormwater Management Plan and accepted by the approving agency.

14.7 Soil Amendment Maintenance Criteria

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

First Year Maintenance Operations. In order to ensure the success of Soil Amendments, the following steps should be undertaken in the first year following soil restoration:

- *Initial inspections.* For the first six months following the incorporation of soil amendments, the site should be inspected at least once after each storm event that exceeds 1/2-inch of rainfall.
- *Spot Reseeding.* Inspectors should look for bare or eroding areas in the contributing drainage area or around the soil restoration area and make sure they are immediately stabilized with grass cover.
- *Fertilization.* Depending on the amended soils test, a one-time, spot fertilization may be needed in the fall after the first growing season to increase plant vigor.
- *Watering.* Water once every three days for the first month, and then weekly during the first year (April-October), depending on rainfall.

Ongoing Maintenance. There are no major on-going maintenance needs associated with Soil Amendments, although the owners may want to de-thatch the turf every few years to increase permeability. The owner should also be aware that there are maintenance tasks needed for filter strips, grass channels, and reforestation areas.

Table 14.4. Typical Soil Amendment Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area and the Soil Amendment area. • Water trees and shrubs planted in the Soil Amendment area. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall. • Conduct weed and invasive plant control
Quarterly or after major storms (>1 inch of rainfall)	• Repair eroded and bare soil areas • Conduct weed and invasive plant control

14.8 References

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15.0 Proprietary Practices

Definition: **Proprietary Practices are manufactured stormwater treatment practices that utilize settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, or other appropriate technology to manage the impacts caused by stormwater runoff.**

Certain Proprietary Practices may be eligible for some amount of treatment credit, provided they have been approved by the Department and meet the performance criteria outlined in this specification. Proprietary practices will generally not be eligible for retention volume credit unless the practice can demonstrate the occurrence of runoff reduction processes.

15.1 Proprietary Practices Stormwater Credit Calculations

Proprietary Practices receive no runoff reduction credits unless approved by the Department. Proprietary Practices may receive pollutant reduction credits as determined by the Department on a case-by-case basis.

15.1 Proprietary Practices Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	TBD on Case-by-Case Basis
TP Reduction	TBD on Case-by-Case Basis
TSS Reduction	TBD on Case-by-Case Basis

15.2 Proprietary Practices Feasibility Criteria

Individual proprietary practices will have different site constraints and limitations. Manufacturer's specifications should be consulted to ensure that proprietary practices are feasible for application on a site-by-site basis.

15.3 Proprietary Practice Conveyance Criteria

All proprietary practices shall be designed to safely overflow or bypass flows from larger storm events to downstream drainage systems. The overflow associated with the 10-yr storms should be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).

Manufactured treatment devices may be constructed on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the water quality design storm and conveying the runoff from larger storms through an overflow. In off-line devices, most or all of the runoff from storms larger than the stormwater quality design storm bypass the device through an upstream diversion.

15.4 Proprietary Practice Pretreatment Criteria

Pretreatment shall be provided in accordance with manufacturer's recommendations for individual Proprietary Practices.

15.5 **Proprietary Practice Design Criteria**

The basic design parameters for a Proprietary Practice will depend on the techniques it employs to control stormwater runoff and remove particulate and dissolved pollutants from runoff. In general, the design of devices that treat runoff with no significant storage and flow rate attenuation should be based upon the peak design flow rate. However, devices that do provide storage and flow rate attenuation should be based, at a minimum, on the design storm runoff volume and, in some instances, on a routing of the design runoff hydrograph.

Design criteria for Proprietary Practices shall be proposed by the manufacturer and approved by the Department. Manufacturers who feel that the performance of their particular product exceeds the CBP performance criteria as currently assigned may request a formal review of their product following the procedures developed by the Scientific and Technical Advisory Committee (STAC) for evaluating stormwater BMPs. In order to be considered for improved performance criteria, the manufacturer should notify the Department in writing of its intention to proceed with such formal review and should forward subsequent findings and results from the STAC.

All Proprietary Practices must be designed so as to be accessible for maintenance. Good access is needed so crews can remove sediments, make repairs and preserve treatment capacity.

- **A maintenance right-of-way or easement must extend to the Proprietary Practice from a public or private road.**
- **Adequate maintenance access must extend to the all components of the Proprietary Practice.**
- **Maintenance access must meet the following criteria:**
    - **Minimum width of fifteen feet.**
    - **Profile grade that does not exceed 10H:1V.**
    - **Minimum 10H:1V cross slope.**

15.6 Proprietary Practice Landscaping Criteria

Proprietary Practices may or may not require landscaping considerations. **Landscaping shall be provided in accordance with manufacturer's recommendations for individual Proprietary Practices.**

15.7 **Proprietary Practice Construction Sequence**

The construction and installation of individual Proprietary Practices will vary based on the specific proprietary practice. **Construction and installation of Proprietary Practices shall be conducted in accordance with manufacturer's recommendations for individual Proprietary Practices.**
Manufacturer's specifications should be consulted to determine the device specific construction sequencing requirements.

Construction reviews are required during the following stages of construction, and shall be noted on the plan in the sequence of construction:

- **Pre-construction meeting**
- **Initial site preparation including installation of erosion and sediment controls**
- **Construction of the Proprietary Practice in accordance with manufacturer's recommendations**
- **Implementation of required stabilization and planting plan as applicable**
- **Final construction review including development of a punch list for facility acceptance**

Post Construction Verification Documentation. **Upon project completion, the owner shall submit Post Construction verification documents to demonstrate that the Proprietary Device has been installed in accordance with manufacturer's recommendations.**

15.8 Proprietary Practice Maintenance Criteria

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

In order to ensure effective and long-term performance of a Proprietary Practice, regular maintenance tasks and inspections are recommended. **All Proprietary Practices shall be inspected and maintained in accordance with the manufacturer's instructions and recommendations.**

15.9 References

No references.

16.0 Source Controls

Definition: **Source Control consists of measures to prevent pollutants from coming into contact with stormwater runoff. Preventing pollutant exposure to rainfall and runoff is an important management technique that can reduce the amount of pollutants in runoff and the need for stormwater treatment.**

Source Control practices and pollution prevention can include a wide variety of management techniques that address nonpoint sources of pollution. These practices are typically non-structural, need minimal or no land area, and involve moderate effort and cost to implement, when compared to structural treatment practices. Therefore, project planning and design should consider measures to minimize or prevent the release of pollutants so they are not available for mobilization by runoff.

Design variants include:

- 16-A **Nutrient Management**
- 16-B **Street Sweeping**

Urban Nutrient Management involves the reduction of fertilizer to grass lawns and other urban areas down to the minimum needed to sustain adequate vegetative cover. The implementation of urban Nutrient Management is based on public education and awareness, targeting suburban residences and businesses, with emphasis on reducing excessive fertilizer use. Although the availability of “Lo-P” or “No-P” fertilizer formulations have improved the situation, managing excess nutrient applications in urban settings will continue to be an important element in the overall goal to minimize impacts from urban stormwater runoff.

Street Sweeping and storm drain cleanout practices rank among the oldest practices used by communities for a variety of purposes to provide a clean and healthy environment, and more recently to comply with their National Pollutant Discharge Elimination System (NPDES) stormwater permits. The ability for these practices to achieve pollutant reductions is uncertain given current research findings. Nevertheless, the use of modern equipment under a well-managed program has been shown to yield measurable benefits and thus this practice should be considered for inclusion in any source control program.

16.1 **Source Controls Stormwater Credit Calculations**

Source controls receive no runoff reduction credits. The ability of these practices to reduce nutrients and particulates varies. Table 16.1(a) summarizes the stormwater performance credits for Nutrient Management. Table 16.1(b) summarizes the stormwater performance credits for street sweeping.

16.1(a) Nutrient Management Performance Credits

Runoff Reduction	
Retention Allowance	**0%**
RPv -A/B Soil	**0%**
RPv - C/D Soil	**0%**
Cv	**0%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**Not less than 17%**
TP Reduction	**Not less than 22%**
TSS Reduction	**Not less than 0%**

16.1(b) Street Sweeping Performance Credits

Runoff Reduction	
Retention Allowance	**0%**
RPv -A/B Soil	**0%**
RPv - C/D Soil	**0%**
Cv	**0%**
Fv	**0%**
Pollutant Reduction	
TN Reduction	**Not less than 3%**
TP Reduction	**Not less than 3%**
TSS Reduction	**Not less than 9%**

16.2 **Source Controls Design Summary**

Source Controls do not have traditional design criteria. Instead, these practices are usually implemented based on guidance documents, or in some cases, formal regulations. The "Urban Nutrient Management Handbook" published by the Virginia Cooperative Extension Service, included as Appendix 16-1 of this document, is an example of the former. The Delaware Nutrient Management Law (3 Del. C. Ch. 22) is an example of the latter.

The Delaware Nutrient Management Law requires any person who owns, leases, or otherwise controls 10 acres to which nutrients are applied to develop a nutrient management plan for those lands. Nutrient management plans must be updated every three years or when significant alterations to the nutrient application occurs. In addition the Law requires anyone who applies nutrients to lands or water in excess of 10 acres to have certification endorsed by the Delaware Nutrient Management Commission. **To receive nutrient management pollutant reduction performance credits, sites must fully comply with the requirements of the Delaware Nutrient Management Law through implementation of a nutrient management plan.**

The ability of Street Sweeping to measurably reduce pollutant loadings is highly dependent on its frequency. The pollutant reductions shown in Table 16.1(b) are based on the values used in the Phase 5.3 Chesapeake Bay Model. These values are based on the following assumptions (from personal correspondence, Ms. Olivia Devereux):

The assumption is that there is a nitrogen, phosphorus, and sediment reduction when the same section of a street is swept approximately every two weeks, or 25 times a year. When a street is swept periodically and less than every two weeks, the accumulated matter can be mobilized and moved into the stream system with any rainfall. Therefore, less regularly swept streets are given credit solely for the sediment removed.

There are three ways to track street sweeping:

1. Streets swept 25 times a year: track the acres that were swept this number of times, not the acres swept once times 25.
2. Streets swept 25 times a year: track as percent of land area. This is the percent of the land area that received this treatment 25 times a year.
3. Street sweeping lbs. Enter the lbs of sediment removed. The number entered is simply subtracted from the total sediment load. This requires weighing the sweeper before it goes out and when it returns to determine the lbs of material removed.

For option 1 and 2, there is a N, P, and SED reduction. The N and P reductions are 3% and the Sed reduction is 9%.

To receive street sweeping pollutant reduction performance credits, sites must submit to the Department or Delegated Agency a plan documenting the street sweeping frequency. Annual street sweeping tracking shall be submitted to the Department or Delegated Agency.

16.3 References

Goatley, Michael, Jr. and Kevin Hensler, "Urban Nutrient Management Handbook", Virginia Cooperative Extension Service. May 2011.

17.0 Afforestation

Definition: **Afforestation includes practices that mimic the hydrologic benefits of a natural forest utilizing a regeneration process within the landscape by selectively planting tree seedlings (less than 1" DBH) or saplings (greater than 1" DBH). Afforestation can be used as both a runoff reduction practice by converting non-forested areas to forested areas as well as a mitigation practice for offsetting the clearing of forested areas during the development process.**

These areas can be positioned in the landscape for capture of stormwater runoff, retention of sediment and nutrients as well as improving the microclimate, such as providing shade, and habitat complexity. This practice should be conducted on non-compacted soils that are suitable for planting. The minimum soil depth should be 4 feet, based upon soils mapping, to ensure adequate rooting of trees. As illustrated in Figure 17.1, full establishment of a mature forest can take decades. However, even a young forest provides hydrologic benefits which can be realized in a relatively short time.

Design variants include:

- 17-A. **Afforestation**
- 17-B. **Urban Tree Planting**

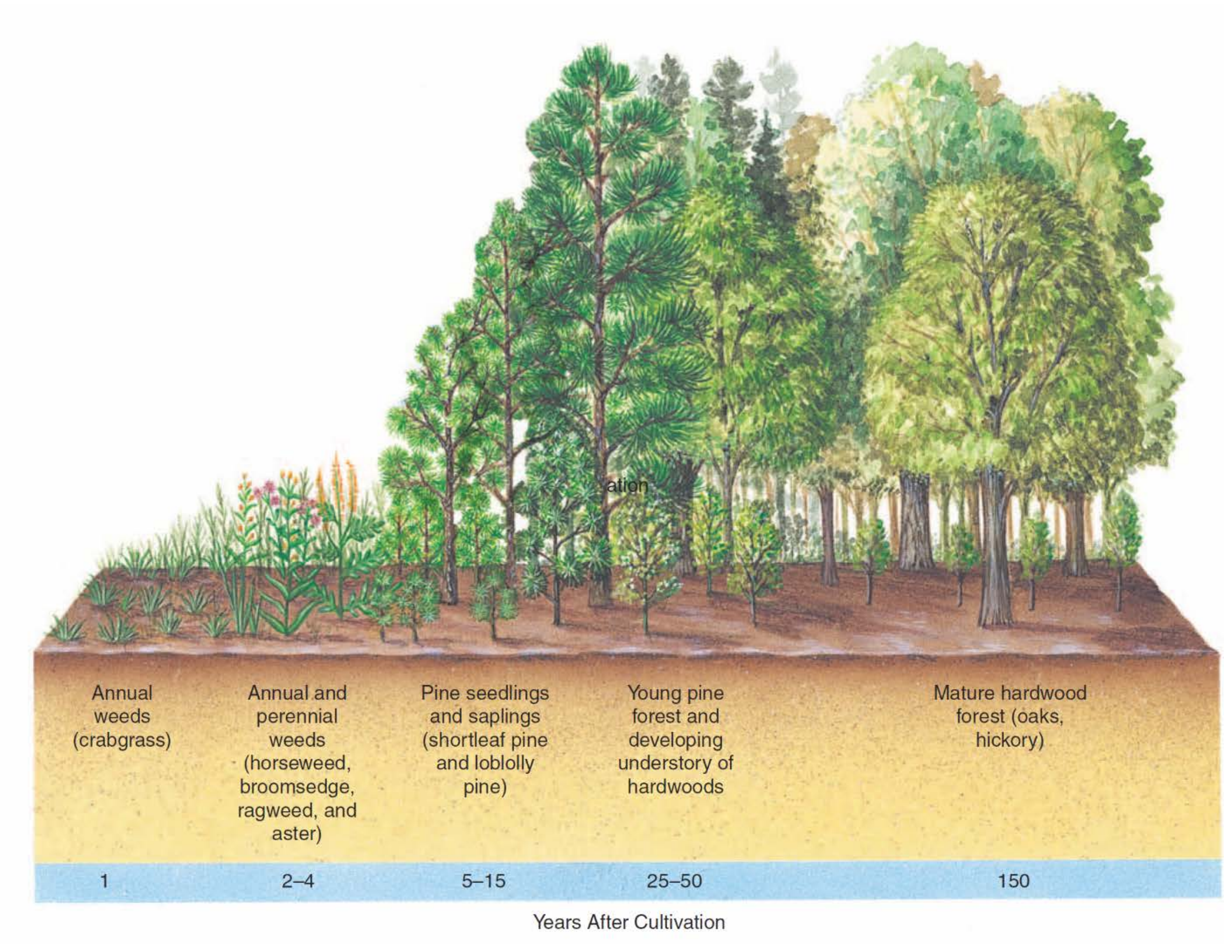

Figure 17.1 Secondary Succession Time Scale

17.1 Afforestation Credit Calculations

Table 17.1 summarizes the runoff reduction allowances for the RPv, Cv and Fv when afforestation is used as a runoff reduction practice. This credit is only given for afforestation and/or urban tree plantings that occur in common open space or conservation easements.

Table 17.1 Afforestation Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv	TBD on Case-by-Case Basis*
Cv	TBD on Case-by-Case Basis*
Fv	TBD on Case-by-Case Basis*
Pollutant Reduction	
TN Reduction	TBD on Case-by-Case Basis**
TP Reduction	TBD on Case-by-Case Basis**
TSS Reduction	TBD on Case-by-Case Basis**

***RPv credit based on runoff reduction from open space (good) condition to wooded (good) condition.**
**Pollutant reduction credit based on load reduction from RPv.

When afforestation is used on areas that would otherwise be stabilized as turf open space, runoff reduction credit is equivalent to the difference in runoff generated by woods in good hydrologic condition compared to grassed open space in good hydrologic condition. The actual reduction is, therefore, dependent on the current USDA NRCS web soil survey or onsite evaluation soil hydrologic soil group (HSG). The following equations can be used to determine the runoff reduction credit for a given area of afforestation on the appropriate HSG.

$$RR_{HSG\ A} = 0.114996*A*43560/12 \quad \text{(Eq. 17.1)}$$

$$RR_{HSG\ B} = 0.144648*A*43560/12 \quad \text{(Eq. 17.2)}$$

$$RR_{HSG\ C} = 0.142903*A*43560/12 \quad \text{(Eq. 17.3)}$$

$$RR_{HSG\ D} = 0.131697*A*43560/12 \quad \text{(Eq. 17.4)}$$

Where:
RR = runoff reduction credit (cf)
A = area (ac)

For areas planted in trees that do not meet the design criteria for afforestation, credit shall be an equivalent 1/200th of an acre per tree. The equations above under the Urban Tree Planting variant may be used for calculating the credit. These equations may also be used to determine equivalent credit for afforestation used as a mitigation practice.

Refer to *Specification 9. Sheet Flow to Filter Strip or Open Space* to determine the runoff reduction credit when runoff is directed as sheet flow into afforested areas that function as either filter strips or conserved open space.

17.2 Afforestation Practice Summary

Table 17.2 summarizes the various criteria for afforestation areas. For more detail, consult Sections 17.3 through 17.7. Sections 17.8 and 17.9 describe afforestation implementation and maintenance criteria.

Table 17.2 Afforestation Practice Summary

Feasibility Criteria (Section 17.3)	• Upland setting, depth to seasonal high water table should be greater than 12 inches • Minimum depth to bedrock should be 4 feet • During the first 10 to 15 years the vegetation will be thick with limited sight distance and this may be a safety concern.
Conveyance Criteria (Section 17.4)	• There are no specific conveyance criteria for this practice.
Pretreatment Criteria (Section 17.5)	• There are no specific pretreatment criteria for this practice.
Design Criteria (Section 17.6)	• **The minimum size of the afforestation area shall be 10,000 square feet with a minimum width of 50 feet.** • **The proposed afforestation area shall be upland.** • **At the end of the second year there shall be at least 200 live plants 6 inches or higher.**
Landscaping Criteria (Section 17.7)	• **The planting density shall account for mortality, which over time can result in more random arrangement of the trees.** • **The planting density shall account for mortality, which over time can result in more random arrangement of the trees.**
Construction Criteria (Section 17.8)	• **The sizes and types of plantings shall be in accordance with the planting schedule developed for the site.** • **Construction reviews are necessary for the success of any phase of a project, including: Pre-construction meeting; Planting Phase (with**

	designer and installation contractor); and Final Review (punch list of corrections for acceptance).
Maintenance Criteria (Section 17.9)	• **Following planting, a period of maintenance and monitoring will begin. The afforestation planting will be considered successful if the survival of trees at the end of the second year is at least 200 combined live, planted or volunteer trees per acre.** • **Final stabilization shall meet EPA requirements at the end of the second year.** • **Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system.**

17.3 Afforestation Feasibility Criteria

Soils. These planting areas should be located in uplands. Depth to bedrock should be 4 feet.

Community and Safety Concerns. During the first 10 to 15 years the planting will grow into a thick vegetated condition. In some cases, this may result in limited visibility or other safety concerns.

17.4 Afforestation Conveyance Criteria

There are no specific conveyance criteria for this practice.

17.5 Afforestation Pretreatment Criteria

There are no specific pretreatment criteria for this practice.

17.6 **Afforestation Design Criteria**

Afforestation plans should be prepared by a qualified professional, including foresters, landscape architects, certified arborists and horticulturists or other disciplines that possess the necessary knowledge, skills and training.

The minimum size of the afforestation area shall be 10,000 square feet with a minimum width of 50 feet. The long dimension of the area should be perpendicular to the slope where feasible.

The proposed afforestation area shall be upland. The minimum depth to bedrock should be 4 feet to provide adequate rooting depth for tree establishment. Provide minimal compaction in filled areas to prevent settlement.

The long-term establishment goal for the afforestation areas is at least 100 trees per acre, with at least 50 percent of those individuals having a diameter at breast height (DBH) of 2 inches at the end of seventh year. Planting of trees is meant to supplement the likely volunteer individuals, if the afforestation area is within 150 feet of mature, native seed trees. The recommended planting density should be at a minimum 400 plants with minimum 25% seedlings per acre. The remaining 75% should consist of tree seeds. In lieu of planting, the afforestation area may be delineated and protected from disturbance to allow natural regeneration to occur**. At the end of the second year there shall be at least 200 live plants 6 inches or higher.** This level of planting addresses both mortality and the potential for volunteers that can be counted toward the long term goal of 100 trees per acre, given that the onsite monitoring will be limited. Invasive and/or exotic species need to be controlled, especially if planting is to occur in an area already stabilized by vegetative cover. Additional information on identifying and controlling invasive species is contained in the National Park Service publication "*Plant Invaders of Mid-Atlantic Natural Areas*". Reference *Appendix 2 – Landscaping Guidelines* for additional afforestation planting and maintenance specifications.

Afforestation areas can be positioned on the landscape for minimizing erosion as well as improving the microclimate, such as providing shade, and habitat complexity. Afforestation areas should be reviewed and adjusted in relation to proposed site development plans, including avoidance of utilities. Afforestation adjacent to existing wooded areas or water bodies, including wetlands, can increase habitat and water quality. These plantings can also serve as visual screens and buffers to absorb air borne pollutants.

17.7 **Afforestation Landscaping Criteria**

Delaware is divided into two major physiographic regions. The Piedmont Region is located above the fall line in New Castle County, while the rest of the state falls in the Coastal Plain Region. Tree selection should be based on species best adapted to these regions. The following is a list of recommended native tree species for different physiographic regions in Delaware:

Piedmont

1. Sugar maple: *Acer saccharum*
2. Tulip tree: *Liriodendron tulipifera*
3. Hophornbeam: *Ostrya virginiana*
4. Sourwood: *Oxydendron arboreum*
5. Swamp white oak: *Quercus bicolor*
6. Shingle oak: *Quercus imbricaria*
7. Chestnut oak: *Quercus prinus*
8. American linden: *Tilia americana*

Coastal Plain

1. Shadblow: *Amelanchier Canadensis*
2. Green hawthorn: *Crataegus viridis*
3. Loblolly pine: *Pinus taeda*

Piedmont or Coastal Plain

1. Red maple: *Acer rubrum*
2. Downy serviceberry: *Amelanchier arborea*
3. Apple serviceberry: *Amelanchier grandflora*
4. Allegheny serviceberry: *Amelanchier laevis*
5. Common pawpaw: *Asimina triloba*
6. River birch: *Betula nigra*
7. Ironwood: *Carpinus caroliniana*
8. Eastern redbud: *Cercis canadensis*
9. Hackberry: *Celitis occidentalis*
10. White fringetree: *Chionanthus virginicus*
11. Pagoda dogwood: *Cornus alternifolia*
12. Eastern flowering dogwood: *Cornus florida*
13. Persimmon: *Diospyros virginiana*
14. American beech: *Fagus grandfolia*
15. White ash: *Fraxinus americana*
16. Green ash: *Fraxinus pennsylvanica*
17. American holly: *Ilex opaca*
18. Eastern red cedar: *Juniperus virginiana*
19. American sweetgum: *Liquidambar styraciflua*
20. Sweetbay magnolia: *Magnolia virginiana*
21. Black tupelo: *Nyssa sylvatic*a
22. Virginia pine: *Pinus vriginiana*
23. American sycamore: *Platanus occidentalis*
24. London plane: *Plantanus x acerifolia*
25. White oak: *Quercus alba*
26. Scarlet oak: *Quercus coccinia*
27. Bur oak: *Quercus macrocarpa*
28. Willow oak: *Quercus phellos*
29. Red oak: *Quercus rubra*
30. Shumard oak: *Quercus shumardii*
31. Common sassafras: *Sassafras albidum*
32. Bald cypress: *Taxodium distichum*

The afforestation plan should include a minimum of five (5) different species selected from the appropriate list above. Suitable substitutions are permitted depending upon availability at the time of planting. Planted species should supplement potential volunteer species from nearby seed trees. Refer to *Appendix 2 – Landscaping Guidelines* for additional plant selection guidance.

Minimize soil disturbance in planting areas whenever possible to increase the chance of success and minimize the need for soil amendments and invasive species control. A combination of nursery material and natural regeneration can be used to provide a greater diversity of species. Plants need to be selected based on site drainage conditions. Seedling planting is quicker and may be less expensive than larger stock. **The planting density shall account for mortality, which over time can result in more random arrangement of the trees.** Plantings that include larger tree stock can result in quicker habitat diversity. Perennial ground cover should be included to minimize sediment transfer by rapidly establishing vegetative cover. **Final stabilization shall meet EPA requirements at the end of the second year.**

17.8 **Afforestation Construction Sequence**

Step #1
A soil test should be conducted for the proposed afforestation area if it has been substantially disturbed or subjected to stripping and filling. Soil amendments are not typically required with this practice unless the soil test indicates low fertility. If the soil test indicates low organic matter content, the designer may consider the addition of compost materials (see *Specification 14. Soil Amendments*). Incorporation of organic material prior to planting will help to ensure the success of the planting by improving the moisture and nutrient holding capacity of the soil.

Step #2
If the area does not have established vegetation prior to planting, the afforestation area should be seeded in accordance with the *Permanent Vegetative Stabilization Specifications* from the *Delaware ESC Handbook.* For sites with existing cover, the afforestation area should be treated with herbicides to control invasive plant cover (if present) prior to mowing for reduction of herbaceous vegetation competition in the fall prior to spring planting.

Step #3
Afforestation planting should occur at the earliest date that will enable project close out to occur as scheduled. **The sizes and types of plantings shall be in accordance with the planting schedule developed for the site.** Installation should be random throughout the planting areas.

Construction reviews are necessary for the success of any phase of a project, including:

- **Pre-construction meeting;**
- **Planting Phase (with designer and installation contractor); and**

- **Final Review (punch list of corrections for acceptance).**

17.9 Afforestation Maintenance Criteria

Following planting, a period of maintenance and monitoring will begin. The afforestation planting will be considered successful if the survival of trees at the end of the second year is at least 200 combined live, planted or volunteer trees per acre. Final stabilization shall meet EPA requirements at the end of the second year.

Before project completion the Owner shall submit a final post construction stormwater management Operation and Maintenance Plan for the entire stormwater management system. Operation and Maintenance Plans remain valid for the life of the stormwater management system. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Maintenance of afforestation areas is driven by annual maintenance reviews that evaluate the condition of the vegetation. Operation and Maintenance Plans should clearly outline how vegetation in the afforestation area will be managed. Invasive plant control actions early in the establishment of the afforestation area are critical to successful establishment of a sustainable forest stand. Based on maintenance review results, specific maintenance tasks may be required. Additional reviews are recommended during the first two years of establishment.

First Two Years:
The proposed planting should be done so as to avoid immediate needs for watering after initial watering at the time of planting. Weed and invasive plant control should be conducted prior to planting to control competing vegetation. Following initial planting, the need for seasonal mowing to control competing vegetation and watering should be assessed. Mowing should occur once during the first year and twice during the second year. The need for watering should be assessed on a monthly basis (more frequently during drought conditions) during the growing season.

In addition, the environmental or forestry consultant should assess the survival rate of installed stock between the period of September 1 and September 30, to determine the need for reinforcement planting the following spring. The owner and their qualified professional should evaluate planting site survival with respect to species and losses from disease, pests or predators. An adaptive management approach should be used when evaluating sites with excessive mortality to ensure afforestation success criteria are met including installation of new species in consultation with the Department or the Delegated Agency and/or use of tree shelters. The inspection should consider the success, progress or failure of the afforestation planting including all necessary remediation measures undertaken. If necessary, reinforcement planting should be conducted after the first year if the survival rate falls below 65 percent based on the planting density.

Annual, On-going Maintenance:
Managing vegetation is an important ongoing maintenance task. Reference the afforestation plan for additional requirements. Occasional mowing, as described above, may be needed early on to minimize competition and aid in the establishment of the trees. Invasive plant control will be an on-going activity.

Table 17.3. Afforestation Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, Year 1	• Conduct weed and invasive plant control prior to planting • Mow once during first year; twice second year • Assess monthly for watering need during growing season • Assess survivability during September 1 – September 30 • Perform reinforcement planting the following Spring if survival rate falls below 65%
Year 2	• Mow twice to control weeds and competing undergrowth • Assess to determine if target 200 live trees per acre 6” or higher has been achieved • Perform reinforcement planting the following Spring if target has not been met
Annually, after Year 2	• Mow as needed to control weeds and competing undergrowth • Control invasive plants using appropriate methods
Year 7	• Assess to determine if target 100 trees per acre with 50% having 2” DBH has been achieved • If target has not been met, use adaptive management techniques to maximize survivability of existing trees and add reinforcement plantings as needed
Year 15	• Assess to determine if target 100 trees per acre with 2” DBH has been achieved • If target has not been met, re-evaluate afforestation plan and adjust as needed

17.10 References

Delaware Code, Title 3, Ch. 10, Subchapter V, Delaware Seed Tree Law.

Delaware Department of Agriculture, Forest Service, Forestry Best Management Practices to Protect Delaware's Water Quality, October 2006.

Delaware Department of Transportation, Roadside Vegetation Concept and Planning Manual, Enhancing Delaware Highways, April 2005.

Maryland Department of Natural Resources, State Forest Conservation Technical Manual, 3rd Edition, 1997.

National Park Service, Plant Invaders of Mid-Atlantic Natural Areas, 4th Edition, 2010.

Thomson, Fiona J., et al. (2011) Seed dispersal distance is more strongly correlated with plant height than with seed mass. *Journal of Ecology*, 99, 1299-1307.

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Appendix 1. **Soil Investigation Procedures for Stormwater Best Management Practices**

This standard provides procedures, guidelines, and requirements for soil investigations performed for stormwater management BMPs being considered for development sites. **All applicable federal, state and local laws, rules, regulations or permit requirements governing soil investigations shall be followed.** This standard does not contain the text of federal, state or local laws. Additional site location requirements may be imposed by other stormwater BMP technical standards.

This standard and specification includes the following:

I. General Soil Investigations to characterize on-site soils and groundwater conditions
II. Infiltration Testing Procedures of areas selected for infiltrating stormwater BMPs within a development site
III. Soil Investigation of on-site soils to meet the structural needs of stormwater embankments, and
IV. Preparation of the Soil Investigation and Infiltration Testing Report.

I. General Soil Investigations

Borings and pits shall be excavated to verify soil profile and to determine depth to limiting layer. Soil borings are acceptable for general soil characterization. Pits are the preferred method for soil characterization for infiltrating BMPs.

A. Soil Characterization

1. **The minimum number of borings or pits shall be conducted for each BMP as follows:**
   a. **For surface area BMPs, two (2) borings or pits required for the first 8,000 square feet, three (3) borings or pits required for up to 16,000 square feet, four (4) borings or pits required for up to 25,000 square feet and one additional boring or pit required for each additional 25,000 square feet. Boring or pit locations shall be distributed within the facility and sufficient to determine variability.**
   b. **For linear BMPs, two (2) borings or pits required up to 500 linear feet and one (1) additional boring or pit per 500 linear feet of trench, and sufficient to determine variability.**
2. **Borings or test pits must be advanced to the depth of the limiting layer or a minimum of 3 feet below bottom of a proposed facility, whichever is encountered first.** If a limiting layer of low permeability soil is encountered, but more permeable soil lies beneath, the more permeable soil at a lower elevation may be investigated for infiltration tests to be conducted at the lower elevation to determine design infiltration rates. The appropriate depth for conducting the infiltration test is at the discretion of the soil professional.

B. Groundwater and Seasonal High Groundwater

1. Seasonal high groundwater is defined as the shallowest depth at which saturation associated with the regional water table occurs for a duration of 21-days during a period of normal precipitation. Historically in Delaware the peak of the water table in the unconfined aquifer occurs during December 1 to May 15, based on well data available from the Delaware Geologic Survey. Evidence of seasonal high groundwater includes redoxomorphic features and direct observation of saturation.
2. Analysis of groundwater mounding potential may be considered on a case by case basis where practices without an underdrain are proposed within two (2) feet of seasonal high groundwater. The altered groundwater level, based on mounding calculations, must be considered in determining the vertical separation distance from the infiltration surface to the highest anticipated groundwater elevation, which is the sum of the calculated mounding effects of the discharge and the seasonal high groundwater level. An analysis of groundwater mounding potential is required for certain classes of infiltration practices, as indicated in Table 1. References include but are not limited to Finnemore 1993 and 1995, and Hantush 1967.
3. Regional historic groundwater elevation data may be supplemented on a case by case basis through the installation of piezometers and the collection of groundwater level data during the wet season (December 1 to May 15) where practices without an underdrain are proposed within two (2) feet of seasonal high groundwater. The depth to the seasonal high groundwater will be determined based on the average of all readings taken within a 21 day consecutive day period during the wet season. It is the responsibility of the delegated agency to evaluate if precipitation levels occurring during the monitoring period are sufficient for accepting the data. If, in the estimation of the delegated agency insufficient precipitation was received, monitoring may be extended an additional wet season. Data collected should be correlated to historical groundwater level data from the nearest Delaware Geological Survey (DGS) monitoring well.

II. Infiltration Testing Procedures

A. Planning and Design Phase

Included herein are procedures to be followed when performing soil infiltration testing required under Article 3.06.2 Post Construction Stormwater BMP Standards & Specifications. In order to minimize inconsistencies in the collection and interpretation of field data, the following procedure has been developed. This document should be taken as the minimum requirements for soils investigation for stormwater infiltration BMPs. The soil professional should rely on his or her experience to develop a site investigation plan based on site and design specific requirements. **Any deviation from these procedures must be approved by DNREC or the delegated stormwater agency having jurisdiction.**

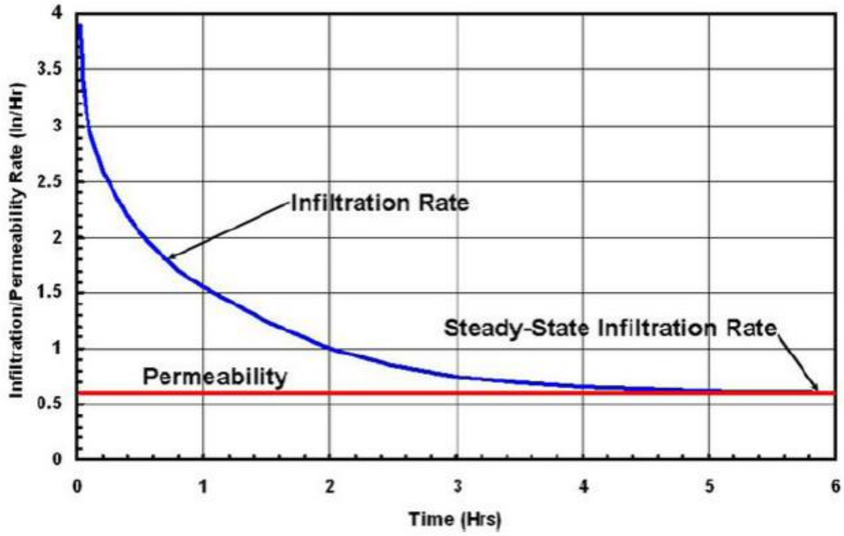
1. **Individuals in responsible charge of infiltration testing shall possess a Class D On-Site License issued by DNREC or be licensed in the State of Delaware as a Professional Engineer or Professional Geologist.**
2. **An initial screening of readily available data is required to determine feasibility of infiltration practices. Screening shall include at a minimum:**
   a. **Site topography**
   b. **Soil characteristics as defined in the USDA NRCS Web Soil Survey**
   c. **Depth to groundwater and seasonal high water table**
   d. **Historical groundwater level data from the nearest Delaware Geological Survey (DGS) monitoring well or wells.**
   e. The collection of on-site soil data is recommended, particularly for larger projects.
3. **Separation to a limiting layer such as bedrock or groundwater shall be at least two (2) feet.**
4. **Field Permeability Testing shall be done in accordance with ASTM-D5126 "Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone".**
   a. **Single Ring or Double Ring Infiltrometer are preferred test methods**. Ring sizes smaller than those specified in ASTM-D5126 are considered to be equivalent to the Cased Borehole Permeameter for the purposes of this specification, including the factor of safety of 2.5 for determining the design infiltration rate.
   b. **Cased Borehole Permeameter method is allowable only in cases where test pit excavation depths or site constraints pose safety or other concerns. Results from tests conducted using the Cased Borehole Permeameter method will only be accepted when approval is granted by the Department or Delegated Agency to use the Cased Borehole Permeameter method prior to conducting the test. Casing for Cased Borehole test shall have a minimum 4 inch diameter.**
5. **The minimum number of field measured infiltration tests are based on the proposed facility's dimensions as follows:**
   a. **For an infiltration trench with less than 10,000 square feet of impervious drainage area, one (1) test required up to 500 linear feet and one (1) additional test per 250 linear feet of trench, and sufficient to determine variability.**
   b. **For an infiltration trench with greater than 10,000 square feet of impervious drainage area, one (1) test required up to 250 linear feet and one (1) additional test per 250 linear feet of system, and sufficient to determine variability.**
   c. **For an infiltration trench used with roadway perforated pipe layouts, one (1) test required up to 500 linear feet and one (1) additional test per 500 linear feet of trench, and sufficient to determine variability.**
   d. **For an infiltrating bioretention system, one (1) test required for the first 8,000 square feet, two (2) tests required for up to 16,000 square feet, three (3) tests required for up to 25,000 square feet and one additional test required for each additional 25,000 square feet. Test locations shall be distributed within the facility and sufficient to determine variability.**
   e. **For a surface infiltration basin, one (1) test required for the first 8,000 square feet, two (2) tests required for up to 16,000 square feet, three (3) tests required for up to 25,000 square feet and one additional test required for each additional 25,000**

square feet. Test locations shall be distributed within the facility and sufficient to determine variability.

f. **For a subsurface infiltrating practice, one (1) test required per infiltration area with an additional test for every 8,000 square feet of infiltration area, and sufficient to determine variability.**

6. **A saturation period of 1 hour or a drop of 12 inches or 30.5 cm is required. The saturation period shall not be used in determining field verified infiltration rate.** However, the saturation period should be included in the test log for reporting purposes.
7. **After the saturation period, a minimum of two (2) test periods are required or until at least two (2) consecutive test periods are consistent.** The general intent for the test period is to take four (4) readings at 15 minute intervals for a total of one (1) hour. However, it is recognized that soils with very high or very low permeability may not lend themselves to this ideal testing procedure. Three (3) different criteria have been established to account for this variability, though the original intent should be followed whenever possible. The report should include a discussion on the basis used to determine consistency between the test periods. **Each test period shall have a maximum reading interval of 15 minutes and meet one (1) of the following criteria:**
   a. **A minimum of one hour (**as determined by the sum of the interval times)**,**
   b. **A drop of at least 12 inches in 15 minutes or less for a minimum of 30 minutes (**as determined by the sum of the interval times)**, or**
   c. **A stabilized infiltration rate as defined below** (based on 15 minute interval times)**.**
      i. **A difference of 0.25 inches or less of drop between the highest and lowest reading of four (4) consecutive readings for infiltration rates greater than 2 inches per hour.**
      ii. **A difference of 0.125 inches or less of drop between the highest and lowest reading of four (4) consecutive readings for infiltration rates equal to or less than 2 inches per hour.**
8. **When using constant head test method, the water level inside the casing shall be maintained at a constant level or refilled to the starting level after each reading throughout the test period at no more than 15 minute intervals.** Refilling to the starting level after each reading is sometimes referred to as the "quasi-constant head" method.
9. **When using falling head test method each test period shall start with the same initial head of 6 inches to normalize the effect of head on the measured drop.** After the initial 6 inch drop, the casing is then refilled to start the test. The time for the initial 6 inch drop should be included in the log, but not used for calculating the infiltration rate for the test period. Refilling is done at the conclusion of a test period.
10. **The field verified infiltration rate shall be the final steady state reading of the test performed.** The steady state condition is determined by the intersection of a horizontal line with the lowest point of the infiltration rate graph included in the Soil Investigation Report.

An example of the infiltration rate graph follows:



11. **Reporting requirements shall be in accordance with Soil Investigation Report.**

B. **Construction Phase**

For all infiltration facilities, confirmatory field verified infiltration testing shall be performed during facility construction. Unless recommended by a soil professional and approved by the Department or Delegated Agency prior to conducting the tests, the minimum number of confirmatory infiltration tests shall be in accordance with the original testing procedures used for design.

The confirmatory infiltration testing rate shall be no less than 150% of the approved design rate (e.g, if the design rate is 2.0 inches per hour the confirmatory infiltration rate shall be no less than 3.0 inches per hour) **for the facility. If a deviation of less than 150% is observed, the design calculation for the facility shall be re-run by the design engineer to demonstrate that the facility will function as originally designed. The computations that confirm performance shall be provided with the Post Construction Verification Documents.**

In addition to confirmatory infiltration testing, a hand auger shall be performed adjacent to the confirmatory infiltration test location or at locations recommended by the soils professional to a minimum depth of 3 feet below the bottom of the facility to confirm that a limiting layer is not present and to log the soils conditions. If a limiting layer is observed at a depth less than 2 feet, the licensed professional shall re-evaluate the design and submit recommendations and any required design changes to the Department or Delegated Agency for review and approval.

If confirmatory infiltration testing is not required by the Department or Delegated Agency, hand augers shall be performed within the proposed practice to log the soils and

groundwater conditions within 3 feet of the bottom of the practice.

III. Soil Investigation for Embankments

A. Introduction

The primary geotechnical issues that impact stormwater embankment performance are:

- Overall stability;
- Internal stability;
- Seepage;
- Settlement;
- Subsurface materials and materials available for construction; and
- Construction.

A detailed review of the existing site conditions and proposed embankment construction shall be performed by the responsible geotechnical engineer as part of the design process. The responsible professional geotechnical engineer should consider the proposed embankment footprint and an area at least two times the width of the embankment on either side of the embankment and any existing or proposed slopes adjacent to the proposed embankment when establishing a field evaluation program.

B. Site Investigation

The goal of the site characterization for embankment design and construction is to develop the subsurface profile and soil property information needed for stability, settlement analyses, and embankment design. **The soil investigation for the embankment plan shall include the following:**

- **Development of performance criteria, which may include but not be limited to allowable settlement, time available for construction, and seismic design requirements.**
- **Identification of potential geologic hazards or areas of concern such as soft soils, and potential variability of local geology.**
- **Identification of engineering analyses to be performed which may include but not be limited to: limit equilibrium slope stability analyses, liquefaction susceptibility, lateral spreading and slope stability deformations, and settlement evaluations.**
- **Identification of engineering properties required for these analyses.**
- **Determination of methods to obtain parameters and assess the validity of such methods for the material type.**
- **Determination of the number of tests or samples needed and appropriate locations for them.**

C. **Methods of Subsurface Exploration**

There are several methods available for subsurface exploration. **The subsurface exploration method shall be selected by the design professional based on the existing and proposed site conditions.** The following are recommended methods for subsurface exploration:

- Excavated test pits;
- Hand augers; and
- Test borings.

Depending on the height and footprint of the embankment, other subsurface exploration methods could be utilized, such as:

- Dynamic Cone Penetrometer;
- Cone Penetrometer.

Minimum Number of Explorations

- **Embankments shall have explorations every 200 feet on center along the length of the embankment.**
- **Pond bottom explorations shall follow the Soil Investigation Procedures. Exploration locations shall be distributed as uniformly as possible within the facility.**

Minimum Depth of Explorations

- **Unless bedrock is encountered at a shallower depth, explorations shall be at a depth twice the proposed height from bottom of pond to top of embankment.**
- **If bedrock is encountered, a minimum 5 foot rock core shall be performed. If organic, plastic, or soils with an actual or estimated N-value less than 4 are encountered, extended exploration to a depth 4 times the proposed embankment height.**

The frequency and spacing of the explorations indicated above are the minimum requirements. Professional engineering judgment shall be applied to address anticipated or potential variation in subsurface conditions and the type of facility to be designed.

Reporting requirements shall be in accordance with Soil Investigation Report.

If there is a potential for a significant groundwater gradient beneath an embankment or surface water levels are significantly higher on one side of the embankment than the other,

the effect of reduced soil strength caused by water seepage shall be evaluated. In this case, installation of piezometers should be considered to estimate the gradient.

Seepage effects shall be considered when an embankment is placed on or near the top of a slope that has known or potential seepage through it. Depending on the hazard class, a flow net or a computer model may be used to estimate seepage velocity and forces in the soil. This information may then be used into the stability analysis to model pore pressures.

IV. **Soil Investigation Report**

A. Introduction

In general, geotechnical reports are based on the following:

- An office review of existing geotechnical data for the site;
- A detailed geologic review of the site; and
- A complete subsurface exploration.

B. Minimum General Geotechnical Report Requirements

The following section describes the minimum requirement for all geotechnical reports. Additional requirements for embankments and infiltration reporting are included in subsequent sections.

The detail contained in each of these sections will depend on the size and complexity of the project or project elements and subsurface conditions. In some cases, design memoranda that do not contain all of the elements described above may be developed prior to developing a final geotechnical report for the project. **Soil investigation reports shall include the following:**

1. **The signature, seal and date of a professional engineer or professional geologist experienced in soils licensed in the State of Delaware. Reports for embankments must be signed, sealed, and dated by a professional engineer licensed in the State of Delaware.**
2. **A general description of the project, project elements, and project background.**
3. **Project site surface conditions and current use.**
4. **Regional and site geology.**
5. If available, a summary of the site data available from project or site records (e.g., final construction records for previous construction activity at the site, as-built or other structure layouts, existing subsurface exploration logs, geologic maps, previous or current geologic reconnaissance results, etc.).
6. A summary of the field exploration conducted, if applicable. A description of the methods and standards should be provided, as well as a summary of the number and types of explorations that were conducted. If applicable, include a description of any field instrumentation installed and its purpose. Refer to the detailed logs located in the report appendices.
7. **Borehole or test pit logs must provide the following information:**
    a. **Project name**

b. **Name of individual collecting the field data**
c. **Date field data was collected**
d. **Type of boring or test pit excavation method and equipment used**
e. **Air temperature and precipitation, including significant precipitation prior to investigation**
f. **Elevation of boring location based on site benchmark**
g. **Visual description of soil profile layers, and depths below grade encountered**
h. **Sample numbers**
i. **Depths of instability such as cave in, sloughing, flowing sands, or obstructions**
j. **Blow counts if Standard Penetration Test (SPT) borings are being performed**
k. **Depth of seasonal high water table indicators such as mottling**
l. **Depth of encountered free water during and after excavation**
m. **Depth to bedrock if encountered**
n. **General observations**
o. **Testing standards**

8. **Depth and type of field testing performed. A summary of the laboratory testing conducted, if applicable.** A description of the methods and standards used should be provided, as well as a summary of the number and types of tests that were conducted. Refer to the detailed laboratory test results in the report appendices.
9. **Project soil/rock conditions shall include a description of the soil/rock units encountered, and how the units tie into the site geology.**
10. **Groundwater conditions shall be described, including the identification of any confined aquifers, artesian pressures, perched water tables, potential seasonal variations, if known, any influences on the ground water levels observed, and direction and gradient of groundwater, if known.**
11. **If rock slopes are present, discuss rock structure, including but not limited to the results of any field structure mapping using photographs as needed, joint condition, rock strength, and potential for seepage.**

NOTE: Use of subsurface profiles (i.e., cut parallel to centerline) and cross-sections (i.e., cut perpendicular to centerline) of the key project features are recommended but not necessary for all reports. A subsurface profile or cross-section is defined as an illustration that assists the reader of the geotechnical report to visualize the spatial distribution of the soil and rock units encountered in the borings and probes for a given project feature (e.g., structure, cut, fill, landslide, etc.). As such, the profile or cross-section will contain the existing and proposed ground line, the structure profile or cross-section if one is present, the boring logs (including SPT values, soil/rock units, etc.), and the location of any water table(s). Interpretive information contained in these illustrations should be kept to a minimum. What appears to be the same soil or rock unit in adjacent borings should not be connected together with stratification lines unless that stratification is reasonably certain. The potential for variability in the stratification must be conveyed in the report, if a detailed stratification is provided. In general, geologic interpretations should not be included in the profile or cross-section, but should be discussed more generally in the report.

12. **Summary of geological hazards identified and their impact on the project design, if any.** Examples include presence of the Cockeysville Formation, highly acidic soils and Water Resource Protection Areas (WRPAs). **Describe the location and extent of the geologic hazard.** Other geologic conditions such as contaminated soils, landfills, Resource Conservation and Recovery Act (RCRA) sites and groundwater management zones should also be included in the report.
13. **For analysis of unstable slopes including existing settlement areas, cuts, and fills, include background regarding the analysis approach, assessment of failure mechanisms, and determination of design parameters. A description of any back-analyses conducted, the results of those analyses, comparison of those results to any laboratory test data obtained, and the conclusions made regarding the parameters that shall be used for final design shall be included in this section.**
14. **Geotechnical recommendations for structural earthwork** (fill design, cut design, etc.) **shall include:**
    a. **Embankment design recommendations, if any are present, such as the slope required for stability, the need and extent of removal of any unsuitable materials beneath the proposed fills, any other measures that need to be taken to provide a stable embankment** (e.g., geosynthetic reinforcement, wick drains, controlled rate of embankment construction, lightweight materials, etc.)**, embankment settlement magnitude and rate.**
    b. **Cut design recommendations, if any are present, such as the slope required for stability, seepage and piping control, erosion control measures needed, and any special measures required to provide a stable slope.**
    c. **Determination of adequacy of excavated material for use as structural fill or spoil and include data for structural designs of BMP outlet works** (e.g., bearing capacity and buoyancy)**.**
15. **Long-term or construction monitoring needs if applicable. Provide recommendations on the types of instrumentation needed to evaluate long-term performance or to control construction, the reading schedule required, how the data should be used to control construction or to evaluate long-term performance, and the zone of influence for each instrument.**
16. **Address issues of construction staging, shoring needs and potential installation difficulties, temporary slopes, potential foundation installation problems, earthwork constructability issues, and dewatering as applicable.**
17. **Appendices to support geotechnical recommendations.** Typical appendices include design detail figures, layouts showing boring locations relative to the project features and stationing, subsurface profiles and typical cross-sections that illustrate subsurface stratigraphy at key locations, all boring logs used for the project design (includes older borings as well as new borings), including a boring log legend for each type of log, laboratory test data obtained, instrumentation measurement results, and special provisions needed.

C. Infiltration Testing Report Requirements

Infiltration reports describe the subsurface conditions along within the proposed facility footprint and provide the results of the in-situ infiltration and permeability testing to estimate the steady state seepage of the materials within three feet of the design invert elevation of a given facility.

The following section includes the minimum geotechnical report requirements for infiltration testing. These requirements are in addition to the general geotechnical reporting requirements listed above. **Infiltration test reports shall include the following:**

1. **Description of approved infiltration testing method performed** (i.e., single ring, double ring, etc.).
2. **Summary table of location of test, depth of test, elevation of test if available and field verified infiltration rate.**
3. **Infiltration test log must state:**
    a. **Name of individual performing test**
    b. **Date test was performed**
    c. **Type of test method** (single/double ring or borehole and whether constant or falling head)
    d. **Air temperature and precipitation**
    e. **Depth of test below ground surface and elevation**
    f. **Diameters of boring and casing**
    g. **Depth of casing penetration**
    h. **Time and depth from reference point for each time increment**
4. **Infiltration rate graph for each test. The graphs shall be field verified infiltration rate vs. elapsed time of test. Appended to each graph shall be a table of the testing results.**
5. **Geotechnical recommendations shall be provided for each stormwater management facility, including design infiltration rate, impact of infiltration on adjacent facilities, effect of infiltration on slope stability, if the facility is located on a slope, stability of slopes within the facility, and foundation bearing resistance.**
    a. **A minimum factor of safety of 2.0 shall be applied to field results from Single Ring and Double Ring Infiltrometer testing.**
    b. **A minimum factor of safety of 2.5 shall be applied to field results from Cased Borehole Permeameter testing.**
    c. **The report shall provide an elevation range over which the recommended design rates are applicable.**
    d. **The maximum design infiltration rate shall be less than or equal to 15 inches per hour.**
6. **If steady state conditions for a given test are not achieved, the professional in responsible charge of infiltration testing shall provide an explanation as to why steady state could not be achieved and their professional opinion regarding the use of the results for design purposes. If steady state is not achieved for a given test and a reasonable professional opinion is not provided, the Department or Delegated Agency may require additional testing.**

D. Embankment Report Requirements

Embankment reports describe the subsurface conditions along the proposed embankment alignment and provide the results of the geotechnical analyses performed to predict the consequence of the embankments construction.

The following section includes the minimum geotechnical report requirements for embankments. These requirements are in addition to the general geotechnical reporting requirements listed above. **Geotechnical reports for embankments shall include the following:**

1. **Summary of design analyses, which provide the project description and basis of the design recommendations.**
2. **Summary of stability analysis, which provides the results of the stability analyses performed for the given embankment dimensions.**
3. **Summary of settlement analyses, including design assumptions and settlement results for above-grade embankments.**
4. **Design recommendations, for embankment construction shall identify the following actions:**
    - **Construction procedures for placement of material in embankment widening areas;**
    - **Embankment cut-off and core trench materials for above-grade embankments;**
    - **Special Notes for excavation of unsuitable material, with specific backfill requirements.**
    - **Specific measures required prior to placing embankment material.**
    - **Installation of appropriate erosion control and vegetative cover.**

References

Finnemore, E. J., 1993. Estimation of Ground-Water Mounding Beneath Septic Drain Fields. Groundwater, Vol. 31 No. 6, pp. 884-889.

Finnemore, E.J., 1995. A program to calculate Ground -Water Mound Heights. Groundwater, Vol. 33, No. 1.

Hantush, M. S., 1967. Growth and Decay of Groundwater-Mounds in Response to Uniform Percolation. Water Resources Research, Vol. 3, No. 1, pp. 227-234.

Appendix A-2. Stormwater BMP Landscaping Guidelines

Landscaping is critical to the performance and function of many stormwater management facilities. Therefore, a landscaping plan shall be provided for any practice that relies on vegetation as a key component.

Minimum plan elements should include the proposed template to be used, delineation of planting areas, the planting plan, including the size, the list of planting stock, sources of plant species, and the planting sequence, including post-nursery care and initial maintenance requirements. It is highly recommended that the planting plan be prepared by a landscape architect, wetland scientist, or horticulturalist in order to tailor the planting plan to the site-specific conditions; however, the plan must be overseen and signed by a qualified, licensed professional registered in the State of Delaware.

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive, and do not exceed 25% of the total landscaping plan. Under no circumstances can aggressive, invasive species be utilized. Native species suitable for stormwater management BMP's are listed below. **Table 1** provides native herbaceous plants, and **Table 2** lists native trees and shrubs. Additional information on Delaware native plants can be found at the following internet links:

- US Department of Agriculture: http://plants.usda.gov
- University of Delaware College of Agriculture and Natural Resources Cooperative Extension Native Plants: http://ag.udel.edu/extension/horticulture/pdf/NativePlants.pdf
- University of Delaware Water Resources Agency Flora of Delaware Online Database: http://www.wra.udel.edu/de-flora
- Delaware Native Plant Society: http://www.delawarenativeplants.org
- Delaware Nature Society Native Plants Resource Links: http://www.delawarenaturesociety.org/links.html#np

BMPs requiring a Landscape Plan:

Bioretention Facilities
The degree of landscape maintenance that can be provided will determine some of the planting choices for urban bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. Typically the bioretention areas are covered with hardwood mulch and planted with a mixture of shrubs, herbaceous flowering plants, ferns, and other perennial species.

Constructed Wetlands
The landscape plan for a constructed wetland should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get

plants started. The plan should outline a detailed schedule for the care, maintenance and possible reinforcement of vegetation in the wetland and its buffer, particularly for the first 10 years of establishment.

Other Stormwater BMPs
Additional stormwater facilities besides bioretention and constructed wetland can and should be vegetated; these include wet ponds, vegetated filter strips and vegetated roofs. The landscape plan for each shall select appropriate plants, planting requirements, and maintenance requirements. Wet ponds, vegetated filter strips and other BMPs can use the recommended native plants listed in the tables below. Vegetated roofs, particularly extensive roofs, require a more drought and wind resistant plant, and shall refer to the specific landscaping requirements mentioned in the Vegetated Roof specification.

Planting Requirements:

1. The Plan view(s) of the Landscape Plan must have topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration. The different planting zones (e.g., high marsh, deep pool, upland floodplain), must be noted with the plant species to be planted.
2. The Landscape Plan shall include a plant schedule corresponding to the planting plan, specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing.
3. The Landscape Plan shall include notes and details regarding the site preparation, soil amendments, construction sequence, soil stabilization, planting specifications, and maintenance criteria.
4. The maintenance criteria must indicate how and when to remove and replace dead plants, eradicate invasive species, and restabilize eroded areas.
5. The planting plan should specify native plant species over non-native plant species. A minimum of 75% of the planting used must be a native species to Delaware, and in no instance can any aggressive invasive species be planted, such as cattails, Phragmites and purple loosestrife.
6. Planting and seeding of the facility to establish a vegetative cover must be completed as quickly as possible after completion of earthwork (following requirements of the Construction Site Stormwater Management Plan). Establishing a groundcover of herbaceous species or 2 to 4 inches of triple shredded hardwood mulch is important for erosion control and site stabilization. The planting of the remainder of the species, i.e., trees, shrubs and flowering herbaceous plants, can be delayed until the appropriate planting season, however, the project will not be closed out until all of the species on the Landscape Plan have been planted and 70% of the species on the Landscape Plan have been established for more than 1 growing season.
7. Trees and shrubs shall not be planted above or immediately adjacent to structural components of the facility such as underdrains, inflow or outflow pipes, structural embankments, or water control structures.
8. Trees must be planted in areas where the soil depth is a minimum of four feet to allow for

the root structure of mature trees.

9. If the stormwater management facility is to accept snow-melt runoff, salt tolerant species should be incorporated into the planting of those portions of the facility subject to prolonged inundation. A bioretention facility shall never to be used for prolonged snow storage.
10. For Constructed Wetlands, trees and shrubs must be incorporated into the design to provide both bank stabilization, shade and a diverse wetland community. By surface area, a minimum of 25% of the Constructed Wetland area must be planted with trees and shrubs. They can be planted in tree islands, peninsulas, high marsh, floodplain, and buffer areas depending on the inundation tolerance of the species. Willow or other live stakes may be planted to help stabilize stream and wetland banks.

Planting Recommendations:

1. Plant species should be located within the facility based on their wetland indicator status and tolerance to inundation and/or soil saturation. Generally, plants with an indicator status of "obligate" or "OBL" will be suitable for planting Zones 3 and 4; plants with an indicator status of "facultative wet" or "FACW" will be suitable for planting in Zones 4 and 5; and plants with an indicator status of "facultative" or "FAC" or "facultative upland" or "FACU" will be suitable for planting in Zone 5. Upland plant species not identified in this document may also be suitable for planting in Zone 5. Relatively few species are suitable for planting in Zones 1 and 2. Consult the inundation tolerance category in the tables within this document for guidance on plant species selection.
2. To increase the success of plant establishment, most plant species should be planted in the drier portion of their inundation tolerance range. Many plants can tolerate flooding or soil saturation only seasonally and do not establish successfully in flooded conditions. This is especially true of trees and shrubs.
3. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally grown container and bare root stock is usually the most successful approach. It is recommended that buffer planting areas be over-planted with a small stock of fast growing successional species to achieve quick canopy closure and to shade out invasive plant species.
4. If trees and shrubs are incorporated in the plan, the recommended spacing between trees is 15 feet on center, and the recommended spacing between shrubs is 5 to 10 feet on center. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes.
5. The recommended spacing for herbaceous plants should be approximately 1.5 feet on center.
6. In cases where herbaceous plants will be planted within the drip-line of trees, shade tolerant species should be considered.
7. Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when transporting them to the planting location.
8. Plants should be ordered well in advance of the installation as several months of lead time may be needed to fill orders for native upland and wetland plant stock.

9. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.
10. For Constructed Wetlands, to add diversity to the wetland and increase survivability, 5 to 7 species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers. If the appropriate planting is achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each grouping of plants.

Inundation Zones:

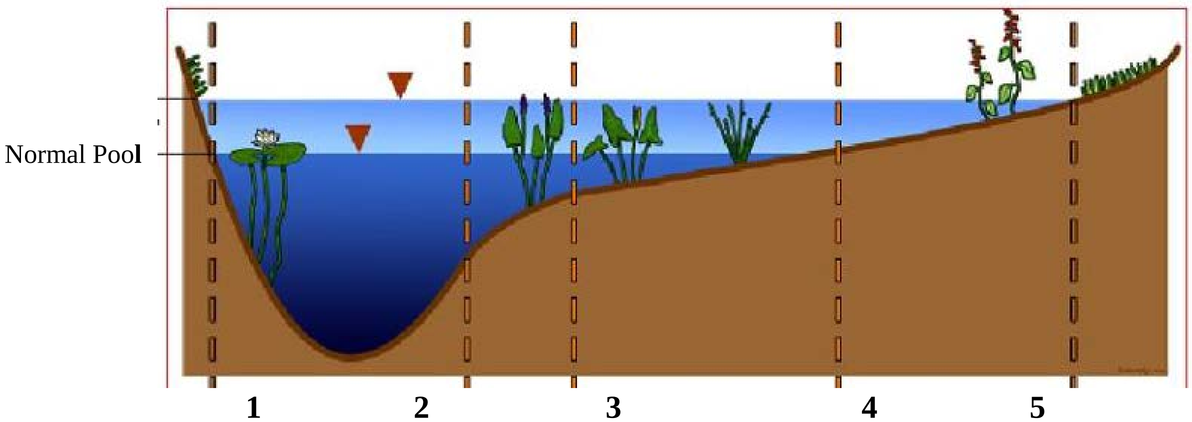


Figure 1. Inundation Zones: (1) Deep Pool (depth -36 to -18 inches), (2) Transition Zone (depth -18 to -6 inches), (3) Low Marsh Zone (depth -6 inches to normal pool), (4) High Marsh Zone (normal pool to +12 inches), and (5) Floodplain (+12 to +30 inches) (adapted from Hunt et al,. 2007). Bioretention Areas, and other facilities without a permanent pool, will only have Zones 4 and 5.

Native Species:

Table 1 and Table 2 below show native plants appropriate for use in stormwater BMPs. Only those species indicated for Zones 4 and 5 are appropriate for bioretention facilities and other BMPs that do not have a permanently saturated zone. Plants indicated for Zones 2 and 3 may be used in Constructed Wetlands and Wet Ponds in addition to the plants indicated for Zones 4 and 5. The plants inundation tolerance should be noted and located appropriately within the facility.

Table 1. Herbaceous Plants for Delaware Stormwater BMP's

Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Arrow Arum (*Peltandra virginica*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Berries are eaten by wood ducks; Inundation up to 1 ft
Arrowhead, Broad-Leaf (Duck Potato) (*Sagittaria latifolia*)	OBL	3, 4	Perennial	Full Sun	Aggressive colonizer; Inundation up to 1 ft
Arrowhead, Bulltongue (*Sagittaria lancifolia*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Aggressive colonizer; Inundation up to 2 ft
Aster, New England *(Aster novae-angliae)*	FACW	4, 5	Perennial	Full Sun-Part Shade	Attractive flowers
Aster, New York *(Aster novi-belgii)*	FACW+	4, 5	Perennial	Full Sun-Part Shade	Attractive flowers; tolerates poor soils
Aster, October Skies *(Aster oblongifolius 'October Skies')*	UPL	5	Perennial	Full Sun	Masses of blue flowers in Sept/Oct
Aster, Perennial Saltmarsh *(Aster tenuifolius)*	OBL	4	Perennial	Full Sun-Part Shade	Salt tolerant
Aster, Raydons Favorite *(Aster oblongifolius 'Raydon's Favorite')*	UPL	5	Perennial	Full Sun	Masses of blue flowers in Sept/Oct
Aster, showy *(Eurybia spectabilis) (Aster spectabilis)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Masses of blue flowers in Sept/Oct
Aster, smooth blue *(Symphyotrichum laeve) (Aster laevis)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Blue cone-shaped clusters with yellow centers
Aster, white heath *(Symphyotrichum ericoides) (Aster ericoides)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Drought tolerant
Beardtongue (*Penstemon digitalis)*	FAC	4, 5	Perennial	Full Sun	Tolerates poor drainage
Beebalm *(Monarda didyma)*	FAC+	4, 5	Perennial	Full Sun-Part Shade	Herbal uses; attractive flower
Black-Eyed Susan *(Rudbeckia hirta)*	FACU	5	Perennial	Full Sun-Part Shade	
Blue star, Blue Ice *(Amsonia 'Blue Ice')*	FACU	5	Perennial	Full Sun-Part Shade	Clusters of steely blue flowers in May
Blue star, Willow leaf *(Amsonia tabernaemontana)*	FACU	5	Perennial	Full Sun-Part Shade	

Table 1. Herbaceous Plants for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Blue vervain *(Verbena hastata)*	FACW	4, 5	Perennial	Full Sun	Tall thin spikes of violet blue
Bluebells, Virginia *(Mertensia virginica)*	FACW	4, 5	Perennial	Part Shade-Full Shade	Attractive flower; dormant in summer
Blueflag Iris (*Iris versicolor*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Inundation up to 6 in.
Blueflag, Virginia *(Iris virginica)*	OBL	3, 4	Perennial	Full Sun-Part Shade	Tolerates standing water
Bluestem, Big *(Andropogon gerardii)*	FAC	5	Grass	Full Sun	Attractive in winter; forms clumps
Bluestem, Little *(Schizachyrium scoparium)*	FACU	5	Grass	Full Sun	Tolerates poor soil conditions
Broomsedge (*Andropogon virginicus*)	FACU+	5	Grass	Part Sun-Part Shade	Inundation up to 3 in., can be fluctuating; winter food and cover
Burreed (*Sparganium americanum*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Inundation 0-6 in.
Cardinal Flower *(Lobelia cardinalis)*	FACW+	4, 5	Perennial	Full Sun-Part Shade	Long bloom time
Common Rush (*Juncus effusus*)	OBL	3, 4	Grass	Full Sun-Part Shade	Aggressive colonizer; Inundation up to 12 in.
Common Three Square *(Schoenoplectus pungens)*	OBL	3, 4	Grass	Full Sun	Aggressive colonizer; Inundation up to 6 in.
Coneflower, Orange *(Rudbeckia fulgida)*	FAC	5	Perennial	Full Sun-Part Shade	Bright gold with brown cone July to October
Coneflower, Purple *(Echinacea purpurea)*	FACU	5	Perennial	Full Sun - Part Shade	Purple flowers with large gold centers July and August
Coreopsis, Lanceleaf *(Coreopsis lanceolata)*	FACU	5	Perennial	Full Sun	Bright yellow 2.5" flowers May-August
Coreopsis, Threadleaf *(Coreopsis verticillata)*	FAC	5	Perennial	Full Sun-Part Shade	Drought tolerant
Fern, New York *(Thelypteris noveboracensis)*	FAC	5	Fern	Part Shade-Full Shade	Drought tolerant

Table 1. Herbaceous Plants for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Fern, Royal *(Osmunda regalis)*	OBL	4	Fern	Full Sun- Full Shade	Tolerates short term flooding; drought tolerant
Fescue, Red *(Festuca rubra)*	FACU	5	Grass	Full Sun- Full Shade	Moderate growth; good for erosion control
Goldenrod, Grassleaf *(Euthamia graminifolia)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Yellow flowers
Goldenrod, Rough-leaf *(Solidago rugosa)*	FAC	4, 5	Perennial	Full Sun	Yellow flowers
Goldenrod, Seaside *(Solidago sempervirens)*	FACW	4, 5	Perennial	Full Sun	Salt tolerant yellow flowers
Hyssop-leaved thoroughwort *(Eupatorium hyssopifolium)*	FACU	5	Perennial	Full Sun - Part Shade	Flat-topped clusters of white fringed flowers in fall
Ironweed, New York *(Vernonia noveboracensis)*	FACW	4, 5	Perennial	Full Sun	Deep purple
Joe Pye Weed *(Eupatorium dubium)*	FACW	4, 5	Perennial	Full Sun - Part Shade	Purple rounded heads
Joe Pye Weed *(Eupatorium fistulosum)*	FACW	4, 5	Perennial	Full Sun - Part Shade	Pink lavender huge rounded heads
Joe Pye Weed *(Eupatorium purpureum)*	FACW	4,5	Perennial	Full Sun - Part Shade	Flat-topped clusters of white fringed flowers in fall; Periodic inundation
Lizard's Tail (*Saururus cernus*)	OBL	3, 4	Perennial	Shade Tolerant	Aggressive colonizer; Inundation up to 3 in.
Lobelia, Great Blue *(Lobelia siphilitica)*	FACW+	4, 5	Perennial	Part Shade- Full Shade	Blooms in late summer; bright blue flowers
Marsh Hibiscus (*Hibiscus moscheutos*)	OBL	3, 4	Perennial	Full Sun	Inundation up to 3 in.; can tolerate periodic dryness
Milkweed , Swamp *(Asclepias incarnata)*	OBL	4	Perennial	Full Sun- Part Shade	Drought tolerant
Milkweed, Butterfly *(Asclepias tuberosa)*	UPL	5	Perennial	Full Sun- Part Shade	Drought tolerant
Pickerelweed (*Pontederia cordata*)	OBL	3, 4	Perennial	Full Sun- Part Shade	Aggressive colonizer; Inundation up to 1 ft.

Table 1. Herbaceous Plants for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Phlox, Garden *(Phlox paniculata)*	FACU	5	Perennial	Full Sun- Part Shade	Large panicles of pink to purple flowers
Phlox, Meadow *(Phlox maculata)*	FACW	4, 5	Perennial	Full Sun	Aromatic; spreads
Pond Weed (*Potamogeton pectinatus*)		2			Full inundation; high wildlife value
Purple-top *(Tridens flavus)*	FACU	5	Grass	Full Sun - Part Shade	
Rice Cutgrass (*Leersia oryzoides*)	OBL	3, 4	Grass	Full Sun	Inundation up to 3 in.; shoreline stabilization
Sea-Oats (*Uniola paniculata)*	FACU-	5	Grass	Full Sun	Salt tolerant; attractive seed heads
Sedge, Broom *(Andropogon virginicus)*	FACU	3, 4	Grass	Full Sun	Drought tolerant; attractive fall color
Sedge, Muskingum *(Carex muskingumensis)*	OBL	3, 4	Grass	Full Sun - Part Shade	
Sedge, Pennsylvania *(Carex pennsylvanica)*	FAC	3, 4	Grass	Full Sun - Shade	
Sedge, Tussock *(Carex stricta)*	FACW	3, 4	Grass	Full Sun - part shade	
Smooth Saltmarsh Cordgrass *(Spartina alternifolia)*	OBL	4	Grass	Full Sun	Salt tolerant
Softstem Bulrush (*Scipus validus*)	OBL	3, 4	Grass	Full Sun	Aggressive colonizer; Inundation up to 2 ft.
Sunflower, Swamp *(Helianthus angustifolius)*	FACW	4, 5	Perennial	Full Sun	Bright yellow flowers late summer to fall covering the plant
Sunflower, Thin-leaved *(Helianthus decapetalus)*	FACU	5	Perennial	Full Sun - Part Shade	Single light yellow flowers in late summer
Swamp rosemallow *(Hibiscus moscheutos)*	OBL	4	Perennial	Full Sun - Part Shade	3-4" rose pink flowers Aug-Sept
Switchgrass (*Panicum virgatum*)	FAC	4, 5	Grass	Full Sun	Inundation up to 3 in.; Tolerates wet/dry conditions

Table 1. Herbaceous Plants for Delaware Stormwater BMP's

Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Switchgrass, Coastal *(Panicum amarum)*	FAC	4, 5	Grass	Full Sun	Adaptable; great erosion control
Turtlehead, White *(Chelone glabra)*	OBL	4	Perennial	Full Sun-Part Shade	Excellent growth
Violet, Common Blue *(Viola papilionacea)*	FAC	5	Perennial	Full Sun-Full Shade	Stemless; spreads
Virginia mountain-mint (*Pycnanthemum virginianum)*	FACW	4, 5	Perennial	Full Sun-Part Shade	Showy silver bracts surround small clusters of pale lavender flowers
Water Lily *(Nymphaea odorata)*	OBL	2, 3	Perennial		
Waterweed (*Elodea canadensis*)	OBL	2	Perennial	Full Sun	High inundation
Wild celery (*Valisneria americana*)		2			High inundation
Wild Rice (*Zizania aquatica*)	OBL	3, 4	Annual	Full Sun	Inundation up to 1 ft.
Wild Rye, Canada *(Elymus canadensis)*	FACW-	4, 5	Grass	Full Shade	Adaptable
Wild Rye, Virginia *(Elymus virginicus)*	FACW-	4, 5	Grass	Part Shade-Full Shade	Adaptable
Woolgrass (*Scirpus cyperinus*)	OBL	3, 4	Grass	Full Sun	Aggressive colonizer; Inundation up to 3 in.

[1] Wetland Indicator:

FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).

FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%); occasionally found on wetlands (estimated probability 1%-33%).

FACW = Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.

OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

[2] Zone:

Zone 1: -48 to -18 inches below the normal pool elevation. Not planted due to poor survival rate.

Zone 2: -18 to -6 inches to the normal pool elevation (plants should not be planted lower than -12 inches).

Zone 3: -6 inches to the normal pool elevation.

Table 1. Herbaceous Plants for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes

Zone 4: Normal pool elevation to +12 inches.

Zone 5: +12 to +30 inches above the normal pool elevation.

Only species that are indicated for Zones 4 and 5 should be planted in bioretention facilities, raingardens, filter strips, and other stormwater facilities that lack a permanent water surface elevation.

Table 2. Trees and Shrubs for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Arrow-wood *(Viburnum dentatum)*	FAC	4, 5	Shrub	Full Sun-Part Shade	Pollution Tolerant
Green Ash *(Fraxinus pennsylvanica)*	FACW	4, 5	Tree	Full Sun-Part Shade	
Azalea , Dwarf *(Rhododendron atlanticum)*	FAC		Shrub	Part Shade	High wildlife value
Azalea, Hoary *(Rhododendron canescens)*	FACW		Shrub	Part Shade	
Azalea, Pinxterbloom *(Rhododendron periclymenoides)*	FAC		Shrub	Part Shade	
Azalea, Swamp *(Rhododendron viscosum)*	OBL	3, 4	Shrub	Part Shade	
Bayberry, Northern *(Myrica pennsylvanica)*	FAC		Shrub	Full Sun-Part Shade	Tolerates some salt; can be maintained as hedge
Birch, River *(Betula nigra)*	FACW	4, 5	Tree	Full Sun-Part Shade	Very adaptable; early spring flowers
Black-Haw *(Viburnum prunifolium)*	FACU		Shrub	Full Sun-Part Shade	Forms thickets; edible nut
Blueberry, Highbush *(Vaccinium corymbosum)*	FACW-		Shrub	Full Sun-Part Shade	
Blueberry, Lowbush *(Vaccinium angustifolium)*	FACU-		Shrub	Full Sun-Part Shade	
Box Elder *(Acer Negundo)*	FACW-	5	Tree	Full Sun-Part Shade	
Button Bush (*Cephalanthus occidentalis*)	OBL	3, 4	Shrub	Full Sun-Part Shade	
Cedar, Atlantic White *(Charnaecyparis thyoides)*	OBL	3, 4	Tree	Full Sun	
Cedar, Eastern Red *(Juniperus virginiana)*	FACU		Tree	Full Sun	Pollution Tolerant
Choke Cherry *(Prunus virginiana)*	FACU		Shrub	Full Sun	Pollutant tolerant; salt tolerant
Chokeberry *(Aronia arbutifolia)*	FACW		Shrub	Part Shade-	

Table 2. Trees and Shrubs for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
				Full Shade	
Chokeberry, Black *(Aronia melanocarpa)*	FACW		Shrub	Part Shade-Full Shade	
Cotton-wood, Eastern *(Populus deltoides)*	FAC		Tree	Full Sun	Winter food source for birds
Cypress, Bald *(Taxodium distichum)*	OBL	3, 4	Tree	Full Sun - Part Shade	Drought tolerant; deciduous conifer
Dogwood, Grey *(Cornus racemosa)*	UPL		Shrub	Full Sun-Part Shade	
Dogwood, Red Twig *(Cornus sericea)*	FACW+		Shrub	Full Sun-Part Shade	
Dogwood, Silky *(Cornus amomum)*	FACW		Shrub	Full Sun-Part Shade	Salt tolerant
Elderberry (*Sambucus canadensis*)	FACW	4, 5	Shrub	Full Sun	
Fringetree, White *(Chionanthus virginicus)*	FAC+		Tree	Full Sun - Part Shade	
Gum, Black *(Nyssa sylvatica)*	FAC	4, 5	Tree	Full Sun-Part Shade	Salt tolerant
Gum, Sweet *(Liquidambar styraciflua)*	FAC	5	Tree	Full Sun - Part Shade	
Hackberry, Common *(Celtis occidentalis)*	FACU		Tree	Full Sun-Full Shade	Drought tolerant; attractive bark
Hazelnut, American *(Corylus americana)*	FACU		Shrub	Part Shade	Attractive bark
Holly, American *(Ilex opaca)*	FACU-		Shrub-Tree	Full Sun-Full Shade	Winter food source for birds
Holly, Inkberry *(Ilex glabra)*	FACW-		Shrub	Full Sun-Part Shade	
Holly, Winterberry *(Ilex laevigata)*	OBL		Shrub	Full Sun-Part Shade	Long lived

Table 2. Trees and Shrubs for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Holly, Winterberry Common *(Ilex verticillata)*	FACW+		Shrub	Full Sun-Full Shade	Edible Fruit
Inkberry *(Ilex glabra)*	FACW	5	Shrub	Full Sun	
Magnolia, Sweetbay *(Magnolia virginiana)*	FACW+	4, 5	Tree	Full Sun - Part Shade	
Maple, Red *(Acer rubrum)*	FAC	4, 5	Tree	Full Sun-Part Shade	Pollution Tolerant
Ninebark, Eastern *(Physocarpus opulifolius)*	FACW-		Shrub	Full Sun-Part Shade	Pollution tolerant
Oak, Pin *(Quercus palustris)*	FACW	4, 5	Tree	Full Sun	Pollution tolerant
Oak, Shingle *(Quercus imbricaria)*	FAC		Tree	Full Sun	
Oak, Swamp White *(Quercus bicolor)*	FACW+		Tree	Full Sun - Part Shade	
Oak, Willow *(Quercus phellos)*	FAC+	4, 5	Tree	Full Sun	
Pepperbush, Sweet *(Clethra alnifolia)*	FAC+	5	Shrub	Part Shade-Full Shade	Salt tolerant
Persimmon *(Diospyros virginiana)*	FAC-		Tree	Full Sun - Part Shade	
Shadblow *(Amelanchier canadensis)*	FAC		Tree	Full Sun-Part Shade	
Smooth Alder *(Alnus serrulata)*	OBL	3, 4	Shrub	Part Shade-Full Shade	
Spicebush *(Lindera benzoin)*	FACW-	3, 4	Shrub	Full Sun-Part Shade	
Swamp Rose *(Rosa palustris)*	OBL	3, 4	Shrub	Full Sun-Part Shade	
Sweetbells leucothoe *(Leucothoe racemosa)*	FACW		Shrub	Full Sun-Full Shade	

Table 2. Trees and Shrubs for Delaware Stormwater BMP's					
Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Sycamore, American *(Platanus occidentalis)*	FAC+	4, 5	Tree	Full Sun	
Viburnum, Nannyberry *(Viburnum lentago)*	FAC		Shrub	Full Sun- Full Shade	
Viburnum, Swamphaw *(Viburnum nudum)*	OBL		Shrub	Full Sun- Part Shade	
Virginia Sweetspire *(Itea virginica)*	OBL		Shrub	Full Sun- Part Shade	
Black Willow *(Salix nigra)*	UPL	4, 5		Full Sun	
Winterberry (*Ilex verticillatta*)	OBL	4, 5	Shrub	Full Sun	
Witch-Hazel, American *(Hamamelis virginiana)*	FAC-		Shrub	Part Shade- Full Shade	Excellent fall color

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Zone 4: Normal pool elevation to +12 inches.

Zone 5: +12 to +30 inches above the normal pool elevation.

Only species that are indicated for Zones 4 and 5 should be planted in bioretention facilities, raingardens, filter strips, and other stormwater facilities that lack a permanent water surface elevation. If a Zone is not listed, professional judgment shall be utilized.

Appendix 3. Compost Material Properties

This specification shall apply for all applications where compost is used as or within a construction or post-construction stormwater best management practice. Particle size specifications vary depending on use, as noted in Table 3.1. Table 3.1: Compost Material Properties

Parameter	Range	Testing Method
Particle Size	For Amendments: 100% pass through a ½" screen For Compost Logs: 99% pass through a 2" screen; max. 40% pass through a 3/8" screen	TMECC 2.02-B
pH	6.0-8.0	TMECC 4.11
Manufactured Inert Material	<1% dry weight basis	TMECC 3.08-A
Organic Matter	35-95% dry weight basis	TMECC 5.07-A
Soluble Salt Concentration	≤ 6.0 mmhos/cm	TMECC 4.10-A
Carbon to Nitrogen Ratio (C:N)	≤ 25:1	
Stability (Carbon Dioxide evolution rate)	≤ 4 C / unit VS / day	TMECC 5.08-B
Maturity (seed emergence and seedling vigor)	>80% relative to positive control	TMECC 5.05-A
Trace Metals	Arsenic < 11 mg/kg[2] Cadmium < 4 mg/kg Chromium < 35 mg/kg[3] Copper < 310 mg/kg Lead < 400 mg/kg Mercury < 10 mg/kg Molybdenum < 2 mg/kg Nickel < 160 mg/kg Selenium < 26 mg/kg Zinc < 2.300 mg/kg	EPA SW-846
Dry Bulk Density	30-45 lb/cu.ft.	
Moisture content	35-55%	

Compost Specifications

Compost used to fulfill regulatory requirements shall meet the criteria set forth in this specification. In addition, it must be provided by an active member of the U.S. Composting Seal of Testing Assurance (STA) program.

The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. No manure or biosolids shall be included. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the following criteria, as reported by the U.S. Composting Council STA Program Compost Technical Data Sheet (See Table 14.3).

Soluble salt refers to the amount of soluble ions in a solution of compost and water. The concentration of soluble ions is typically estimated by determining the solution's ability to carry an electrical current, i.e., electrical conductivity. The units of measure for soluble salts are either mmhos/cm or dS/m (they are 1:1 equivalent). Plant essential nutrients are actually supplied to plants in a salt form. While some specific soluble salts, (e.g., sodium, chloride), may be more detrimental to plants, most composts do not contain sufficient levels of these salts to be a concern in landscape applications. Plant species have a salinity tolerance rating and maximum tolerable quantities are known. Excess soluble salts can cause phytotoxicity to plants. Compost may contribute to, or dilute, the cumulative soluble salts content of a growing media or soil. Reduction in soluble salts content can be achieved through thorough watering at the time of planting. Most composts have a soluble salt conductivity of 1.0 to 10.0 mmhos/cm, whereas typical conductivity values in soil range from 0 to 1.5 in most areas of the country. 6 mmhos/cm is moderately saline and will inhibit the growth of some plants. The final selection of plants should be made after a soil test identifies the limiting characteristics of the soil mix.

The *Carbon to Nitrogen Ratio* is the first step in evaluating the maturity and stability of a compost sample. A Carbon to Nitrogen (C:N) ratio of less than or equal to 25 is acceptable prior to the additional tests of maturity and stability. Currently there are a number of tests available to determine compost stability and maturity. Some have been published in Test Methods for the Examination of Composting and Compost (TMECC) by the U.S. Composting Council (USCC), while commercial laboratories have developed others.

Stability refers to a specific stage or state of organic matter decomposition during composting, which is related to the type of organic compounds remaining and the resultant biological activity in the material. The stability of a given compost is important in determining the potential impact of the material on nitrogen availability, volume, and porosity in soil or growth media. Compost as a soil amendment requires a stable to very stable product that will prevent nutrient tie up and maintain or enhance oxygen availability in soil or growth media.

Maturity is the degree or level of completeness of composting. Maturity is not described by a single property and therefore maturity is best assessed by measuring two or more compost characteristics. Some immature composts may contain high amounts of free ammonia, certain organic acids or other water-soluble compounds which can limit seed germination and root development, or cause odor. All uses of compost require a mature product free of these potentially phytotoxic components. The bioassay used in the STA Program uses a seed germination and growth test to measure the percent of seed emergence and relative seedling vigor.

Trace metals are elements whose concentrations are regulated due to the potential for toxicity to humans, animals, or plants. Regulations governing the heavy metal content of composts, fertilizers, and certain other horticultural and agricultural products have been promulgated on both the State and Federal levels. Specific trace elements, often referred to as heavy metals include arsenic, cadmium, chromium, copper, lead, mercury, molybdenum nickel, selenium, and zinc. The quantity of these elements are measured on a dry weight basis and expressed as mg/kg (milligram per kilogram) or ppm (parts per million). Many of these elements are actually needed by plants for normal growth, although in limited quantities. Therefore, measuring the concentration of these elements, as well as other plant nutrients, can provide valuable management data relevant to the fertilizer requirements of plants and subsequent fertilizer application rates. All composts that contain regulated feedstocks must meet national and/or state safety standards for metals in order to be marketed.

Moisture content (percent) is the measure of the quantity of water present in a compost product; expressed as a percentage of total weight. The moisture content of compost affects its *bulk density* (weight per unit volume) and, therefore, affects handling and transportation. Overly dry compost (35% moisture, or below) can be dusty and irritating to work with, while very wet compost (55 to 60%) can become heavy and clumpy, making its application more difficult and delivery more expensive. A preferred moisture percent for finished compost is 35-55%.

Pathogens, such as bacteria and other infectious microorganisms, should be limited in compost derived from plant-based material, versus bio-solids, but may be present due to animal feces and other sources. Pathogen removal of the compost shall be in compliance with Title 40 of the Code of Federal Regulations Part 503 (or 40 CFR 503).

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Appendix 4. Stormwater Hotspots Guidelines

Stormwater hotspots are defined as commercial, industrial, institutional, municipal, or transport-related operations that produce higher levels of stormwater pollutants, and/or present a higher potential risk for spills, leaks or illicit discharges. Hotspot sources can be separated into two main categories: vehicles and outdoor storage. Additional information for each of the listed operations is included following the plan requirements in the profile sheets. The following post construction operations may be classified as storm water hotspots operations:

- Vehicle Maintenance and Repair
- Vehicle Fueling
- Vehicle Washing
- Vehicle Storage
- Loading and Unloading
- Outdoor or Bulk Material Storage

If any of the above operations occur on a site during construction, management of these operations will be handled through pollution prevention details on the approved Sediment and Stormwater Management Plan.

However, if any of the above operations are expected to occur as part of post construction operations on a planned development site, NPDES general permit coverage to discharge stormwater from an industrial use may be required. DNREC Division of Water's Surface Water Discharges Section should be contacted regarding the need for an Industrial Stormwater Discharge permit.

Projects that will have any of the above as part of post construction operations on the project site, regardless of whether the project has an industrial stormwater discharge permit, should consider the following hotspot operation pollution prevention BMPs in design of the project site.

Vehicle Maintenance and Repair Operations

- Provide locations for recycling collection of used antifreeze, oil, grease, oil filters, cleaning solutions, solvents, batteries, hydraulic and transmission fluids.
- Cover all vehicle and equipment repair areas with a permanent roof of canopy.
- Connect outdoor vehicle storage areas to a separate storm water collection system with an oil/grit separator or sand filter.
- Designate a specific location for outdoor maintenance activities that is designed to prevent storm water pollution (paved, away from storm drains, and with storm water containment measures)
- Stencil or mark storm drain inlets with "No Dumping, Drains to ______" message.

Vehicle Fueling

- Cover fueling stations with a canopy or roof to prevent direct contact with rainfall.
- Design fueling pads to prevent the run-on of storm water and pretreat any runoff with an oil/grit separator or a sand filter.
- Locate storm drain inlets away from the immediate vicinity of the fueling area.

- Stencil or mark storm drain inlets with "No Dumping, Drains to ______" message.
- Pave fueling stations with concrete rather than asphalt.

Vehicle Washing

- Include flow-restricted hose nozzles that automatically turn off when left unattended.
- Provide a containment system for washing vehicles such that wash water does not flow into storm drain system.
- Label storm drain inlets with “No Dumping, Drains to ______” signs to deter disposal of wash water in the storm drain system.
- Design facilities with designated areas for indoor vehicle washing where no other activities are performed (e.g. fluid changes or repair services).

Vehicle Storage

- Label storm drain inlets with “No Dumping, Drains to ______” message.
- All stormwater runoff from the fleet storage area must receive pretreatment via an oil/grit separator or sand filter.
- Untreated stormwater from the fleet storage area may not be discharged off site.
- Connect outdoor vehicle storage areas to a separate storm water collection system with an oil/grit separator or sand filter.

Loading and Unloading

- Design liquid storage areas with impervious surfaces and secondary containment.
- Minimize storm water run-on by covering storage areas with a permanent canopy or roof.
- Slope containment areas to a drain with a positive control (lock, valve, or plug) that leads to the sanitary sewer (if permitted) or to a holding tank.
- Provide permanent cover for building materials stored outside.
- Direct runoff away from building material storage areas.
- Install a high-level alarm on storage tanks to prevent overfilling.

Outdoor or Bulk Material Storage

- Grade the designated loading/unloading to prevent run-on or pooling of storm water.
- Cover the loading/unloading areas with a permanent canopy or roof.
- Install an automatic shutoff valve to interrupt flow in the event of a liquid spill.
- Install a high-level alarm on storage tanks to prevent overfilling.
- Pave the loading/unloading area with concrete rather than asphalt.
- Position roof downspouts to direct storm water away from loading/unloading areas.

Profile Sheet	Hotspot Source Area: Vehicles
	VEHICLE MAINTENANCE AND REPAIR

Description

Vehicle maintenance and repair operations can exert a significant impact on water quality by generating toxins such as solvents, waste oil, antifreeze, and other fluids. Often, vehicles that are wrecked or awaiting repair can be a storm water hotspot if leaking fluids are exposed to storm water runoff (Figure 1). Vehicle maintenance and repair can generate oil and grease, trace metals, hydrocarbons, and other toxic organic compounds. Table 1 summarizes a series of simple pollution prevention techniques for vehicle maintenance and repair operations that can prevent storm water contamination. You are encouraged to consult the Resources section of this sheet to get a more comprehensive review of pollution prevention practices for vehicle maintenance and repair operations.

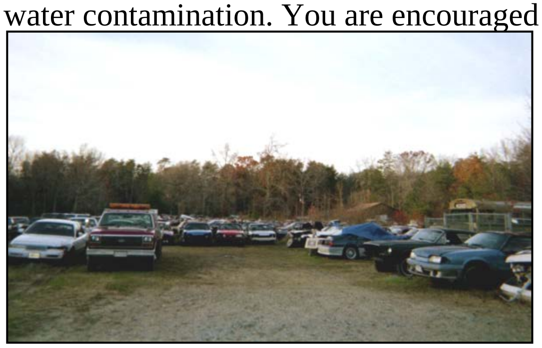

Figure 1: Junkyard and Potential Source of Storm Water Pollution

Application

Pollution prevention practices should be applied to any facility that maintains or repairs vehicles in a subwatershed. Examples include car dealerships, body shops, service stations, quick lubes, school bus depots, trucking companies, and fleet maintenance operations at larger industrial, institutional, municipal or transport-related operations. Repair facilities are often clustered together, and are a major priority for subwatershed pollution prevention.

Table 1: Pollution Prevention Practices for Vehicle Maintenance and Repair Activities
• Avoid hosing down work or fueling areas • Clean all spills immediately using dry cleaning techniques • Collect used antifreeze, oil, grease, oil filters, cleaning solutions, solvents, batteries, hydraulic and transmission fluids and recycle with appropriate agencies • Conduct all vehicle and equipment repairs indoors or under a cover (if done outdoors) • Connect outdoor vehicle storage areas to a separate storm water collection system with an oil/grit separator that discharges to a dead holding tank, the sanitary sewer or a storm water treatment practice • Designate a specific location for outdoor maintenance activities that is designed to prevent storm water pollution (paved, away from storm drains, and with storm water containment measures) • Inspect the condition of all vehicles and equipment stored outdoors frequently • Use a tarp, ground cloth, or drip pans beneath vehicles or equipment being repaired outdoors to capture all spills and drips • Seal service bay concrete floors with an impervious material so cleanup can be done without using solvents. Do not wash service bays to outdoor storm drains • Store cracked batteries in a covered secondary containment area until they can be disposed of properly • Wash parts in a self-contained solvent sink rather than outdoors

Primary Training Targets

Owners, fleet operation managers, service managers, maintenance supervisors, mechanics and other employees are key targets for training.

Feasibility

Pollution prevention techniques for vehicle repair facilities broadly apply to all regions and climates. These techniques generally rely on changes to basic operating procedures, after an initial inspection of facility operations. The inspection relies on a standard operations checklist that can be completed in a few hours.

Implementation Considerations

Employee training is essential to successfully implement vehicle repair pollution prevention practices. The connection between the storm drain system and local streams should be emphasized so that employees understand why any fluids need to be properly disposed of. It is also important to understand the demographics of the work force; in some communities, it may require a multilingual education program.

Cost - Employee training is generally inexpensive, since training can be done using posters, pamphlets, or videos. Structural practices can vary based on what equipment is required. For instance, solvent sinks to clean parts can cost from $1,500 to $15,000, while spray cabinets may cost more than $50,000. In addition, proper recycling/disposal of used or spilled fluids usually requires outside contractors that may increase costs.

Resources

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs.
http://www.ecy.wa.gov/biblio/9914.html

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial.
http://www.cabmphandbooks.com/

Coordinating Committee For Automotive Repair (CCAR) Source: US EPA CCAR-*Green*Link®, the National Automotive Environmental Compliance Assistance Center CCAR-*Green*Link® Virtual Shop
http://www.ccar-greenlink.org/

Auto Body Shops Pollution Prevention Guide. Peaks to Prairies Pollution Prevention Information Center.
http://peakstoprairies.org/p2bande/autobody/abguide/index.cfm

Massachusetts Office of Technical Assistance for Toxics Use Reduction (OTA). Crash Course for Compliance and Pollution Prevention Toolbox
http://www.state.ma.us/ota/pubs/toolfull.pdf

Model Urban Runoff Program: A How-To Guide for Developing Urban Runoff Programs for Small Municipalities.
http://www.swrcb.ca.gov/stormwtr/murp.html

US EPA. Virtual Facility Regulatory Tour: Vehicle Maintenance. FedSite Federal Facilities Compliance Assistance Center.
http://permanent.access.gpo.gov/websites/epagov/www.epa.gov/fedsite/virtual.html

City of Santa Cruz. Best Management Practices for Vehicle Service Facilities (in English and Spanish).
http://www.ci.santa-cruz.ca.us/pw/pdf/vehiclebmp.pdf

City of Los Angeles Bilingual Poster of BMPs for Auto Repair Industry
http://www.lastormwater.org/downloads/PDFs/autopstr.pdf

Profile Sheet

Hotspot Source Area: Vehicles

VEHICLE FUELING

Description

Spills at vehicle fueling operations have the potential to directly contribute oil, grease, and gasoline to storm water, and can be a significant source of lead, copper and zinc, and petroleum hydrocarbons. Delivery of pollutants to the storm drain can be sharply reduced by well-designed fueling areas and improved operational procedures. The risk of spills depends on whether the fueling area is covered and has secondary containment. The type, condition, and exposure of the fueling surface can also be important. Table 1 describes common pollution prevention practices for fueling operations.

Application

These practices can be applied to any facility that dispenses fuel. Examples include retail gas stations, bus depots, marinas, and fleet maintenance operations (Figure 1). In addition, these practices also apply to temporary above-ground fueling areas for construction and earthmoving equipment. Many fueling areas are usually present in urban subwatersheds, and they tend to be clustered along commercial and

Figure 1: Covered Retail Gas Operation Without Containment for Potential Spills

Table 1: Pollution Prevention Practices For Fueling Operation Areas
• Maintain an updated spill prevention and response plan on premises of all fueling facilities (see Profile Sheet H-7)
• Cover fueling stations with a canopy or roof to prevent direct contact with rainfall
• Design fueling pads for large mobile equipment to prevent the run-on of storm water and collect any runoff in a dead-end sump
• Retrofit underground storage tanks with spill containment and overfill prevention systems
• Keep suitable cleanup materials on the premises to promptly clean up spills
• Install slotted inlets along the perimeter of the “downhill” side of fueling stations to collect fluids and connect the drain to a waste tank or storm water treatment practice. The collection system should have a shutoff valve to contain a large fuel spill event
• Locate storm drain inlets away from the immediate vicinity of the fueling area
• Clean fuel-dispensing areas with dry cleanup methods. Never wash down areas before dry clean up has been done. Ensure that wash water is collected and disposed of in the sanitary sewer system or approved storm water treatment practice
• Pave fueling stations with concrete rather than asphalt
• Protect above ground fuel tanks using a containment berm with an impervious floor of Portland cement. The containment berm should have enough capacity to contain 110% of the total tank volume
• Use fuel-dispensing nozzles with automatic shutoffs, if allowed
• Consider installing a perimeter sand filter to capture and treat any runoff produced by the station

highway corridors. These hotspots are often a priority for subwatershed source control.

Primary Training Targets

Training efforts should be targeted to owners, operators, attendants, and petroleum wholesalers.

Feasibility

Vehicle fueling pollution prevention practices apply to all geographic and climatic regions. The practices are relatively low-cost, except for structural measures that are installed during new construction or station remodeling.

Implementation Considerations

Fueling Area Covers - Fueling areas can be covered by installing an overhanging roof or canopy. Covers prevent exposure to rainfall and are a desirable amenity for retail fueling station customers. The area of the fueling cover should exceed the area where fuel is dispensed. All downspouts draining the cover or roof should be routed to prevent discharge across the fueling area. If large equipment makes it difficult to install covers or roofs, fueling islands should be designed to prevent storm water run-on through grading, and any runoff from the fueling area should be directed to a dead-end sump.

Surfaces - Fuel dispensing areas should be paved with concrete; the use of asphalt should be avoided, unless the surface is sealed with an impervious sealant. Concrete pads used in fuel dispensing areas should extend to the full length that the hose and nozzle assembly can be pulled, plus an additional foot.

Grading - Fuel dispensing areas should be graded with a slope that prevents ponding, and separated from the rest of the site by berms, dikes or other grade breaks that prevent run-on of urban runoff. The recommended grade for fuel dispensing areas is 2 - 4% (CSWQTF, 1997).

Cost - Costs to implement pollution prevention practices at fueling stations will vary, with many of the costs coming upfront during the design of a new fueling facility. Once a facility has implemented the recommended source control measures, ongoing maintenance costs should be low.

Resources

Best Management Practice Guide – Retail Gasoline Outlets. Prepared by Retail Gasoline Outlet Work Group.
http://www.swrcb.ca.gov/rwqcb4/html/programs/stormwater/la_ms4_tentative/RGO BMP Guide_03-97_.pdf

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs.
http://www.ecy.wa.gov/biblio/9914.html

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: New Development and Redevelopment.
http://www.cabmphandbooks.com/

City of Los Angeles, CA Best Management Practices for Gas Stations
http://www.lacity.org/SAN/wpd/downloads/PDFs/gasstation.pdf

City of Dana Point Stormwater Best Management Practices (BMPs) For Automotive Maintenance And Car Care
http://www.danapoint.org/water/WC-AUTOMOTIVE.pdf

Alachua County, FL Best Management Practices for Controlling Runoff from Gas Stations
http://environment.alachua-county.org/Natural_Resources/Water_Quality/Documents/Gas%20Stations.pdf

California Stormwater Regional Control Board Retail Gasoline Outlets: New

Development Design Standards For Mitigation Of Storm Water Impacts
http://www.swrcb.ca.gov/rwqcb4/html/programs/stormwater/la_ms4_tentative/RGOpaper.pdf
http://www.swrcb.ca.gov/rwqcb4/html/programs/stormwater/la_ms4_tentative/RGOPaperSupplement_12-01_.pdf

Canadian Petroleum Products Institute Best Management Practices Stormwater Runoff from Petroleum Facilities
http://www.cppi.ca/tech/BMPstormwater.pdf

City of Monterey (CA). Posters of Gas Station BMPs.
http://www.monterey.org/publicworks/stormeduc.html

Pinole County, CA Typical Stormwater Violations Observed in Auto Facilities and Recommended Best Management Practices (BMPs)
http://www.ci.pinole.ca.us/publicworks/downloads/AutoStormwater.pdf

Profile Sheet	Hotspot Source Area: Vehicles
	VEHICLE WASHING

Description

Vehicle washing pollution prevention practices apply to many commercial, industrial, institutional, municipal and transport-related operations. Vehicle wash water may contain sediments, phosphorus, metals, oil and grease, and other pollutants that can degrade water quality. When vehicles are washed on impervious surfaces such as parking lots or industrial areas, dirty wash water can contaminate storm water that ends up in streams.

Application

Improved washing practices can be used at any facility that routinely washes vehicles. Examples include commercial car washes, bus depots, car dealerships, rental car companies, trucking companies, and fleet operations. In addition, washing dump trucks and other construction equipment can be a problem. Washing operations tend to be unevenly distributed within urban subwatersheds. Vehicle washing also occurs in neighborhoods, and techniques to keep wash water out of the storm drain system are discussed in the car washing profile sheet (N-11). Table 1 reviews some of the pollution prevention techniques available for hotspot vehicle washing operations.

Primary Training Targets

Owners, fleet managers, and employees of operations that include car washes are the primary training target.

Feasibility

Vehicle washing practices can be applied to all regions and climates. Vehicle washing tends to occur more frequently in summer months and in drier regions of the country. Sound vehicle washing practices are not always used at many sites because operators are reluctant to change traditional cleaning methods. In addition, the cost of specialized equipment to manage high volumes of wash water can be too expensive for small businesses.

Improved vehicle washing practices are relatively simple to implement and are very effective at preventing storm water contamination. Training is essential to get owners and employees to adopt these practices, and should be designed to overcome cultural and social barriers to improved washing practices.

Table 1: Pollution Prevention Practices for Vehicle Washing
• Wash vehicles at indoor car washes that recycle, treat or convey wash water to the sanitary sewer system • Use biodegradable, phosphate-free, water-based soaps • Use flow-restricted hose nozzles that automatically turn off when left unattended • Wash vehicles on a permeable surface or a washpad that has a containment system • Prohibit discharge of wash water into the storm drain system or ground by using temporary berms, storm drain covers, drain plugs or other containment system • Label storm drains with “No Dumping” signs to deter disposal of wash water in the storm drain system • Pressure and steam clean off-site to avoid runoff with high pollutant concentrations • Obtain permission from sewage treatment facilities to discharge to the sanitary sewer

Implementation Considerations

The ideal practice is to wash all vehicles at commercial car washes or indoor facilities that are specially designed for washing operations. Table 2 offers some tips for indoor car wash sites. When washing operations are conducted outside, a designated wash area should have the following characteristics:

- Paved with an impervious surface, such as Portland cement concrete
- Bermed to contain wash water
- Sloped so that wash water is collected and discharged to the sanitary sewer system, holding tank or dead-end sump
- Operated by trained workers to confine washing operations to the designated wash area

Outdoor vehicle washing facilities should use pressurized hoses without detergents to remove most dirt and grime. If detergents are used, they should be phosphate-free to reduce nutrient loading. If acids, bases, metal brighteners, or degreasing agents are used, wash water should be discharged to a treatment facility, sanitary sewer, or a sump. In addition, waters from the pressure washing of engines and vehicle undercarriages must be disposed of using the same options.

Discharge to pervious areas may be an option for washing operations that generate small amounts of relatively clean wash water (water only - no soaps, no steam cleaning). The clean wash water should be directed as sheet flow across a vegetated area to infiltrate or evaporate before it enters the storm drain system. This option should be exercised with caution, especially in environmentally sensitive areas or protected groundwater recharge areas.

The best way to avoid stormwater contamination during washing operations is to drain the wash water to the sanitary sewer system. Operations that produce high volumes of wash water should consider installing systems that connect to the sewer. Other options for large and small operations include containment units to capture the wash water prior to transport away for proper disposal (Figure 1). If vehicles must be washed on an impervious surface, a storm drain filter should be used to capture solid contaminants.

Table 2: Tips for Indoor Car Wash Sites *(Adapted from U.S. EPA, 2003)*
▪ Facilities should have designated areas for indoor vehicle washing where no other activities are performed (e.g. fluid changes or repair services)
▪ Indoor vehicle wash areas should have floor drains that receive only vehicle washing wastewater (not floor washdown or spill removal wash waters) and be connected to a holding tank with a gravity discharge pipe, to a sump that pumps to a holding tank, or to an oil/grit separator that discharges to a municipal sanitary sewer
▪ The floor of indoor vehicle wash bays should be completely bermed to collect wash water
▪ Aromatic and chlorinated hydrocarbon solvents should be eliminated from vehicle-washing operations
▪ Vehicle-washing operations should use vehicle rinsewater to create new wash water through the use of recycling systems that filter and remove grit.

Cost - The cost of using vehicle-washing practices can vary greatly and depends on the size of the operation (Table 3). The cost of constructing a commercial grade system connected to the sanitary sewer can exceed $100,000. Disposal fees and frequency of washing can also influence the cost. Training costs can be minimized by using educational materials available from local

Figure 1: Containment System Preventing Wash Water from Entering the Storm Drain

governments, professional associations or EPA's National Compliance Assistance Centers (http://www.assistancecenters.net/). Temporary, portable containment systems can be shared by several companies that cannot afford specialized equipment independently.

Table 3: Sample Equipment Costs for Vehicle Washing Practices	
Item	**Cost**
Bubble Buster	$2,000 –2,500*
Catch basin insert	$65*
Containment mat	$480-5,840**
Storm drain cover (24" drain)	$120.00 **
Water dike/ berm (20 ft)	$100.00 **
Pump	$75-3,000**
Wastewater storage container	$50-1,000+**
*Source: *U.S. EPA, 1992 **Robinson, 2003*	

Resources

EPA FedSite Virtual Facility Regulatory Tour, Vehicle Maintenance Facility Tour. Vehicle Washing - P2 Opportunities http://permanent.access.gpo.gov/websites/epagov/www.epa.gov/fedsite/virtual.html

Alachua County Pollution Prevention Fact Sheet: Best Management Practices for Controlling Runoff from Commercial Outdoor Car Washing. http://environment.alachua-county.org/Natural_Resources/Water_Quality/Documents/Commercial Outdoor Car Wash.pdf.

Kitsap County Sound Car Wash Program. http://www.kitsapgov.com/sswm/carwash.htm.

Washington Department of Ecology. 1995. Vehicle and Equipment Wash Water Discharges: Best Management Practices Manual. Olympia, Washington. http://www.ecy.wa.gov/pubs/95056.pdf

U.S. Environmental Protection Agency. Pollution Prevention/Good Housekeeping for Municipal Operations. http://cfpub2.epa.gov/npdes/stormwater/menuofbmps/poll_18.cfm

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial. http://www.cabmphandbooks.com/

Profile Sheet

Hotspot Source Area: Vehicles

VEHICLE STORAGE

Description

Parking lots and vehicle storage areas can introduce sediment, metals, oil and grease, and trash into storm water runoff. Simple pavement sweeping, litter control, and storm water treatment practices can minimize pollutant export from these hotspots. Table 1 provides a list of simple pollution prevention practices intended to prevent or reduce the discharge of pollutants from parking and vehicle storage areas.

Application

Pollution prevention practices can be used at larger parking lots located within a subwatershed. Examples include regional malls, stadium lots, big box retail, airport parking, car dealerships, rental car companies, trucking companies, and fleet operations (Figure 1). The largest, most heavily used parking lots with vehicles in the poorest condition (e.g., older cars or wrecked vehicles) should be targeted first. This practice is also closely related to parking lot maintenance source controls, which are discussed in greater detail in profile sheet H-11.

Primary Training Targets

Owners, fleet operation managers, and property managers that maintain parking lots are key training targets.

Figure 1: Retail Parking Lot

Table 1: Pollution Prevention Practices for Parking Lot and Vehicle Storage Areas
Parking Lots • Post signs to control litter and prevent patrons from changing automobile fluids in the parking lot (e.g., changing oil, adding transmission fluid, etc.) • Pick up litter daily and provide trash receptacles to discourage littering • Stencil or mark storm drain inlets with "No Dumping, Drains to ______" message • Direct runoff to bioretention areas, vegetated swales, or sand filters • Design landscape islands in parking areas to function as bioretention areas • Disconnect rooftop drains that discharge to paved surfaces • Use permeable pavement options for spillover parking (Profile sheet OS-11 in Manual 3) • Inspect catch basins twice a year and remove accumulated sediments, as needed • Vacuum or sweep large parking lots on a monthly basis, or more frequently • Install parking lot retrofits such as bioretention, swales, infiltration trenches, and storm water filters (Profile sheets OS-7 through OS-10 in Manual 3)
Vehicle Storage Areas • Do not store wrecked vehicles on lots unless runoff containment and treatment are provided • Use drip pans or other spill containment measures for vehicles that will be parked for extended periods of time • Use absorbent material to clean up automotive fluids from parking lots

Feasibility

Sweeping can be employed for parking lots that empty out on a regular basis. Mechanical sweepers can be used to remove small quantities of solids. Vacuum sweepers should be used on larger parking lot storage areas, since they are superior in picking up deposited pollutants (See Manual 9). Constraints for sweeping large parking lots include high annual costs, difficulty in controlling parking, and the inability of current sweeper technology to remove oil and grease. Proper disposal of swept materials might also represent a limitation.

Implementation Considerations

The design of parking lots and vehicle storage areas can greatly influence the ability to treat storm water runoff. Many parking areas are landscaped with small vegetative areas between parking rows for aesthetic reasons or to create a visual pattern for traffic flow. These landscaped areas can be modified to provide storm water treatment in the form of bioretention (Figure 2).

Figure 2: Parking Lot Island Turned Bioretention Area

Catch basin cleanouts are also an important practice in parking areas. Catch basins within the parking lot should be inspected at least twice a year and cleaned as necessary. Cleanouts can be done manually or by vacuum truck. The cleanout method selected depends on the number and size of the inlets present (see Manual 9).

Most communities have contractors that can be hired to clean out catch basins and vacuum sweep lots. Mechanical sweeping services are available, although the cost to purchase a new sweeper can exceed $200,000. Employee training regarding spill prevention for parking areas is generally low-cost and requires limited staff time.

Resources

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial
http://www.cabmphandbooks.com/

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs. WA Dept. of Ecology
http://www.ecy.wa.gov/biblio/9914.html

Profile Sheet	**Hotspot Source Area: Outdoor Materials**	
	LOADING AND UNLOADING	

Description

Outdoor loading and unloading normally takes place on docks or terminals at many commercial, industrial, institutional, and municipal operations. Materials spilled or leaked during this process can either be carried away in storm water runoff or washed off when the area is cleaned. As a result, many different pollutants can be introduced into the storm drain system, including sediment, nutrients, trash, organic material, trace metals, and an assortment of other pollutants. A number of simple and effective pollution prevention practices can be used at loading/unloading areas to prevent runoff contamination, as shown in Table 1.

Application

While nearly every commercial, industrial, institutional, municipal and transport-related site has a location where materials or products are shipped or received, the risk of storm water pollution is greatest for operations that transfer high volumes of material or liquids, or unload potentially hazardous materials. Some notable examples to look for in a subwatershed include distribution centers, grocery stores, building supply outlets, lawn and garden centers, petroleum wholesalers, warehouses, landfills, ports, solid waste facilities, and maintenance depots (Figure 1). Attention should also be paid to industrial operations that process bulk materials, and any operations regulated under industrial storm water NPDES permits.

Primary Training Targets

Owners, site managers, facility engineers, supervisors, and employees of operations with loading/unloading facilities are the primary training target.

Table 1: Pollution Prevention Practices for Loading and Unloading Areas
• Avoid loading/unloading materials in the rain • Close adjacent storm drains during loading/unloading operations • Surround the loading/unloading area with berms or grading to prevent run-on or pooling of storm water. If possible, cover the area with a canopy or roof • Ensure that a trained employee is always present to handle and cleanup spills • Inspect the integrity of all containers before loading/unloading • Inspect equipment such as valves, pumps, flanges, and connections regularly for leaks, and repair as needed • Install an automatic shutoff valve to interrupt flow in the event of a catastrophic liquid spill • Install a high-level alarm on storage tanks to prevent overfilling • Pave the loading/unloading area with concrete rather than asphalt • Place drip pans or other temporary containment devices at locations where leaks or spills may occur, and always use pans when making and breaking connections • Position roof downspouts to direct storm water away from loading/unloading areas and into bioretention areas • Prepare and implement an Emergency Spill Cleanup Plan for the facility (see Profile Sheet H-7) • Sweep loading/unloading area surfaces frequently to remove material that could otherwise be washed off by storm water • Train all employees, especially fork lift operators, on basic pollution prevention practices and post signs • Use seals, overhangs, or door skirts on docks and terminals to prevent contact with rainwater

Feasibility

Loading/unloading pollution prevention practices can be applied in all geographic and climatic regions, and work most effectively at preventing sediment, nutrients, toxic materials, and oil from coming into contact with storm water runoff or runon. Few impediments exist to using this practice, except for the cost to retrofit existing loading and unloading areas with covers or secondary containment.

Implementation Considerations

Loading/unloading pollution prevention practices should be integrated into the overall storm water pollution prevention plan for a facility. Employee training should focus on proper techniques to transfer materials, using informational signs at loading docks and material handling sites and during routine safety meetings.

Cost - Costs to implement loading/unloading pollution prevention practices consist of one-time construction costs to retrofit new or existing loading areas, but annual maintenance costs are relatively low thereafter. Exceptions include industries that elect to use expensive air pressure or vacuum systems for loading/unloading facilities, which can also be expensive to maintain (U.S. EPA, 1992). Ongoing costs include employee training and periodic monitoring of loading/unloading activities.

Figure 1: Loading/Unloading Area of Warehouse

Resources

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial. http://www.cabmphandbooks.com/

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs. WA Dept. of Ecology 99-14 http://www.ecy.wa.gov/biblio/9914.html

Ventura County Flood Control District Clean Business Program Fact Sheet http://www.vcstormwater.org/sheet-materials.htm

Business Best Management Practices Stormwater Bmp #3 - Shipping/Receiving/Loading Docks http://www.cleancharles.org/stormwater_bmp3.shtml

City of Los Angeles, CA Reference Guide For Stormwater Best Management Practices http://www.lastormwater.org/downloads/PDFs/bmp_refguide.pdf

Profile Sheet

Hotspot Source Area: Outdoor Materials

OUTDOOR STORAGE

Description

Protecting outdoor storage areas is a simple and effective pollution prevention practice for many commercial, industrial, institutional, municipal, and transport-related operations. The underlying concept is to prevent runoff contamination by avoiding contact between outdoor materials and rainfall (or runoff). Unprotected outdoor storage areas can generate a wide range of storm water pollutants, such as sediment, nutrients, toxic materials, and oil and grease (Figure 1).

Materials can be protected by installing covers, secondary containment, and other structures to prevent accidental release. Outdoor storage areas can be protected on a temporary basis (tarps or plastic sheeting) or permanently through structural containment measures (such as roofs, buildings, or concrete berms). Table 1 summarizes pollution prevention practices available for outdoor storage areas.

Application

Many businesses store materials or products outdoors. The risk of storm water pollution is greatest for operations that store large quantities of liquids or bulk materials at sites that are connected to the storm drain system. Several notable operations include nurseries and garden centers, boat building/repair, auto recyclers/body shops, building supply outlets, landfills, ports, recycling centers, solid waste and composting facilities, highway maintenance depots, and power plants. Attention should also be paid to industrial operations that process bulk materials, which are often regulated under industrial storm water NPDES permits.

Figure 1: Mulch Stored Outdoors at a Garden Center

Primary Training Targets

Owners, site managers, facility engineers, supervisors, and employees of operations with loading/unloading facilities are the primary training target.

Feasibility

Outdoor storage protection can be widely applied in all regions and climate zones, and requires routine monitoring by employees. Most operations have used covering as the major practice to handle outdoor storage protection (U.S. EPA, 1999). The strategy is to design and maintain outdoor material storage areas so that they:

- Reduce exposure to storm water and prevent runon
- Use secondary containment to capture spills
- Can be regularly inspected
- Have an adequate spill response plan and cleanup equipment

Table 1: Pollution Prevention Practices for Protecting Outdoor Storage Areas
• Emphasize employee education regarding storage area maintenance • Keep an up-to-date inventory of materials stored outdoors, and try to minimize them • Store liquids in designated areas on an impervious surface with secondary containment • Inspect outdoor storage containers regularly to ensure that they are in good condition • Minimize storm water run-on by enclosing storage areas or building a berm around them • Slope containment areas to a drain with a positive control (lock, valve, or plug) that leads to the sanitary sewer (if permitted) or to a holding tank • Schedule regular pumping of holding tanks containing storm water collected from secondary containment areas

Implementation Considerations

Covers - The use of impermeable covers is an effective pollution prevention practice for non-hazardous materials. Covers can be as simple as plastic sheeting or tarps, or more elaborate roofs and canopies. Site layout, available space, affordability, and compatibility with the covered material all dictate the type of cover needed for a site. In addition, the cover should be compatible with local fire and building codes and OSHA workplace safety standards. Care should be taken to ensure that the cover fully protects the storage site and is firmly anchored into place.

Secondary Containment - Secondary containment is designed to contain possible spills of liquids and prevent storm water run-on from entering outdoor storage areas. Secondary containment structures vary in design, ranging from berms and drum holding areas to specially-designed solvent storage rooms (Figure 2).

Secondary containment can be constructed from a variety of materials, such as concrete curbs, earthen berms, plastic tubs, or fiberglass or metal containers. The type of material used depends on the substance contained and its resistance to weathering. In general, secondary containment areas should be sized to hold 110% of the volume of the storage tank or container unless other containment sizing regulations apply (e.g., fire codes).

If secondary containment areas are uncovered, any water that accumulates must

Figure 2: Secondary Containment of Storage Drums Behind a Car Repair Shop

be collected in a sanitary sewer, a storm water treatment system, or a licensed disposal facility. Water quality monitoring may be needed to determine whether the water is contaminated and dictate the method of disposal. If the storm water is clean, or an on-site storm water treatment practice is used, a valve should be installed in the containment dike so that excess storm water can be drained out of the storage area and directed either to the storm drain (if clean) or into the storm water treatment system (if contaminated). The valve should always be kept closed except when storm water is drained, so that any spills that occur can be effectively contained. Local sewer authorities may not allow discharges from a large containment area into the sewer system, and permission must be obtained prior to discharge. If discharges to the sanitary sewer system are prohibited, containment should be provided, such as a holding tank that is regularly

Table 2: Sample Equipment Costs for Outdoor Storage Protection	
Storage Protection Device	**Cost**
Concrete Slab (6”)	\$3.50 to \$5.00 per ft^2
Containment Pallets	\$50 to \$350 based on size and # of barrels to be stored
Storage buildings	\$6 to \$11 per ft^2
Tarps & Canopies	\$25 to \$500 depending on size of area to cover
Sources: Costs were derived from a review of Ferguson et al.*, 1997 and numerous websites that handle proprietary spill control or hazardous material control products*	

pumped out.

Employee training on outdoor storage pollution prevention should focus on the activities and site areas with the potential to pollute storm water and the proper techniques to manage material storage areas to prevent runoff contamination. Training can be conducted through safety meetings and the posting of on-site informational signs. Employees should also know the on-site person who is trained in spill response.

Cost - Many storage protection practices are relatively inexpensive to install (Table 2). Actual costs depend on the size of the storage area and the nature of the pollution prevention practices. Other factors are whether practices are temporary or permanent and the type of materials used for covers and containment. Employee training can be done in connection with other safety training to reduce program costs. Training costs can also be reduced by using existing educational materials from local governments, professional associations or from EPA’s National Compliance Assistance Centers (http://www.assistancecenters.net).

Resources

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial. http://www.cabmphandbooks.com/

Rouge River National Wet Weather Demonstration Project. Wayne County, MI. http://www.rougeriver.com/geninfo/rougeproj.html

Storm Water Management Fact Sheet: Coverings. USEPA, Office of Water, http://www.epa.gov/owm/mtb/covs.pdf.

EPA Office of Wastewater Management Storm Water Management Fact Sheet: Coverings http://www.epa.gov/owm/mtb/covs.pdf

California Stormwater Quality Association Factsheet: Outdoor Storage of Raw Materials http://www.cabmphandbooks.com/Documents/Municipal/SC-33.pdf

Alameda Countywide Clean Water Program Outdoor Storage of Liquid Materials http://www.cleanwaterprogram.com/outdoor_stor_liquid_fact_sht.pdf

Washtenaw County, MI Community Partners for Clean Streams Fact Sheet Series #1: Housekeeping Practices http://www.ewashtenaw.org/content/dc_drnbmp1.pdf

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Appendix 5. Design of Stormwater Conveyance Systems

The Chezy-Manning formula is to be used to compute the system's transport capacities:

$$Q = \frac{1.486}{n} \times A \times R^{2/3} \times S^{1/2}$$

Where:

Q = channel flow (cfs)
n = Manning’s roughness coefficient (Table A.1)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = channel slope (ft/ft)

Table A-5.1 Manning’s Roughness Coefficient (n) Values for Various Channel Materials

Channel Materials	Roughness Coefficient
Concrete pipe and precast culverts	0.013
Monolithic concrete in boxes, channels	0.015
PVC pipes 24" to 36" 42" and larger	0.011 0.019 0.021
Sodded channel with water depth < 1.5'	0.050
Sodded channel with water depth >1.5'	0.035
Smooth earth channel or bottom of wide channels with sodded slopes	0.025
Rip-rap channels	0.035

Note: Where drainage systems are composed of more than one of the above channel materials, a composite roughness coefficient must be computed in proportion to the wetted perimeter of the different materials.

Also, the computation for the flow velocity of the channel shall use the continuity equation as follows:

$$Q = A \times V$$

Where:

V = velocity (ft/sec)
A = cross-sectional area of the flow (ft^2)

Appendix 6. Design of Flow Control Structures

Flow control devices are orifices and weirs. The following formulas shall be used in computing maximum release rates from the designed stormwater management facility

1) Circular Orifices:

$$Q = CA(2gh)^{0.5}$$

Where:
Q = orifice discharge (cfs)
C = discharge coefficient = 0.6
A = orifice cross-sectional area = 3.1416(D^2/4) (ft^2)
g = 32.2ft/sec^2 (gravitational acceleration)
h = hydraulic head above the center of the orifice (ft)

When h < D, the orifice shall be treated as a weir:

$$Q = CLH^{3/2}$$

Where:
Q = flow through the weir (cfs)
C = 3
L = diameter of orifice (ft)
H = hydraulic head above bottom of weir opening (ft)

2) Flow Under Gates:

Flow under a vertical gate can be treated as a square orifice. For submerged conditions:

When outflow is not influenced by downstream water level:

$$Q = b \times a \times C \times \left[2g \times \left(\frac{H_0}{H_0 + H_i}\right) \right]^{0.5}$$

Where:
Q = flow through the gate (cfs)
b = width of gate (ft)
a = gate opening height (ft)
C = discharge coefficient
g = 32.2 ft/sec^2 (gravitational acceleration)

When outflow is influenced by downstream water level:

$$Q' = KQ$$

Where K = coefficient found in Figure B.1

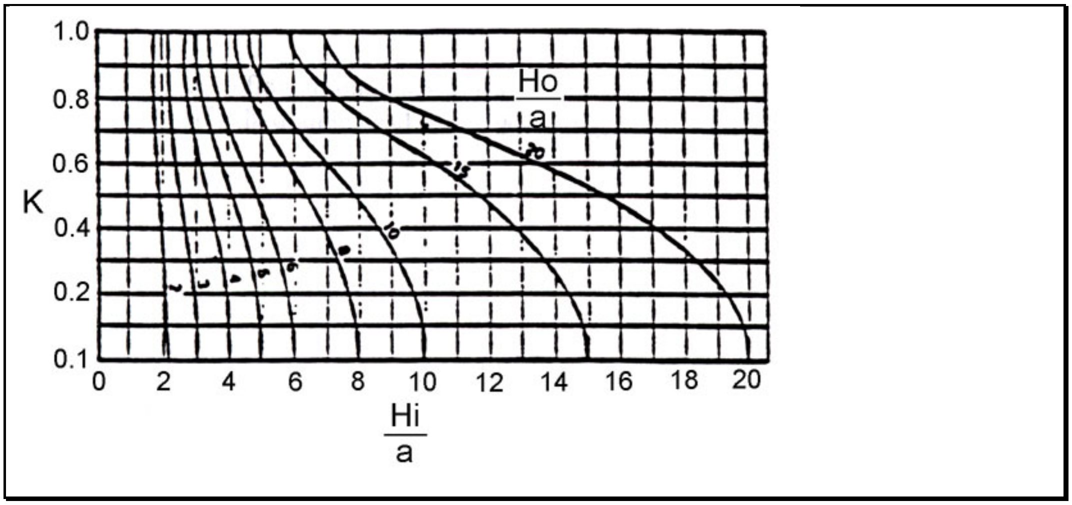

Figure B.1 Absolute Downstream Control of Flow Under Gate

3) Weirs:

Rectangular: $Q = 3.33H^{1.5}(L - 0.2H)$

60° V-notch: $Q = 1.43H^{2.5}$

90° V-notch $Q = 2.49H^{2.48}$

Where: Q = flow through the weir (cfs)
H = hydraulic head above the bottom of the weir (ft)
L = length of the weir crest (ft)

Appendix 7. Alternative Methods for RPv Compliance

The following tables may be used to compute the Resource Protection event (RPv) surface recharge reductions. The BMP Performance percentage is based on the soil classification of the BMP and the Runoff Volume entering the BMP in the RPv event.

1. Bioswale:

RPv Bioswale Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	44%	21%
0.76 - 1.50 in / acre	47%	23%
0.16 - 0.75 in / acre	57%	27%
0.00 - 0.15 in / acre	95%	95%

2. Grassed Channel:

RPv Grassed Channel Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	16%	8%
0.76 - 1.50 in / acre	18%	9%
0.16 - 0.75 in / acre	22%	11%
0.00 - 0.15 in / acre	100%	100%

3. Sheet Flow to Turf Filter Strip:

RPv Turf Filter Strip Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	21%	8%
0.76 - 1.50 in / acre	23%	9%
0.16 - 0.75 in / acre	28%	11%
0.00 - 0.15 in / acre	100%	100%

4. Sheet Flow to Forested Filter Strip:

RPv Forested Filter Strip Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	34%	16%
0.76 - 1.50 in / acre	37%	18%
0.16 - 0.75 in / acre	45%	22%
0.00 - 0.15 in / acre	95%	95%

5. Sheet Flow to Turf Open Space:

RPv Turf Open Space Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	44%	16%
0.76 - 1.50 in / acre	48%	18%
0.16 - 0.75 in / acre	57%	22%
0.00 - 0.15 in / acre	97%	97%

6. Sheet Flow to Forested Open Space:

RPv Forested Open Space Performance		
Runoff Volume (in/acre)	BMP performance	
	HSG A/B	HSG C/D
> 1.50 in / acre	59%	34%
0.76 - 1.50 in / acre	64%	37%
0.16 - 0.75 in / acre	75%	45%
0.00 - 0.15 in / acre	100%	97%

Effective Curve Number Calculation

Method to determine effective curve number after Surface Recharge Reductions.

1. Determine RPv inches of runoff entering BMP.

   RPv for Contributing Area = Runoff Volume / BMP Contributing Area * 12

   Where: RPv for Contributing Area = Inches of runoff entering BMP (in.)
   Runoff Volume = Runoff Volume Entering BMP (acre feet)
   BMP Contributing Area = BMP drainage area (acre)

2. Determine surface recharge BMP RPv runoff reduction per tables above.

3. Determine RPv runoff after BMP reduction:

   RPV runoff after reduction = RPv for Contributing Area * (1 - BMP Performance Reduction Percentage)

   Where: RPv runoff after reduction = Inches of runoff existing BMP (in.)
   RPv for Contributing Area = Inches of runoff entering BMP (in.)
   BMP Performance Reduction Percentage = Decimal percentage from tables above.

4. Determine effective Curve Number (CN):

   $$\text{Effective CN} = 46.3241 * [(\text{RPv runoff after reduction} + 0.025831)^{0.5} + 0.538054]$$

   Where: Effective CN = CN after BMP performance reduction
   RPv runoff after reduction = Inches of runoff existing BMP (in.)

5. Compare effective CN to Native BMP CN:

   NOTE: No additional runoff reduction credit can be taken for surface recharge practices once the equivalent CN for BMP reaches the native soil-cover condition (i.e. for Sheet Flow to Turf Filter Strip on B soils cannot be below a 61 CN.).

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Appendix 8. **Setbacks**

This standard provides procedures, guidelines, and requirements for setback distances between stormwater management BMPs and other site features or structures. **All applicable federal, state and local laws, rules, regulations or permit requirements governing setbacks shall be followed.** This standard does not contain the text of federal, state or local laws. **Where multiple setbacks exist, the greatest setback requirement shall apply.** Additional site location requirements may be imposed by other stormwater BMP technical standards.

This standard and specification includes the following:

I. Determining Setback Distances, and

II. Applicable Setbacks.

I. Determining Setback Distances

Horizontal setback distances for all applicable best management practices (BMPs) shall be shown on the design plans with dimensions. **The setback distances shall be measured from the BMPs water surface elevation for the Cv event to the following:**

- **Center of a public or domestic well.**
- **Closest point of a drainfield or components of a septic system.**
- **Outer edge of pipe or conduit for utilities.**
- **Outside edge of slabs or vertical walls of buildings or structures.**
- **Closest point of a property line.**

II. **Applicable Setbacks**

A. **Public and Domestic Wells**

Setbacks in this section do not apply to irrigation wells.

Setbacks from public and domestic wells are applicable to the following stormwater BMPs: infiltration practices, bioretention, permeable pavement systems, constructed wetlands, detention practices, and wet ponds.

The minimum setback from a public well as defined by the Office of Drinking Water shall be 150 feet. The minimum by right setback from a domestic well as defined by the DNREC Water Supply Section shall be 100 feet. In cases where the 100-foot setback cannot be met for a domestic well, the Department or Delegated Agency may consider an alternative method of compliance (AMC). The AMC shall consist of the following:

- **Developer shall notify owner of adjacent domestic well that a stormwater BMP is proposed on an adjacent property.** Notification should be in writing and acknowledgement of receipt such as a certified mail receipt collected.
- **Developer shall offer to sample adjacent domestic well prior to installation of the stormwater BMP and two years after installation of the stormwater BMP.** The owner of the adjacent domestic well should provide a written response to the sampling offer. The written response should either grant access to the adjacent domestic well for sampling purposes or refuse sampling. The written response may be facilitated by the developer by including a response card within the required notification.
- **Developer shall install a monitoring well between the proposed BMP and the adjacent well in accordance with Delaware regulations governing the construction and use of wells.**
- **Prior to plan approval, developer shall perform a minimum of one (1) test of the groundwater from both the monitoring well and the adjacent domestic well, if access is granted. If accepted by the adjacent domestic well owner, developer shall perform a minimum of one (1) test of the groundwater from the adjacent domestic well two years after installation of the stormwater BMP.**
- **All tests of groundwater shall monitor for the following constituents:**
    - **pH**
    - **Total Dissolved Solids**
    - **Total Phosphorus**
    - **Total Chloride**
    - **Specific Conductance**
    - **Nitrate Nitrogen**
    - **Total Nitrite/Nitrate**
    - **Total Carbon(Particulate Total Carbon)**
    - **Total Organic Carbon**
    - **Total Petroleum Hydrocarbons**
    - **Turbidity**
    - **Total Coliform**
    - **Sodium**
    - **Antimony**
    - **Arsenic**
    - **Barium**
    - **Beryllium**
    - **Cadmium**
    - **Chromium**
    - **Lead**
    - **Nickel**
    - **Selenium**
    - **Silver**
    - **Thallium**
    - **Mercury**
    - **Fluoride**
    - **Nitrite Nitrogen**
    - **Cyanide, Total**
    - **Benzene**
    - **Carbon Tetrachloride**
    - **Chlorobenzene**
    - **o-Dichlorbenzene**
    - **p-Dichlorobenzene**
    - **1,2-Dichloroethane**
    - **1,1-Dichloroethene**
    - **cis-1,2-Dichloroethylene**
    - **trans--1,2-Dichloroethylene**
    - **Dichloromethane**
    - **1,2-Dichloropropane**
    - **Ethylbenzene**
    - **Styrene**
    - **Tetrachloroethene**
    - **Toluene**
    - **1,2,4-Trichlorobenzene**
    - **1,1,1-Trichloroethane**
    - **1,1,2-Trichloroethane**
    - **Trichloroethene**
    - **Vinyl Chloride**
    - **m-Xylene**
    - **o-Xylene**
    - **p-Xylene**

- **Developer shall submit testing results of monitoring well and the adjacent domestic well, if applicable, to DNREC Source Water Assessment and Protection Program (SWAPP) and the Department Sediment & Stormwater Program or Delegated Agency.**

The minimum setback distances for domestic wells with alternative method of compliance from applicable BMPs are as follows in Table A-8.1.

Table A-8.1

HORIZONTAL SETBACK DISTANCES FROM DOMESTIC WELLS WITH AMC

Best Management Practice	**Runoff From The Following Land Use Types**	
	Residential Commercial Institutional	**Highway**
Groundwater Discharge		
Infiltration Practices	**50**	**100**
Bioretention	**50**	**100**
Permeable Pavement Systems	**50**	**100**
Constructed Wetlands	**50**	**100**
Wet Ponds (into water table)	**50**	**100**
Surface Water Discharge		
Detention Practices	**10**	**50**
Wet Ponds (above water table)	**10**	**50**

B. **Septic Systems**

Setbacks from septic system drainfields and components are applicable to the following stormwater BMPs: infiltration practices, bioretention, permeable pavement systems, constructed wetlands, detention practices, wet ponds, restoration practices, rooftop disconnection, vegetated channels, sheet flow, stormwater filtering systems, proprietary practices and afforestation. The minimum setbacks for septic system drainfields and components from applicable BMPs shall be as follows in Table A-8.2.

Table A-8.2

HORIZONTAL SETBACK DISTANCES FROM SEPTIC SYSTEMS

Best Management Practice	Drainfield (ft.)	Component (ft.)
Groundwater Discharge		
Infiltration Practices	**10**	**10**
Bioretention	**10**	**10**
Permeable Pavement Systems	**10**	**10**
Surface Water Discharge		
Detention Practices	**10**	**10**
Constructed Wetlands	**50**	**25**
Wet Ponds	**50**	**25**
Ephemeral		
Restoration Practices	**10**	**10**
Rooftop Disconnection	**10**	**10**
Vegetated Channels	**10**	**10**
Sheet Flow	**10**	**10**
Stormwater Filtering Systems	**10**	**10**
Proprietary Practices	**10**	**10**
Afforestation	**10**	**10**

C. Utilities

BMPs shall not be located within a non-blanket utility easement unless a letter of no objection from the utility owner is provided. Utilities shall not impact existing BMPs unless a letter of no objection from the BMP owner is provided.

Stormwater BMPs should be sited to avoid conflicts with existing or proposed utilities. Demonstration that conflicts will not adversely affect the integrity of either the BMP or the utility and that proper maintenance can be performed by both entities should be submitted to the Department or Delegated Agency.

BMP setbacks from tax ditch rights-of-way and crossings through tax ditch rights-of way should be consistent with tax ditch policies.

D. **Buildings and Structures**

All BMP's other than filter strips, forested, reforested or afforested areas, sheet flow, rooftop disconnection, rainwater harvesting, soil amendments, vegetated roofs and permeable pavement systems should have adequate maintenance access extending to the perimeter of the practice (BMP) and any outlet structure.

Setbacks from buildings or structures are applicable to the following stormwater BMPs: Infiltration Practices, Bioretention, Permeable Pavement Systems (excluding sidewalks or minor linear paved areas), Detention Practices, Constructed Wetlands, and Wet Ponds.

BMPs shall be setback from buildings or structures having a below-grade crawl space or basement such that the below-grade crawl space or basement of the building or structure is outside of the calculated or assumed 4:1 phreatic zone of the BMP unless the building or structure is designed to be waterproof.

Building and structure setback distances shall be no less than that needed for maintenance.

E. Property Lines

Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines unless other setback requirements are more restrictive.

Property line setback distances shall be no less than that needed for maintenance unless a shared use agreement exists between property owners.

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