Tennessee Permanent Stormwater Management and Design Guidance Manual

First Edition
December 2014






Tennessee Department of Environment and Conservation
Division of Water Resources

TENNESSEE STORMWATER MANAGEMENT

Tennessee Permanent Stormwater Management and Design Guidance Manual

Prepared by:

Tennessee Department of Environment and Conservation
Division of Water Resources

Stormwater Management, Assistance,
Research and Training (SMART) Center
The University of Tennessee

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Acknowledgements

This **Permanent Stormwater Management and Design Guidance Manual** has been prepared by the Tennessee Department of Environment and Conservation, Division of Water Resources (the division). It is intended for the design, installation and maintenance of runoff reduction and pollutant removal stormwater management practices that will help to protect and restore water bodies in communities across the state. This manual is suitable for jurisdictions and other entities that desire to manage stormwater effectively.

Many resources were consulted during the development of this manual, and when possible, permission has been granted to reproduce the information. Any omission is unintentional, and should be brought to the attention of the division.

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Chapter 1

Introduction to the Manual

1.1 Permanent Stormwater Management Approach in Tennessee

1.2 Purpose and Intended Audiences of this Manual

1.3 Permanent Stormwater Management Requirements

1.4 Other Regulatory Drivers That Influence Site Design and Stormwater Management

1.5 Site Design Drivers and Their Regional Variability Across Tennessee

1.6 Detailed Design Guidance for Permanent Stormwater Control Measures

1.7 How to Use This Manual for Design

What's in this Chapter?

Section 1.1 provides an overview of the permanent stormwater management approach in Tennessee.

Section 1.2 addresses the purpose of this manual and its intended audiences.

Section 1.3 outlines the permanent stormwater management requirements specified in Municipal Separate Storm Sewer System (MS4) permits and the sections of the manual that provide more detailed guidance on meeting these requirements.

Section 1.4 explains how MS4 permit requirements intersect with other regulatory drivers for site design and stormwater management.

Section 1.5 directs the user to parts of the manual that outline the design methodology for the various permanent stormwater control measures (SCMs) that can be used to comply with the standards specified in MS4 permits under regionally-variable conditions.

Section 1.6 points to the detailed design guidance and pictorial explanation for the SCMs contained in the manual.

Section 1.7 includes a table with a brief overview of each chapter and appendix of the manual.

1.1 Permanent Stormwater Management Approach in Tennessee

The transition from native landscapes to a built environment often results in increased pollutant loadings into receiving waters, erosion of stream channels, downstream flooding, as well as decreased infiltration and recharge of groundwater. The traditional design approach to managing these impacts has been based on the peak rate of discharge to control downstream flooding. Unfortunately, this approach doesn't take into account the increased frequency, volume, and duration of discharges, among other changes in the hydrologic response of the contributing watershed, and fails to protect the ecological (the combined physical, chemical, and biological) characteristics of receiving waters.

Traditional permanent stormwater management controls have proven to be inadequate due to the inherent limitations of poor peak control for frequent small storms, negligible runoff volume reduction, and increased duration of peak flow (NRC, 2008). Without adequate controls, urban runoff can degrade the water quality of our natural water resources; negatively affecting our drinking water, aquatic life, and outdoor recreation.

The **permanent stormwater control measures (SCMs)** identified in this manual, are runoff reduction best management practices that are intended to address the traditional permanent stormwater management limitations mentioned above by reducing stormwater runoff volume and/or pollutants. There are two major categories of SCMs: non-structural and structural.

Non-structural SCMs are passive practices that tend to be source control or pollution prevention actions that reduce the opportunity for stormwater to be generated or be exposed to potential pollutants. Non-structural SCMs are the preferred way of reducing stormwater impacts, because they avoid and minimize the amount of stormwater generated on a site. Chapter 3 of this manual focuses on using site planning as a nonstructural SCM.

Structural SCMs are physical structures designed to capture stormwater, remove pollutants, protect receiving stream channels, and promote groundwater recharge. A suite of structural SCMs are described in Chapter 5 of this manual.

There is a large body of research demonstrating that structural SCMs that are designed to infiltrate, evapotranspirate, and harvest stormwater serve to mimic the way natural vegetated landscapes respond to precipitation events. This approach is simultaneously advantageous for protecting the channel stability and ecological characteristics of receiving waters.

As a result, the Tennessee Department of Environment and Conservation (TDEC) has established runoff reduction as the treatment objective for new development and redevelopment projects. This manual provides detailed information on how to design permanent stormwater practices that meet this treatment objective.

1.2 Purpose and Intended Audiences for this Manual

The primary purpose of this manual is to serve as design guidance and technical reference for designated and non-designated (unregulated) MS4 communities in Tennessee. It is intended to provide the information necessary to properly meet minimum permanent stormwater management requirements as specified in MS4 permits.

The target audiences who will use this manual include:

1. Local officials and administrators in designated MS4 communities that must comply with Permanent Stormwater Management requirements.
2. Other localities or entities in Tennessee that choose to develop a stormwater management program or implement stormwater SCMs to protect their water resources.
3. Designers, consultants, or other individuals or companies that engage in regulated new and/or redevelopment activities.
4. Others interested in stormwater management technical criteria (e.g. businesses, state agency staff, watershed groups and citizens).

The design professional is responsible for the proper design of a functioning system that meets all the applicable requirements and considers all unique conditions of individual sites. It is the construction operator that is responsible for proper installation of the approved design. Ultimately, it is the property owner/operator's responsibility to ensure that all permanent SCMs are functioning as designed at all times.

This manual does not cover every aspect of engineering necessary for proper SCM system design, construction, and implementation, nor does it cover every possible design scenario. Where the designer determines that conformance with this manual would not be technically or financially feasible, alternative design approaches, materials, and methods will be considered on a case-by-case basis.

Throughout this manual, the words "should" and "recommended" are used for items that are recommended for good design practice and optimal performance. The words "shall," "must," and "required" indicate items that are required to achieve approval of a design based on the requirements specified in MS4 permits.

Table 1.1: Suggested Use of Manual for Intended Audiences.

MS4 Operator or Program Manager	To Create an Effective Program: Chapter 2 explains the MS4 Permanent Stormwater Management requirements, Chapter 3 describes the self-crediting “Smart Site Design” technique, and Chapter 5 lays out the range of approved structural stormwater SCMs. It is important for program managers to understand how these combine to create an effective permanent stormwater management program.
MS4 Plan Reviewer	To Effectively and Efficiently Review Plans: Chapters 3 and 4 describe the technical aspects of design for meeting regulatory standards, and Appendix E provides checklists to assist in plans review.
Designer/Consultant	To Produce Successful Designs that Achieve Site Compliance: Chapter 3 explains how to use “Smart Site Design” to maintain hydrologically functional landscapes to minimize the need for structural stormwater SCMs, and Chapter 5 provides specifications for the suite of approved structural SCMs.
Tennessee Department of Environment and Conservation (TDEC) Staff	To Provide Technical Assistance to Local Programs: The manual allows TDEC to gauge how site plans translate to achieving performance standards. This manual is an important outreach and technical assistance tool to MS4s.
Non-Regulated Local Government or Other Entity	To Set Up A Local Program: Chapter 2 provides a framework for implementing a local program for stormwater management, and the subsequent chapters may be used to provide design options for the development community.
Interested Stakeholder (Businesses, Watershed Groups, Citizens)	To Be Engaged: The manual is an education, outreach and technical assistance tool for stakeholder use as guidance in SCM selection, site development and public education.

1.3 Permanent Stormwater Management Requirements

Permanent stormwater management is required at new development and redevelopment projects that disturb one acre or greater of land, or less than one acre if part of a larger common plan of development, and are located within a designated MS4. These requirements protect water quality by addressing stormwater runoff reduction and pollutant removal at different scales of application:

1. Watershed Protection Scale
2. Site and Neighborhood Scale

1. The watershed protection scale includes a series of SCMs that serve to influence land use decisions that minimize water quality impact on a watershed scale. The approaches identified in this manual include evaluating and revising local land use regulations in an effort to prevent or reduce the impacts of stormwater runoff through policy.

- *Chapter 2 provides a brief overview of the regulatory drivers associated protecting water quality at the watershed scale.*
- *Chapter 3 describes “Smart Site Design” techniques that can be applied at multiple scales to minimize the need for structural SCMs.*

2. The site and neighborhood scale includes a series of SCMs and site design decisions and implemented in an effort to protect receiving waters. This manual provides guidance on “Smart Site Design” techniques that maintain a hydrologically functional site by managing stormwater runoff and pollution with practices that provide infiltration, evapotranspiration, harvest and/or use.

- *Chapter 3 provides a general design objective for “Smart Site Design” and associated runoff reduction credits as well as SCM implementation.*
- *Chapter 5 provides detailed guidance on the design and performance criteria for each structural SCM.*

1.4 Other Regulatory Drivers that Influence Site Design and Stormwater Management

It is important to acknowledge that, for many sites, there are overlapping regulations at the local, state, and federal levels. In addition to managing stormwater runoff, new development and redevelopment projects may need to comply with other requirements related to stormwater, such as but not limited to floodplains, wetlands, streams, flood control, karst features and dam safety. Any new development or redevelopment project that disturbs one acre or greater of land or less than one acre that is part of a larger plan of development will also be required to obtain coverage under the Construction Stormwater General Permit (CGP) that provides the details for erosion prevention and sediment control (among other construction-related measures) during the construction process. The CGP and the Tennessee Erosion and Sediment Control Handbook can be found at the following website:

http://www.tn.gov/environment/permits/conststrm.shtml.

While this manual makes reference to flood control aspects of stormwater management for larger storms, this is not its intended use. In Tennessee, flood control (also called stormwater detention) remains under the purview of local government codes, ordinance, and policy. Flooding is not regulated through MS4 Permits. As such, it should be understood that the practices in this manual are not intended to solve existing flooding and drainage issues in Tennessee communities. The practices identified here may provide additional benefit of mitigating water quantity issues, but only when they are used in conjunction with other stormwater control and floodplain management measures.

For MS4s, this manual is not intended to supersede existing procedures and policies for the review of site, drainage, or infrastructure plans. This manual can complement existing procedures by specifying the types of practices that can be used to comply with permanent stormwater management requirements.

- *Chapter 2 contains an overview of how MS4 permits intersect with other regulatory programs. MS4 managers, plan reviewers, and designers should be cognizant of the array of programs that may affect a particular site throughout the entire development or redevelopment process.*

1.5 Site Design Drivers and Their Regional Variability Across Tennessee

Successful Smart Site Designs address stormwater runoff reduction and pollutant removal by first avoiding the generation of runoff, and then managing resultant runoff volume and quality as directed in the site water balance approach and the SCM selection process detailed in Chapter 4 of this manual. Site design standards apply to relatively small storm events (1st inch of rainfall or less), as these are the high frequency storms that have the greatest potential for water quality impact. Therefore, selected SCMs tend to fit into the development infrastructure and require careful consideration of the limiting design elements such as depth, volume and long-term maintenance.

Incentives for redevelopment or exceeding performances standards may be available and will vary dependent on the local MS4 program. Also, MS4s are required to allow the use of a reasonable suite SCMs, which may not consist of all those identified in this manual. Consult applicable local ordinances or guidance for MS4-specific requirements.

Once all the requirements for the development or redevelopment project have been determined, the designer must establish the site layout and select the appropriate SCMs that fit the physical characteristics of the site and meet permanent stormwater management performance standards.

- *Chapter 3 describes "Smart Site Design" and outlines how to use this technique to retain an existing hydrologically functional landscape in order to minimize the need for structural SCMs.*
- *Chapter 4 explains the design methodology and selection process for SCMs as well as the basis for technical design (sizing and design storms) that will influence the selection process. This chapter also references the Tennessee Runoff Reduction Assessment Tool (TNRRAT) available on the internet (www.tnpermanentstormwater.org) and Site Assessment and Inventory Checklist in Appendix E. These tools will help the designer and the plan reviewer gauge compliance with the performance standards identified in MS4 permits.*

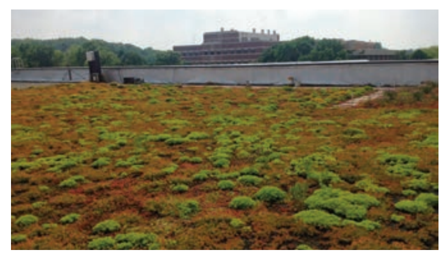
1.6 Detailed Design Guidance for Permanent Stormwater Control Measures

The selection and design of Smart Site Design elements and SCMs require the designer to be familiar with the minimum design elements and the environmental factors that influence performance.

- *Chapter 3 provides detailed instruction and practical guidance on implementing "Smart Site Design" techniques on sites and various scales.*
- *Chapter 5 provides detailed design specifications and performance standards for structural and nonstructural SCMs for compliance with the Site and Neighborhood Design Elements. Table 1.2 provides an overview of several practices.*

Table 1.2: An overview of several SCM practices described in the manual that are appropriate for implementation in Tennessee.

Permanent Stormwater Control Measures	Example
Bioretention (Residential Rain Gardens) Lot-scale measure that captures, infiltrates, and treats runoff through physical, chemical, and biological processes; sized to retain a target storage volume, designed with specific vegetation and engineered media.	
Bioretention (Linear, Ultra-Urban) Application of bioretention measure at a sub-basin scale or linear space, which necessitates the use of an underdrain to route, treated water to a receiving drainage system.	
Dry Detention A basin that provides stormwater flow control designed to release stormwater at an acceptable rate (for permanent stormwater control). This basin is typically dry between storm events. A Dry Detention Basin relies on maximum 24-hour detention of stormwater runoff after each rain event.	
Extended Detention A basin that treats stormwater in a permanent pool of water to remove common pollutants from urban stormwater runoff through sedimentation, biological uptake, and plant filtration. An Extended Detention Basin relies on 72-hour detention of stormwater runoff after each rain event.	

Permanent Stormwater Control Measures	Example
Wet Pond A basin that treats stormwater in a permanent pool of water to remove common pollutants from urban stormwater runoff through sedimentation, biological uptake, and plant filtration.	
Filter Strip Vegetated strip with uniform grade used to slow runoff and facilitate deposition of sediment in runoff before runoff reaches surface water.	
Grass Channel A vegetated, shallow drainage conveyance with relatively gentle side slopes and longitudinal grade and generally conveys flows of less than one foot of water depth.	
Green Roof A rooftop that is covered with beds or a single bed of soil and vegetation and designed to infiltrate precipitation. Also known as a vegetated roof.	
Infiltration Areas Measures that capture, filter and temporarily store runoff before allowing it to infiltrate into the underlying soil over a period of two to three days.	

Permanent Stormwater Control Measures	Example
Stormwater Treatment Wetland An area that contains hydric soils, hydrophilic vegetation, and shallow water table and is designed specifically to capture and remove pollutants.	
Manufactured/Proprietary Treatment Devices Manufactured systems that use proprietary settling, filtration, absorption/adsorption, vortex principles, vegetation, and other processes to meet the Stormwater Management Standards.	
Permeable Pavement Measure used to provide a hard surface and consists of layers designed to allow water to percolate through the surface, into a sub-base, and potentially infiltrate into the ground.	
Rainwater Harvesting Collecting and storing rainfall for later use. If managed appropriately, these systems slow and reduce runoff and provide a source of water for vegetation and base flow.	

1.7 How to Use This Manual for Design

The intended audiences for this manual have varied educational backgrounds and experience as well as interest in stormwater management. The primary objective of this manual is to provide tools for the design community and municipalities to achieve requirements for permanent stormwater management as identified in MS4 permits. Table 1.3 provides an overview of the content of each chapter of the manual.

Table 1.3: Content of the Tennessee Permanent Stormwater Management and Design Guidance Manual.

Chapter	Content
Introduction (Chapter 1)	Purpose, scope, and content of this design manual.
Background and Legal (2)	Overview of legal programs and regulations related to MS4 permits.
"Smart Site Design" (3)	Detailed description and step-by-step process of this self-crediting design technique that preserves natural hydrologic function to minimize the need for SCMs; site assessment protocols; how to handle design on challenging or special sites (e.g. karst, brownfields, shallow bedrock or groundwater, stormwater hotspots, outstanding water resources, impaired waterways, etc.).
Universal Runoff Reduction Method (4)	Instructions on how to determine project needs for storage/treatment volume in geographic regions.
Permanent Stormwater Control Measures (5)	Detailed specifications for recommended SCMs used to achieve design goals. Specifications include feasibility, sizing, design, materials, construction, and maintenance.
Using the Design Tool Package (6)	Step-by-step instructions with examples on how to use the sizing calculator and other available resources to ensure project success at meeting requirements.
Long-Term Operation and Maintenance (7)	Guidance on how to create the regulatory framework and legal foundation to ensure SCMs and site design elements function within a site as intended for the lifetime of the facility.

REFERENCES

National Research Council (NRC). 2008. Urban Stormwater Management in the United States. Washington, DC: The National Academies Press.

Chapter 2

Why Green Infrastructure as a Stormwater Solution for Tennessee?

2.1 How Development Can Threaten Tennessee's Water Resources

2.2 Overview of Permanent Stormwater Management Requirements in Tennessee and National Guidance

2.3 Other State and Federal Programs that Influence Local Stormwater Programs

2.4 General Compliance Procedure for New Development and Redevelopment Projects in Tennessee

What's in this Chapter?

Section 2.1 provides background information on the potential impacts of development on water resources and cites scientific literature that supports the use of low impact development as an effective solution.

Section 2.2 provides a brief overview of MS4 permit requirements for stormwater control and outlines the overarching stormwater regulatory framework.

Section 2.3 outlines how the permanent control standards intersect with other state and federal permits and programs.

Section 2.4 details a general compliance procedure for MS4s and other local stormwater programs to administer the permanent control standards and the development community to meet these standards.

2.1 How Development Can Threaten Tennessee's Water Resources

Clean water resources are essential to the economic viability of Tennessee, where we have over 60,000 miles of rivers and streams and over 570,000 acres of lakes and reservoirs. This section describes how development can affect receiving waters and threaten water resource sustainability.

Hydrology

Native Tennessee forests and meadows intercept, store, and slowly release rainfall through complex hydrology. Water budget studies indicate that up to 50% of the annual rainfall is intercepted by foliage and evaporated during the growing season in deciduous forest in the Southeastern United States (Wilson, 2001). Native soils also play a critical role in storing and conveying Tennessee rainfall. Further studies have shown soil hydraulic properties to be compensating mechanisms of soil water supply to meet forest transpiration demands (Luxmoore, 1983). These native landscape characteristics combine to construct naturally functioning hydrology.

The transformation from native landscapes to a built environment increases the amount of impervious surfaces, such as roads, parking areas, and rooftops. Native soils are altered during the construction process such that their infiltration properties are generally degraded. These changes reduce, disrupt, or eliminate natural drainage features, such as infiltratable soils, native vegetation, shallow depressions, and native drainage patterns. As development progresses, the land area that contributes overland flow (or runoff) in short time periods (minutes) increases, while the land area that stores, infiltrates, and recharges groundwater over long periods of time (days, weeks) decreases (Booth, 2002). The cumulative effect of these changes on the water budget (Figure 2.1) results in destabilized stream channels, impacted groundwater resources, degraded water quality, and more frequent flooding.

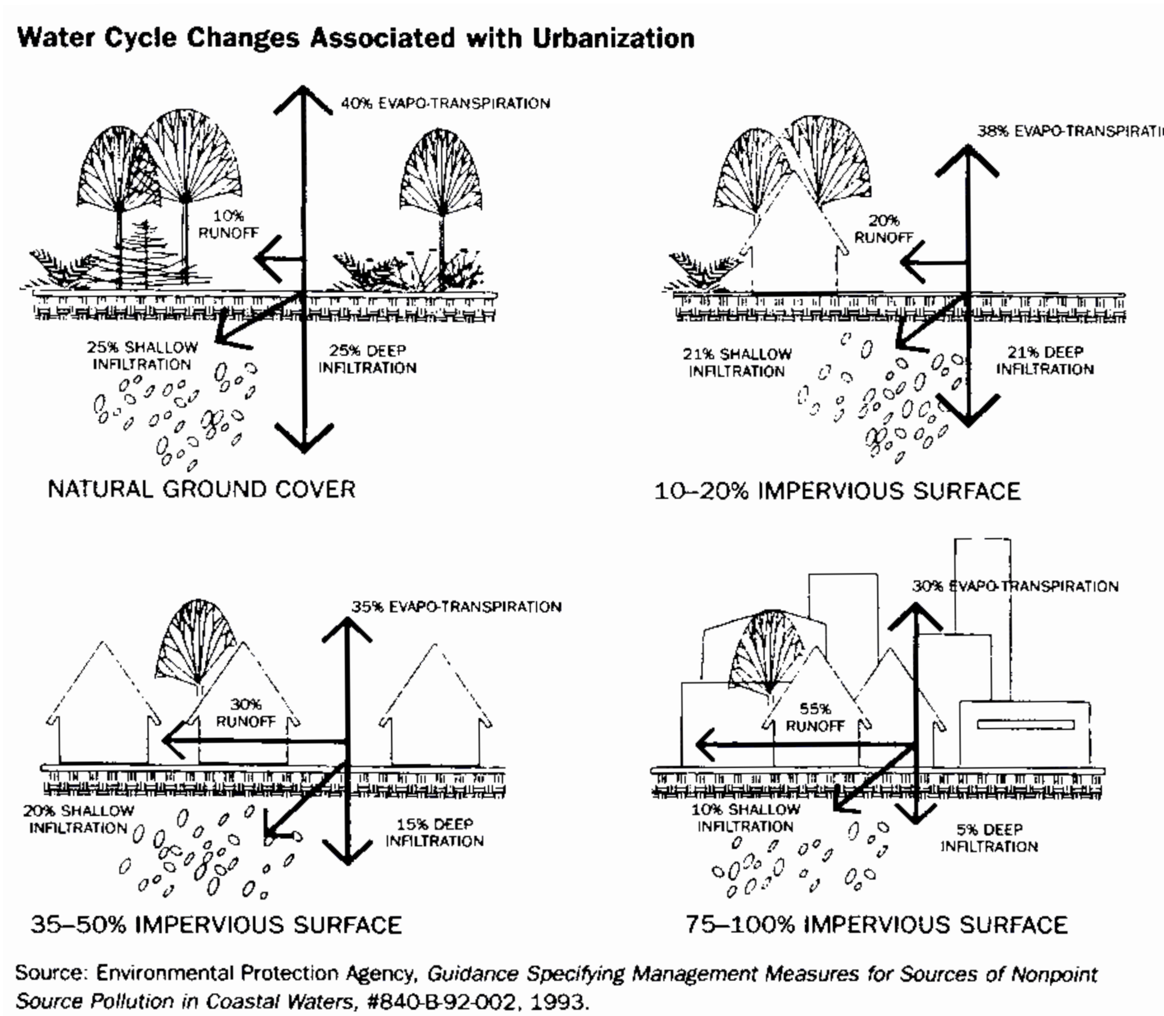


Figure 2.1: Water Cycle changes in response to development.

Streams

Development changes the permeability of land cover in watersheds, and this affects the way water flows in streams and rivers. As explained in Figure 2.2 by using hydrographs (or a diagrams of flow rate, or discharge, over time), there are two major changes in surface water flow patterns as a response to rainfall: 1) an increase in peak flow rate, and 2) a shortened lag time (e.g. time of concentration) of peak flow. Runoff is then accumulated in stream channels, where similar compounding effects are seen (Figure 2.3). These major physical changes in water flow affect stream channel shape and transport mechanisms for sediment and generally translate to large-scale watershed degradation or persistent undesirable conditions as described in Table 2.1. Often times, urban streams possess these degraded conditions, which is documented as the urban stream syndrome. Symptoms of urban stream syndrome include: flashy hydrology, elevated concentrations of nutrients and pollutants, altered channel shape and stability, and reduced biotic richness with an increased dominance of tolerant species (Walsh et al., 2005).

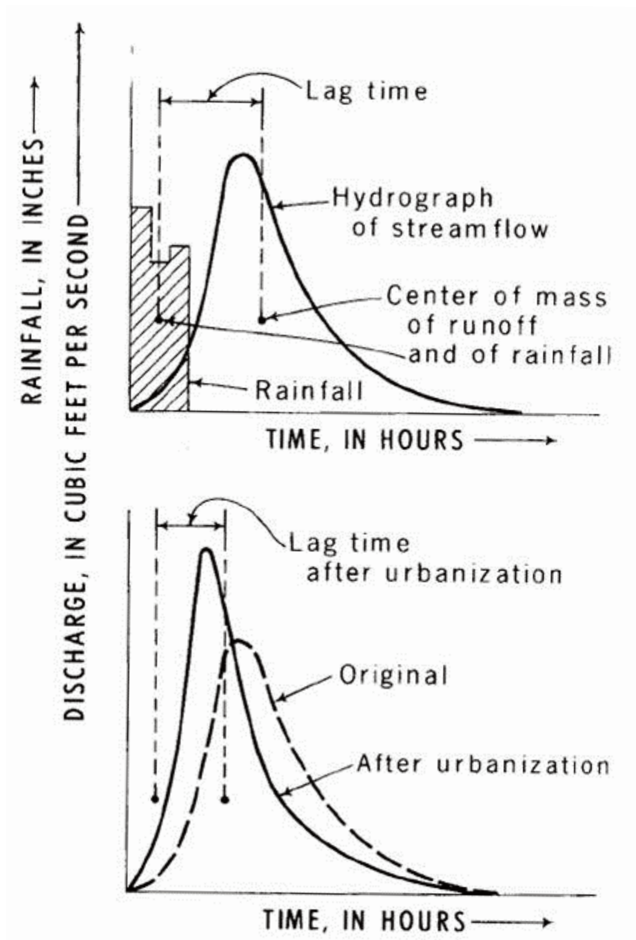


Figure 2.2: Comparison of hydrographs in a natural system *(top)* versus an urban system *(bottom)* to show changes in hydrologic response to rainfall (Leopold, 1968).

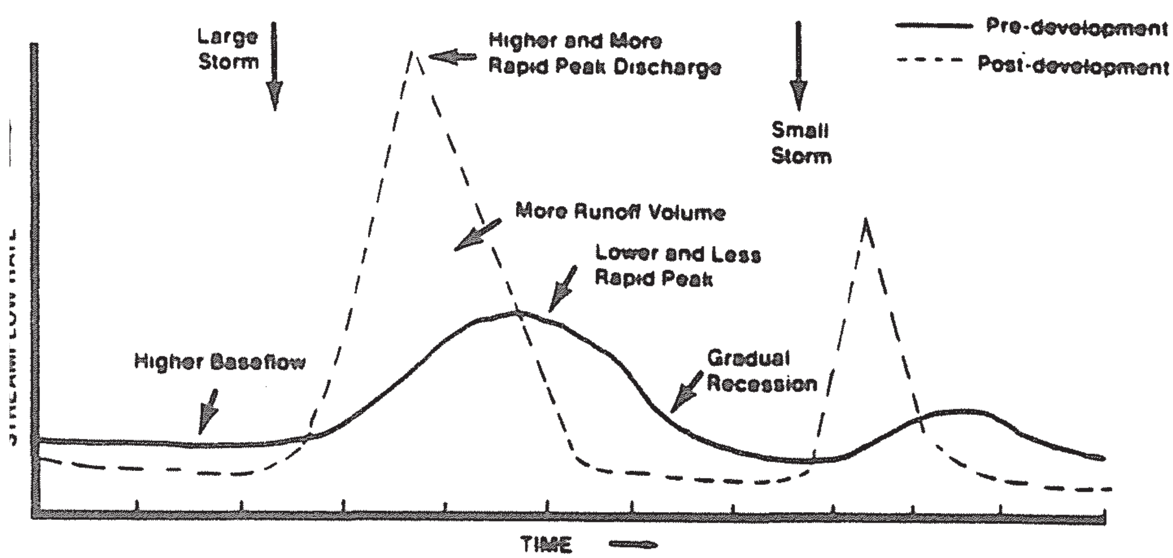


Figure 2.3: Changes in stream hydrology in response to development (From US EPA 2000 after Schuler, 1992).

Table 2.1: Watershed conditions due to development and their respective impacts on water resources (Modified from Hinman and Wulkan, 2012).

Change in Watershed Condition	Response
Increased impervious area	- Increased flow volume from runoff, peak flow rate and frequency, and channel erosion. - Increased fine sediment and urban stormwater runoff pollutants. - Potential reduction in local groundwater recharge and stream base flow conditions.
Increased road networks, road crossings, and stormwater drainage pipes	- Increased flow volume from runoff, peak flow rate and frequency, and channel erosion. - Increased fine sediment and urban stormwater runoff pollutants. - Increased fish passage barriers.
Increased fine sediment deposition	- Reduced interstitial space (between gravels/cobbles) dissolved oxygen levels. - Loss of fish spawning and macroinvertebrate habitat.
Loss or fragmentation of riparian area	- Reduced bank stability and loss of bank habitat structure. - Reduced shading and temperature buffer. - Increase potential for harmful algal blooms. - Decreased wildlife habitat. - Decreased beneficial woody debris and organic matter inputs.
Increased pollutant concentrations and loads	- Metals: increase toxicity to sensitive aquatic species. - Nutrients: excessive aquatic plant growth and drastic diurnal oxygen fluctuations. - Pesticides and herbicides: toxic to sensitive aquatic plants and animals. - Synthetic organic compounds and trace elements: tumors in fish, altered migration and spawning activities, synergistic influence of multiple types of pollutants not well understood.

There are over 60,000 miles of streams and rivers in Tennessee. Every two years, TDEC publishes an updated list of impaired waterways across the state (the 303(d) List) and a report on the status of water resources (the 305(b) Report). In the 2012 305(b) Report, approximately 26% of total stream miles in the state were identified as impaired to some degree. The sources of water pollution used in the report that are commonly associated with development are municipal discharges, construction, and hydrologic modification. These three sources account for approximately 43% of the impacts to rivers and streams. Municipal discharges alone account for 15% of the sources of water pollution, which is generally attributed to storm sewer discharges, combined sewer overflows, municipal point source discharges, and sanitary sewer overflows. Furthermore, approximately 30% of posted "Pathogen Contamination" stream miles are attributed to urban runoff/storm sewer.

Wetlands and Reservoirs

The 2012 305(b) Report identified approximately 32% of total lake and reservoir acres as impaired and over 54,000 wetland acres lost or impaired. Development impacts reservoirs by creating discharges of contaminated sediments and increasing sedimentation, nutrient runoff, drainage, filling, and loss of wetlands due to land clearing.

Water Quality

Runoff from the variety of land cover found in the urban environment carries pollutants to surface waters and has great potential to degrade water quality and aquatic habitat. Common sources of pollutants include industrial zones, commercial areas, and material handling/storage facilities. Table 2.2 lists the potential parameter of concern that affects water quality and its relative propensity to originate from different urban land uses.

Table 2.2: Relative Sources of Parameters of Concern for Different Land Uses in Urban Areas.

Problem Parameter	Residential	Commercial	Industrial	Freeway	Construction
High flow rates (energy)	Low	High	Moderate	High	Moderate
Large runoff volumes	Low	High	Moderate	High	Moderate
Debris (floatables and gross solids)	High	High	Low	Moderate	High
Sediment	Low	Moderate	Low	Low	Very High
Inappropriate discharges (mostly sewage and cleaning wastes)	Moderate	High	Moderate	Low	Low
Microorganisms	High	Moderate	Moderate	Low	Low
Toxicants (heavy metals/organics)	Low	Moderate	High	High	Moderate
Nutrients (eutrophication)	Moderate	Moderate	Low	Low	Moderate
Organic debris (SOD and DO)	High	Low	Low	Low	Moderate
Heat (elevated water termperature)	Moderate	High	Moderate	High	Low

NOTE: SOD, sediment oxygen demand; DO, dissolved oxygen. SOURCE: Summarized from Burton and Pitt (2002), and CWP and Pitt (2008).

A national project was conducted to summarize water quality monitoring data collected by MS4s across the country. The goal of the project was to characterize the chemical makeup of urban stormwater runoff. The National Stormwater Quality Database is available here:

http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/Mainms4paper.html

Water quality degradation due to urban runoff also creates the need for costly water treatment at drinking water plants, increased maintenance of municipal infrastructure, and increased risk to public health. A study found that the estimated annual cost of waterborne illness in the U.S. is comparable to the long-term capital investment needed for improved drinking water treatment and stormwater management (Gaffield et al., 2003). Preventative measures can alleviate impacts. For example, a downspout disconnection program near Flint, MI, contributed to a reduction of over 25% of mean flow volume in sanitary sewers during rain events, which translates into fewer sewer overflows. This program was also credited for a significant cost reduction for wastewater treatment at the local facility (Kaufman and Wurtz, 1997).

Low Impact Development as a Solution

In the mid-1990s, Prince George's County, Maryland, Departmental of Environmental Resources began to adopt an approach for stormwater management that used technology-based practices to ensure that a site's post-development hydrology mimicked those of the pre-development conditions, and they termed this approach Low Impact Development (LID; Coffman, 2000). The goals of LID were to retain the land's hydrologic functions of groundwater recharge, infiltration, and frequency and volume of discharges. Figure 2.4 shows how incorporating LID into development re-establishes some of the lost hydrologic functions of a traditionally developed urban environment and mimics the balance of a natural water cycle. The recommended practices (according to Prince George's County) that help create that shift back towards a natural cycle are:

- Preserve open space and minimize land disturbance
- Protect sensitive natural features and natural processes
- Identify and link on- and off-site conservation lands
- Incorporate natural features (wetlands, riparian corridors, mature forests) into site designs
- Customize site design according to the site analysis
- Decentralize and micromanage storm water at its source

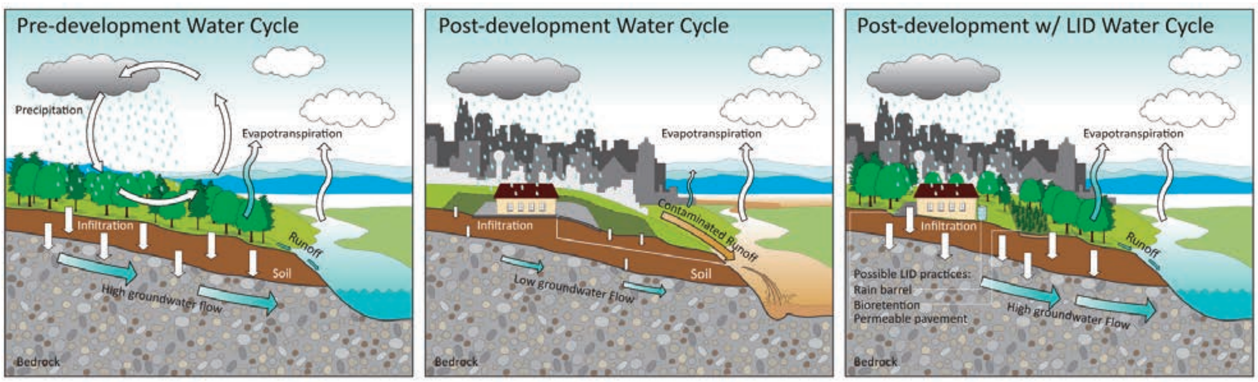


Figure 2.4: Comparison of the natural and urban water cycles and a depiction of how low impact development creates opportunities in the urban environment to mimic the natural cycle (modified from The Auckland City Council, 2010).

Copious volumes of scientific and technical literature support the use of LID and other policy and planning avenues as a means to minimize the impact of development on surface and ground water resources. Studies have found that preserving forested areas and limiting effective impervious area (e.g. impervious surface that drains into receiving waters) will lessen the risk of degradation to stream channels (Booth et al, 2002, Konrad and Burges, 2001). Case studies further support that LID is practical in varied applications and community scenarios. Several notable national examples are described below (from USEPA, 2013):

Alachua County, Florida – ***Driver: development pressures of a growing population.*** Through a Comprehensive Plan and Land Development Code, the county has protected 31% of open space, 67% of tree canopy, 27% of upland habitat, 59% of strategic ecosystems, and 100% of wetlands. This is captured in approximately 18,000 acres worth over $81 million.

Lenexa, Kansas – ***Driver: regulatory changes.*** Through their Rain to Recreation initiative, the suburb of Lenexa purchases land in priority areas to provide flood mitigation, stream protection, water quality improvement, and recreational amenities. The funding for this project comes from a combination of state and federal grants as well as a stormwater utility program and a 1/10 cent sales tax.

Olympia, Washington – ***Driver: regulatory changes.*** Olympia's stormwater regulations require development to infiltrate 91% of runoff on site. The city began to use permeable streets and sidewalks, and found that construction and maintenance of pervious sidewalks ($54/yd2) was lower than that of traditional sidewalks ($101/yd^2).

Stafford County, Virginia – ***Driver: flooding and water quality concerns.*** After policy review and ordinance approval, almost 95% of developers are using bioretention, including rain gardens, as the primary method of on-site stormwater management.

Green infrastructure and stormwater control measures (SCMs) are an integral part of the LID approach. SCMs are defined by the USEPA (1999) as "a technique, measure, or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner." SCMs can be engineered or constructed facilities, such as bioinfiltration basins and constructed wetlands, or preventative measures, such as education and better site design policies. Case studies have shown that structural SCMs; such as bioretention, green roofs, permeable pavements, and vegetated swales; can be implemented to achieve LID goals (USEPA 2000). Through the remainder of this manual, discussion of SCMs will be limited to strictly the engineered structural facilities used for runoff reduction, water quality treatment, or stormwater detention. Chapter 5 describes in depth the breath of practices that are available and their effective application and design.

2.2 Overview of Permanent Stormwater Management Requirements in Tennessee and National Guidance

Permanent stormwater is the runoff generated from impervious surfaces and other non-native land surfaces in development projects after site construction has been completed. This section provides a brief overview of permanent stormwater control requirements in Tennessee MS4 permits for the development, implementation and enforcement of permanent stormwater management programs for new development and redevelopment projects.

National Green Infrastructure Permit Language

The US EPA guides the creation of permits related to water pollution control at the state level. According to their MS4 Permit Writers' Manual and Improvement Guide, permits can be written to foster green infrastructure implementation by "establishing performance standards for post- construction stormwater volume control for sites undergoing development/redevelopment. Performance standards to control the volume of discharges and to mimic the pre-construction hydrology of a site will lead to implementation of SCMs and green infrastructure to infiltrate, evapotranspirate, and/or harvest and beneficially use stormwater." Tennessee utilized the guidance and selected runoff reduction as the preferred control practice for permanent stormwater management performance standards. The standard was expressed as a volume capture approach (rather than a percentile storm approach) in an effort to create universal, consistent and straight forward requirements statewide.

Permanent Stormwater Management Requirements in Tennessee

Under authority of the Tennessee Water Quality Control Act of 1977 and approval from the US EPA under the Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977 and Water Quality Act of 1987, operators are authorized to discharge stormwater runoff into waters of the State of Tennessee in accordance with the various eligibility criteria, administrative procedures, program requirements, reporting requirements set forth in Tennessee MS4 permits. These permits require operators to develop, implement and enforce a Stormwater Management Program designed to reduce the discharge of pollutants from the MS4 to protect water quality. The Stormwater Management Program must include management practices; control techniques, system design and engineering methods; and such other provisions as determined appropriate for the control of pollutants of concern.

To obtain permit compliance with permanent stormwater management requirements, MS4 operators must:

- Develop, implement, and enforce a program to address permanent stormwater runoff management from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development, that are within the MS4 jurisdiction instead of discharge into the MS4;
- Develop and implement strategies which include a combination of structural and/or non- structural SCMs appropriate for the MS4 community;
- Develop and implement a set of requirements to establish, protect, and maintain a permanent water quality buffer along all waters of the state at new development and redevelopment projects; and
- Use an ordinance or other regulatory mechanism to address permanent runoff from new development and redevelopment projects to the extent allowable under state or local law. All stormwater SCMs, including SCMs used at mitigation projects, installed and implemented to meet the permit performance standards must be maintained in perpetuity. The MS4 must ensure the long-term maintenance of these stormwater SCMs through a local ordinance or other enforceable policy.

MS4 performance standards influence the ordinance and policy for project-level permanent stormwater management plans. The MS4 operators must implement and enforce permanent stormwater controls that are comprised of runoff reduction and pollutant removal. If runoff reduction and pollutant removal cannot be fully accomplished onsite, then the MS4 may propose alternatives of off-site mitigation and/or payment into a fund for public stormwater projects. The MS4 must develop and apply conditions for determining the circumstances under which these alternatives will be available. These conditions cannot be based solely on the difficulty or cost of implementing measures, but must include multiple criteria that would rule out an adequate combination of infiltration, evapotranspiration, and reuse. Examples of such site conditions are lack of available area to create necessary infiltration, a site use that is inconsistent with capture and reuse of stormwater, or physical conditions that preclude use of these practices.

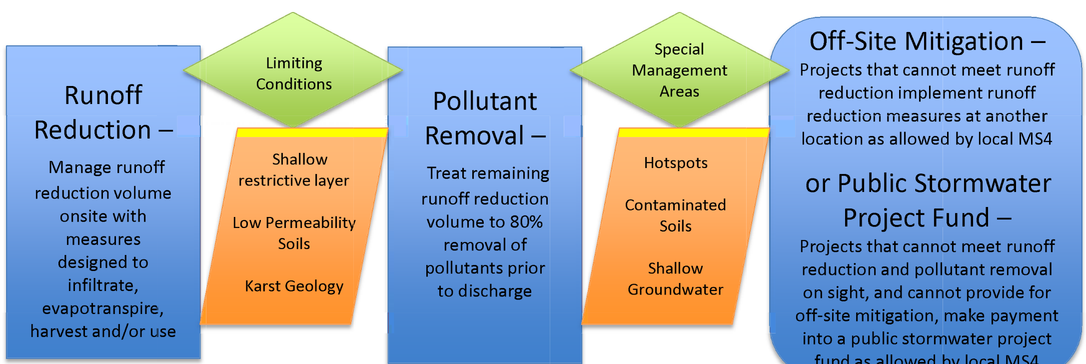


Figure 2.5: Decision Diagram of Permanent Stormwater Control requirements and the determination criteria for allowable alternative management methods.

Runoff Reduction and Pollutant Removal with Smart Site Design

Site design standards for all new development and redevelopment require management measures that are designed, built, and maintained to infiltrate, evapotranspire, harvest and/or reuse, at a minimum, the first inch of every rainfall event preceded by 72 hours of no measurable precipitation. The first inch of rainfall must be 100% managed with no stormwater runoff being discharged to surface waters. For site design and assessment purposes, this manual expresses the first inch standard in terms of a timing component and an overall volume, as discussed in detail in Chapter 3, Section 3.4.

Limitations to the application of runoff reduction requirements include, but are not limited to:

- Where a potential for introducing pollutants into the groundwater exists, unless pretreatment is provided;
- Where pre-existing soil contamination is present in areas subject to contact with infiltrated runoff;
- Presence of sinkholes or other karst features.

Incentive standards and credits may be developed by an MS4 for redevelopment sites. The MS4 may provide a 10% reduction in the volume of rainfall to be managed for any of the following types of development. These credits can be additive such that a maximum reduction of 50% of the volume of rainfall to be managed is possible for a project that meets all 5 criteria:

1) Redevelopment projects;
2) Brownfield redevelopment;
3) High density (>7 units per acre);
4) Vertical density (Floor to Area Ratio (FAR) of 2 or >18 units per acre); and
5) Mixed use and transit oriented development (within ½ mi of transit).

Elements of Smart Site Design may be useful in minimizing total management volume for runoff reduction requirements and are described in detail in Chapter 3. Permanent SCMs can be used to meet the performance standard for runoff reduction and pollutant removal. Pre-development infiltrative capacity of soils at the project site must be taken into account in selection of runoff reduction management measures. For projects that cannot meet the runoff reduction requirement, the remainder of the stipulated volume of rainfall must be treated prior to discharge with a technology reasonably expected to remove 80% total suspended solids. Runoff reduction and treatment design targets for structural SCMs are discussed in Chapter 4. Ensure that your local MS4 recognizes the practices you intend to use at your project site as approved for use and appropriate for your project location.

2.3 Other State and Federal Programs that Influence Local Stormwater Programs

MS4 Permits do not function alone. There are several other state and/or federal regulatory drivers that will influence how stormwater is managed by an MS4 or other local program. While the MS4 is not responsible for administering or enforcing state or federal permits, it may be placed in the role of integrating or coordinating state and federal permits with local stormwater ordinances and standards for certain new development and redevelopment projects. For instance, the MS4 may need to be aware of approval of the stormwater plan with other approvals for activities in streams and wetlands, underground injection, or dam safety.

Table 2.3: Regulatory Programs and Drivers that influence or intersect with site design and stormwater management.

Responsible Agency	Program Name	How it interacts with permanent stormwater management
TDEC-DWR	Construction Stormwater General Permit	Applies to all sites with disturbance of one acre or greater to regulate sediment discharges into waters of the state. Projects disturbing at least one acre are required to submit a Notice of Intent applications and Stormwater Pollution Prevention Plan (SWPPP). The permit is reissued on a periodic basis (e.g. every five years) The permit program is accompanied by the Tennessee Erosion and Sediment Control Handbook (2012). *Link With Stormwater Program:* This permit provides an opportunity for local programs to coordinate construction and post-construction stormwater in plan review, inspection and maintenance. Contact: Tennessee Department of Environment and Conservation (TDEC), Division of Water Resources: http://www.tn.gov/environment/permits/conststrm.shtml

<table>
<tr><th>Responsible Agency</th><th>Program Name</th><th>How it interacts with permanent stormwater management</th></tr>
<tr><td>TDEC-DWR</td><td>Multi-Sector Stormwater General Permits (Industrial Activities)</td><td>In order to minimize the impact of stormwater discharges from industrial facilities, the National pollutant Discharge Elimination System (NPDES) program includes an industrial stormwater permitting component. Operators of industrial facilities that discharge or have the potential to discharge stormwater to an MS4 or directly to waters of the state are required to obtain coverage under the TMSP by submitting a NOI application to TDEC.

Link With Stormwater Program: This permit provides an opportunity for local programs to coordinate stormwater review and inspections for industrial operators.

Contact: Tennessee Department of Environment and Conservation (TDEC), Division of Water Resources:
http://www.tn.gov/environment/permits/tmsp.shtml</td></tr>
<tr><td>TDEC-DWR</td><td>Aquatic Resources Alteration Permit (ARAP)</td><td>Persons who wish to make an alteration to a stream, river, lake or wetland must first obtain a water quality permit. Physical alterations to properties of waters of the state requires an Aquatic Resource Alteration Permit (ARAP) or a §401 Water Quality Certification (§401 certification). Examples of stream alterations that require a permit from the Tennessee Division of Water Pollution Control (division) include:
• Dredging, excavation, channel widening, or straightening
• Bank sloping; stabilization
• Channel relocation
• Water diversions or withdrawals
• Dams, weirs, dikes, levees or other similar structures
• Flooding, excavating, draining and/or filling a wetland
• Road and utility crossings
• Structural fill

A federal permit may also be required from the U. S. Army Corps of Engineers (Corps) for projects that include the discharge of dredged or fill material into waters of the U.S. including wetlands. This permit is called a §404 permit. When a §404 is required from the Corps, a §401 certification must first be obtained from the division. A §401 certification affirms that the discharge would not violate Tennessee's water quality standards. The application process for a §401 certification is the same as the ARAP process.

Link With Stormwater Program: Often construction stormwater and permanent stormwater control measures and related activities could involve some physical alteration of a water bodies and would require coverage under the ARAP program.

Contact: Tennessee Department of Environment and Conservation (TDEC), Division of Water Resources
http://www.tn.gov/environment/permits/arap.shtml</td></tr>
</table>

Responsible Agency	**Program Name**	**How it interacts with permanent stormwater management**
TDEC-DWR	Underground Injection Control Permits (UIC)	TDEC-DWR Groundwater Section regulates Class V injection wells (shallow non-hazardous) under the Underground Injection Control (UIC) program. There are cases where stormwater infiltration practices are regulated as Class V wells. The division encourages the use of infiltration practices and notes that when designed to manage only the treatment volume specified in MS4 permits, these practices do not meet the Class V definition and can be installed without requiring UIC permits. Any additional volumes must daylight or bypass the infiltration practice. There are two general exceptions, with the following practices requiring UIC permits: 1) Commercially manufactured stormwater devices include a variety of pre-cast or pre-built proprietary subsurface detention vaults, chambers or other devices designed to capture and infiltrate stormwater runoff. These devices are Class V wells since their designs often meet the Class V definition of subsurface fluid distribution. 2) Improved sinkholes include any bored, drilled, driven, or dug shaft or naturally occurring karst feature where stormwater is infiltrated. A naturally occurring karst feature receiving runoff that has been modified in volume or quantity is also considered an improved sinkhole. These practices are Class V wells since their designs often meet the Class V definition of subsurface fluid distribution. *Link with Stormwater program:* At the local level, a UIC program integrated with careful planning and the utilization of SCMs and other ground water protection initiatives can significantly reduce the threat to drinking water supplies. Contact: Tennessee Department of Environment and Conservation (TDEC), Division of Water Resources, Groundwater Management Section http://www.tn.gov/environment/permits/injetwel.shtml
U.S. Army Corps of Engineers TDEC-DWR	Clean Water Act Section 404 Permit and 401 Certification	A federal permit may be required from the U. S. Army Corps of Engineers (Corps) for projects that include the discharge of dredged or fill material into waters of the U.S. including wetlands. This permit is called a §404 permit. When a §404 is required from the Corps, a §401 certification must first be obtained from the division. A §401 certification affirms that the discharge would not violate Tennessee's water quality standards. The application process for a §401 certification is the same as the ARAP process. *Link With Stormwater Program:* See above for ARAP. The effort on behalf of the MS4 to avoid or prevent hydromodification of stream and other water bodies overlaps with the intent of the Section 404 permit to avoid and minimize impacts. Contact: U.S. Army Corps of Engineers, TDEC-DWR

Responsible Agency	Program Name	How it interacts with permanent stormwater management
U.S. Environmental Protection Agency	Section 438 of the Energy Independence and Security Act (EISA)	Section 438 of EISA states that "the sponsor of any development or redevelopment project involving Federal facility with a footprint that exceeds 5,000 square feet shall use site planning design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow." In 2009, the U.S. Environmental Protection Agency (EPA) issued technical guidance for implementing this provision of EISA. *Link With Stormwater Program:* The local program should be aware of the EISA requirements and guidance for federal facilities that may be constructed or redeveloped within the community. The local program may not have the authority to review federal projects, but these federal facilities can often seek to coordinate with any local requirements. In addition, federal facilities can often discharge into an MS4; therefore the MS4 should be aware of this discharge and have the ability to address adverse impacts to their system. Contact: U.S. Environmental Protection Agency http://www.epa.gov/owow/NPS/lid/section438/
Tennessee Department of Economic and Community Development Tennessee Emergency Management Agency Local governments	Floodplain Permits	The National Flood Insurance Program (NFIP) in Tennessee works closely with private insurance companies to offer flood insurance to property owners and renters. In order to qualify for flood insurance, a community must join the NFIP and agree to enforce sound floodplain management standards. The National Flood Insurance Program (NFIP) is a federal program created in 1968 that allows citizens in participating communities to purchase insurance coverage for potential property damage as a result of flooding. This voluntary program for local communities is administered by the Mitigation Division of the Federal Emergency Management Agency (FEMA). The three components of the NFIP are: • Flood Insurance • Floodplain Management • Flood Hazard Mapping In return for a local community adopting and enforcing local floodplain management regulations, flood insurance is available in the community. Currently, nearly 400 Tennessee communities participate in the NFIP. Of all natural disasters, flooding is historically responsible for the most loss of life and the greatest damage to property in the state. There are currently more than 21,000 stream miles that have identified flood hazard risks in Tennessee. *Link With Stormwater Program:* The local program will have to coordinate reviews for any controls that are authorized to be located in the floodplain. Also preservation, protection, and/or restoration of floodplains and riparian corridors can be very beneficial for stormwater management. Contact: Tennessee Department of Economic & Community Development http://www.tn.gov/ecd/CD_flood_insurance_prg.shtml

Responsible Agency	Program Name	How it interacts with permanent stormwater management
TDEC-DWR	Total Maximum Daily Load (TMDL)	Section 303(d) of the Clean Water Act establishes the Total Maximum Daily Load (TMDL) program. TMDLs provide a system to develop studies and plans for stream segments that do not meet water quality standards. A TMDL is a study that: 1) quantifies the amount of a pollutant in a stream, 2) identifies the sources of the pollutant, and 3) recommends regulatory or other actions that may need to be taken in order for the stream to cease being polluted. Some of the actions that might be taken involve re-allocation of limits on the sources of pollutants documented as impacting streams. It might be necessary to lower the amount of pollutants being discharged under NPDES permits or to require the installation of other control measures, if necessary, to ensure that water quality standards will be met. *Link With Stormwater Program:* If an MS4 discharges into a water body with an approved or established TMDL, then the Stormwater Management Program must include BMPs (SCMs) specifically targeted to achieve the wasteload allocations and requirements prescribed by the TMDL. Contact: Tennessee Department of Environment and Conservation (TDEC), Division of Water Resources http://www.tn.gov/environment/wpc/tmdl/

Local policy and ordinances specific for MS4 jurisdictions may also guide or dictate permanent stormwater management planning and design. Examples of these include land use codes, right-of-way easements, roadway setbacks, impervious surface ratios and a suite of other policies that affect how development is distributed. Check local municipal offices for more information on development codes and policy.

2.4 General Compliance Procedure for New Development and Redevelopment Projects in Tennessee

The MS4 Permit establishes general standards for plan review, approval, and enforcement of permanent stormwater management programs to control runoff from new development and redevelopment. Successful implementation requires coordinated efforts by both the MS4 operator and the owner or applicant for new development or redevelopment projects. The program elements include preparation, submittal, review, and approval of stormwater management plans as well as construction, inspection, and maintenance of permanent stormwater SCMs.

Figure 2.6 illustrates the general order of recommended actions for both the MS4 program and the project applicant in order to be compliant with the MS4 permit provisions. The left side lists the responsibilities of the MS4 program, and the right side those of the project applicant. This is the typical order of actions, but individual local programs may have alternative plan review and inspection procedures that take precedence. Local governments can adapt or modify individual components of this process if the local program deems alternatives more effective.

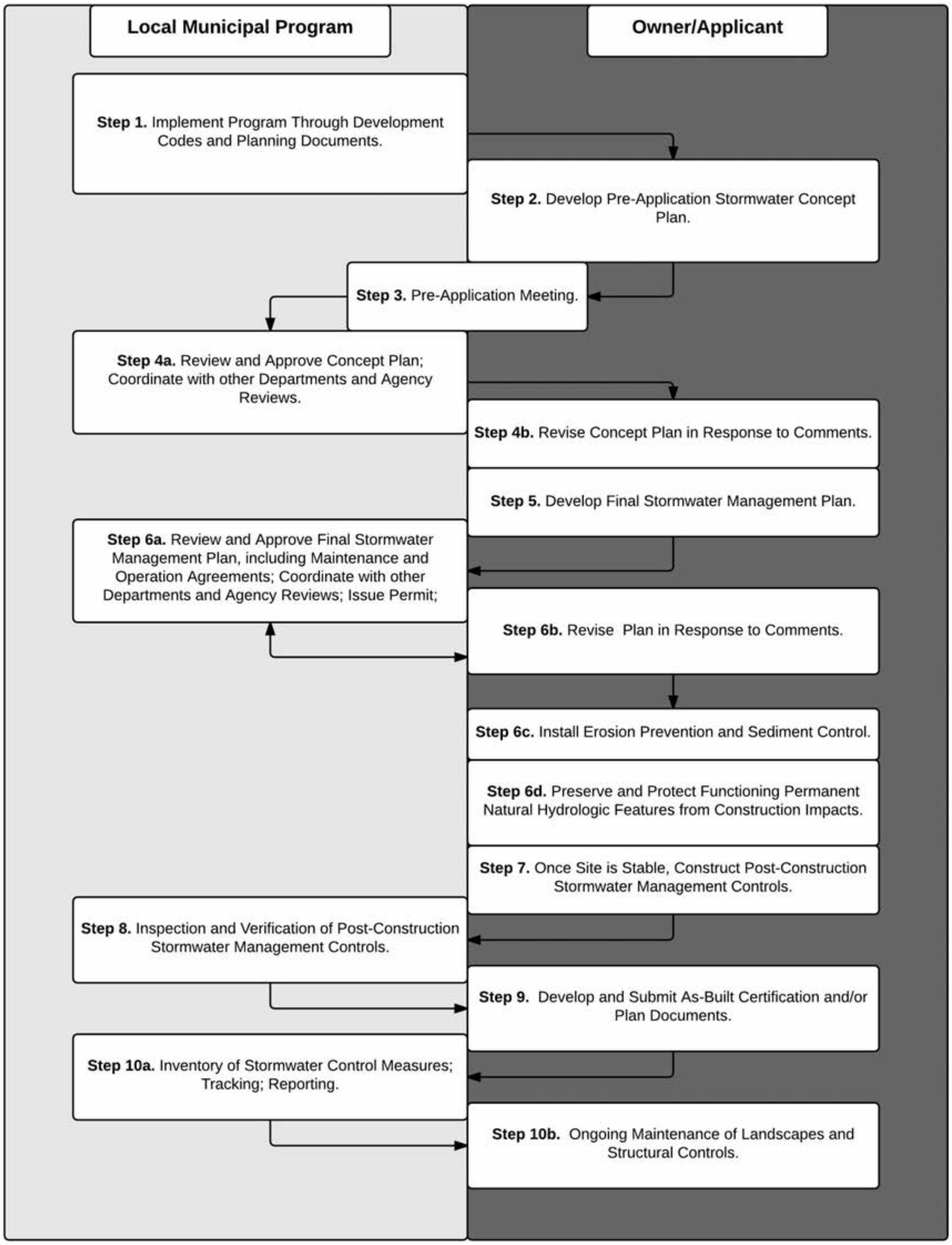


Figure 2.6: Typical Compliance Pathway for Permanent Stormwater Runoff Management for New Development and Redevelopment Projects.

The following are recommended steps in Permanent Stormwater Management Control Implementation and Project-Level Compliance:

Step 1 Implement Program Through Ordinance or other Regulatory Mechanisms

Who Does This Step?

- The MS4 or local stormwater program

When Does This Step Occur?

- At initial program development prior to plans being submitted

Description: The MS4 Permit contains provisions for the development, implementation and enforcement of a local program to address permanent stormwater runoff management from new development and redevelopment projects This program should include strategies which use a combination of structural and/or non-structural stormwater control measures (SCMs) appropriate for your community, requirements to establish, protect and maintain a permanent water quality buffer along all waters of the state and the use of ordinances or other regulatory mechanisms to address permanent runoff from new development and redevelopment projects.

Step 2 Develop Pre-Application Stormwater Concept Plan

Who Does This Step?

- The owner/applicant/design engineer for a new development or redevelopment project that disturbs one-acre or greater, including projects of less than one acre that are part of a common plan of development.

When Does This Step Occur?

- Very early in the site planning process before infrastructure and lot configurations are locked down.

Description: The Concept Plan provides the opportunity for the applicant to put basic stormwater design ideas and measures on paper before expending time and resources preparing complex engineered plans and computations. This step can help both the local stormwater program and the developer avoid problems that could occur if the plan is submitted later in the process.

Step 3 Pre-Application Meeting

Who Does This Step?

- Both the MS4/local stormwater program AND the owner/applicant along with the project design engineer.

When Does This Step Occur?

- Soon after the owner/applicant prepares the Concept Plan outlined in Step 2. However, it may be advantageous for the parties to meet in the office or in the field prior to the completion of the Concept Plan if site design and stormwater discussions would aid the applicant in preparing the Concept Plan.

Description: The intent of this meeting is to discuss compliance issues and allow for constructive interaction between the parties. It is hoped that this meeting will result in a higher quality submittal and a faster compliance schedule. The meeting is particularly relevant to discuss site design issues that could reduce the volume of rainfall to be managed on the site, application of site design incentives, and the most applicable SCMs for the site.

Step 4a Review & Approve Concept Plan; Coordinate with Other Departments & Agency Reviews

Who Does This Step?

- MS4/local stormwater program

When Does This Step Occur?

- Within the specified time for review of the Concept Plan after accepting the submittal as complete

Description: The approval to the Concept Plan should mean that there is enough information to confirm that the Final Stormwater Management (Step 5) is very likely to achieve compliance. This is the time to coordinate with other internal reviews such as roads and drainage plans, plats, water and sewer, floodplains, erosion and grading. This is the chance to vet and resolve possible internal conflicts that may limit or omit the use of certain measures. The plan reviewer should also coordinate the review with external reviews, especially for plans subject to state or federal reviews, such as wetlands and stream permits, and other discharge permits required for the site.

Step 4b Revise Concept Plan in Response to Comments

Who Does This Step?

- Owner/applicant and design engineer

When Does This Step Occur?

- After receiving comments, if any, from the plan reviewer

Description: The design engineer revises the Concept Plan components in response to the reviewer comments. The objective at this point is to ensure that there is enough information to develop a complete and compliant Final Stormwater Management Plan. Engineering details and final computations are not expected at the concept plan stage.

Step 5 Develop Final Stormwater Management Plan

Who Does This Step?

- Owner/applicant and design engineer

When Does This Step Occur?

- After approval of Concept Plan

Description: Using the approved Concept Plan, as a framework, the Final Stormwater Management Plan is developed. A typical plan submittal package would include the items listed in Table 2.4. It should be noted that the final stormwater management plan is often coordinated with other final plan such as grading and drainage, erosion control, utilities and road plans. The actual content for the final plans is dictated by the local program requirements, the items in Table 2.4 are guidelines.

Step 6a Review and Approve Final Stormwater Management Plan; Coordinate with Other Departments & Agency Review; Issue Permit; Collect Bond;

Who Does This Step?

- MS4/local stormwater program

When Does This Step Occur?

- Within the specified time for the review of the Final Stormwater Management Plan after accepting the submittal as complete.

Description: This is a detailed review to verify compliance with the standards in the MS4 permit and the local ordinance. The reviewer should verify that the information submitted matches up with the information shown on the plan sheets, the engineering design specifics, narrative and computational elements of the plan. The plan reviewer can at this point develop specific comments that need to be addressed in order for the plan to receive approval. Final plan approval requires coordination with other internal and external reviews for the project. Some programs specify that a performance bond be posted as a condition of final approval.

Step 6b Revise Final Plan in Response to Comments

Who Does This Step?

- Owner/applicant and design engineer.

When Does This Step Occur?

- After receiving comments from the plan reviewer.

Description: The design engineer responds to comments from the reviewer. This is an iterative step with Step 6a.

Table 2.4: Recommended Components of a Comprehensive Stormwater Management Plan (Adapted from Claytor, 2006).

Component	Component Items
Graphical	• Vicinity map • Plan view showing SCM locations, sizing, post-development drainage areas, and layout with storm sewer and other utilities • For each SCM necessary, cross-sections and profile details with elevations of critical components • Graphical portrayal of coordination with erosion prevention and sediment control SCMs (i.e. how will they transition) • Typical details and notes • Soil survey, geology, slope, land cover, and other relevant maps for design
Narrative and Computations	• Cover: Project Title, client, nature of computations • Copy of summary of Design Compliance Spreadsheet • Table of proposed SCMs with target treatment volume per drainage area, storage volume, and sizing • Contributing area delineation for pre- and post-development conditions with times of concentrations, land use, and soils • Narrative of stormwater management systems • Summary of hydrology and hydraulics • Table of drainage areas, curve numbers, time of concentration, and peak discharge (pre-and post-development) that summarizes the performance of proposed stormwater SCMs • Detailed hydraulic calculations • Hydrologic analyses • Supporting calculations (i.e. channel sizing, outfall channel, downstream analyses, structural calculations) • Site photographs • List of permit requirements and how project is in compliance (including other pertinent permits) • Soil test pits or borings; results of infiltration tests • Pollutant monitoring data • Groundwater table elevation • Habitat evaluations • Tree surveys • Threatened and endangered species • Receiving waters classification • Topographic maps
Supporting Documents	• Maintenance agreements • Maintenance plan for each SCM • Submittal fees • Engineer's certification statement • Documentation of other permits • Performance bond • Other permits applied for • Land use restrictions or deed restrictions

Step 6c Install Erosion Prevention and Sediment Control

Who Does This Step?

- Owner/applicant and site contractor.

When Does This Step Occur?

- After receiving comments from the plan reviewer.

Description: The design engineer responds to comments from the reviewer. This is an iterative step with Step 6a.

Step 6d Preserve and Protect Functioning Permanent Natural Hydrologic Features from Construction Impacts

Who Does This Step?

- Owner/applicant and site contractor.

When Does This Step Occur?

- After receiving comments from the plan reviewer.

Description: Mark and protect these permanent natural hydrologic features from construction impacts using proper fencing materials with signage.

Step 7 Once Site is Stable, Construct Post-Construction Stormwater Management Controls

Who Does This Step?

- Owner/applicant and site contractor

When Does This Step Occur?

- After receiving final approval of the Stormwater Management Plan. Posting performance bond (if required by the local program), receiving all necessary permits and approvals, and following the proper construction/SCM installation sequence as specified in the plan.

Description: Depending on the SCM, a very specific construction sequence should be followed. In particular, SCMs that have a filter media, rely on infiltration into the underlying soil, and/or that are vulnerable to construction sediments should only be installed once the contributing drainage areas reach a specific level of stabilization. The Final Stormwater Management Plans should be coordinated with the grading and drainage and erosion and sediment plans to ensure that the installation of permanent stormwater SCMs follows the proper sequence. It is often helpful for the design engineer to have a role in ensuring that post-construction SCMs are built according to the plan.

Step 8 Inspection & Verification of Post-Construction Stormwater Management Controls

Who Does This Step?

- MS4/local stormwater program

When Does This Step Occur?

- Permanent SCMs should be inspected at critical stages during installation, and a final inspection should be conducted to verify that the SCM is installed in accordance with the plan and/or any approved field changes.

Description: Many SCMs do not perform as intended due to improper installation and construction issues. Figure 2.7 illustrates several common construction and installation pitfalls, using bioretention as an example. Inspection frequency depends on the type of measure. Measures with multiple materials and layers, subgrade construction, and multiple-step construction sequences usually require more interim inspections. One of the most important roles of inspectors during SCM installation is to ensure that the drainage areas are adequately stabilized in order to install permanent SCMs. For instance, premature installation of bioretention soil media is one of the major causes of failure of these measures.

Appendix F of this manual contains checklists for various SCMs that can be used as a tool for the inspection process.

Bioretention swale, installed too early during active construction, has become clogged with sediment.

Bioretention area does not drain because of improper soil media, soils compacted during installation, and/or filter fabric under media.

Curb inlets to bioretention swale have eroded because of improper sizing of stone.

High plant mortality has occurred because improper species were substituted during construction.

Site runoff bypasses bioretention swale because of small elevation changes during construction.

Some site runoff bypasses bioretention because of inadequate slope of filter strip.

Figure 2.7: Common issues with installation of permanent SCMs, using bioretention as an example (Adapted from West Virginia, 2012).

Step 9 Develop & Submit As-Built Certification and/or Plan Documents

Who Does This Step?

- Owner/applicant, site contractor and/or design engineer.

When Does This Step Occur?

- Once the final sign-off occurs from the inspector. The MS4 General Permit requires a verification process to ensure that permanent SCMs have been installed per design specifications, that includes enforceable procedures for brining noncompliant projects into compliance. It is recommended that MS4 communities require the submittal of "as-built certifications" be submitted within 90 days of completion of the project

Description: Once the SCM installation is complete, as verified by the inspector, the applicant's design consultant prepares an as-built plan for each SCM based on actual site conditions. This plan can take the form of a "red-lining" approved design plan to note any discrepancies. The design professional also certifies that the constructed SCM meets or exceeds plan specification. It is important for the as-built plan to confirm:

- Placement of SCMs within easements
- Proper sizing, dimensions, and materials
- Elevations of inlets, outlets, risers, embankments, etc.
- Vegetation per the planting plan and any approved substitutions
- Location of permanent access easements for maintenance

Step 10a Inventory of SCMs, tracking, and reporting

Who Does This Step?

- MS4/local stormwater program

When Does This Step Occur?

- Ongoing, as part of an SCM maintenance, tracking, and reporting program.

Description: The proper installation of a permanent SCM is only the beginning of its life-cycle. Long-term maintenance and operation are needed to ensure continued performance and functioning. In this regard, the MS4 General Permit contains provisions for maintenance agreements, inventory, inspection and tracking of SCMs. Table 2.5 outlines the MS4 General Permit sections for each of these topics. The MS4 General Permit should be consulted for full details concerning these programs requirements.

Step 10b Ongoing Maintenance of Landscapes and Structural Controls

Who Does This Step?

- Owner/applicant or as determined by MS4/local stormwater program

When Does This Step Occur?

- Ongoing, as part of an SCM maintenance, tracking, and reporting program.

Description: Long-term maintenance and operation are needed to ensure continued performance and functioning. In this regard, the MS4 General Permit contains provisions for maintenance agreements, inventory, inspection and tracking of SCMs. Table 2.5 outlines the MS4 General Permit sections for each of these topics. The MS4 General Permit should be consulted for full details concerning these programs requirements.

Table 2.5: Outline of MS4 General Permit Sections Pertaining to Long-Term BMP (SCM) Maintenance, Inventory and Tracking Management Practices and Owner/Operator Inspections.

Topic	MS4 General Permit Section	Brief Description
BMP (SCM) Maintenance	Section 4.2.5.5	All stormwater BMPs (SCMs) must be maintained in perpetuity. The MS4 must ensure the long-term maintenance of these stormwater SCMs through a local ordinance or other enforceable policy. Specifies that owners/operators must develop and implement a maintenance agreement addressing maintenance requirements and provide verification of maintenance for the approved stormwater BMPs (SCMs). Authorizes MS4 to perform necessary maintenance or take corrective actions if necessary.
Inventory and Tracking Management Practices	Section 4.2.5.6	Requires MS4 to establish an inventory and tracking system (e.g. database or GIS) of BMPs (SCMs) deployed at new development and redevelopment projects. It is recommended to begin during the plan review and approval process through to long-term maintenance. It specifies minimum content for the database or tracking system.
Owner/Operator Inspections	Section 4.2.5.7	MS4 is to require owners/operators to perform a minimum annual to ensure that the BMPs (SCMs) and other stormwater management facilities are properly functioning. Once every five years, at minimum, owners/operators will perform comprehensive inspections with a professional engineer or landscape architect. Owners or operators shall maintain documentation of these inspections. The MS4 may require submittal of this documentation.

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Chapter 3

Watershed Protection and *Smart* Site Design Requirements

3.1 Elements of Smart Site Design

3.2 Watershed Protection – From Downspout to River Mouth

3.3 Site Inventory and Assessment

3.4 Site Design Targets (1" runoff reduction vs. pollutant removal vs. off-site mitigation)

What's in this Chapter?

Section 3.1 discusses the elements of a Smart site design approach and define terminology that is used throughout the remainder of this manual.

Section 3.2 describes the process of effective runoff reduction with green infrastructure for integrated stormwater management at different scales, at which stormwater runoff is avoided, minimized, and managed from downspout to river mouth.

Section 3.3 discusses site inventory and assessment protocols and checklists as well as descriptions of special management areas, which are areas that possess characteristics and/or limitations that affect the manner in which runoff reduction strategies may be implemented on a site.

Section 3.4 describes permanent stormwater design targets that are delineated into categories of runoff reduction, pollutant removal, and off-site mitigation.

3.1 Elements of *Smart* Site Design

3.1.1 What are Green Infrastructure and Runoff Reduction? (common terminology)

Tennessee's approach to permanent stormwater management on new and redevelopment projects addresses the following goals for protecting watershed hydrology and municipal and private property: 1) recharging groundwater and maintaining a natural hydrologic balance, 2) maintain water quality and ecological services that have historically characterized Tennessee's abundant natural water resources, and 3) prevent localized flooding. This is accomplished through a process that includes an integrated approach for stormwater management using a combination of structural and nonstructural strategies (ie. practices), which can be defined by the following common terms:

- **Stormwater Management:** any action taken to minimize and mitigate the negative impacts of hydrologic modification and pollutant additions (associated with stormwater infrastructure. This includes physical devices and techniques, but also more general strategies like minimizing fertilizer and pesticide use, reducing illicit discharges to drains, etc. Note that management will often take place between storm events through preventative approaches, though the purpose is to minimize contaminant availability and hydrologic impact during those events.
- **Stormwater Control Measures (SCMs):** are *Measures* meant to directly affect the flow of stormwater and/or contaminants, and that have defined specifications and standards. These Measures have one or both of two parts: 1) a defined surface *Management* to encourage infiltration and contaminant removal; and/or 2) a clear *Protocol* defining engineering design, installation, and maintenance. A *Measure* such as a "good forest" has just a Management, a *Measure* such as a manufactured stormwater treatment device has just an engineering *Protocol*, and a "bioretention cell" has both.

- **Management:** a clearly defined state of soil and vegetation that provides the desired degree of infiltration and contaminant removal under the design conditions. This design condition is considered to be 15 years following stabilization, when the site has reached a reasonable level of maturity and is undergoing only gradual changes. The Management is the defined desired endpoint, and depends on a series of Techniques to get from the current disturbed condition to that endpoint. A Management has clearly defined specifications in the Manual including vegetation type and density, soil hydrologic characteristics, etc. The term Cover is sometimes used to describe a Management that has minimal inputs.
- **Technique:** Method or operation that progresses or sustains progress from one state of management to another higher-functioning management. These can fall in either of two general categories:
  1) Methods of getting from “here” to “there”; from the presumed worst-case condition immediately following development to the desired *Management* endpoint. The *Techniques* used in a specific site design will vary greatly depending on these starting conditions. For example, if an area of “good forest” is left undisturbed, no Technique at all is necessary to achieve a “good forest” *Management*. On the other hand, if the post-construction condition is a bare highly-disturbed mixture of surface and subsoil and is heavily compacted by traffic, the required Techniques to achieve a “good forest” *Management* in 15 years may well include the following: soil ripping; soil amendments; temporary vegetative cover; slope erosion control to allow establishment of the temporary vegetation; planting of trees of a specified type, size, and density; and perhaps fertilization and irrigation schemes and other maintenance requirements.
  2) The operations necessary to maintain the required trajectory towards the desired design condition, and to maintain that condition once it is achieved. In other words, the Protocol for maintenance of a “good forest” *Management* may refer to *Techniques* for tree thinning, tree fertilization, and invasive removal. Note that the Protocol for a “fair forest” *Management* might refer to the same *Techniques*, but with less intensive requirements.

Figure 3.1: Stormwater management approach of storm drain stenciling, which identifies drains that discharge to local streams and states a no dumping regulation.

3.1.2 Design Goals and Approaches

Successful permanent stormwater management programs and plans integrate effective management early on in the planning process, prevent rather than mitigate stormwater impacts, and conserve site resources and lead design with the terrain in mind. In the following sections of this chapter, we introduce ***Smart*** site design as a process to achieve watershed protection elements in new development, maximize use of project site resources for stormwater management, and assist in minimizing the total treatment volume required for structural runoff reduction practices.

The goal of ***Smart*** site design is to plan how to generally reduce runoff volume while minimizing changes to pre-development site hydrology, and mitigate other environmental impacts as spatially close to the impact as possible. The benefits of ***Smart*** site design are most apparent when incorporated into the site planning process as early as possible. This typically requires that certain considerations and allowances for green infrastructure are made in the project concept phase. When applied early, the ***Smart*** site design approach can sharply reduce stormwater runoff and pollutants generated by development. This can reduce both the size and cost of stormwater conveyance infrastructure.

There are three guiding principles that help achieve a ***Smart*** site design. These guiding principles will ensure that the required runoff treatment volume (and cost) is as low as possible under given site conditions and project considerations. The guiding principles are as follows:

1. ***Avoid*** generating stormwater runoff all together by preserving natural features.
2. ***Minimize*** impacts of necessary land disturbance and total impervious surfaces.
3. ***Manage*** stormwater runoff with green infrastructure.

The ***Smart*** site design techniques described in the following section are proactive management practices that minimize treatment volumes and the need for structural practices as well as ensure the longevity of a hydrologically-functional project site.

***Smart* site design objectives include:**

- Avoiding the generation of stormwater runoff;
- Managing stormwater (quantity and quality) as close to the point of origin as practically possible and minimizing the use of large or regional-scale collection and conveyance systems;
- Preserving natural areas, topography, vegetation, and soils to reduce overall impact on watershed hydrology;
- Using simple, nonstructural methods for stormwater management that are lower in cost and lower maintenance needs than structural controls;
- Creating multifunctional landscapes; and
- Using natural drainage pathways (the site's hydrology) as a framework for site design.

Actions that can be taken to reach objectives:

- Shrinking cleared/disturbed land area and impervious surface footprints
- Increasing travel distances of concentrated runoff
- Maximizing sheet flow and vegetated areas
- Minimizing site and lot slopes
- Use open conveyances with undisturbed soil bottoms.

Avoid: In the project concept phase, there are many actions that may be taken to preserve or improve a site's capacity to absorb rainfall and minimize runoff – or as defined within, the landscape capacity for infiltration. These include preserving undisturbed natural areas, preserving riparian buffers, preserving or planting trees, avoiding development in floodplains, avoiding steep slopes, and minimizing disturbance on erodible soils.

There is a growing body of evidence indicating that headwater streams are the formative biogeochemical features of a watershed and have a profound effect on seasonal hydrology of stream systems. This evidence is contributing to the growing unified voice of researchers and professionals that recommend natural resource managers pay specific attention to headwater streams in conservation and protection elements of policy. While riparian buffers are requirements of site development plans and municipal stormwater permits, these areas are implicit volume reduction practices that minimize the need for explicit (or structure) management practices. Riparian buffers and protected natural areas do not contribute runoff volume in the overall site mass balance approach to green infrastructure implementation. Preservation of natural areas allows a designer to use "self-crediting" features on the site design plan. This may be accomplished by a combination of the following approaches: preserve natural topography within project layout, use natural drainage flowpaths and vegetated swales instead of storm pipes and curb and gutter, drain runoff to pervious areas, preserve landscape capacity for infiltration with minimizing grading extents, and berming and terraforming sloped areas to create small areas of depressional storage in infiltratable soils.

Minimize: Reducing impervious surface coverage reduces the need for runoff reduction and green infrastructure. When appropriate the following actions will reduce the volume of runoff for management in stormwater control measures: 1) reduce roadway lengths and widths, 2) reduce building footprints, 3) reduce parking area footprints, 4) reduce setbacks and frontages, 5) use fewer or alternative cul-de-sacs, 6) fit layout to terrain, 7) reduce limits of clearing and grading, and 8) utilize open space development.

Manage: Once all efforts are taken to avoid and minimize stormwater generation, there will be the need to implement structural SCPs to capture, manage, infiltrate, treat, and reuse runoff on site or in off-site mitigation projects. A suggested list of stormwater control practices including design specifications can be found in Chapter 5 of this manual. Check with you local municipal stormwater program for a list of locally-approved SCPs.

3.2 Watershed Protection – From Downspout to River Mouth

3.2.1 Green Infrastructure at Multiple Scales

Development patterns (e.g. where people live), community design, population density, and water availability have been intractably linked throughout the course of history. These development factors significantly affect how communities function in terms of water use and quality. Decisions are made regarding water resources on a daily basis that affect lifestyles, quality of life, and the overall sustainability of regions. Managing critical water and land resources through ***Smart*** site design can reveal multiple benefits to communities related to economic prosperity and good quality of life experiences for citizens. Water resource management is done using the watershed as the operational unit. We now know that using a watershed approach to development is also crucial for the sustainable growth of our communities.

The greatest benefit of implementing permanent stormwater management through green infrastructure and smart site design will be seen at the watershed scale in the improved quality and protection of our rivers and streams. By utilizing practices on multiple spatial scales (single lot, streetscape, neighborhood, city) to mimic natural hydrology at the watershed level, we will experience healthier streams and rivers in our communities. Community planning actions at the watershed-scale that will work to achieve this include:

1. **Compact and Mixed-Use Development** – Using small lots, higher densities, and a connected street system, compact designs are a strategy for reducing development footprints of city centers. Mixed-use development also decreases footprints by increasing transportation options and minimizing the need for wide/large freeways.
2. **Street Networks** – Creating a network of well-connected streets enhances traffic circulation while decreasing road footprints.
3. **Infill and Redevelopment** – Reusing existing impervious surfaces and existing infrastructure minimizes the generation of additional stormwater runoff.
4. **Stormwater Management Retrofits** – Investing in replacing gray infrastructure with green infrastructure decreases the impact on streams and rivers that receive urban runoff from existing developments.
5. **Open Space Development** – Clustering houses into one area and preserving open space minimizes land disturbance, protects native soils and vegetation, and creates opportunity for disconnection practices.

The fundamental difference between conventional and ***Smart*** site design development is the way in which a project is initially conceived. A conventional development typically deals with runoff as something to move away from the project site as quickly as possible. A ***Smart*** site design development project is conceived with rainfall and runoff management in mind throughout the planning phase, by placing value on the natural landscape capacity to absorb rainfall and preserving these elements of a site. When runoff is generated in excess of the landscape capacity, then that runoff is managed as close to its source as possible. Implementing the following principles in the concept phase of project development will ensure that the minimal amount of stormwater runoff is generated, therefore minimizing the size and extent of runoff reduction practices.

From the watershed scale to lot scale, the elements of ***Smart*** site design may be implemented in different applications to guide community development, neighborhood design, and individual parcel layout. The following tables outline the course of water resources from rainfall on a rooftop, through a watershed, and into receiving surface waters, and document how management practices have changed to achieve a watershed approach. Table 3.1 examines applications in a residential setting. Table 3.2 in a commercial setting.

Table 3.1: From Rooftop to Stream: Stormwater Management in a Residential Setting (Adapted from NAS 2009).

Approach	What it is	What it replaced	How it works
Land-Use Planning	Early site assessment	Performing stormwater management design after site layout	Map and design plan submitted at earliest stage of project development review showing environmental, drainage, and soil features
Conservation of Natural Areas	Maximize forest canopy, green space	Mass clearing	Preservation of priority forests and meadow and reforestation of turf areas to intercept rainfall
Earthwork Minimization	Conserve soils with good infiltration as well as existing contours	Mass grading and soil compaction	Construction practices to conserve soil structure and only disturb small site footprint
Impervious Cover Minimization	Smart site design	Large streets, lots and cul-de-sacs	Narrower streets, permeable driveways, clustering lots, and other actions to reduce pavement
Runoff Reduction – Impervious Surface Disconnection and Rainwater Harvesting	Using rooftop runoff	Directly connected roof gutters	A series of practices to capture, disconnect, store, infiltration, or harvest rooftop runoff
Runoff Reduction – Infiltration and Filtration	Front yard bioretention and vegetated swales	Drainage from roof to roadway; curb/gutter and storm drain pipes	Grading to treat roof, lawn, driveway, and roadway runoff using vegetated depressional storage and conveyance
Peak Reduction and Treatment	Linear wetlands	Large detention ponds	Long, multi-celled, forested wetlands located in the stormwater conveyance system
Aquatic Buffers and Managed Floodplains	Stream buffer management	Unmanaged stream buffers (building, mowing up to the stream bank)	Active revegetation of buffers and restoration of degraded stream channels

Table 3.2: From Rooftop to Stream: Stormwater Management in an Industrial Setting.

Approach	What it is	What it replaced	How it works
Pollution Prevention	Drainage mapping	No map	Analysis of the locations and connections of the stormwater and wastewater infrastructure from the site
	Hotspot site investigation	Visual inspection	Systematic assessment of runoff problems and pollution prevention opportunities at the site
	Rooftop management	Uncontrolled rooftop runoff	Use of alternative roof surfaces or coatings to reduce metal runoff, and disconnection of roof runoff for stormwater treatment
	Exterior maintenance practices	Routine plant maintenance	Special practices to reduce discharges during painting, powerwashing, cleaning, sealcoating, and sandblasting
	Extending roofs for no exposure	Exposed hotspot operations	Extending covers over susceptible loading/unloading, fueling, outdoor storage, and waste management operations
	Vehicular pollution prevention	Uncontrolled vehicle operations	Pollution prevention practices applied to vehicle repair, washing, fueling, and parking operations
	Outdoor pollution prevention practices	Outdoor materials storage	Prevent rainwater from contact with potential pollutants by covering, secondary containment, or diversion from storm drain system
	Waste management practices	Exposed dumpster or waste streams	Improved dumpster location, management, and treatment to prevent contact with rainwater or runoff
	Spill control plan and response	No plan	Develop and test response to spills to the storm drain system, train employees, and have spill control kits available on site
	Greenscaping	Routine landscape and turf maintenance	Reduce use of pesticides, fertilization, and irrigation in pervious areas, and conversion of turf to forest or bioretention
	Employee stewardship	Lack of stormwater awareness	Regular ongoing training of employees on stormwater problems and pollution prevention practices
	Site housekeeping and stormwater maintenance	Dirty site and unmaintained infrastructure	Regular sweeping, storm drain cleanouts, litter pickup, and maintenance of stormwater infrastructure
Runoff Treatment	Stormwater Retrofitting	No stormwater treatment	Filtering retrofits to remove pollutants from most severe hotspot areas
Illicit Discharge	Detection and Elimination	Outfall analysis	Monitoring of outfall quality to measure effectiveness

3.2.1.1 Watershed Scale

Approaches to avoid and minimize stormwater runoff are essentially design decisions that reduce impervious surface footprints. These design decisions are best implemented during the concept and initial development phase of a project. If these approaches are implemented correctly, then overall stormwater management costs will be minimized for a project.

Alternative and/or vertical (taller) building designs should be considered to reduce impervious rooftop area. Consolidate functions and buildings or segment facilities to reduce the footprint of individual structures. Figure 3.2 shows the reduction in impervious footprint by using a taller building design (Rhode Island, 2011).

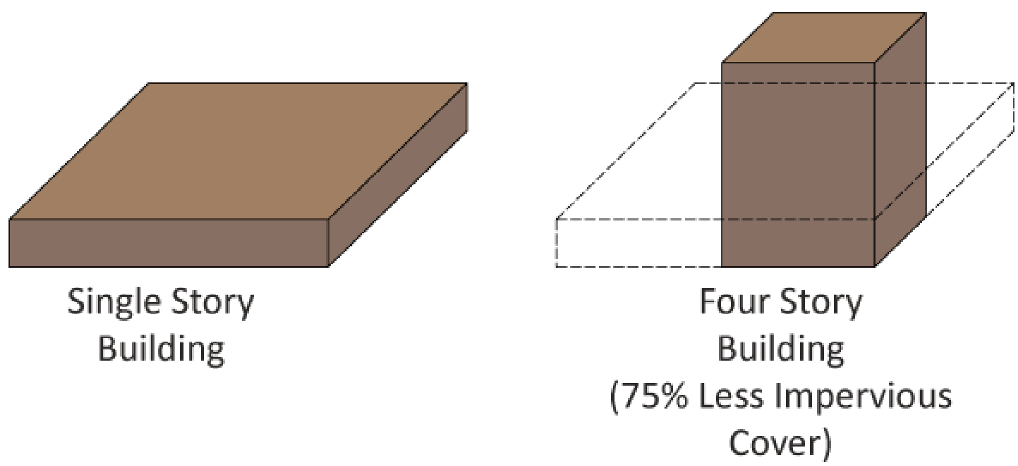


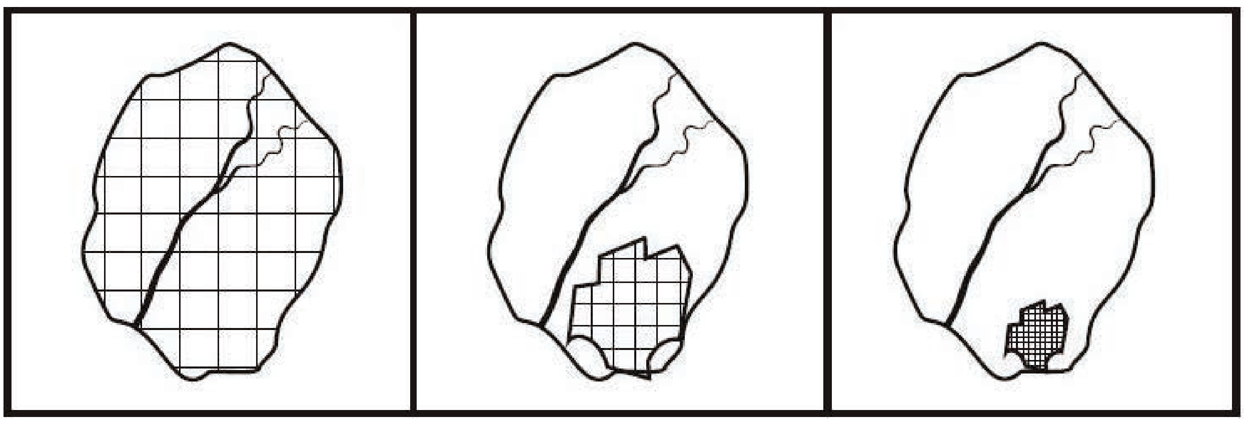
Figure 3.2: Simplistic representation of how a vertical design decreases the total amount of impervious surface created.

Higher housing densities may also better protect water quality, especially at watershed scale. According to the American Housing Survey, 35% of new housing is built on lots between two and five acres, and the median lot size is just below one-half acre (Census, 2001). Local zoning may encourage building on relatively large lots, in part because local governments often believe that it helps protect their water quality (US EPA, 2006). Communities have assumed that low-density development at the site level results in better water quality. Such conclusions are often drawn from analysis that assumes a one-acre site has one or two homes with a driveway and a road passing by the property and the remainder of the site is well-established lawn. However, this logic overlooks two key caveats.: first, that the “pervious” surface remaining in low-density development is in fact additional land disturbance and may create a hydrologic response that looks more similar to impervious surface than predevelopment forests, and that secondly, low-density developments often require more off-site impervious infrastructure for utilities, transportation, and safety (US EPA, 2006).

In the experimental scenario below (Figure 3.3), the USEPA used commonly accepted hydrologic models to examine the question of which type of development (high density or low density) protects overall watershed services better. At the watershed scale, there is less overall runoff generated from a high-density development than a low-density development due to the fact that there is more preserved undisturbed areas in the high-density development, which will naturally absorb much of the frequent small storm precipitation.

Scenario 1	Scenario 2	Scenario 3
Impervious cover = **20%**	*Impervious cover* = **38%**	*Impervious cover* = **65%**
Runoff/acre = **18,700 ft^3/yr**	*Runoff/acre* = **24,800 ft^3/yr**	*Runoff/acre* = **39,600 ft^3/yr**
Runoff/unit = **18,700 ft^3/yr**	*Runoff/unit* = **6,200 ft^3/yr**	*Runoff/unit* = **4,950 ft^3/yr**

Figure 3.3: Total average annual stormwater runoff for all scenarios (US EPA, 2006).



10,000 houses *built on* **10,000 acres** *produce:*	**10,000 houses** *built on* **2,500 acres** *produce:*	**10,000 houses** *built on* **1,250 acres** *produce:*
10,000 acres x 1 house x 18,700 ft^3/yr of runoff =	2,500 acres x 4 houses x 6,200 ft^3/yr of runoff =	1,250 acres x 8 houses x 4,950 ft^3/yr of runoff =
187 million ft^3/yr of stormwater runoff	**62 million ft^3/yr of stormwater runoff**	**49.5 million ft^3/yr of stormwater runoff**
Site: *20% impervious cover*	***Site:*** 38% impervious cover	***Site:*** 65% impervious cover
Watershed: *20% impervious cover*	***Watershed:*** 9.5% impervious cover	***Watershed:*** 8.1% impervious cover

Figure 3.4: 10,000-acre watershed accommodating 10,000 houses (US EPA, 2006).

3.2.1.2 Project Site Scale

Mixed-use development can also reduce parking lot footprint with shared parking. Shared parking can be defined as parking utilized jointly among different buildings and facilities in a single area to take advantage of different peak parking characteristics that vary by time of day or day of the week. Since most parking spaces are only used part time, shared parking arrangements are designed to more efficiently meet the needs of areas that exhibit a mix of uses with varying peak parking demands. For example, many businesses or government offices experience their peak business hours during the daytime on weekdays, while restaurants and bars peak in the evening hours and on weekends. This presents an opportunity for shared parking arrangements where several different groups can use an individual parking lot without creating conflicts (RIDEM, 2011).

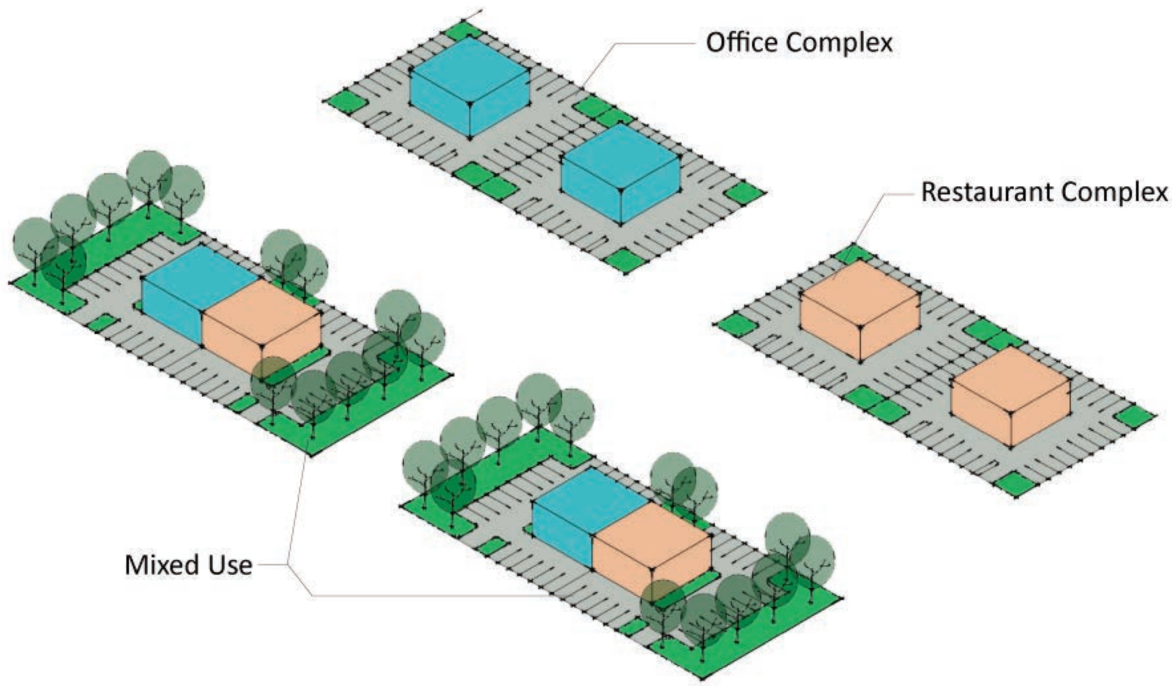


Figure 3.5: Example of separate complex development and mixed-use development.

Mixed-use development is not a new planning concept. Many of the region's older downtowns and neighborhood centers have homes, shops, offices, and schools built closer together and connected by a fine grid of streets that allow people to walk, bike or take transit in order to meet their daily needs. This approach not only replicates the pedestrian-friendly character of the older parts of the cities, but also benefits water quality by reducing the overall amount of impervious surface dedicated to streets and parking lots (US EPA, 2009).

Residential road layout generally fall into 3 categories: grid, curvilinear, and hybrids of the two. As illustrated in the figure and table below, grid and curvilinear layouts have practical benefits, and hybrid designs attempt to take the best features of the two (Hinman, 2005).

Table 3.3: Description of residential road layout.

Road pattern	Impervious coverage	Site disturbance	Vehicle Efficiency	Biking, Walking, Transit
Grid	27-36%	Less adaptive to site features and topography	More efficient – disperses traffic through multiple access points	Promotes by more direct access to services and transit
Curvilinear	15-29%	More adaptive for avoiding natural features, and reducing cut and fill	Less efficient – concentrates traffic through fewer access points and intersections	Generally discourages with longer, more confusing, and less connected system

Figure 3.6: From left to right: grid, curvilinear, and hybrid pattern (AHBL Engineering).

Streets offer unique opportunities for handling and treating their runoff, but conventional street design practices focus primarily on moving the automobile and diverting runoff to the curb and gutter, contributing to increased runoff volume and poor water quality (US EPA, 2009). Residential streets and private streets within commercial and other development should be designed for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency access. Many communities require minimum street widths that are much wider than needed to support travel lanes, on-street parking, and emergency access. Access streets in subdivisions often are wider than the collector and higher order streets that receive their traffic. Ironically, excessively wide streets encourage excessive speed as well (RIDEM, 2011). Narrower streets can be used in most residential development that generate less than 500 average daily trips (ADT), perhaps widths of 22–26 feet (Cook, 2007). Narrower streets could also be feasible for streets with 500–1,000 ADT (US EPA 2014).

Road length also is an important issue. Road length should first be addressed from a macro level planning perspective. Obviously overall dense patterns of development result in dramatically less road construction than low density patterns, holding net amount of development constant. High-density development and vertical development contrast sharply with low density sprawl, which has proliferated in recent years and has required vast new highway systems throughout urban fringe zones (RIDEM, 2011).

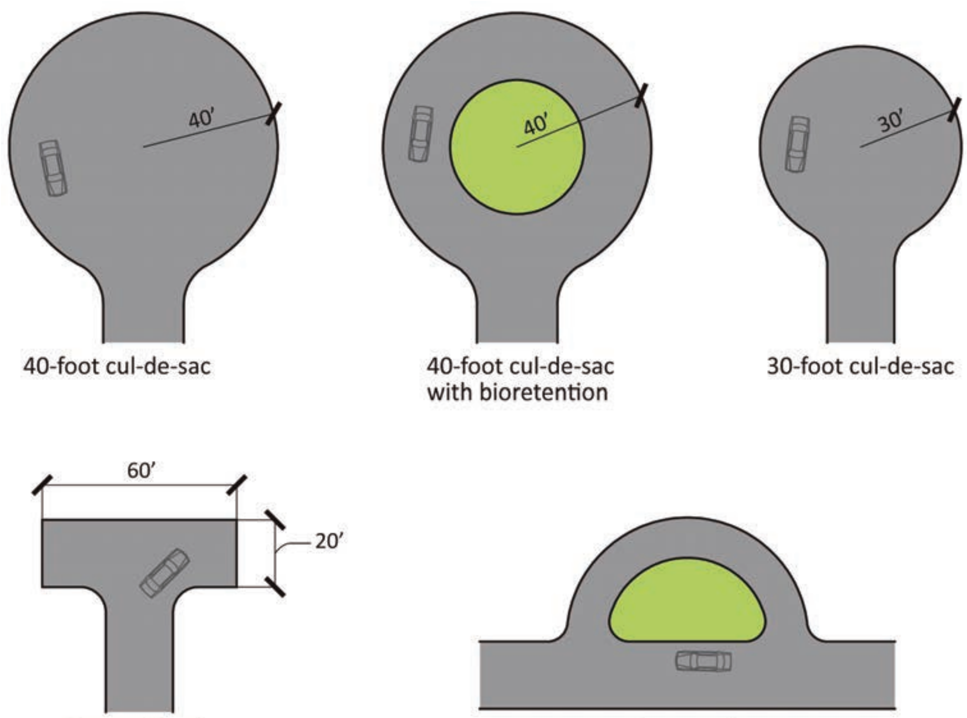


Figure 3.7: Various road designs. (adapted from Schueler, 1995).

Parking lots, like streets, make up large areas of impervious surface and contribute to polluted runoff. Set appropriate parking ratios for development projects and allow businesses to count underused nearby on-street parking spaces toward meeting their parking requirements.

Cul-de-sacs can also needlessly increase impervious area. In general, cul-de-sac should be discouraged; however, a number of alternatives are available where topography, soils, or other site-specific conditions suggest this road design.

Numerous alternatives create less impervious cover than the traditional 40-foot cul-de-sac (Fig. 3.6). These alternatives include reducing cul-de-sacs to a 30-foot radius and creating hammerhead tee or a loop. Sufficient turnaround area is a significant factor to consider in the design of cul-de-sacs. In particular, the types of vehicles entering into the cul-de-sac should be considered. In addition, many newer large service vehicles are designed with a tri-axle (requiring a smaller turning radius) and many school buses usually do not enter individual cul-de-sacs (RIDEM, 2011).

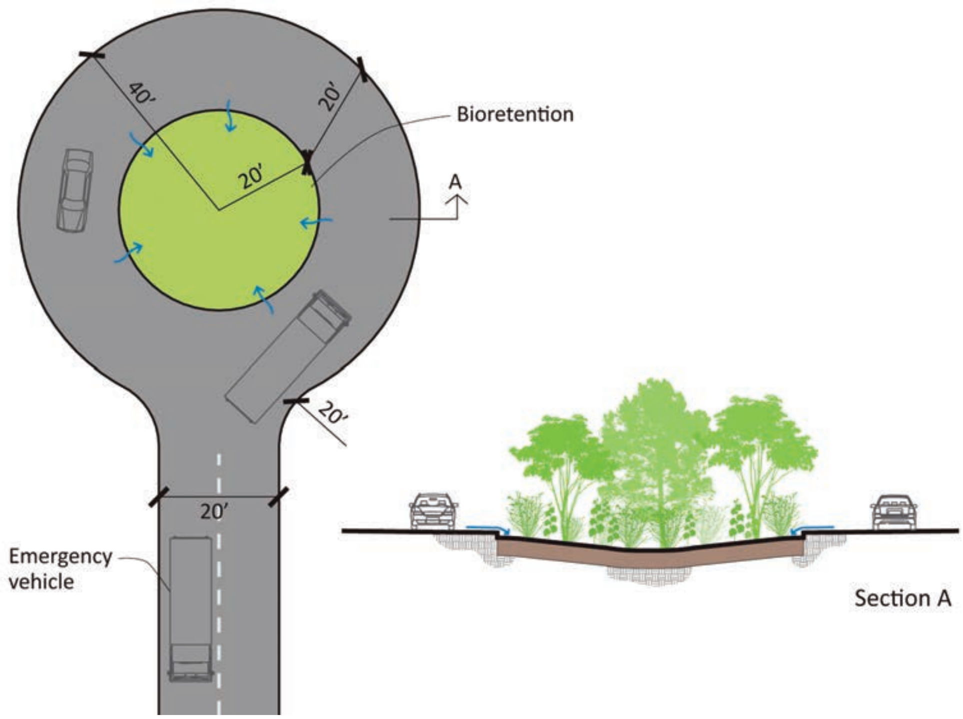


Figure 3.8: Cul-de-sac with bioretention.

Right-of-ways (ROWs) are pieces of land reserved for transportation, utilities and other uses. One inch of rain falling on one block of typical city street (40' x 300') generates some 6700 gallons of stormwater runoff. This runoff can become a problem for communities in the form of downstream flooding and non-point source pollution or it can become a resource providing moisture for neighborhood vegetation if captured close to the source. Many ROWs are un-vegetated, featuring only earthen areas of compacted dirt or uniform gravel. These areas can be turned into rain gardens that infiltrate stormwater from neighborhood streets. ROWs are legally and logistically easier to work in than the street itself, making them good locations for volunteer-led neighborhood tree-planting efforts and green infrastructure projects (McAdam, 2010).

Figure 3.9: A low-density street in Knoxville, TN (Source: SMART Center).

Figure 3.10: Some street retrofitted with linear bioretention, bike lane, and street trees (Source: SMART Center).

Eliminating curbs and gutters on streets will typically require installation of a grass or vegetated swales to accept the stormwater runoff from the street. Traditional curbs and gutters are very effective at quickly collecting and delivering stormwater runoff to a central location for storage and possibly treatment. As a result, they provide no opportunity for removal of pollutants. Elimination of curbs and gutters and the introduction of vegetated swales, bioretention and filter strips to collect and convey runoff are suitable for a range of conditions. Where adequate space exists and traffic conditions will allow, this approach will allow for filtering, infiltration, and reduction of peak runoff volumes and flow velocity. (Cook, 2007)

3.2.1.3 Lot Scale

Structural SCMs can also be used in conjunction with the previously mentioned nonstructural approaches for runoff reduction. SCM design specification and implementation information can be found in Chapter 5. These practices are designed to capture a specific volume of runoff from the impervious surfaces of a residential or commercial site and can be integrated into a larger site plan.

Lot scale stormwater management is greatly effective because it captures and manages stormwater runoff close to the point of origin. Using a system of small, diffuse structural measures to meet runoff reduction and pollutant removal targets is generally less demanding with regards to the level of complexity in engineering design and needed physical materials. However, this approach requires more coordination between property owners and their involvement in the maintenance of structural measures to ensure they are functioning as designed.

Figure 3.11: Photographs of lot scale runoff reduction measures. Left: a roadside vegetated verge (ie. no curb or gutter) that accepts roadway runoff, uses engineered soils to infiltrate runoff, and conveys excess runoff to a small treatment wetland. Right: a residential rain garden captures and infiltrates runoff from half of the house rooftop and driveway.

3.2.2 The Role of Redevelopment

Redevelopment is defined as new construction on a site that has pre-existing uses. Promoting infill development and redevelopment is desirable because it takes pressure off the suburban fringes, thereby preventing sprawl, and it minimizes the creation of new impervious surfaces. However, redevelopment is more complex because of the need to upgrade existing infrastructure, the limited availability and affordability of land, and the complications caused by rezoning. These sites also may require cleanup or remediation before redevelopment can occur (see section 3.3 for special management areas). Innovative zoning incentives along with careful selection of SCPs are needed to achieve fair and effective stormwater management systems in these areas.

Table 3.4: From Rooftop to Stream: Stormwater Management in Redevelopment Projects.

Approach	What it is	What it replaced	How it works
Smart Site Design	Site design to prevent pollution through minimizing impervious cover	Conventional site design	Designing redevelopment footprint to restore natural area remnants, minimize needless impervious cover, and reduce hotspot potential
Runoff Volume Reduction – Disconnection and Rainwater Harvesting	Rooftop treatment on the roof or in the landscaping	Traditional rooftops and directly connected downspouts	Use green roofs to reduce runoff generation; Use rain tanks to capture and reuse rainfall; Use rain gardens to capture and infiltrate parking lot and rooftop runoff.
Soil Conservation and Reforestation	Runoff reduction in pervious areas and increased tree canopy	Impervious or compacted soils and turf grass	Reduce runoff from compacted soils through tilling and compost amendments; Providing adequate rooting depth for mature tree development.
Runoff Reduction – Subsurface	Increase permeability of impervious cover	Impermeable asphalt or concrete	Use of permeable pavements to decrease runoff and infiltrate/store in subsurface.
Runoff Reduction – Vegetated	Runoff treatment in the street	Sidewalks, curb and gutter, and storm drains	Use bioretention planter boxes to capture, filter, and/or infiltrate runoff.
Runoff Treatment	Filtration for water pollutants	Catch basins and storm drain pipes	Use underground sand filters or other devices to treat hotspot runoff.

Approach	What it is	What it replaced	How it works
Municipal Good Housekeeping	Street cleaning	Unswept streets	Targeted street cleaning on priority streets to remove trash and sediment/solids.
Watershed Planning	Off-site stormwater treatment or mitigation	On-site waivers	Stormwater retrofits or restoration projects elsewhere in the watershed to compensate for stormwater requirements that cannot be met on-site.

3.3 Site Inventory and Assessment

Smart site design may only be fully attained with a complete and thorough initial site inventory and assessment of existing hydrologic function and documentation of special management conditions. The section below outlines the components of a site inventory and assessment, as well as delineates special management areas based upon the presence of native and built conditions.

There are many conditions that affect the way water moves through a site. As the MS4 permit states, pre-development infiltrative capacity of soils at the site, otherwise defined as a site's ***landscape capacity*** throughout the remainder of this manual, must be taken into account when determining runoff reduction requirements. ***Special management areas***, defined later in this chapter, must also be taken into account through conditional design requirements in order to ensure the protection of water quality and SCM function. Local stormwater programs must create provisions that allow development to occur under these special circumstances while not setting requirements that force design and implementation to go above and beyond practicable efforts.

3.3.1 Protocols and Checklists

The intended use of a project site greatly affects the selection and performance of stormwater management approaches, the implementation of smart site design and selection of stormwater control measure. Characteristics that delineate land use types are described in generalities below:

- **Rural:** Impervious surface is generally widely dispersed, significant percentage of acreage is in managed turf, and areas are especially suited for minimization and avoidance approaches as well as vegetated infiltration controls. Generally the existing condition for a greenfield development project.
- **Residential:** Medium to high density residential developments (< 1/3 acre lot size), generally limited open space relative to rural areas, and measures are likely to be proximate to homes and buildings, creating a greater need to address safety, mosquito, and maintenance considerations.
- **Roads and Highways:** Linear corridors that typically generate high stormwater pollutant loads due to vehicle traffic and road maintenance activities (ie. deicing), and limitations on use of measures are generally dependent on adequate space for pretreatment as well as design for large storm conveyance.
- **Commercial:** Variable size and managements of drainage areas, potential for large sub-basin drainage scale measures, and limitations due to site-specific characteristics and flowpath routing.
- **Industrial:** Variable size and managements of drainage areas, high potential for hotspots, and limitations due to site-specific characteristics and flowpath routing.

The following table shows how specific SCMs are recommended or considered conditional for use within a project land use context (Table 3.5).

Table 3.5: Stormwater Control Measure Recommendations Based on Project Land Use.

Stormwater Control Measure	Rural	Residential	Roads & Highways	Commercial	Industrial
Filter Strips[1]	preferred	preferred	preferred	preferred	limited[2]
Infiltration Areas	preferred	preferred	conditional[2]	limited[3]	conditional[2,3,5]
Bioretention	preferred	preferred	conditional[2]	limited[2]	conditional[2,5]
Permeable Pavement	limited[6]	limited[6]	limited[6]	preferred	conditional[2,5]
Vegetated Swales	preferred	preferred	preferred	limited[7]	limited[7]
Managed Vegetated Areas	preferred	preferred	preferred	preferred	preferred
Rainwater Harvesting	preferred[4]	preferred[4]	NA	conditional[4]	conditional[4]
Manufactured Filter Device	limited[9]	limited[9]	preferred*	preferred*	preferred[2]
Stormwater Wetlands	preferred[2*]	preferred[2*]	preferred[2*]	preferred[2*]	preferred[2*]
Green Roofs	limited[8]	limited[8]	NA	limited	limited

* *Preferred method for water quality treatment where infiltration is not allowed.*
Preferred – Most effective selection.
Limited – Likely not the best selection, but may be applicable. May have conditional use requirements.
Conditional – May be permitted under certain conditions and needs granted approval from the local stormwater program.

1 Filter Strips include sheet flow to infiltration areas.
2 May require pretreatment depending on land use and pollutant loading.
3 Intended for residential or other small impervious surface areas.
4 Requires a designated reuse activity.
5 Depending on land use, may limit infiltration and require additional maintenance.
6 Maintenance requirements.
7 Drainage area and large storm conveyance.
8 Typical residential roof geometry restricts application.
9 Excessive maintenance burden of underground systems in residential areas.

Existing Hydrologic Function: The first step in creating a conceptual development plan is to document existing site conditions, which greatly affect site hydrology and have an impact on the practicality and successful implementation of runoff reduction practices. Designers must identify any physical constraints at the project site that may restrict or preclude the use of particular SCMs and determine the ***landscape capacity*** for infiltration of rainfall. The primary factors to assess are described in detail below. More detailed site investigations may be required to adequately address some constraints and may be necessary on a site-by-site basis.

1. **Soil Texture:** The most relevant soil information is the Hydrologic Soil Group classifications and can be found for most areas in the web soil database (NRCS site link). In areas that are not mapped, field core data must be provided to describe soil texture and color as well as any redoximorphic features. Soil hydraulic conductivity information may be found in the web soil survey (http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm) but also must be verified through one of the suggested field tests (See Appendix A).
2. **Depth to Water Table:** Shallow water tables may lead to SCM failure or contamination of groundwater if certain practices are used. This information may be found in soil surveys and should be verified through field observations.
3. **Depth to Bedrock:** Shallow bedrock may limit the effectiveness of infiltration practices. Depth to bedrock information must be either obtained through the soil survey or determined through field observations.
4. **Topography:** This is the overall lay of the land and dictates the flow of surface water and groundwater. Topography may be found in online databases for conceptual planning purposes or surveyed in the field using surveyor's equipment for complete project design. Land slope governs the way water moves in overland flow and concentrated flow and has a large influence on retention capacity

of a site. Slope can be determined using topographic maps (1:24,000) but must also be documented through a detailed site survey at the scale required for plan submission by the local stormwater program.

5. **Contributing Drainage:** This is the land area that drains to a point of interest. For structural SCMs, the contributing drainage area must be determined from the final grading plan in order to accurately design the system.

3.3.2 Special Management Areas

These areas are those that possess a characteristic or condition that either limits the use of runoff reduction techniques or changes the design of structural practices to accommodate for the condition. These are divided into two general categories, natural conditions and built conditions. They are described below. These conditions are those that limit the landscape capacity for infiltration, and therefore affect the applicable runoff reduction approach and design level for practices. If these conditions exist on your site, then actions must be taken either through SCM selection or design to account for these conditions. Check with your local stormwater program for special procedures.

1. **Natural Conditions**: Natural conditions that create special management areas are those that are characteristic to the physiographic region and limit the landscape's capacity to infiltrate stormwater runoff. Conditions of concern for green infrastructure design are described below. Additional conditions may be identified by the local stormwater program.

   a. **Karst geology** – a unique type of landscape that is formed by the dissolution of rocks, such as limestone and dolomite. Karst areas have aquifers and a high potential to contain large preferential pathways in soil overburden that are directly connected with the groundwater. This is a concern regarding green infrastructure design because increasing infiltration in a karst area may lead to structural failures in subsurface layers and above ground structures. See Appendix B for detailed guidance on green infrastructure design in karst geology.

   b. **Steep Slopes/Erodible Soils** – a combination of steep topographic relief (greater than 25%) and non-colloidal soils that are easily erodible. This is a concern in green infrastructure design because the preferred method for runoff reduction and pollutant removal is through infiltration. The preferred method of development on sites containing steep slopes is to protect these areas (e.g. exclude in extent of site disturbance) and not increase the amount of run-on to these areas. If this is not possible, the options for use of green infrastructure on steep slopes is to: 1) re-vegetate or use biotechnical stabilization practices, 2) divert water away from the steep slope area, to a lower elevation without causing erosion, and 3) use a combination of terracing and vegetative filter strips on the slope as a stormwater control measure.

   c. **High Water Table** – areas that have a seasonally high water table that exists within 4 feet of the soil surface. This limits the use of infiltration-based green infrastructure practices and may indicate desirable conditions for stormwater wetlands. If this condition exists on only a portion of a project site, the remainder of the project site would be better suited for infiltration-based practices.

   d. **Shallow Soils** – soil profiles that measure less than 4 feet above bedrock or confining soil layer. The presence of shallow soils on a site limits the effectiveness of infiltration-based stormwater control measures and may indicate the need for alternative pollutant removal goals (rather than runoff reduction). If this condition exists on only a portion of a project site, the remainder of the project site would be better suited for infiltration-based practices.

   e. **Low Permeability Soils** – soils that have low infiltration rates and therefore cause rainfall to runoff the surface at a relatively faster rate than soils with high infiltration rates. These soils have high clay content and may be the result of compaction.

   f. **Sensitive or Impaired Receiving Waters** – areas within the watershed boundaries of a sensitive or impaired waterway (designated by a state or local program) may have unique requirements for stormwater management that changes the selection and design of green infrastructure practices. For a list of impaired waterways, access the State's 303(d) list at the Tennessee Department of Environment and Conservation's website :

      (http://www.tn.gov/environment/water/water-quality_publications.shtml)

Check with your local municipal program for information on local sensitive water resources and additional requirements.

2. **Built Conditions** – As with natural physical conditions, pre-existing built (or anthropogenic) conditions on a project site may also affect site hydrology and successful implementation of runoff reduction measures. These are described below:
   a. **Brownfield/Soil Contamination** – Previously designated contamination due to a pre-existing land use on the project site. These conditions generally need to be remediated to a level where green infrastructure and site development will not transport contaminants downstream or into groundwater.
   b. **Pollution Hotspots** – land use characteristics that pose a relatively higher potential to contribute to surface or groundwater pollution due to the nature of contaminants that are associated with the operations and land use. Some examples of these are, but not limited to, gasoline stations, trash collection areas, mulching operations, chemical storage facilities, car washes, nurseries, etc.
   c. **Groundwater Pollution Potential** – projects that contain land use characteristics that have the potential to contribute groundwater pollution if infiltration was used on site.

3.4 Site Design Targets

The MS4 permit requires a design to meet specific performance standards for the management of the first inch of a representative rainfall event. Runoff reduction is the preferred approach, as it can achieve both volume reduction and pollutant removal. Through the site assessment, if it can be shown that site limitations exist that make it a hardship to achieve performance goals with runoff reduction, then provisions allow for a designed system to address a secondary set of performance goals to reduce runoff to the maximum extent possible and treat all remaining runoff from the first inch of rainfall for pollutant removal.

The following is a preference-based list of characteristics for systems of stormwater control measures within the Tennessee Runoff Reduction Assessment Tool (TNRRAT) to show performance-based outcomes:

1) Measures that increase infiltration, as those meet all three overarching goals of reducing runoff, protecting baseflow, and removing pollutants.
2) Measures that reduce runoff without infiltration (capture and reuse), as these minimize the long-term stream degradation and generally result in a decrease of pollutants reaching a stream.
3) Measures that solely treat the runoff to remove pollutants without affecting total runoff volume.

Smart site design may be accomplished along a spectrum of levels depending on landscape capacity and existing site conditions. The applicable level of design is determined through the site assessment process as well as during the pre-concept design meetings between the project manager/developer and the local stormwater program. The three basic design levels are described below.

Primary – ***SCMs for Runoff Reduction:*** These project designs meet the minimum runoff reduction requirement for new development and redevelopment projects through Smart Site Design to achieve optimal practice performance and maintain landscape capacity.

Secondary – ***Pollutant Removal Treatment:*** These project designs are implemented in areas deemed unable to meet the Primary design level minimum requirement for runoff reduction by site assessment protocols or other special management conditions. These projects meet the secondary minimum requirement for 80% TSS removal.

Tertiary – ***Resource Protection for Special Conditions or Mitigation:*** These project designs go above the minimum 1” retention standard in that the site utilizes the full elements of Smart site design to protect natural features, design stormwater management facilities for a greater design rainfall capture depth, and minimize disturbance (i.e. managing stormwater run-on from adjacent, existing areas, or retrofitting). Retrofit or redevelopment projects meeting this level may be eligible to generate mitigation credits, depending on the local municipal program.

Elements of *Smart* Site Design

1. **Minimize impervious surfaces** – shrink the impervious footprint of sites by reducing the width of roads, replacing impervious surfaces with permeable alternatives, and avoiding gridded street layouts.
2. **Preserve, protect, create, and restore ecologically sensitive areas** – during development stages, take actions to protect perennial streams, wetlands, 100-year floodplains, karst features, and steep slopes.
3. **Prevent or reduce thermal impacts to streams** – create and maintain riparian buffer vegetation and use practices that disconnect runoff from impervious surface conveyances and directs it onto permeable areas.
4. **Avoid or prevent hydromodification of streams and other waterbodies** – Minimize the number of stream crossings or other water resources modificiations to prevent water quality and resources degradation due to hydromodification.
5. **Protect trees and other native vegetation** – limit the clearing of native vegetation, integrate open green spaces when possible, and include provisions to protect existing trees and their root systems during the site development process.
6. **Protect native soils** – Avoid removing the topsoil layer and compaction, and use construction phasing to minimize disturbance footprint.

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Chapter 4

Smart Design for Stormwater Management

4.1 Site Assessment for Runoff Reduction Requirements

4.2 Site Water Balance

4.3 Runoff Reduction Volume

4.4 Runoff Treatment Volume

4.5 Flood Control and Channel Protection

What's in this Chapter?

Section 4.1 transitions from site assessment to quantitative analysis of runoff reduction targets. We discuss the decisions and resultant pathways for setting design targets and showing they are met for a proposed project.

Section 4.2 describes mass-time approach as the foundation for implementing the Tennessee Runoff Reduction Assessment Tool (TNRRAT) for stormwater management compliance.

Section 4.3 explains runoff reduction volume calculations..

Section 4.4 explains runoff treatment volume calculations.

Section 4.5 describes how flood and channel protection are carried out after runoff reduction requirements are met.

4.1 Site Assessment for Runoff Reduction Requirements

In implementing the site assessment protocols and checklist (see Chapter 3), the existing hydrologic function was determined through documenting the effects of soil properties, depth to water table, depth to bedrock, topography, and contributing drainage areas. In extreme cases, natural conditions may be documented and trigger the designation of a special management area by the local stormwater program. Special management areas of karst (or other feature that leads to increased groundwater pollution potential), pollution hotspots, or brownfields were also identified.

Upon completion of site assessment and design layout, runoff reduction design targets are set based on the prevalence of special management areas and the final land cover and management characteristics of a project site. The **Tennessee Runoff Reduction Assessment Tool** (TNRRAT) is a time-mass approach to estimating the potential for infiltration and retention to determine whether a project design meets the runoff reduction and pollutant removal requirements set forth in the MS4 General Permit. The TNRRAT was developed to provide a consistent method to determine the success of a project for runoff reduction and treatment, which takes into account environmental and climactic variability across the state.

The Site Assessment and Inventory Checklist (Appendix E) should be used in conjunction with the TNRRAT. Documented special management areas will help complete the input requirements and identify design targets built into the model. When an MS4 program has implemented an incentive program, runoff reduction volume "credits" are allocated for projects that include redevelopment, brownfield redevelopment, high density, vertical density, mixed use, and transit-oriented development.

As delineated in Chapter 3, there exists a preference for runoff reduction and treatment approaches based on site characteristics and general project goals.

4.2 Site Water Balance

The overarching goal of runoff reduction with green infrastructure is to mimic the natural water cycle, or in other words create a design that preserves overall pre-development hydrology of the landscape by using control measures to mitigate for changes in land cover. A water balance approach is used to determine whether this goal is met. This approach follows a water volume through the hydrologic cycle of a project site, from rainfall through the hydrologic processes that transport, store, treat, and transform that water volume.

The TNRRAT is not coefficient-based, but rather calculates a water balance for each time step within a *representative storm* simulation for the duration that stormwater is required to be managed on site. This time frame during precipitation when storage and transport processes are occurring is referred to as *opportunity time.* This model emphasizes estimating potential for infiltration and retention within a system of connected units. A unit is a user-defined area that has consistent properties (such as management and soil type) and may or may not have a surface area.

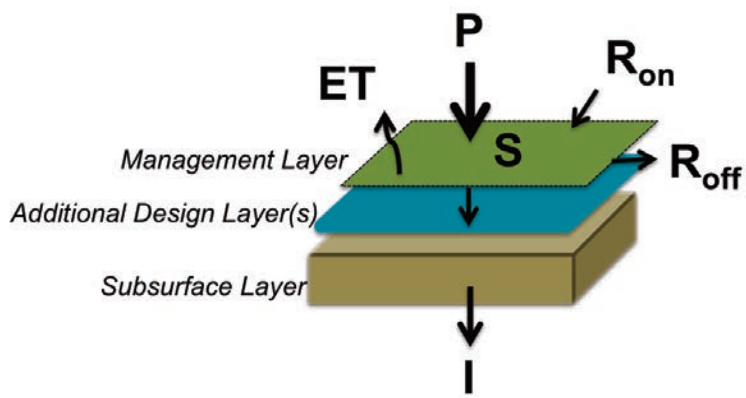

Figure 4.1: A conceptual diagram of the water balance of a unit.

$$S_2 = S_1 + P + R_{on} - R_{off} - I - ET$$
(Equation 1)

Table 4.1: Description of components in Equation 1.

Component (Abbrev.)	Description	Method of Estimation
Storage (S)	Volume captured above the surface	Direct model input of available volume and other pertinent soil properties
Precipitation (P)	Volume added from direct rainfall	A relatively-severe representative storm with a specific depth and intensity for a geographic location
Run-on (R_{on})	Volume added from contributions coming from adjacent units	Direct model input
Runoff (R_{off})	Volume loss due to gravity	Mass balance
Infiltration (I)	Volume moving through the ground surface; dependent on soil properties, management, and supply	Kostiakov-Lewis relationship with adjustments for land management
Evapotranspiration (ET)	Volume loss due to combined effects of evaporation and plant transpiration; only occurs after infiltration occurs	Function of management cover and soil properties

Using the TNRRAT allows the designer to estimate the needed amount of on-site storage based on a resultant water balance from the gains of rainfall and run-on and losses of soil-based infiltration. The target is to fully manage the representative storm event with no generated runoff. Storage is a function of topography and soil/media properties. Infiltration is estimated in the model using the Kostiakov-Lewis method, which was selected because it best represented the general spatial scale at which stormwater management is applied, a relatively large-scale as compared with plot-scale data. A coefficient-based adjustment factor (ie. curve number) may be applied in the model to represent the effects of land management (or cover) on soil-based infiltration. An assumption is made here that the landscape response to large storms is directly proportional to small storms for a given land management. Storage within the surface layer only consists of interception and surface depression storage for units with surface area, or the specific storage volume for a device within a specified surface area. Units with multiple layers route water from the surface layer downward through sequential subsurface layers. Water movement is controlled by the filed capacity of the layer based on its properties as well as saturation.

The representative rainfall event was identified for many different locations across the state in order to capture the spatial variability of those storm factors and create a consistent target in the presence of regional climactic variability. These storms were identified from approximately 30 years of rainfall data to represent a relatively severe, real world event with a specific amount, intensity, and duration. Rainfall records were analyzed, first defining rainfall events as being separated by at least 6 hours with no measureable rainfall in between. Data sets were not truncated in any way. Representative rainfall events are available for Bristol, Knoxville, Chattanooga, Monterey/Crossville, Nashville, Jackson, and Memphis. It may be assumed that proximate areas have the same representative rainfall event. The 95th percentile storm depth was selected, and the duration was set to the median event duration of the range from the 92.5 to 97.5 percentile storms. Finally, the event was then defined with Type II distribution.

4.3 Runoff Reduction Volume

The volume of runoff to be managed on-site is iteratively calculated within the TNRRAT on a 15-minute time step for the duration of the opportunity time during the representative rainfall event. The potential for infiltration rate changes over time, which is especially important because of how this timing coincides with water supply (or rainfall rate). Excess rainfall after losses of infiltration and available storage retention is accounted for as runoff. Based on user-input design element areas, steady-state runoff volume is routed from one area to the next until an outfall is indicated.

The logic for each user-defined unit for each time step is as follows:

1. If the unit has surface area, calculate the rainfall depth during the time step based on rainfall intensity (defined by event depth, Type II distribution, and 15-minute time step).
2. Add in the run-on additions coming from adjacent units and any water currently stored in this unit to determine total available water for this time step.
3. If this is an infiltration unit, then use the infiltration capacity (based on soil type, management, and current infiltration depth) to calculate potential infiltration during this time step.
4. Calculate the actual infiltration by adjusting the potential to account for available supply, and calculate a new total infiltration depth at the end of this time step.
5. If this is a reuse unit, remove the reused volume from the available storage.
6. Calculate the amount of water remaining in this subarea at the end of the time step as initial storage plus additions (rainfall and run-on) minus losses (infiltration and use).
7. Compare this remaining volume to the available unit storage. If the remaining volume is greater than the storage, then the difference is runoff and routed to the next downstream unit or offsite. If the remaining volume is less than or equal to the available unit storage, then the volume is stored in this unit until the next time step.

The TNRRAT requires the designer to take the following actions in order to obtain a final result:

- Selection of the project location from a pre-defined list of Tennessee cities, choosing a location most similar to the design location.
- Delineating units and routing information included in the project plan, each representing a unique combination of soil, SCM/management, contributing unit(s), and downstream unit.
- Identifying unit properties of area, unit to which it discharges (or offsite), SCM or management, soil type from a pre-defined list, and if there is soil, then depth to impending layer (such as a saturated zone, tight clay lens, man-made barrier, etc.).

A pre-defined list of SCMs and management descriptions are included in the TNRRAT. Each description includes a list of properties, including:

- The type of SCM, which indicates whether it collects rainfall, performs infiltration, or is simply a volume-based device.
- If the SCM is exposed to the surface, whether it includes vegetation, and the type of vegetation.
- For infiltration SCMs, the best estimates of curve number values for the land management at the soil/water contact surfaces based on hydrologic soil group.
- Definition of rainfall interception and depressional storage resulting from the SCM/management.
- Special characteristics of the SCM, including whether the practice contributes pollutants, the TSS removal efficiency, and any water removal (reuse) rate.
- If the SCM has multiple layers, then the characteristics of each layer, including fill media, normal layer thickness, presence of an underdrain, whether there is an impervious bottom, and rate of removal (or reuse).
- For each layer media, water content at saturation, field capacity, and wilting point.
- For each layer media, the analogous material that could be said to control infiltration into this material.

4.4 Runoff Treatment Volume

The treatment volume is any runoff generated from the first inch of rainfall from site elements that can potentially contribute pollutants. These areas include impervious surfaces (such as rooftops, pavements, dirt roads, etc.). This is equivalent to the minimum treatment volume for the performance-based criteria for 80% TSS removal. In order to be compliant with treatment requirements, this volume must run through an SCM that is approved for treatment.

The TNRRAT assumes 100% TSS removal for infiltrated water, 100% TSS removal for all harvested and reused water, and specifies a pollutant removal efficiency (based on TSS removal) for all other approved SCMs based on the best and most recent published data available. Any deviations from these values or efficiencies given to additional measures require validation by the designer with the local stormwater program. Table 4.2 shows a summary of literature findings on TSS removal by SCMs.

Table 4.2: Summary of literature findings on TSS removal by SCMs.

Stormwater Control Measure	Pollutant Removal Efficiency (%)			
	By Storage Infiltration	Drain Discharge	Surface Removal (Flowthrough)	Literature (Average)
Dry Detention	100	NA	40	40
Extended Detention	100	NA	60	80
Wet Ponds	100	NA	80	70
Vegetated Swales	100	NA	25	65 / 85
Managed Vegetated Areas	100	NA	NA	NA
Filter Strips	100	NA	30-35	70
Bioretention	100	85	10	85
Infiltration Areas	100	NA	25	65
Permeable Pavement	100	65	NA	80
Green Roofs	100	NA	NA	NA
Rainwater Harvesting	NA	100	100	NA
Stormwater Treatment Wetlands	80	NA	50-80	80
Manufactured Treatment Devices	NA	NA	50-80	50-100
Underground Infiltration Systems	100	40	NA	50

NA – Not Applicable. References: Chesapeake Bay Program (2006), Center for Watershed Protection (2007), New Hampshire Department of Environmental Services (2008)

Treatment train systems are systems comprised of multiple measures in series to meet design requirements. The TNRRAT accounts for the runoff reduction with treatment train measures through mass balance. The TNRRAT also tracks flow routing through treatment train systems and the assigned pollutant removal efficiency of the individual measures. Total flow and treatment efficiency is accounted for volumetrically through the indicated flow routing paths. No additional inputs are needed to account for treatment train practices in the tool.

4.5 Flood Control and Channel Protection

Flood control and channel protection remain primary goals of stormwater management while runoff reduction is a new standard for lower impact development. Flood protection controls are designed based on a design storm with a specific return frequency that is identified by local regulating jurisdictions. Generally, a 10-year or 25-year return design storm is used to size storm drainage infrastructure and a 100-year return design storm is used to protect from downstream flooding. Channel protection is performed when outflow rates from flood controls are held at or below the 1-year or 2-year return design storm. This outflow rate protects the receiving channel from erosive flowrates that destabilize streambanks and channels. While flood control and channel protection is greatly encouraged, it is not mandated by state standards. Check your local stormwater program for flood control and channel protection regulations.

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Chesapeake Bay Program. 2006. Best Management Practices for Sediment Control and Water Clarity Enhancement. CBP/TRS-282-06.

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Chapter 5

Permanent Stormwater Management Measures

5.1 Stormwater Avoidance and Minimization Approaches

5.2 Summary of Stormwater Management Techniques and Control Measures

5.3 Management Techniques

5.4 Stormwater Control Measures (SCMs)

5.5 Inlets, Outlets and Flow Control

What's in this Chapter?

Section 5.1 describes approaches to be taken in the concept and preliminary site design layout phases that will avoid and minimize the generation of stormwater runoff from new and redevelopment projects.

Section 5.2 provides an overview of the different stormwater control measures and management techniques.

Section 5.3 describes management techniques for establishing land use cover and protocol on how to apply specific techniques.

Section 5.4 provides engineering design specification and management protocol for individual stormwater control measures (SCMs) that can be used in stormwater management systems to achieve Smart Site Design goals for runoff reduction, pollutant removal, andpeak flow control.

Section 5.5 describes and provides design protocol for elements that are common to most SCMs such as pretreatment, inlets and outlets.

5.1 Stormwater Avoidance and Minimization Approaches

5.1.1 Protect Sensitive and Special Value Resources

This source control approach seeks to protect the innate characteristics of the landscape that absorb rainfall and provide other ecological services, such as wildlife habitat, runoff filtration, and nutrient cycling. Conservation of natural features and environmental resources help maintain the predevelopment hydrology of a site by reducing runoff, promoting infiltration, preventing soil erosion, and protecting areas that function as pockets of rainfall retention. Examples of these features include forests, wetlands, native grasslands, floodplains, riparian corridors, zero-order stream channel, springs and seeps, ridge tops, and shoreline buffers. In general, conservation of these areas should maximize contiguous area and avoid fragmentation.

Zero-order streams (or headwaters) provide important watershed functions, including groundwater recharge and discharge, nutrient storage and transformation processes, storage and retention of eroded hill slope sediments, and delivery of leaf and woody debris inputs. Compared to high-order streams, zero-order streams are disproportionately disturbed by mass grading, burying, or channelization.

The conservation approach should be implemented during the conception of the project plan. First, preserve the natural/native topography of a site as much as possible, then delineate drainage and conveyance patterns and protect these areas as much as possible, and finally, ensure that adequate buffers surround these areas including the largest buffer around the sensitive headwaters and wetland habitats. Continuing with the project-planning phase from this perspective will ensure that these sensitive hydrologic areas are preserved and remain linked to other habitat corridors from adjacent areas, minimize the need for grading, and maximize the land's natural retention processes.

Preserving natural areas may also provide secondary benefits of reducing noise pollution, providing valuable wildlife habitat, and creating scenic views and aesthetically-pleasing spaces. These benefits may equate to increased property value as well as quality of life components within the community.

5.1.2 Minimize Land Disturbance

This source control approach seeks to limit the degree of clearing and grading on a project site in order to prevent soil compaction, conserve native soil structure, prevent erosion, and protect zero-order streams. This approach is applied by setting grading limits to minimize the total site area that must be cleared and graded, and/or minimizing the disturbed site area at any one time by completing the project in phases, stabilizing one phase as the next phase is being cleared. This is accomplished by 1) identifying key soils, drainage features, and slopes in the initial site inventory, and then 2) establishing limits of disturbance beyond which construction equipment is excluded. Minimizing grading limits may reduce overall landscape costs as well as help preserve the natural character and aesthetic of a site, which may increase property value.

Specific landscape features on a site may also be more prone to contributing runoff and/or sediment erosion. Avoid disturbing long, steep sloped areas. If these areas are cleared, by essence of gravity and the propensity of water to concentrate and carry energy, then these areas may contribute more runoff and erosion relative to flatter areas. Furthermore, the footprint of impact for grading on a slope is greater than that on a flatter slope because of the efforts required to create a level building pad. General guidelines for slope development are listed in the Table 5.1. Development on slopes > 25% is strongly discouraged.

Table 5.1: Guidelines for slope development related to soil erosion risk exposure (Prince George's County, 2000).

Grade	Maximum Slope Length (ft)	Erosion Risk
0-7%	300	Low
7-15%	150	Moderate
Over 15%	75	High

5.1.3 Reduce and Disconnect Impervious Surfaces

A broad variety of actions can be taken to minimize the creation of new impervious surface and allow for disconnection of needed/existing impervious surface. Collectively, with the other avoidance and minimization approaches and stormwater control measures, these actions are key elements to the smart site design. The following is a list of common impervious surface reduction approaches in residential and commercial settings:

- Reduce residential street width, street right-of-way width, and cul-de-sac radius.
- Use swales and other linear control measures that can be located within the right-of-way.
- Install bioretention or vegetation on the island in the center of the cul-de-sac or other unused space.
- Use narrow sidewalks on one side of the street only, or move pedestrian pathways away from the street entirely.
- Provide greenspace for downspout disconnection of rooftops from storm drain systems.
- Minimize driveway length and width or use shared driveways.

- Allow for cluster or open-space designs (e.g. zero lot line) that reduces lot size or setbacks in exchange for conservation of open spaces.
- Use alternative permeable pavements instead of impervious surfaces.
- Design buildings and parking to have multiple levels.
- Store rooftop runoff in green roofs, foundation planters, bioretention areas, or cisterns.
- Reduce parking lot size by reducing parking demand ratios and stall dimensions.
- Use landscaping areas, tree pits, and planter boxes for stormwater runoff treatment.

Existing local development codes and ordinance may discourage or even prohibit the application of these elements of smart site design. Impervious surface reduction must be applied at the site layout phase of a project in order to be effective. Check with local jurisdictions to ensure that plans to incorporate these elements into a project design will not be contrary to any code or ordinance. If so, the local stormwater program should consider making changes to not only allow for these beneficial actions but, ideally, encourage their wide use.

Impervious surface disconnection is a stormwater control strategy that incorporates an infiltration zone into a site plan that is engineered to accept runoff from an adjacent rooftop, pavement, or other impervious surface (See Sec 5.4). While the detailed design of the infiltration zone is completed using a ratio of green area to impervious surface area, the disconnection approach needs to be implemented in the concept phase such that the site layout includes adequate areas for infiltration between impervious surfaces and stormwater drainage infrastructure or natural drainages.

5.2 Summary of Stormwater Management Techniques and Control Measures

Chapters 1-4 of this manual are a guide to integrating permanent stormwater management systems into development projects, including the conceptual, preliminary, final, and build-out phases. This approach improves upon traditional practices used across Tennessee, shifting from “end of pipe” and “single purpose solutions” to an integrated design, which includes systems of stormwater management techniques and control measures discussed later in this chapter.

The remainder of this chapter provides detailed guidance for the proper design and application of structural SCMs as well as management techniques that preserve and restore the intrinsic value and hydrological performance of the land. These landscape-based SCMs require a new approach to site design where landforms, soils, and vegetation are used together with structural SCMs to effectively achieve the required runoff reduction, pollutant removal and other site-specific goals. Developers and their designers are encouraged to integrate and combine management techniques and SCMs presented in here to achieve stormwater management goals and optimize preservation and restoration of natural features that play critical roles in hydrologic processes.

Each SCM is covered in this chapter, including an overview fact sheet and detailed review of function, design, construction requirements, and maintenance and management. Selecting the best SCM for a given development is heavily dependent on existing site characteristics (slopes, soil type, contributing area use, etc.) as well as the ultimate intended function, benefits and long-term operations of the SCM. Table 5.2 compares benefits of SCMs relative to each other on a categorical scale of low-moderate-high. Use this information along with additional pertinent considerations when selecting SCMs.

Table 5.2: Relative benefits comparison of SCMs on a categorical scale.

Stormwater Control Measures	Runoff Reduction[1]	Pollutant Removal[2]	Peak Rate Control	Land Consumption (per Impervious Area Managed for Runoff Reduction)	Maintenance Frequency[3]	Safety Concerns[4]	Land Cost[5]	Design and Build Cost[5]	Maintenance Cost[5]	Average Annual Costs[5,6]	Provide Water Source	Improves Community Livabillity	Provides Wildlife Habitat
Dry Detention	○	○	●	–	○	◐	●	◐	◐	◐	–	○	○
Wet Ponds	○	◐	●	–	◐	●	◐	◐	○	○	●	●	◐
Vegetated Swale	○	○	○	●	○	○	◐	○	○	○	–	◐	○
Water Quallity Swale	●	●	◐	○	◐	○	◐	◐	○	◐	–	◐	○
Managed Vegetated Areas	●	–	○	●	○	○	○	○	○	○	–	●	●
Filter Strips	○	●	○	–	◐	○	●	◐	◐	◐	–	◐	○
Rain Gardens	●	●	◐	◐	◐	○	◐	◐	◐	◐	–	●	◐
Bioretention	●	●	◐	◐	●	○	◐	◐	◐	◐	–	●	◐
Ultra-Urban Bioretention	●	●	◐	○	●	○	◐	●	●	●	–	●	◐
Infiltration Areas	●	◐	◐	●	◐	○	◐	◐	○	◐	–	●	●
Permeable Pavement	●	○	◐	◐	●	○	○	●	●	●	–	●	○
Subsurface Infiltration	●	○	●	◐	●	○	○	●	●	◐	◐	○	○
Green Roofs	◐	–	○	◐	●	○	○	●	●	◐	–	◐	○
Rainwater Harvesting	●	–	◐	○	●	○	○	◐	◐	◐	●	◐	○
Stormwater Treatment Wetlands	○	●	●	–	◐	◐	◐	○	○	○	●	●	●
Manufactured Treatment Devices	–	●	–	–	●	○	○	○	●	◐	–	○	○

1 Potential to store and retain runoff through infiltration
2 Potential pollutant removal from flowthrough water
3 Low: semi-annual to quarterly, Moderate: semi-seasonal, High: after rain events
4 Safety concerns related to deep ponded water
5 Cost data from King and Hagan, 2011
6 Average annual costs over 20 years

– Not Applicable ○ Low ◐ Moderate ● High

Chapter 5.3

Management Techniques

Installing SCMs prior to site preparation may result in failure of the measures due to sedimentation and/or compaction. Timing their installation (pre-planning) is important to protecting these SCMs and avoiding sometimes extensive post-construction rehabilitation or complete re-installation. Infiltration SCMs depend on quality of soils and their porosity. These SCMs depend on soil mixtures, types, and pH. For example, a standard functional bioretention facility should have sand, loam and compost mixture. No other materials or substance should be mixed in it that may be harmful to plant growth or prove a hindrance to planting or maintenance to operations. The planting soil must be free of plant or seed material of non-native invasive species or noxious weeds. Sediment run-on from disturbed areas can clog practices and change the soils composition and pH. Also, compaction due to construction disturbance can also impact their effectiveness and result in the necessity of spending more resources to restore their functionality.

This chapter will describe management techniques required to achieve the practice/management goal. The amount of required techniques depends on the initial condition and the management goal of each project (see Figure 5.1). As example, it takes more steps to get to good forest condition from compacted soil than from good turf.

Management is a clearly defined state of soil and vegetation that provides the desired degree of infiltration and pollutant removal under the optimal design condition. The design condition is assumed to be 15 years following stabilization, when the site has reached a reasonable level of maturity and is undergoing only gradual changes. Management is the defined desired endpoint and depends on a series of techniques to get from the current possibly highly disturbed condition to that endpoint. A management has clearly defined specifications including soil hydrologic characteristics and vegetation type and density. The term cover is sometimes used to describe a management that has minimal inputs.

A ***Technique*** as pertaining to permanent stormwater management is a method or operation that progresses or sustains progress from one state of management to a higher-functioning state of management. These can fall in two general categories:

1) Methods of getting from “here” to “there,” from the presumed worst-case condition immediately following development to the desired management endpoint. The techniques used in a specific site design will vary greatly depending on the starting conditions. For example, if an area of “good forest” is left undisturbed, no technique is necessary to achieve a “good forest” management. On the other hand, if the post-construction condition is a bare highly-disturbed mixture of topsoil and subsoil that is heavily compacted, the required technique to achieve a “good forest” management in 15 years may include all or some of the following: soil ripping, soil amendments, temporary vegetative cover, slope erosion control, planting of trees, fertilization and irrigation.
2) The operations necessary to maintain the required trajectory towards the desired design condition, and to maintain that condition once it is achieved. In other words, the protocol for maintenance of a “good forest” management may include the techniques of tree thinning, fertilization, and invasive species removal. Note that the protocol for a “fair forest” management may include the same techniques, but with less intensive requirements.

Timing of SCM installation and protection of the SCM area are two critical techniques. Installing SCMs prior to adequate site preparation may result in failure due to sedimentation and/or soil compaction. Timing of their installation is important in protecting these SCMs and avoiding sometimes extensive post-construction rehabilitation or complete re-installation. Infiltration SCMs depend on the quality of soils and their characteristics of porosity, organic matter, pH, and texture. SCM performance is highly sensitive to compaction or deviation from good growing conditions. For example, a bioretention facility should have a mixture of sand, loam and compost. No other materials or substance should be mixed into these media because it may be harmful to plant growth or prove a hindrance to maintenance and operation. The planting soil should be free of plant or seed material of non-native invasive species or noxious weeds.

Sediment run-on from disturbed areas can clog practices and change soil composition or pH. Compaction due to construction disturbance can also impact their effectiveness and result in the necessity of spending more resources to restore their functionality.

Management may be thought of as a spectrum, and techniques are used to mitigate impacts expressed in a site's initial condition to achieve a goal of a managed vegetated area or other end management. Initial conditions are described in the left side of Figure 5.1, and a list of techniques used to move from the impacted end of the spectrum to the optimal soil condition are also listed. On the right side is the spectrum of managed vegetated, and below it is a list of techniques used to establish the desired vegetation.

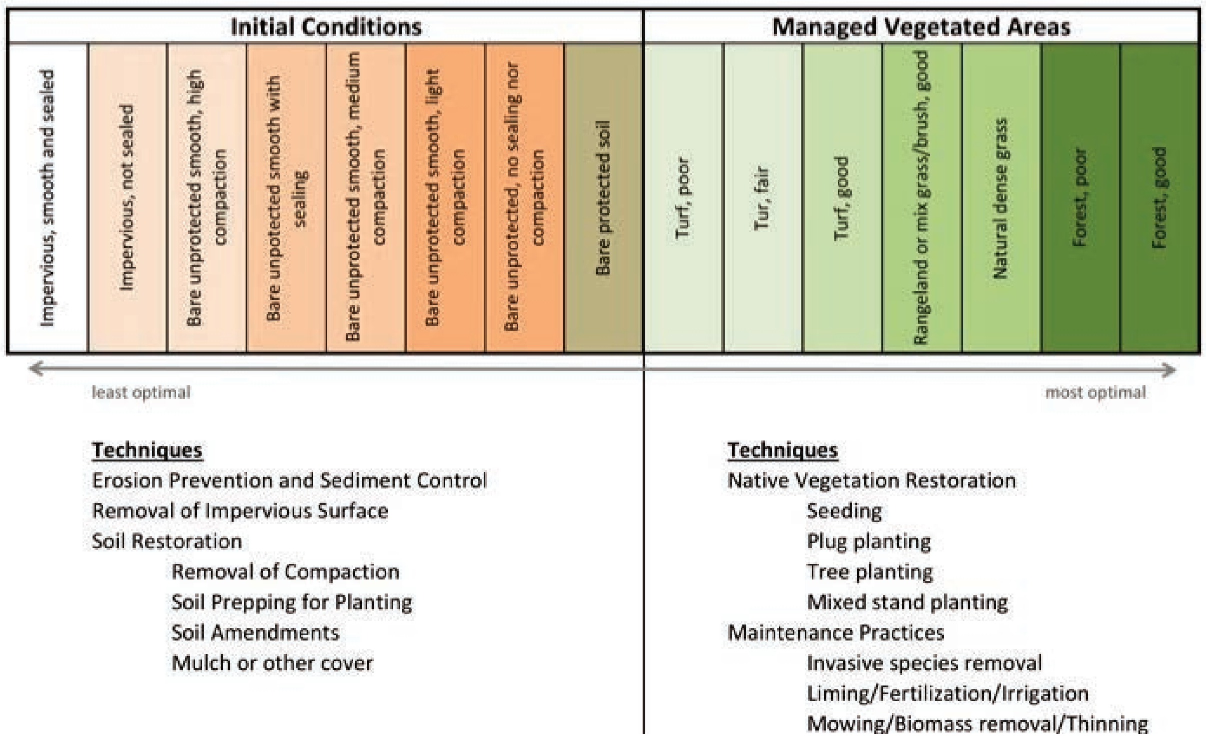

Figure 5.1: Spectrum of initial condition managements and permanent managements along with associated techniques used to improve from a least optimal state to a more optimal state.

Techniques are used to achieve a management goal. The amount and rigor of technique(s) applied depends on the initial condition and the management goal of each project element. For example, it takes the application of more techniques to establish a good forest condition from compacted bare soil than from a porous clay soil with established temporary cover. Soil ripping or removal of compaction is needed in the compacted clay scenario before fertilization techniques could be applied and a forest stand established.

Soil quality and vegetation are key factors in the effectiveness of an SCM at reducing runoff volume and removing pollutants. Soils must possess the structure and texture that allows water to infiltrate and plant roots to penetrate. Design of stormwater management systems is conducted through modeling that assumes disturbed soils are ameliorated back to a condition that resembles an undisturbed natural soil. A designer is responsible for documenting the initial condition and including in their plan the necessary technique(s) for soil amelioration and plant establishment to accomplish the projected target management for each element containing disturbed soils. This amelioration process should be included in the project application as part of the permanent stormwater management plan.

5.3.1 Erosion Prevention and Sediment Controls

To ensure the greatest potential of success of a LID facility, SCMs should not be installed until construction activity is completed and stabilized within the entire contributing drainage area; this means having all areas both fully landscaped and mulched or having well established grass or other ground cover. Construction drawings should clearly state the designer's intentions and an appropriate stage of construction should be shown on the plans. This staging should be covered in detail at the pre-construction meeting (including the on-site responsible construction personnel) and then enforced by an appropriate inspection program throughout the construction period. On-site education of contractor and/or subcontractors would also be advised. Storing and reestablishing top soil on site is important to reestablishing the overall infiltration of the site. Each site is unique, and this strict construction staging approach may not be necessary, such as in the case of bioretention in parking lot islands with little contributing pervious areas. It is critical that the designer understands these realities and plans accordingly. For more details, refer to TDEC E&S Handbook chapter 6 and 7 (TDEC E&S Handbook p:94).

5.3.2 Soil Restoration

Soil restoration is a technique used to enhance and restore soils by physical treatment and/or mixture with additives – such as compost – in areas where soil has been compacted. Soil media restoration increases the water retention capacity of soil, reduces erosion, improves soil structure, immobilizes and degrades pollutants (depending on soil media makeup), supplies nutrients to plants, and provides organic matter. Soil restoration is also used to reestablish the soil's long term capacity for infiltration and to enhance the vitality of the soil as it hosts all manner of microbes and plant root systems in complex, symbiotic relationships. .

Figure 5.2: Soil amended with compost (Source: USDA NRCS).

Restored soils result in increased infiltration and decreased volume of runoff. Designers can receive credit based on areas (acres) complying with the requirements of desired SCMs. For example, a bare soil can be assigned a management reflecting a "good" condition instead of "poor" condition.

A healthy soil (Figure 5.3) provides a number of vital functions including water storage and nutrient storage, regulate the flow of water, and immobilize and degrade pollutants. Healthy soil contains a diverse community of beneficial microorganisms, a sufficient amount of plant nutrients (nitrogen and phosphorous), some trace elements (e.g., calcium and magnesium), and organic matter (generally five to 10%).

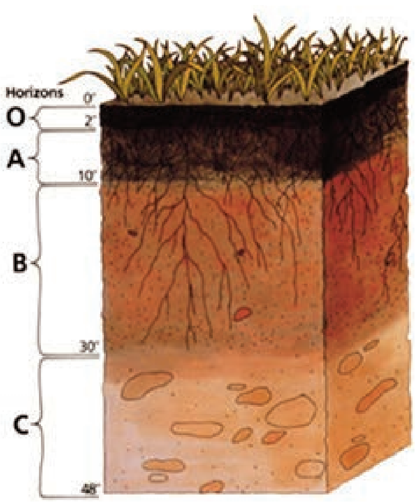

Figure 5.3: A healthy soil profile (Source: USDA NRCS).

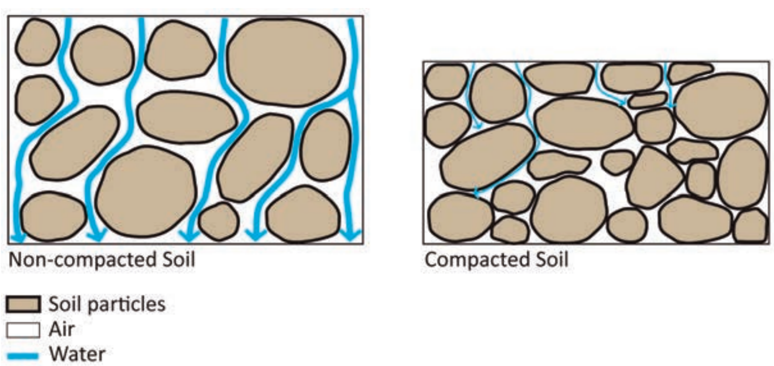

Figure 5.4: Compacted soil constraints movement of air and water (Source: USDA NRCS).

Healthy soil typically has a neutral or slightly acidic pH and good structure which includes various sizes of pores to support water movement, oxygenation, and a variety of other soil processes.

Caring for soil is also a critical component of water management, especially during development activities, such as construction grading, which often result in erosion, sedimentation, and soil compaction. Proper protection and restoration of soil are critical management techniques to combat these issues. Soil restoration prevents and controls erosion by enhancing the soil surface to prevent the initial detachment and transport of soil particles.

Soil compaction is the enemy of water quality protection. Soil compaction occurs when soil particles are pressed together, reducing the pore space necessary to allow for the movement of air and water throughout the soil (Figure 5.4). This decrease in porosity causes an increase in bulk density (weight of solids per unit volume of soil). The greater the bulk density of the soil means the lower the infiltration and the larger the volume of runoff (Table 5.3).

Compaction limits vegetative root growth, restricting the health of plants as well as the biological diversity of the soil. Compaction also affects the infiltrating and water quality capacity of soils. Soil compaction can lead to increased erosion and stormwater runoff, low infiltration rates, increased flooding, and decreased water quality from polluted runoff. After compaction, a typical soil has strength of about 6,000 kilopascals (kPa), while studies have shown that root growth is not possible beyond 3,000 kPa. . There are two types of compaction, minor and major, each of which requires a particular restoration technique(s) or method:

- **Minor compaction** – Surface compaction within 8-12 inches due to contact pressure and axle load <20 tons can compact through root zone up to one foot deep. Soil restoration activities can include: subsoiling, organic matter amendment, and native landscaping. Tilling/scarifying is an option as long as it is deep enough (i.e., 8-12 inches) and the right equipment is used (should not be performed with common tillage tools such as a disk or chisel plow because they are too shallow and can compact the soil just beneath the tillage depth).
- **Major compaction** – Deep compaction, contact pressure and axle load > 20 tons can compact up to two-feet deep (usually large areas are compacted to increase strength for paving and foundation with overlap to “lawn” areas). Soil restoration activities can include: deep tillage, organic matter amendment, and native landscaping.

To evaluate the level of compaction in soils, bulk density field tests are conducted. Table 5.3 shows the ideal bulk densities for various textures of soils.

Table 5.3: Bulk density for soil texture (Source: USDA NRCS).

Soil Texture	Ideal Bulk densities, g/cm^3	Bulk densities that may affect root growth, g/cm^3	Bulk densities that restrict root growth, g/cm^3
Sands, loamy sands	<1.60	1.69	1.8
Sandy loams, loams	<1.40	1.63	1.8
Sandy clay loams, loams, clay loams	<1.40	1.6	1.75
Silt, silt loams	<1.30	1.6	1.75
Silt loams, silty clay loams	<1.10	1.55	1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	1.58
Clays (>45% clay)	<1.10	1.39	1.47

5.3.2.1 Applications

Soil restoration can occur anywhere to alleviate soil compaction. It can be specifically addressed in the following examples:

- **new development (residential, commercial, industrial)** – Heavily compacted soils can be restored prior to lawn establishment and/or landscaping to increase the porosity of the soils and aid in plant establishment.
- **detention basin retrofits** – The inside face of detention basins is usually heavily compacted, and tilling the soil mantle will encourage infiltration to take place and aid in establishing vegetative cover.
- **golf courses** – Using compost as part of landscaping upkeep on the greens has been shown to alleviate soil compaction, erosion, and turf disease problems.

5.3.2.2 Removal of compaction

Table 5.4 describes various soil disturbance activities related to land development, soil types and the requirements for soil restoration for each activity. Soil Restoration or runoff reduction is a required practice. Restoration is applied across areas of a development site where soils have been compacted and will be vegetated according to the criteria defined in Table 3. Compacted soil can be amended by first tilling the soil, breaking apart the compaction, and then applying various soil media.

Table 5.4: Soil Restoration Recommendations [NY, 2010. P:99].

Type of Soil Disturbance	Soil Restoration Requirement	Comments/Examples
No soil disturbance	Restoration not permitted	Preservation of Natural Features
Minimal soil disturbance	Restoration not required	Clearing and grubbing
Minor soil compaction	Six inches of soil media (18.5 cubic yards per 1,000 square feet of soil) should be applied, and then tilled into the existing soil up to eight inches	Protect area from any ongoing construction activities.
Major soil compaction	10 inches of soil media (31 cubic yards per 1,000 square feet of soil) should be applied and then tilled into the existing soil up to 20 inches	
Areas where Runoff Reduction and/or Infiltration practices are applied	Restoration not required, but may be applied to enhance the reduction specified for appropriate practices.	Keep construction equipment from crossing these areas. To protect newly installed practice from any ongoing construction activities construct a single phase operation fence area
Redevelopment projects	Soil Restoration is required on redevelopment projects in areas where existing impervious area will be converted to pervious area.	

- **Tilling consideration:**

Tilling the soil (also referred to as aeration, scarification, ripping, or subsoiling):

a. Effective when performed on dry soils.

b. Should be performed where subsoil has become compacted by equipment operation, dried out, and crusted, or where necessary to obliterate erosion rills.

c. Should be performed using a solid-shank ripper and to a depth of 20 inches, (eight inches for minor compaction).

d. Should be performed before amending media is applied and after any excavation is completed.

e. Should not be performed within the drip line of any existing trees, over underground utility installations within 30 inches of the surface, where trenching/drainage lines are installed, where compaction is by design, and on inaccessible slopes.

f. The final pass should be parallel to slope contours to reduce runoff and erosion.

g. Tilled areas should be loosened to less than 1,400 kPa (200 psi) to a depth of 20 inches below final topsoil grade.

h. The subsoil should be in a loose, friable condition to a depth of 20 inches below final topsoil grade and there should be no erosion rills or washouts in the subsoil surface exceeding three inches in depth.

i. Tilling should form a two-directional grid. Channels should be created by a commercially available, multi-shanked, parallelogram implement (solid-shank ripper), capable of exerting a penetration force necessary for the site.

j. No disc cultivators, chisel plows, or spring-loaded equipment should be used for tilling. The grid channels should be spaced a minimum of 12 inches to a maximum of 36 inches apart, depending on equipment, site conditions, and the soil management plan.

k. The channel depth should be a minimum of 20 inches or as specified in the soil management plan. If soils are saturated, delay operations until the soil, except for clay, will not hold a ball when squeezed.

l. Only one pass should be performed on erodible slopes greater than one vertical to three horizontal.

5.3.2.3 Soil preparation for planting

5.3.2.3.2 Lime, fertilizer, and topsoil application

When conventional seeding is to be used, topsoil should be applied to any area where the disturbance results in subsoil at the final grade surface. Figure 3 provides guidance on the volume of topsoil required to provide specific topsoil depths. Soil pH should be above 5 – preferably between 6.0 and 6.5. Soil should be submitted to a soils specialist or County Agricultural Extension agent for testing and soil amendment recommendations. In the absence of soil test results, the following application rates can be used:

- **Ground agricultural limestone:**
  Light-textured, sandy soils: 1- 1 1/2 tons/acre.
  Heavy-textured, clayey soils: 2-3 tons/acre.
- **Fertilizer:**
  Grasses: 800-1200 lb/acre of 10-10-10 (or the equivalent).
  Grass-legume mixtures: 800-1200 lb/acre of 5-10-10 (or the equivalent) (TDEC E&S Handbook p:119).

- **Topsoil**

Table 5.5: Cubic Yards of Topsoil Required to Attain Various Soil Depths (TDEC E&S Handbook, P:120).

Depth (in)	Per 1,000 Square feet	Per acre
1	3.1	134
2	6.2	268
3	9.3	403
4	12.4	537
5	15.5	672
6	18.6	806

5.3.2.3.3 Herbicide application

Application of herbicides: This is a method of last resort, but necessary in some cases. Herbicide treatments should be applied only to a specific plant and never broadcast, especially near water bodies. Use a colored dye in the herbicide mix to identify areas that have been sprayed. Use the least persistent pesticide available to accomplish the job.

5.3.2.4 Soil amendment

Soil media used for amendment may be comprised of either organic or inorganic material (table 3). Organic media can increase soil organic matter content, which improves soil aeration, water infiltration, water and nutrient holding capacity, and is an important energy source for bacteria, fungi, and earthworms.

Table 5.6: Restoration Media (MI, 2011).

Organic Media	Inorganic Media
Compost*	Vermiculite
Aged manure*	Perlite
Biosolids* *(must be a Grade 1 biosolid)*	Pea gravel
Sawdust *(can tie up nitrogen and cause deficiency in plants)*	Sand
Wood ash *(can be high in pH or salt)*	
Wood chips *(can tie up nitrogen and cause deficiency in plants)*	
Grass clippings	
Straw	
Sphagnum peat *(low pH)*	

** Materials containing animal wastes can cause phosphorus*

- **Soil amendment considerations**

  Applying soil media for amendment:

  a. Soil media should not be used on slopes greater than 30 percent. In these areas, deep-rooted vegetation can be used to increase stability.

  b. Soil restoration should not take place within the critical root zone of a tree to avoid damaging the root system. To determine the critical root zone, measure the tree diameter four and half feet above grade. For every inch of diameter measured, the critical root zone will be one foot radius from the tree. (For example, a tree that measures 20 inches in diameter will have a critical root zone of 20 foot radius).

c. Onsite soils with an organic content of at least five percent can be stockpiled and reused to amend compacted soils, saving costs. Note: These soils must be properly stockpiled to maintain organic content.

d. Soils should generally be amended at about a 2:1 ratio of native soil to media. If a proprietary product is used, follow the manufacturer's instructions for the mixing and application rate.

e. Add six inches compost or other media and till up to eight inches for minor compaction. (Six inches of compost equates to 18.5 cubic yards per 1,000 square feet of soil.)

f. Add 10 inches compost or other amendment and till up to 20 inches for major compaction. 10 inches of compost equates to approx. 30.9 cubic yard per 1,000 square feet.

g. Compost can be amended with bulking agents, such as aged crumb rubber from used tires, or wood chips. This can be a cost-effective alternative that reuses waste materials while increasing permeability of the soil.

h. Compost shall be aged, from plan or dust produced when handling, pass through a half inch screen and have a pH suitable to grow desired plants.

5.3.2.5 Mulch and other cover applications (TDEC E&S Handbook, p:104)

Surface mulch is considered the most effective, practical means of controlling runoff and erosion on disturbed land prior to vegetative establishment. Mulch reduces soil moisture loss by evaporation, prevents crusting and sealing of the soil surface, moderates soil temperatures, provides a suitable microclimate for seed germination, and may increase the infiltration rate of soil.

Straw mulch is the most common type of mulch used in conjunction with seeding or providing a temporary groundcover. The straw should come from wheat or oats ("small grains"), and may be spread by hand or with a mulch blower. Note that straw may be lost to wind and must be tacked down. The recommended application rate for straw mulch is 2 tons per acre, dry unchopped, unweathered.

Mulch, as well as wood chip, bark chips, shredded bark, wood fiber, and other material are temporary stabilization practices. Those materials can only increase initial condition of unprotected bare soil to protected bare soil.

5.3.2.6 Winter considerations

Since soil restoration is performed in conjunction with plantings, this management technique should be undertaken in spring or autumn and during dry weather, so that plantings can establish.

5.3.2.7 Other considerations

- During periods of relatively low to moderate subsoil moisture, the disturbed subsoils are returned to rough grade and the following soil restoration steps applied:

  1. Apply 3 inches of compost over subsoil
  2. Till compost into subsoil to a depth of at least 20 inches using a cat-mounted ripper, tractor mounted disc, or tiller, mixing, and circulating air and compost into subsoils
  3. Rock-pick until uplifted stone/rock materials of four inches and larger size are cleaned off the site
  4. Apply topsoil to a depth of 6 inches
  5. Vegetate as required by approved plan.

Figure 5.5: Attachments used for soil decompaction.

At the end of the project an inspector should be able to push a 3/8" metal bar 12 inches into the soil just with body weight. Figure 5.5 shows two attachments used for soil decompaction (NY, 2010, p:100).

- Soil restoration may need to be repeated over time, due to compaction by use and/or settling. Taking soil core samples will help to determine the degree of soil compaction and if additional media application is necessary. Two points help ensure lasting results of decompaction:
  1. Planting the appropriate ground cover with deep roots to maintain the soil structure
  2. Keeping the site free of vehicular and foot traffic or other weight loads. Consider pedestrian footpaths. (Sometimes it may be necessary to de-thatch the turf every few years) [MI, P:298].

5.3.3 Native Vegetation Restoration

Native species are generally described as those existing in a given geographic area prior to European settlement. Over time, native vegetation does not typically require significant chemical maintenance by fertilizers and pesticides. This results in additional water quality benefits. Native species are typically more tolerant and resistant to pest, drought, and other local conditions than non-native species. In addition to chemical applications, minimum maintenance also means minimal mowing and irrigation in established areas. Native grasses and other herbaceous materials that do not require mowing or intensive maintenance are preferred.

"Restoration" implies returning a landscape to a former, more pristine state. In reality, historic conditions cannot be replicated. For most development and redevelopment projects, a realistic goal is to remove or mitigate destructive impacts and reintroduce significant missing processes and components, where possible. The intent of these actions is to allow natural processes to bring about gradual recovery.

While there are many benefits to improving existing native cover types, the primary purpose of this management technique is to increase the potential for effective stormwater management on a site and to provide the developer with another means of stormwater management. This management technique functions by reestablishing a healthy plant community with thick, spongy soil layers that:

- Generates less runoff.
- Absorbs a greater volume of water through infiltration, evaporation, and evapotranspiration.
- Improves soil conditions through the addition of organic material, which increases soil pore space.
- Reduces the need for maintenance by fertilizers, herbicides, and pesticides.
- Reduces the force of precipitation by leaf interception.

5.3.3.1 Variations

Species selection for any native landscape should be based on function, availability, and level of appropriateness for site conditions. Native species plantings can achieve variation in landscape across a variety of characteristics, such as texture, color, and habitat potential.

Properly selected mixes of flowering prairie species can provide seasonal color; native grasses offer seasonal variation in texture. Seed production is a food source for wildlife and reinforces habitat. In all cases, selection of native species should strive to achieve species variety and balance, avoiding creation of single-species or limited species "monocultures" which pose multiple problems. In sum, many different aspects of native species planting reinforce the value of native landscape restoration, typically increasing in their functional value as species grow and mature over time. Examples include:

- **Prairie** – Install Big Bluestem, Little Bluestem, Indian Grass, Switchgrass and others that resemble the Native Americans grassland [Shea, 1999]. Prairies have a tendency to establish and regain function rather quickly (3-10 years), and can provide lower-growing vegetation with highly attractive native grasses and wildflowers.
- **No-mow lawn area** – Install low-growing native grasses that are used as a substitute for lawn or cool-season grass plantings.
- **Woodland** – Install a balance of native trees, shrubs, forbs, grasses, and sedges. Woodlands will provide shade, vertical structure, and a high level of rainfall interception in the long term. It typically requires a significant amount of time to mature.
- **Constructed wetlands** – Historic drained wetlands or existing artificial low areas may be planted with wetland species that will thrive in standing water or saturated conditions.
- **Buffer areas** – Bands of re-established native vegetation occurring between impermeable surfaces, lawns, or other non-native land uses and existing natural areas.
- **Replacement lawn areas** – Existing turf lawns may be converted to native prairies, wetlands, or woodlands to minimize maintenance while increasing stormwater benefits and wildlife habitat.

Figure 5.6: Tennessee native no-mow lawn and woodland (Source: The SMART Center).

5.3.3.2 Calculation

Native revegetation and reforestation will increase infiltration capacity and reduce runoff volume. Designers can receive managed vegetated area credit based on the square feet of trees or shrubs being added. The credit is reflected through label "Good, fair, or poor", that is described below:

- **Good condition**
  - ≤ 200 ft^2 / tree, or expected full canopy cover
  - ≤ 25 ft^2 / shrub
  - > 90% turf cover, with no continuous bare areas
  - Trees or shrubs with lush undergrowth, with > 90% of surface under either canopy or ground cover

- **Fair condition**
  - 200 - 350 ft^2 / tree, or expected canopy cover > 75%
  - 25 - 40 ft^2 / shrub
  - > 75% turf cover, with no contiguous bare area > 50 ft^2
  - Trees or shrubs with fair undergrowth, with > 75% of surface under either canopy or ground cover
- **Poor condition**
  - 350 - 500 ft^2 / tree, or expected canopy cover > 50%
  - 40 - 60 ft^2 / shrub
  - > 50% turf cover, with no contiguous bare area > 75 ft^2
  - Trees or shrubs with some undergrowth, with > 50% of surface under either canopy or ground cover
- Below these targets, is not considered an adequate measure for which to claim credit, due to both very limited infiltration capacity and potential to serve as a source of TSS
- Minimum seeding/planting will receive “poor” credit, while optimize seeding/planting will receive “fair” credit. “Good” credit can only be achieved when optimized seeding/planting is followed by a maintenance practice (see Figure 5.1).

5.3.3.3 Materials

Whenever practical, native species should be from the same ecoregion as the project area. When necessary, species may be used from adjacent ecoregions for aesthetic or practical purposes. Information relating to Tennessee native species and their use in landscaping is available from on Appendix D.

Developments should use native trees for replacement in areas separate from residential lots, or storm drainage areas adjacent to roadway or parking lots. Species selection shall be based on the underlying soils and the historic, native indigenous plant community type for the site, if existing conditions can support the plant community.

Native plan restoration/reforestation is eligible under the following qualifying conditions:

- Avoid the use of a single species of tree. No more than 20% of the area composes of any single tree species. Reforestation should consider the composition of area forests, and two thirds of selected trees must be large canopy. Reforestation methods should achieve full canopy cover within ten to fifteen years.
- The minimum size requirement for reforestation is saplings 6-8 feet in height. The minimum size requirement for shrubs is 18-24 inches, or 3 gallon size. In addition, the entire reforestation should be covered with 2-4 inches of organic mulch or with a native seed mix in order to help retain moisture and provide a beneficial environment for the reforestation.
- The trees must be free from injury, pests, diseases, and nutritional disorders; and must be fully branched and have a healthy root
- A long-term vegetation management plan must be prepared and included in the site’s maintenance agreement in order to demonstrate the ability to maintain the reforestation area in an appropriate forest canopy condition. The plan should include a scale drawing showing the area to be planted, along with a plant list which includes species, size, number, and packaging. In addition, the reforestation area shall be clearly identified on all construction drawings and EPSC plans during construction.
- The reforestation area must be protected in perpetuity such that no future development or disturbance may occur within the area.
- The planting plan must be approved by the local jurisdiction including any special site preparation needs.
- It is recommended that the construction contract contain a care and replacement warranty extending at least two growing seasons, to ensure adequate growth and survival of the plant community.

- The final size of the trees should be considered when designing the planting plan. Tennessee One-Call (811) must be contacted prior to the submission of the planting plan to ensure that no utilities will be impacted by the tree planting. The planting plan must also avoid placing trees under overhead utilities.

5.3.3.4 Restoration process

1. **Assess vegetation onsite and delineate areas to be preserved.** Note landscape cover type, size, condition, and age.
2. **Integrate areas selected for protection into site and stormwater plans** to meet multiple objectives and create environmental and social connections (trail systems, hedgerows, etc.).
3. **Identify glaring problems within the selected enhancement area**, e.g., fill and soil pushed over the slope into the valley, extreme cut, exposed subsoil or bedrock, bare and eroded soil, invasive exotic plants, trash, and toxic materials. Particularly note erosion and sedimentation problems such as gullies and bare soil. Also note influences beyond the site that may undermine enhancement efforts.
4. **Identify and address factors that suppress regeneration of native plants or contribute to overall plant community decline before replanting or amending the soil.** If these factors are not addressed, efforts spent on enhancement will be wasted.
5. **Where relevant, identify major cyclical processes that shape the site**, e.g., floods, fire, etc. These recurring natural events may help to sustain the native plant community and prevent colonization by invasive exotics.
6. **Search for a healthy model in the neighborhood to serve as a design reference:**
   - Plant community structure and pattern—Use the model to determine the arrangement, types, and density of plants.
   - Identify and protect desirable and sensitive species and any rare, threatened, or endangered plant (or animal) species. Particularly identify “keystone” species. If absent, replace these species where possible.
   - An unusual amount of dead or dying plants requires a determination of cause.
7. **General Recommendations**
   - In healthier systems with minimal disturbance, native seeds may be present in the soil. Areas adjacent to other healthy natural areas can benefit from seeds transported by wind, water, and animals. If time is not a factor, and rapid cover is not critical, these areas can be left to regenerate on their own.
   - Plant tough, vigorous, generalist species, which will create immediate cover and discourage invasive species.
   - Stabilize edges. Where a remnant natural area meets a manmade landscape, the design should create a graceful, smooth transition. Construction often leaves these transition areas highly disturbed. Repair of these newly exposed edges is critical.
   - Regrade where necessary, stabilize the soil, and replant with fast-growing, tough, native edge species. Repair of damaged edges will protect the health of the natural landscape and enhance its stormwater benefits.
   - Newly exposed, existing trees are often vulnerable to wind throw. Replant a strip along newly formed edges (where a portion of the natural landscape has been cut away) to buffer the remaining native landscape from increased wind, light, noise, and other impacts.

5.3.3.5 Tree planting guidelines

Figure 5.7: Tree planting guidelines.

For more guidance about planting tree, visit:

http://www.tn.gov/agriculture/publications/forestry/treeline_hbook.pdf

http://www.arborday.org/trees/planting/index.cfm

http://www.tn.gov/twra/pdfs/treeplanting.pdf

http://www.oregon.gov/odf/privateforests/docs/ReforestationGuide.pdf

5.3.4 Maintenance Practices

The requirements for the Maintenance Document are in Appendix F .They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to the local stormwater program.

First year maintenance operations includes

- Initial inspections for the first six months (once after each storm greater than half- inch).
- Reseeding to repair bare or eroding areas to assure grass stabilization.
- Water once every three days for first month, and then provide a half in year. Irrigation plan may be adjusted according to the rain event.
- Fertilization may be needed in the fall after the first growing season.

Ongoing maintenance

Two points help ensure lasting results of decompaction:

1. Planting the appropriate ground cover with deep roots to maintain the soil structure
2. Keeping the site free of vehicular and foot traffic or other weight loads. Consider pedestrian footpaths. (Sometimes it may be necessary to de-thatch the turf every few years)

- Soil restoration may need to be repeated over time, due to compaction by use and/or settling. Taking soil core samples will help to determine the degree of soil compaction and if additional media application is necessary.
- Mowing is permitted but not encouraged between the trees while they are being established. Eventually, the canopy should shade out the grass and forest undergrowth will be established removing the need to mow. Vegetation management plans should consider if residents would prefer the site mowed in perpetuity.
- Additional maintenance activities include:
  - Watering the trees as needed.
  - Repairing areas of erosion or reseeding areas that are bare.
  - Removing trash and debris from area.
  - Replanting any trees that die throughout the year (the construction contract should contain a care and replacement warranty extending at least two growing seasons, to ensure adequate growth and survival of the plant community).
  - Addressing areas of standing water which might breed mosquitoes.
  - Picking up branches that have fallen.
  - Grooming trees or shrubs as needed.
  - Removing any trees or limbs damaged in storms that might pose a danger.

Removing invasive species

- **Where necessary, remove masses of aggressive, invasive exotic species to expose the potential of the area.**
  - Invasive exotic species often occur as dense shrub thickets or extensive, heaping vine cover. Vines in trees and climbing over shrubs suppress reproduction on the ground and shade older trees and shrubs, eliminating seed sources. Privet, Japanese honeysuckle, kudzu, mimosa trees, and tree of heaven are the most prevalent invasive exotics.
  - Remove large tangles of aggressive exotic species to allow an accurate evaluation of the site and suggest appropriate repair strategies.

General considerations:

- Effective control treatments vary by species. In some cases, non-chemical options exist.
  - o Emphasize techniques that minimize soil disturbance and that remove the exotic plants by the roots where possible, while leaving adjacent, desirable plants undamaged. When removing existing invasive plants, either pull up by the roots or eliminate re-sprouts later.
- Some invasive exotics are more troublesome than others. For example, highly aggressive species such as kudzu and privet are particularly difficult to eradicate and should be removed as early as possible, before they are well established.
- Phase removal of exotic canopy trees to keep a shady forest cover.

Specific removal methods

- Hand pulling: Suggested for restricted areas of herbaceous weeds or small seedlings of woody plants.
- Tools: A weed wrench allows the user to pull up young tree seedlings (too large to pull by hand) by the roots. This tool disturbs the adjacent areas only minimally.
- Mowing: In general, broadleaved herbaceous plants will diminish with regular mowing. Broadleaved herbaceous plants include both weeds and wildflowers, and a meadow mown more than three times a year will become predominantly grasses.
- Controlled burning: This technique can be used to manage any landscape cover type. However, in meadow management, fire is used to reduce the number of trees and increase the amount of grasses and wildflowers.
  - o Burning can be used in two major ways: 1) If the remnant natural area is small, or only a small portion of it requires treatment, a single person, with a backpack propane torch, can burn small areas (approximately 10 feet by 10 feet). Generally, small-scale burns are done as a patchwork of squares, with unburned vegetation between burned patches. Extreme caution must be used to prevent wildfire; 2) Where a relatively large-scale burn is considered (approximately 1 acre or more), property managers should coordinate with the local fire department and state conservation agencies. Permits are required from the local government.
  - o Caution: Some undesirable species, such as black locust, are "fire increasers." If these species are already present, burning may encourage them. Conversely, successful regeneration of oak forests in the eastern United States has historically required fire.
- Tilling: For large areas of infestation, tilling can uproot and kill undesirable species. However, tilling can also kill native species and encourage invasive plants that spread by underground rhizomes or stolons, such as kudzu *(Pueraria lobata)*.

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Chapter 5.4

Stormwater Control Measures (SCMs)

This section provides engineering design specifications and management protocols for individual SCMs that can be used in stormwater management systems to achieve Smart Site Design goals for runoff reduction and pollutant removal control.

The design specifications presented in the subsequent sections of this chapter were created based on a synthesis of information from the best available sources across the country. Critical design specifications are emphasized for each SCM. The TNRRAT is the preferred method to determine the needed size of SCMs. Some sizing information on contributing areas and maximum allowable SCM sizes are included here to provide a guide for designers and plan reviewers in SCM siting and design. Often times, "rules of thumb" are commonly used to size SCMs based on contributing area size or impervious surface ratios. This approach does not take into account specific site characteristics and circumstances. TNRRAT sizing results are produced from specific user inputs and tailored to a unique application. Because of this, TNRRAT results may differ from those found using general "rules of thumb." It is up to the designer to provide sufficient justification to use sizing tools other than the TNRRAT in SCM design.

Certain SCMs are sized to capture and treat a "runoff reduction volume" and "treatment volume," respectively. These volumes can be easily determined for specific project plans using the TNRRAT. See chapter 6 for guidance. Alternatively, use the methodology supported by local municipal programs in determining these values.

Please note: While this manual makes reference to flood control aspects of stormwater management for larger storms, this is not its intended use. In Tennessee, flood control remains under the purview of local government codes, ordinance, and policy. Flooding is not regulated through MS4 permits. As such, it should be understood that the practices in this manual are not intended to solve existing flooding and drainage issues in Tennessee communities. The practices identified here may provide additional benefit of mitigating water quantity issues, but only when they are used in conjunction with other stormwater control and floodplain management measures.

The following outline of information is used in subsequent sections, one for each individual SCM:

1. A "quick page" that includes a brief description of the SCM and bulleted breakdown of key considerations during the design process; including site constraints, key design criteria, maintenance recommendations, relative advantages and disadvantages, and a design checklist.
2. Following each summary page is detailed information on the SCM which includes:
   a. **Section 1: Design** – Technical procedures to be followed for site-specific SCM design.
      i. **Application and Major design elements** – Feasibility and applicability depended on the project land use and natural conditions.
      ii. **Design criteria** – Key elements of the SCM from inflow to outflow, including materials specifications and management requirements.
      iii. **Calculation** – Detail guidance on sizing criteria, both within the TNRRAT and using manual calculation.
      iv. **Typical detail drawings**

   b. **Section 2: Construction** – Details of pre-construction, construction and inspections. However, this section does not specifically address erosion prevention and sediment control methods. Users should refer to TDEC's Tennessee Erosion and Sediment Control Handbook in addition to this manual.

   c. **Section 3: Maintenance** – Recommendations on agreements and schedules needed to properly maintain SCM performance.

The following SCMs are approved for use as runoff reduction and/or pollutant removal technologies based on their wide acceptance and implementation in stormwater management systems

- 5.4.1 Dry Detention
- 5.4.2 Wet Ponds
- 5.4.3 Vegetated Swale (Water Quality Swale)
- 5.4.4 Managed Vegetated Areas (Urban Forest, Grassland and Riparian Buffers)
- 5.4.5 Filter Strips
- 5.4.6 Bioretention
- 5.4.6a Urban Bioretention
- 5.4.7 Infiltration Areas (Impervious Area Disconnection)
- 5.4.8 Permeable Pavement
- 5.4.9 Green Roofs
- 5.4.10 Rainwater Harvesting
- 5.4.11 Stormwater Treatment Wetlands
- 5.4.12 Manufactured/Proprietary Treatment Devices

5.4.1 Dry Detention

Description: Temporarily ponding runoff in basins to enable particulate pollutants to settle out and reduce the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of receiving streams. The primary pollutant removal mechanism is gravitational settling. This measure is mainly used for peak flow attenuation and receives little credit for runoff reduction or pollutant removal, therefore, basins should be a part of a greater system of SCMs.

Figure 1: A dry detention basin with a pilot channel.

Site Constraints:
- Minimum contributing area of 10 ac
- Minimum 6-10 ft hydraulic head
- Minimum 3 ft to bedrock

Key Design Criteria:
- Preconstruction geotechnical review
- Size of contributing drainage area
- Permanent and temporary storage volumes
- Design flows/drawdown time
- Pretreatment forebay
- Side slopes
- Internal conveyance flowpath

Maintenance:
- Dredging accumulated sediment
- Vegetation management

Relative Factors:
- Estimated Costs: Moderate
- Runoff reduction: Low
- Pollutant removal: Low
- Risk of Failure: High

Advantages:
- Efficient suspended solids removal
- Reduces stream channel erosion
- Can be a landscape amenity

Disadvantages:
- Can be hard to landscape and maintain due to fluctuating water levels
- Must be benched for safety reasons
- Inefficient at removing dissolved solids
- Can harbor pests
- Relatively large footprint requirement
- Not applicable in high water tables

Design Checklist:
- ❑ Identify management goal(s)
- ❑ Review site constraints
- ❑ Review design criteria
- ❑ Protect site resources
- ❑ Size channel for site conditions
- ❑ Submit plans for review

1. Design

Generally, dry detention basins temporarily store peak flows such that post-construction outflow matches that of pre-construction conditions. While this practice protects receiving channels, it does little for runoff reduction and pollutant removal when used alone. Dry detention may be designed with an outlet structure that allows for detention for some minimum time (usually 24 hours) to provide some runoff reduction and pollutant removal. 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 wet ponds, dry detention basins generally do not have a permanenet pool of water. However, a micropool may be incorporated at the outlet to facilitate pollutant removal.

1.1 Suggested Applications

Dry detention is normally combined with other stormwater treatment options within the stormwater management system (e.g., wet ponds, and constructed wetlands) enhances its performance and appearance. Other design variations are also possible where a portion of the runoff is directed to, for example, a bioretention cell that is within the overall basin footprint but housed in a separate cell, where the ponding depth of the treatment volume and/or flood protection storage is limited by the criteria of that particular practice. This SCM will rarely provide adequate runoff volume reduction and pollutant removal to serve as a stand-alone compliance strategy. Therefore, designers should always maximize the use of upland runoff reduction practices, (e.g., rooftop disconnections, small-scale infiltration, rainwater harvesting, bioretention, grass channels, and water quality swales) that reduce runoff at its source rather than merely treating the runoff at the terminus of the storm drain system. Upland runoff reduction practices will greatly reduce the size, footprint and cost of the downstream basin or pond.

1.2 Site Constraints

Contributing Drainage Area

- Minimum recommended contributing area = 10 ac
- Basin footprint typically 1% to 3% of CDA
- Minimum 6-10 ft hydraulic head
- Depth to bedrock ≥ 3 ft
- Distance from property lines ≥ 10 ft
- Distance from building foundations ≥ 25 ft
- Distance from septic fields ≥ 50 ft
- Distance from private wells ≥ 100 ft

A minimum contributing drainage area of 10 acres is recommended for basins to protect against clogging small orifices that would be required for detention of runoff from smaller contributing areas. Detention may still work with drainage areas less than 10 acres, but designers should be aware that these "pocket" ponds will typically (1) have very small orifices that will be prone to clogging, (2) experience fluctuating water levels, and (3) generate more significant maintenance problems. Water balance calculations should also support a contributing drainage area (CDA) less than 10 acres. A typical basin requires a footprint of 1% to 3% of its contributing drainage area, depending on the depth of the pond (i.e., the deeper the pond, the smaller footprint needed). The depth of a basin is usually determined by the amount of hydraulic head available at the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the basin discharges. Typically, a minimum of 6 to 10 feet of head is needed for the dry basin to function.

Soils, Topography, Water Table and Bedrock

Soil infiltration tests need to be conducted at proposed pond sites to estimate infiltration rates, which can be significant in Hydrologic Soil Group (HSG) A soils and some Group B soils. Infiltration through the bottom of the basin is encouraged unless it will impair the integrity of the embankment. Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed detention basin. If karst features are observed on site, then an alternative practice or combination of practices should be employed at the site where possible. See Appendix B for guidance on stormwater design in karst terrain. The basin should be the option of last resort and, if used in karst, must have an impermeable clay liner or, preferably, a geosynthetic liner to prevent groundwater contamination or sinkhole formation. If less than 3 feet of vertical separation exists between the bottom of the basin and the underlying soil-bedrock interface, basins should not be used unless they have an acceptable liner. Steep sloped areas constrain the use dry detention due to the relatively large and flat footprint that is needed. This SCM should not be used in areas with greater than 15% slopes.

Minimum Setbacks

Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, and wells. Generally, basins should be set back at least 10 feet from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from private wells.

Environmental Considerations

Detention basins should never be constructed within existing natural wetlands, nor should they inundate or otherwise change the hydroperiod of existing wetlands. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during design and pond construction. Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Cappiella *et al.,* 2007).

Safety Risks

Detention basins are generally considered to be safer than other basin options, since they have few deep pools. Steep side-slopes and unfenced headwalls, however, can still create some safety risks. Gentle side slopes should be provided to avoid potentially dangerous drop-offs, especially where detention ponds are located near residential areas. The fluctuating water levels within detention ponds have potential to create conditions that lead to mosquito breeding. Mosquitoes tend to be more prevalent in irregularly flooded ponds than in ponds with a permanent pool (Santana *et al.,* 1994). Designers can minimize the risk by combining ED with a wet pond or wetland.

Aesthetics

Basins tend to accumulate sediment and trash, which residents are likely to perceive as unsightly and creating nuisance conditions. Fluctuating water levels in basins can al.so create a difficult landscaping environment.

1.3 Design criteria

Overall Sizing

In general, the dry basin is sized to detain the volume of water that is equal to the difference in runoff produced from post-construction land cover to that of pre-construction conditions. The outlet discharge is controlled with an outlet device that regulates flow to a rate that protects receiving channels. Sizing detention basins in drainages with green infrastructure controls is different than that with conventional drainage because the use of certain SCMs creates pockets of diffuse storage throughout the drainage. This storage volume up in the contributing area may be accounted for when sizing the volume needed in a dry detention basin, resulting in a smaller volume needed in the basin. Designers may use a site-adjusted curve number that reflects the use of upland runoff reduction practices to compute the remaining treatment and flood protection volumes that must be treated by dry basin. Basins should then be designed to capture and treat the volume as necessary, using volume and discharge requirements set by local MS4 programs.

Treatment volume (cf) = Total treatment volume–volume
reduced by upstream SCM(s) as allowed by local programs

Routing elements, such as pipes, channels, and the basin inlet/outlet, should be designed to carry flows calculated using an un-adjusted curve number. While SCMs decrease the total volume of water making it to a detention basin, these measures to little for the larger events, and therefore the routing network should accommodate the full potential runoff flowrate. As for the basin acting as an SCM itself, runoff reduction volume credit may be taken for infiltrated water in basin footprint while water is stored in the basin, assuming no liner. No runoff reduction may be credited for areas with an impermeable liner.

The dry detention basin should be sized to detain this treatment volume for treatment between 24 and 48 hours. After calculating the total treatment volume, the forebay should be designed using guidance in Sec 5.5 and sized to hold at least 10% of the treatment volume. The outlets must then be sized for appropriate storm events. If the pond is additionally going to address peak flow attenuation, the downstream impacts must be considered for the 2-through 100-year events, which are defined by the local MS4 program. The post-construction peak flow must not exceed the pre-construction peak flow as well as meet other channel protection requirements for individual projects as specified by the local MS4 program. Refer to Chapter Section 5.5 for more information on the use of outlet orifices and weirs.

Table 1 provides specific design criteria. The low flow orifice may be sized using the methods outline in Section 5.4 or locally approved alternative methods. Once the low flow orifice has been sized, design embankments and emergency spillways, investigate potential dam hazard classifications, and finally design inlets, sediment forebays, outlet structures, maintenance access, and safety features per guidelines of the local MS4 program.

Table 1: Dry Detention Design Criteria.

Treatment Volume = (Total Treatment Volume, no SCMs) – (SCM Volume Redution permitted by local program)
Length: Width >= 1.5
Shortest Flowpath Length / Overall Length >= 0.7
Maximum temporary storage depth 10 ft, Maximum micropool depth 4 ft
Includes additional cells or features (micropools, forebay, interlan baffles, etc.)
Contributing drainage area > 10 acres
Runoff reduction volume = Soil-specific infiltration rate*basin area*detention time

Pretreatment Forebay

Sediment forebays are considered to be an integral design feature to maintain the longevity of dry detention basins and to facilitate efficient sediment cleanout. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pretreatment criteria found in Chapter 5.4.6. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the ED pond's contributing drainage area.
- The forebay consists of a separate cell, formed by an acceptable barrier (e.g., an earthen berm, concrete weir, or gabion baskets).
- The forebay should be at least 4 feet deep and equipped with a variable width aquatic bench for safety purposes. The aquatic benches should be 4 to 6 feet wide at a depth of 18 inches below the water surface.
- The volume of a forebay should be approximately 10% of the treatment volume. For multiple forebay designs, the total volume of all forebays should be at least 15% of the treatment volume. The relative size of individual forebays should be proportional to the percentage of the total inflow to the pond. Similarly, any outlet protection associated with the end section or end wall should be designed according to state or local design standards.
- The forebay should be designed in such a manner that it acts as a level spreader to distribute runoff evenly across the entire bottom surface area of the main treatment cell.
- The bottom of the forebay may be hardened (e.g., concrete, asphalt, or grouted riprap) in order to make sediment removal easier.

Conveyance and Overflow

Pilot Channels: Consult with local MS4 programs on the use of pilot channels. If there is little risk of soil erosion (eg. soils are colloidal or coure enough to resist the sheet flow shear stress and dense vegetation is established), then basins shall not have a low flow pilot channel, but instead must be constructed in a manner whereby flows are evenly distributed across the pond bottom, to promote the maximum infiltration possible. If there is a high risk of soil erosion due to soil texture, then a shallow pilot channel with a wide cross-section may be used to link the forebay and micropool.

Internal Slope: The maximum longitudinal slope through the basin should be approximately 0.5% to 1% to promote positive flow through the basin.

Primary Spillway: The primary spillway shall be designed with acceptable anti-flotation, anti-vortex, and trash rack devices. The spillway must be accessible from dry land.

Non-Clogging Low Flow Orifice: Basins with drainage areas of 10 acres or less are prone to chronic clogging by organic debris and sediment. Orifices less than 3 inches in diameter may require extra attention during design to minimize the potential for clogging. Designers should always look at upstream conditions to assess the potential for higher sediment and woody debris loads and also consider the detrital load from basin vegetation. The risk of clogging in outlet pipes with small orifices can be reduced by:

- Providing a micropool at the outlet structure:
  - Use a reverse-sloped pipe that extends to a mid-depth of the permanent pool or micropool.
  - Install a downturned elbow or half-round CMP over a riser orifice (circular, rectangular, V-notch, etc.) to pull water from below the micropool surface.
  - The depth of the micropool should be at least 4 feet deep, and the depth may not draw down by more than 2 feet during 30 consecutive days of dry weather in the summer.
- Providing an over-sized forebay to trap sediment, trash and debris before it reaches the ED pond's low-flow orifice.
- Installing a trash rack to screen the low-flow orifice.
- Using a perforated pipe under a gravel blanket with an orifice control at the end in the riser structure to supplement the primary outlet.

Emergency Spillway: Dry detention basins must be constructed with overflow capacity to pass the 100-year design storm event through either the primary spillway or a vegetated or armored emergency spillway.

Adequate Outfall Protection: The design must specify an outfall that will be stable for the 10-year design storm event. The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This is typically done by placing appropriately sized riprap over filter fabric which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps depending on the channel lining material). Flared pipe sections that discharge at or near the stream invert or into a step pool arrangement should be used at the spillway outlet.

Inlet Protection: Inlet areas should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 10-year storm event). Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation.

In-line basins must be designed to detain the required treatment volume and either manage or be capable of safely passing larger storm events conveyed to the basin (e.g., 10-year flood protection, and/or the 100-year design storm event).

Internal Design Features

Side Slopes: Side slopes leading to the dry basin should generally have a gradient of at least 4:1. Mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Long Flow Path: Dry detention basins should have an irregular shape and a long flow path from inlet to outlet to increase water residence time, treatment pathways, and pond performance. 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. These ratios must be at least 3:1. 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 must be at least 0.7. 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.

Treatment Volume Storage: The total treatment volume storage should be comprised within the temporarily inundated detention storage and micropool.

Safety Features

- Mild basin side slopes of 3:1 or greater are strongly encouraged.
- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.
- An emergency spillway and associated freeboard must be provided in accordance with applicable local or state dam safety requirements. The emergency spillway must be located so that downstream structures will not be damaged by spillway discharges.
- Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.

Landscaping and Planting Plan

A landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage within the ED basin. Minimum elements of a plan include the following:

- Delineation of landscaping zones within the basin
- Selection of corresponding plant species
- Quantity, size, species, root condition, location, and sources of plants.
- The planting plan should allow the vegetation to mature in the right places, but yet kept mowable turf along the embankment and all access areas and preferred no-mow, native grasses and forbs in all other areas.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.

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. For more guidance on planting trees and shrubs in detention ponds, consult Cappiella et al (2006).

Maintenance Reduction Features

Good maintenance access is needed so crews can remove sediments from the forebay, alleviate clogging and make riser repairs. The following maintenance issues can be addressed during design, in order to make ongoing maintenance easier:

- Adequate maintenance access must extend to the forebay, micropool, any safety benches, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.

- The riser should be located within the embankment for maintenance access, safety and aesthetics.
- Access roads must (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 12 feet, and (3) have a profile grade that does not exceed 15%. Steeper grades are allowable if appropriate stabilization techniques are used, such as a gravel road.
- A maintenance right-of-way or easement must extend to the ED basin from a public or private road.

Material Specifications

Dry detention basins 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 filter fabric for lining banks or berms. The basic material specifications for earthen embankments, principal spillways, vegetated emergency spillways and sediment forebays shall be as specified in Tennessee state guidelines.

Dam Safety

The Tennessee Safe Dams Act applies to ponds with storage volumes and embankment heights large enough to fall under the regulation for dam safety, as applicable. Size emergency spillway for any overtopping of a pond in case of a rain event in excess of 100-year storm and for instances of malfunction or clogging of primary outlet structure.

1.4 Typical Details

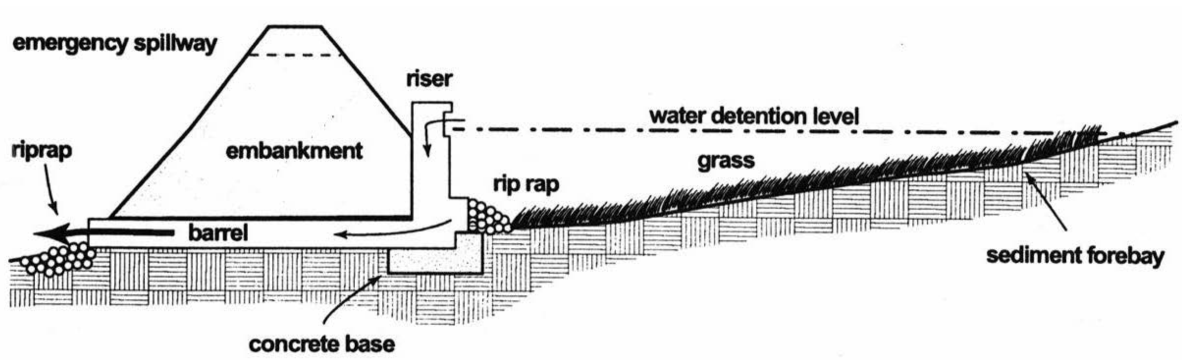

Figure 2: Dry detention pond cross-section (US EPA).

2. Construction

2.1 Pre-Construction

Soil borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the proposed basin area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material, (2) determine its adequacy for use as structural fill, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine compaction/composition needs for the embankment, (5) determine the depth to groundwater and bedrock and (6) evaluate potential infiltration losses and the potential need for a liner if a micropool will be implemented.

2.2 Construction

The following is a typical construction sequence to properly install a dry detention basin. The steps may be modified to reflect different dry basin designs, site conditions, sizes, complexity and configuration of the proposed facility.

Step 1: Converting from a sediment basin. A basin may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (erosion and sediment control requirement vs. water quality treatment requirement). 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 basin in mind. The bottom elevation of the basin should be lower than the bottom elevation of the temporary sediment basin to allow for sedimentation during construction. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a basin.

Step 2: Stabilize the Drainage Area. Dry basins should only be constructed after the contributing drainage area to the pond is completely stabilized or if water is routed around them during construction. If the proposed 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 3: Assemble Construction Materials onsite, make sure they meet design specifications, and prepare any staging areas.

Step 4: Clear and Prepare the project area to the desired elevation with desired soil quality (see Section 5.3).

Step 5: Install EPSC Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 6: Excavate the Core Trench and Install the Spillway Pipe.

Step 7: Install the Riser or Outflow Structure and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 8: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts and compact the lifts with appropriate equipment.

Step 9: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the basin.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Pipes, including downstream rip-rap apron protection and/or channel armor, as necessary.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for the pond. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

Step 13: Plant the Area, following the landscaping plan (see Appendix D).

2.3 Inspections

Inspections are recommended during the following stages of construction:

- Pre-construction meeting
- Initial site preparation (including installation of EPSC controls)
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the landscaping plan and vegetative stabilization
- Final inspection (develop a punch list for facility acceptance)

If basin has a micropool, then to facilitate maintenance the contractor should measure the actual constructed pond depth at three areas within the micropool (forebay, mid-pond and at the riser), and he/she should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

3. Maintenance

3.1 Agreements

Examples of the maintenance document are in Appendix F. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities.

3.2 Schedules

Maintenance Inspections

Maintenance of dry detention basins is driven by annual inspections that evaluate the condition and performance of the basin, including the following:

- Measure sediment accumulation levels in forebay.
- Monitor the growth of wetlands, trees and shrubs planted, and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the pond for material damage, erosion or undercutting.
- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine embankment integrity.
- Inspect pond outfall channel 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, reverse sloped pipes or flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and locks can be opened and operated.
- Inspect internal and external side slopes of the pond for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.

As-Built Inspections

After the basin is constructed, an as-built certification of the basin, performed by a registered Professional Engineer, must be submitted to the local stormwater program. The following are components which should be addressed in the as-built certification:

1. Pretreatment for coarse sediments must be provided.
2. Surrounding drainage areas must be stabilized to prevent sediment from clogging the filter media.
3. Correct ponding depths and infiltration rates must be maintained to prevent killing vegetation.
4. Internal baffling or berms to elongate flowpaths as needed to meet requirements.
5. A mechanism for overflow for large storm events must be provided.

Common Ongoing Maintenance Issues

Dry detention basins are prone to clogging at the outlet orifice. This component of the basin's conveyance should be inspected at least twice a year after initial construction. The constantly changing water levels in the basin makes it difficult to mow or manage vegetative growth. The bottom of basin often becomes soggy, and water-loving trees such as willows may take over. The maintenance plan should clearly outline how vegetation in the pond will be managed or harvested in the future. Any signs of erosion of internal berms or baffles should be addressed with grading, adding armoring, or establishing cover. The maintenance plan should schedule a cleanup at least once a year to remove trash and floatables that tend to accumulate in the forebay, micropool, and on the bottom of the basins. Frequent sediment removal from the forebay is essential to maintain the function and performance of a basin. Maintenance plans should schedule cleanouts every 5 to 7 years, or when inspections indicate that 50% of the forebay capacity has been filled. Excavated sediments are not usually considered toxic or hazardous, and can be safely disposed by either land application or land filling.

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5.4.2 Wet Pond

Description: Wet ponds consist of a permanent pool of standing water that promotes pollutant removal through gravitational settling, biological uptake and microbial activity. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts to minimize re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, wet ponds have a permanent pool residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate.

Figure 1: Wet pond with permanent pool storage and temporary detention in a residential setting (Source: SMART Center).

Feasibility:
- Contributing impervious drainage area of 10-25 acres.
- Available space

Key Design Criteria:
- **Space required:** typically 1%-3% of the CDA.
- Other design criteria include soils, landscaping/plant selection, slope, outlet structure and safety.

Site Constraints:
- **Available hydraulic head:** 6-8 feet
- **Soils:** HSG C and D to maintain permanent pool; HSG A and B need a liner.
- **Minimum setbacks from:**
  Property lines: 20 feet
  Building foundations: 25 feet
  Septic system and private wells: 100 feet
- **Karst:** not recommended in or near karst terrain

Maintenance:
- Remove debris and blockages
- Repair undercut, eroded, and bare soil areas
- Mowing embankment
- Forebay Sediment Removal
- Repair pipes as needed

Advantages:
- Maximize nutrient removal
- Ponds do not consume a large area relative to the drainage size of the watershed
- Can be used as an aesthetic amenity
- Increased biodiversity
- Reduces channel/stream erosion
- Opportunity for multiple use

Disadvantages:
- There is no runoff volume reduction credit for this SCM because of limited infiltration
- Project may be required to comply with TN Safe Dam regulation
- Large space requirement
- Safety concerns
- Not to be used in areas of high groundwater table

Design Checklist:
- ❑ Check soil type and depth to water table and bedrock, and determine whether liner is needed
- ❑ Determine which design is suitable for the project.
- ❑ Check Wet Pond sizing guidance.
- ❑ Select erosion control measures
- ❑ Prepare landscape plan

1. Design

Designers should note that a wet pond is typically the final element in the "roof-to-stream pollutant removal "sequence" and provides no volume reduction credit, and **should therefore be considered only if there is remaining pollutant removal or Channel Protection Volume to manage after all other upland runoff reduction options have been considered and properly evaluated.**

In instances where a wet pond is proposed as an aesthetic amenity, the design parameters contained here represent good engineering design to maintain a healthy pond. The treatment volume requirements for water quality and detention requirements for channel protection may be more economically met through the upstream runoff reduction practices; however, the basic wet pond features related to aesthetics (pool volume and geometry) and safety (aquatic and safety benches, side slopes, maintenance, etc.) remain as important neighborhood or site design features.

There is no runoff volume reduction credit for wet ponds since the runoff reduction pathways of infiltration and extended filtration are generally limited. The wet pond functions as a basin that generally discharges a volume equivalent to the entire inflow runoff volume.

1.1 Design Guidance

Single Pond Cell (with forebay) or a Multiple Cell Design (see **Section 1.8**)
Length/Width ratio OR Flow path = 2:1 or more; Length of shortest flow path/overall length = 0.8 or more (see **Section 1.6**)
Standard aquatic benches or wetlands more than 10% of pond area (see **Section 1.6**)
Turf in pond, trees, shrubs, and herbaceous plants in pond buffers; Shoreline landscaping to discourage geese (see **Section 1.10**)
Aeration (preferably bubblers that extend to or near the bottom or floating islands (see **Section 1.11**)

1.2 Physical Feasibility

Space Required	The surface area of a wet pond will normally be at least 1% to 3 % of its contributing drainage area, depending on the impervious cover, pond geometry, etc.
Contributing Drainage Area (CDA)	A contributing drainage area of 10 to 25 acres or more is typically recommended for wet ponds to maintain a healthy 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 and experience extreme fluctuations in seasonal water levels and be susceptible to creating nuisance conditions. A water balance should be calculated to assess whether the wet pond will draw down by more than 2 feet after a 30-day summer drought (see **Section 1.5**).
Available Hydraulic Head	The depth of a wet pond is usually determined by the hydraulic head available on the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the wet pond discharges. Typically, a minimum of 6 to 8 feet of head are needed for a wet pond to function.
Minimum Setbacks	Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks for impoundments to property lines, structures, and wells. Generally, wet ponds should be set back at least 20 feet from property lines, 25 feet from building foundations, 50 feet from septic system fields and 100 feet from private wells. Setbacks are measured from the toe of the embankment on the downstream side and the design high water on the upstream side.

Depth-to-Water Table and Bedrock	Shallow water table or depth to bedrock may make excavation difficult and expensive. Groundwater inputs can also reduce the pollutant removal rates of wet ponds. Refer to Chapter 3.3 for design variations when encountering high water table, bedrock, or karst topography.
Soils	Highly permeable soils make it difficult to maintain a constant level for the permanent pool. Soil explorations should be conducted at proposed pond sites to identify soil infiltration and the presence of karst topography. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most group A soils and some group B soils will require a liner in order to maintain the permanent pool. A wet pond should be the option of last resort if karst topography is present. Refer to Chapter 3.3 and Appendix B for additional guidance when designing near karst topography. At a minimum, an impermeable clay or (preferably) geosynthetic liner will be required. Geotechnical explorations should also be conducted at the proposed pond embankment to properly design the embankment cut-off trench and fill material.
Karst	Wet ponds are not recommended in or near karst terrain. An alternative practice or combination of practices should be employed at the site.
Trout Streams	The use of wet ponds in watersheds containing trout streams is strongly discouraged because the discharge can cause stream temperature warming.
Use of or Discharges to Natural Wetlands	It can be tempting to construct a wet pond within an existing natural wetland, but wet ponds cannot be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate state or federal regulatory agency. 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., 2006b, for guidance on minimizing stormwater discharges to existing wetlands).
Perennial streams	Locating wet ponds on perennial streams is typically not allowed and will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

1.3 Design Applications

Wet ponds are applicable for most land uses and are best suited for larger development projects due to the large footprint required. While the pollutant reduction credit of a wet pond may be adequate to achieve compliance, it is recommended to use upland runoff reduction SCMs such as rooftop disconnections, small-scale infiltration, rainwater harvesting, bioretention, grass channels and dry swales that reduce runoff volume at its source (rather than merely treating runoff at the terminus of the storm drain system). Upland runoff reduction practices can be used to satisfy some or all of the water quality requirements at many sites, which can help to reduce the footprint and volume of wet ponds.

The use of upland runoff reduction features may give designers the flexibility to select the most practical design configuration. The design configurations, as illustrated in Figure 2, below include:

- Wet pond with 100% of the permanent pool in a single cell.
- Wet Extended Detention and/or multi-cell wet pond meeting additional requirements for pond geometry, landscaping, etc.
- Pond/Wetland Combination (see Section 5.4.11 for additional guidance on the design of the wetland element).

1.4 Typical Details

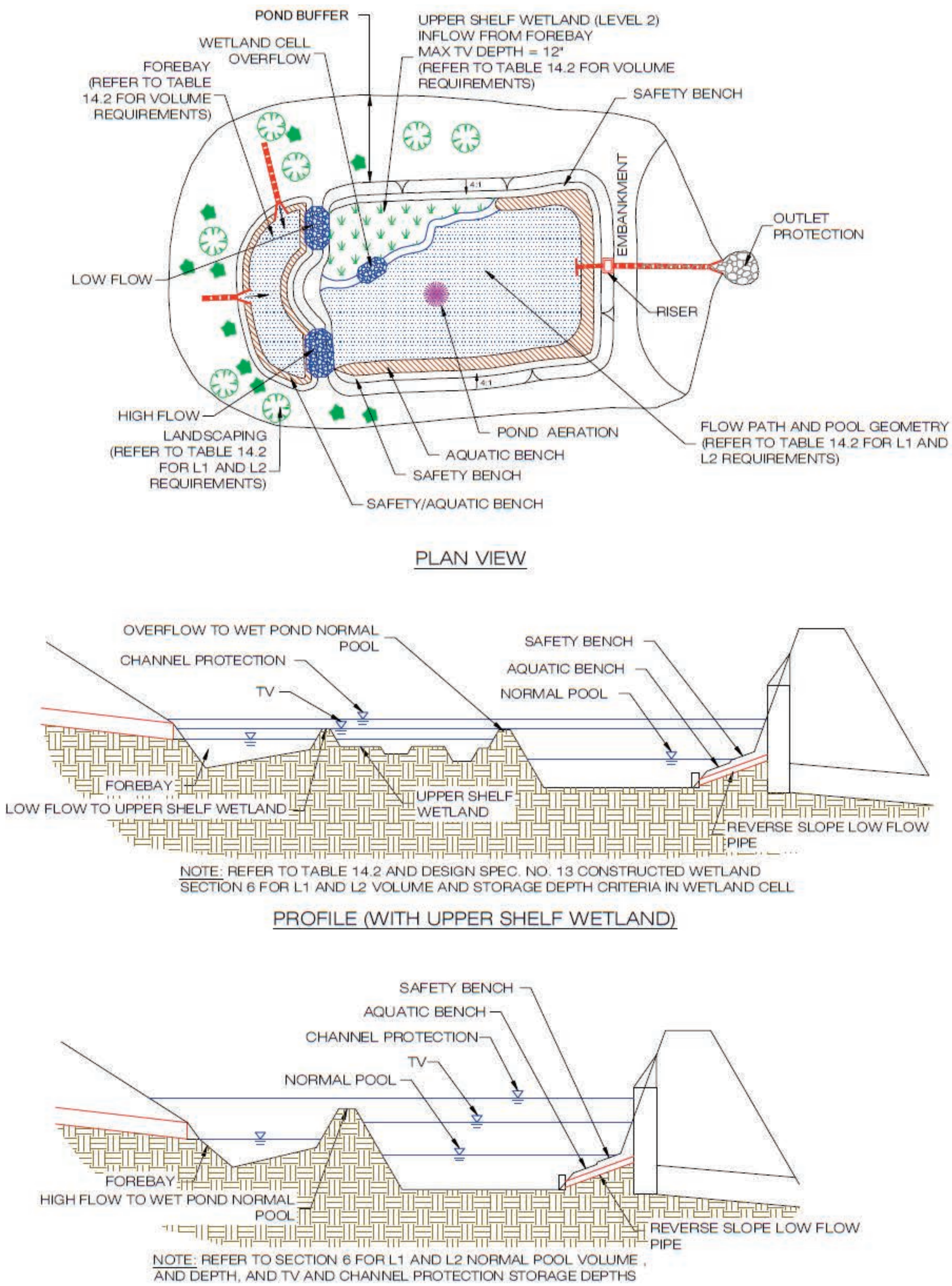

Figure 2: Wet Pond Design Schematics (Source: Virginia).

1.5 Design Calculations

1.5.1 Sizing

A wet pond is comprised of a permanent pool, multiple permanent pool cells, or a combination of the permanent pool and extended detention storage. The design goal is two-fold: 1) store the pollutant removal volume in the permanent pool, and 2) provide temporary storage above the permanent pool elevation for attenuation of large storm events. The permanent pool volume must be equal to 100% of the treatment volume. Stormwater runoff from the representative storm event displaces water already in the pool. See Chapter Section 5.4.1 Dry Detention for sizing specifications for temporary storage above permanent pool elevation. Research has demonstrated that larger wet ponds with longer residence times enhance algal uptake and nutrient removal rates (CWP 2008), therefore oversizing this practice is allowed as long as adequate water balance estimates are determined and the design minimizes nuisance species and safety concerns.

Sizing using the TNRRAT is strongly encouraged. If alternative sizing methods are employed, then it is up to the designer to justify the appropriateness of the selected method and provide sufficient design calculations to support the design.

Other Design Variants: Wet ponds can be designed to promote runoff volume reduction through water reuse (e.g., pumping pond water back into the contributing drainage area for use in seasonal landscape irrigation). While this practice is not common, it has been applied to golf course ponds, and accepted computational methods are available (Wanielista and Yousef, 1993 and McDaniel and Wanielista, 2005). It is recommended that designers be allowed to take credit for annual runoff reduction achieved by pond water reuse, as long as acceptable modeling data is provided for documentation.

Treatment Volume Storage. The permanent pool volume equal to the Treatment Volume can consist of the forebay (or multiple forebays as needed) and the main pool. A minimum depth of 4 feet and a maximum depth of 6 feet are recommended. The minimum depth encourages proper mixing while a maximum depth helps to minimize stratification and an imbalance between pool volume and surface area.

The wet pond can consist of multiple cells or an extended detention (ED) storage above the permanent pool. When incorporating multiple cells, wet ponds with a single inflow point and forebay may count the forebay as one cell; (however, multiple forebays do not count as multiple cells). The remaining Runoff Reduction Volume should be divided among the remaining cells and may include a wetland cell and a deep pool cell.

Maximum Extended Detention Levels. The maximum extended detention volume may not extend more than 12 inches above the wetland cell permanent pool at its maximum water surface elevation. The maximum ED and channel protection detention levels can be up to 5 feet above the wet pond permanent pool.

Water Balance Testing. A water balance calculation is recommended to document that sufficient inflows to the pond exist to compensate for combined infiltration and evapotranspiration losses during a 30-day summer drought without creating unacceptable drawdowns (Equation 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.

Water Balance Equation for Acceptable Water Depth in a Wet Pond

Equation 1

$$DP > ET + INF + RES - MB$$

Where:

- ***DP*** = Average design depth of the permanent pool (inches)
- ***ET*** = Summer evapotranspiration 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 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.

Translating the baseflow to inches refers to the depth within the pond. Therefore, the following equation can be used to convert the baseflow, measured in cubic feet per second (ft^3/s), to pond-inches:

Equation 2

$$\text{Pond inches} = ft^3/s * (2.592E6) * (12''/ft) / \text{SA of Pond } (ft^2)$$

Where:

- ***2.592E6*** = Conversion factor: ft^3/s to $ft^3/month$
- ***SA*** = surface area of pond in ft^2

1.6 Internal Design Geometry

Side Slopes. Side slopes for the wet pond should generally have a gradient of 4:1 to 5:1. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Long Flow Path. Wet pond designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time and pond performance. 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 must be at least 2L:1W. Internal berms, baffles, or vegetated peninsulas 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 must be at least 0.5. 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.

Safety Features. Several design features of impounding structures are intended to provide elements of safety. The perimeter of all pool areas greater than 4 feet in depth must be surrounded by two benches, as follows:

- A ***Safety Bench*** is a minimum 10-foot wide bench with a minimal cross slope (2%) located immediately above and adjacent to the permanent pool. A safety bench is not necessary if the stormwater pond side slopes above the permanent pool are 5H:1V or flatter.
- An ***Aquatic Bench*** is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash. The aquatic bench extends 10 feet inward from the permanent pool shoreline, from a depth of 0 to 18 inches (maximum) below the normal pool water surface elevation.

- Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool. Thick shoreline vegetation also serves to discourage geese.
- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a fall hazard. Local stormwater program should be consulted.
- An emergency spillway and associated freeboard must be provided in accordance with applicable local or state dam safety requirements. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- Warning signs prohibiting swimming should be posted.

1.7 Required Geotechnical Testing

Soil borings should be conducted within the footprint of the proposed embankment, in the vicinity of the proposed outlet structure, and in at least two locations within the proposed wet pond treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material to determine its adequacy as structural fill or other use, (2) determine the need and appropriate design depth of the embankment cut-off trench; (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine the depth to groundwater and bedrock and (5) evaluate potential infiltration losses (and the potential need for a liner).

1.8 Pretreatment Forebay

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. A major inlet is defined as one that carries runoff from 10% or more of the total contributing area. Pre-treatment and inlet design must be sufficient as to not create erosion potential and to maximize sediment deposition. See Section 5.5 for design guidance on inlets and pre-treatment.

1.9 Conveyance and Overflow

Internal Slope. The longitudinal slope of the pond bottom should be at least 0.5% to 1%.

Principal Spillway. The principal spillway shall be designed with acceptable anti-flotation, anti-vortex and trash rack devices. The spillway must generally be accessible from dry land.

Non-Clogging Low Flow Orifice. A low flow orifice must be provided that is adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection that may allow for smaller diameters. Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging. There are many design options including, but not limited to:

- A submerged reverse-slope pipe that extends downward from the riser to an inflow point 1 foot below the normal pool elevation.
- Alternative methods may employ a broad crested rectangular or V-notch (or proportional) weir, protected by a half-round CMP that extends at least 12 inches below the normal pool elevation.

Emergency Spillway. Wet ponds must be constructed with overflow capacity to pass the 100-year design storm event through either the Primary Spillway (with two feet of freeboard to the settled top of embankment) or a vegetated or armored Emergency Spillway (with at least one foot of freeboard to the settled top of embankment).

Pond Drain. Wet ponds should be equipped with 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 pond, or a pond in the coastal plain where a low level outlet is available), a pump wet well should be provided to accommodate a temporary pump intake when needed to drain the pond.

- The drain pipe should have an upturned elbow or protected intake within the pond, to prevent sediment deposition, and a diameter capable of draining the pond within 24 hours.
- The pond drain must 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.

Adequate Outfall Protection. The design must specify an outfall that will be stable for the maximum (pipe-full) design discharge (the 10-year design storm event or the maximum flow when surcharged during the emergency spillway design event, whichever is greater). The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. Outlet protection should be provided consistent with state or local guidance.

Inlet Protection. Inlet areas should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 10-year storm event). Inlet pipe inverts should generally be located at or slightly below the permanent pool elevation.

Dam Safety Permits. Wet ponds with high embankments or large drainage areas and impoundments may be regulated under the Tennessee Safety Dam Act.

1.10 Landscaping and Planting Plan

A landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the pond and its buffer. Minimum elements of a plan include the following:

- Delineation of pondscaping zones within both the pond and buffer
- Selection of corresponding plant species
- The planting plan
- The sequence for preparing the wetland benches (including soil amendments, if needed)
- Sources of native plant material
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl within the stormwater wetland and buffers. **However, to the extent possible, the aquatic and safety benches should be planted with dense shoreline vegetation to help establish a safety barrier, as well as discourage resident geese.**
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- A vegetated buffer of native plants that requires minimal maintenance should be provided that extends at least 25 feet outward from the maximum water surface elevation of the wet pond. Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction.
- The soils in the stormwater buffer area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the root ball for ball-and-burlap stock, and five times deeper and wider for container-grown stock.
- 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.

For more guidance on planting trees and shrubs in wet pond buffers, see Appendix D of this manual.

1.11 Maintenance Features

The following wet pond maintenance criteria should be addressed during the design, in order to facilitate on-going maintenance:

- ***Maintenance Access.*** Good access is needed so crews can remove sediments, make repairs and preserve pond treatment capacity.
  - Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
  - The riser should be located within the embankment for maintenance access, safety and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

- Access roads must (1) be constructed of materials that can withstand the expected frequency of use, (2) have a minimum width of 12 feet, and (3) have a profile grade that does not exceed 15%. Steeper grades are allowable if appropriate stabilization techniques are used, such as a gravel road.
- A maintenance right-of-way or easement must extend to the stormwater pond from a public or private road.

- ***Pond Aerators.*** Electric or mechanical aeration is used to place as much oxygen into contact with water as economically practical. This can be accomplished by mixing large quantities of water (both volume and total surface area) with atmospheric oxygen. Aerators can be utilized on a continuous, seasonal, or temporary basis as needed to maintain minimum oxygen levels. Several different types and scales of aeration devices are available. Most aeration equipment will require electricity at the pond bank.

1.12 Wet Pond Material Specifications

Wet ponds are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possible stone for inlet and outlet stabilization, filter fabric for lining banks or berms, and a liner when required.

- ***Liners.*** When a stormwater pond is located over highly permeable soils or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include the following: (1) a clay liner following the specifications outlined in **Table 1** below; (2) a 30 mil poly-liner; (3) bentonite; (4) use of chemical additives; or (5) an engineering design, as approved on a case-by-case basis by the local review authority. A clay liner should have a minimum thickness of 12 inches with an additional 12-inch layer of compacted soil above it, and it must meet the specifications outlined in **Table 1**. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table 1: Clay Liner Specifications (Source: VADCR, 1999).

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	Cm/sec	1 x 10^{-6}
Plasticity Index of Clay	ASTM D-423/424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of standard proctor density

1.13 Regional & Special Case Design Adaptations

Karst Terrain

Designers should always conduct geotechnical investigations in areas of karst terrain to assess this risk and rule out the presence of karst during the project planning stage. If these studies indicate that less than 3 feet of vertical separation exists between the bottom of the ED pond and the underlying soil-bedrock interface, ED ponds should not be used due to the risk of sinkhole formation, groundwater contamination, and frequent facility failures (see Appendix B). At a minimum, designers must specify the following:

- A minimum of 6 feet of unconsolidated soil material exists between the bottom of the basin and the top of the karst layer.
- Maximum temporary or permanent water elevations within the basin do not exceed 6 feet.

- Annual maintenance inspections must be conducted to detect sinkhole formation. Sinkholes that develop should be reported immediately after they have been observed, and should be repaired, abandoned, adapted or observed over time following the guidance prescribed by the appropriate local or state groundwater protection authority (see Chapter 3.3 and Appendix B)
- A liner is installed that meets the requirements outlined in Table 2.

Table 2: Required Groundwater Protection Liners for Ponds in Karst Terrain (WVDEP, 2006 and VADCR, 1999).

Situation	Criteria
Pond not excavated to bedrock	24 inches of soil with a maximum hydraulic conductivity of 1 x 10-5 cm/sec.
Pond excavated to or near bedrock	24 inches of clay[1] with a maximum hydraulic conductivity of 1 x 10-6 cm/sec.
Pond excavated to bedrock within a wellhead protection area, in a recharge area for a domestic well or spring, or in a known faulted or folded area	Synthetic liner with a minimum thickness of 60 mil.
1 Clay properties as follows: *Plasticity Index of Clay = Not less than 15% (ASTM D-423/424)* *Liquid Limit of Clay = Not less than 30% (ASTM D-2216)* *Clay Particles Passing = Not less than 30% (ASTM D-422)*	

Steep Terrain

The use of wet ponds is highly constrained at development sites with steep terrain. Some adjustment can be made by terracing pond cells in a linear manner, using a 1- to 2-foot armored elevation drop between individual cells. Terracing may work well on longitudinal slopes with gradients up to approximately 10%.

Cold Climate and Winter Performance

Pond performance decreases when snowmelt runoff delivers high pollutant loads. Ponds can also freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing pond performance. Salt loadings are higher in cold climates due to winter road maintenance. The following design adjustments are recommended for wet ponds installed in higher elevations and colder climates:

- Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC, 2005).
- Plant salt-tolerant vegetation in pond benches.
- Do not submerge inlet pipes, and provide a minimum 1% pipe slope to discourage ice formation.
- Locate low flow orifices so they withdraw at least 6 inches below the typical ice layer.
- Place trash racks at a shallow angle to prevent ice formation.
- Oversize riser and weir structures to avoid ice formation and pipe freezing.
- If winter road sanding is prevalent in the contributing drainage area, increase the forebay size to accommodate additional sediment loading.

Linear Highway Sites

Wet ponds are poorly suited to treat runoff within open channels located in the highway right of way, unless storage is available in a cloverleaf interchange or in an expanded right-of-way. Guidance for pond construction in these areas is provided in Profile Sheet SR-5 in Schueler et al (2007).

2. Construction

2.1 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: Install E&S Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 2: Use of Wet Pond as an E&S Control. A wet pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (erosion and sediment control requirement vs. water quality treatment requirement). 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 wet pond in mind. The bottom elevation of the wet pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a wet pond.

Step 3: Stabilize the Drainage Area. Wet ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the proposed 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 4: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 5: Clear and Strip the project area to the desired sub-grade.

Step 6: Excavate the Core Trench and Install the Spillway Pipe.

Step 7: Install the Riser or Outflow Structure, and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 8: Construct the Embankment and Any Internal Berms in 8- to 12-inch lifts, or as directed by geotechnical recommendations, and compact as required with appropriate equipment.

Step 9: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the pond.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Protection, including emergency and primary outlet apron protection.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for the pond buffer. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

Step 13: Plant the Pond Buffer Area, following the pondscaping plan (See Section 1.10).

2.2 Construction Inspection

Multiple inspections are critical to ensure that stormwater ponds are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting
- Initial site preparation (including installation of E&S controls)
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the pondscaping plan and vegetative stabilization
- Final inspection (develop a check list for facility acceptance)

An example of a construction phase inspection checklist for wet ponds is available in Section 5 of this specification.

In order to facilitate and anticipate maintenance, contractors should measure the actual constructed pond depth at three areas within the permanent pool (forebay, mid-pond and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

3. Maintenance

3.1 Agreements

The Tennessee MS4 permit specifies the circumstances under which a maintenance agreement must be executed between the owner and the local stormwater management authority, and sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- Restrictive covenants or other mechanism enforceable by the local stormwater program must be in place to help ensure that wet ponds are maintained, as well as to pass the knowledge along to any subsequent property owners.
- Access to wet ponds should be covered by a drainage easement to allow access by the local stormwater program staff to conduct inspections and perform maintenance when necessary.
- All wet ponds must include a long term maintenance agreements consistent with the provisions of the local stormwater program and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- The maintenance agreement should also include contact information for owners to get local or state assistance to solve common nuisance problems, such as mosquito control, geese, invasive plants, vegetative management and beaver removal.

3.2 First Year Maintenance Operations

Successful establishment of wet ponds requires that the following tasks be undertaken during the first year following construction.

Initial Inspections. It is recommended that for the first six months following construction, the site should be inspected at least twice after storm events that exceed a 1/2-inch of rainfall.

Planting of Aquatic Benches. The aquatic benches should be planted with emergent wetland species, following the planting recommendations contained in Stormwater Treatment Wetland section (5.4.11).

Spot Reseeding. Inspectors should look for bare or eroding areas in the contributing drainage area or around the pond buffer, and make sure they are immediately stabilized with grass cover.

Watering. Trees planted in the pond buffer need to be watered during the first growing season. In general, consider watering every 3 days for first the month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.

3.3 Maintenance Inspections

Maintenance of a wet pond is driven by annual inspections that evaluate the condition and performance of the pond, including the following:

- Measure sediment accumulation levels in the forebay.
- Monitor the growth of wetland plants, trees and shrubs planted. Record the species and their approximate coverage, and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the pond for material damage, erosion or undercutting.
- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine embankment integrity.

- Inspect the pond outfall channel for erosion, undercutting, rip-rap displacement, woody growth, etc.
- Inspect the condition of the principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc.
- Inspect the condition of all trash racks, reverse-sloped pipes, or flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and locks can be opened and operated.
- Inspect internal and external side slopes of the pond for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.

Based on inspection results, specific maintenance tasks will be triggered. An example maintenance inspection checklist for Wet Ponds can be found in Appendix F.

3.4 Common Ongoing Maintenance Tasks

Maintenance is needed so stormwater ponds continue to operate as designed on a long-term basis. Routine stormwater pond maintenance, such as removing debris and trash, is needed several times each year (See Table 3). More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Inspection and repair of critical structural features (e.g., embankments and risers) needs to be performed by a qualified professional engineer who has experience in the construction, inspection, and repair of these features.

The maintenance plan should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way 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.

Table 3: Typical Wet Pond Maintenance Tasks and Frequency.

Maintenance Items[1]	Frequency[1]
• Remove debris and blockages • Repair undercut, eroded, and bare soil areas	Quarterly or after major storms (>1 inch of rainfall)
• Mowing embankment	Twice a year
• Shoreline cleanup to remove trash, debris and floatables • A full maintenance inspection • Open up the riser to access and test the valves • Repair broken mechanical components, if needed	Annually
• Pond buffer and aquatic bench reinforcement plantings	One time – during the second year following construction
• Forebay Sediment Removal	Every 5 to 7 years
• Repair pipes, the riser and spillway, as needed	From 5 to 25 years
1 Maintenance items and required frequency should be verified with local requirements	

3.5 Sediment Removal

Frequent sediment removal from the forebay is essential to maintain the function and performance of a wet pond. For planning purposes, maintenance plans should anticipate cleanouts approximately every 5 to 7 years, or when inspections indicate that 50% of forebay sediment storage capacity has been filled. Absent an upstream eroding channel or other source of sediment, the frequency of sediment removal should decrease as the drainage area stabilizes. The designer should also check to see whether removed sediments can be spoiled on-site or must be hauled away. 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.

4. Community & Environmental Concerns

Wet ponds can generate the following community and environmental concerns that need to be addressed during design.

Aesthetic Issues. Many residents feel that wet ponds are an attractive landscape feature, promote a greater sense of community and are an attractive habitat for fish and wildlife. Designers should note that these benefits are often diminished where wet ponds are under-sized or have small contributing drainage areas.

Existing Wetlands. A wet pond should never be constructed within an existing natural wetland. Discharges from a wet pond into an existing natural wetland should be minimized to prevent pollution damage and changes to its hydroperiod.

Existing Forests. Construction of a wet pond may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction.

Stream Warming Risk. Wet ponds can warm streams by 2 to 10 degrees Fahrenheit, although this may not be a major problem for degraded urban streams. To minimize stream warming, landscaping plans for wet ponds should emphasize shading with a combination of emergent vegetation and overstory shading. When all upgradient runoff reduction options have been exhausted, designers should utilize the multiple cells, and not the ED option..

Safety Risk. Pond safety is an important community concern. Gentle side slopes and safety benches should be provided to avoid potentially dangerous drop-offs, especially where wet ponds are located near residential areas.

Mosquito Risk. Mosquitoes are not a major problem for larger wet ponds (Santana et al., 1994; Ladd and Frankenburg, 2003, Hunt et al, 2005). However, fluctuating water levels in smaller or under-sized wet ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC (2005).

Geese and Waterfowl. Wet ponds with extensive managed turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl, whose droppings add to the nutrient and bacteria loads, thus reducing the removal efficiency for those pollutants. Several design and landscaping features can make wet ponds much less attractive to geese (see Schueler, 1992).

Harmful Algal Blooms. Designers are cautioned that recent research on wet ponds in the coastal plain has shown that some ponds can be hotspots or incubators for algae that generate harmful algal blooms (HABs). The type of HAB may include cyanobacteria, raphidophytes, or dinoflagellates, and the severity appears to be related to environmental conditions and high nutrient inputs. Given the known negative effects of HABs on the health of shellfish, fish, wildlife and humans, this finding is a cause for concern for coastal stormwater managers.

5. Wet Pond Checklist Example

Sample Construction Inspection Checklist for Wet Ponds: The following checklist provides a basic outline of the anticipated items for the construction inspection of a wet pond. Inspectors should review the plans carefully, and adjust these items and the timing of inspection verification as needed to ensure the intent of the design and the inspection is met.

Pre-Construction Meeting

- ❑ Pre-construction meeting with the contractor designated to install the wet pond has been conducted.
- ❑ Identify the tentative schedule for construction and verify the requirements and schedule for interim inspections and sign-off.
- ❑ Subsurface investigation and soils report supports the placement of a wet pond in the proposed location.
- ❑ Impervious cover has been constructed/installed and area is free of construction equipment, vehicles, material storage, etc.
- ❑ All pervious areas of the contributing drainage areas have been adequately stabilized with a thick layer of vegetation and erosion control measures have been removed.
- ❑ Certification of Stabilization Inspection: Inspector certifies that the drainage areas are adequately stabilized in order to convert the sediment pond or trap (if used for sediment control) into a permanent wet pond.

Construction of Wet Pond Embankment and Principal Spillway

- ❑ Stormwater has been diverted around or through the area of the wet pond embankment to a stabilized conveyance; and perimeter erosion control measures to protect the facility during construction have been installed.
- ❑ Materials for construction of the embankment and principal spillway are available and meet the specifications of the approved plans.
- ❑ Construction of key trench, principal spillway, including the riser and barrel, anti-seepage controls, outlet protection, etc., is built in accordance with approved plans.
- ❑ Geotechnical analysis and approval of the core (if required) and embankment material has been provided, and the material has been placed in lifts and compacted in accordance with the approved plans.
- ❑ Certification of Embankment and Principal Spillway Inspection: Inspector certifies that each element of the embankment and principal spillway has been constructed in accordance with the approved plans.

Excavation of Wet Pond

- ❑ Excavation of the wet pond geometry (including bottom width, side slopes, check dams, weir overflow and outlet protection, etc.) achieves the elevations in accordance with approved plans.
- ❑ Excavation of internal micro-topographic features: deep pool, forebays, etc., is in accordance with approved plans.
- ❑ Impermeable liner, when required, meets project specifications and is placed in accordance with manufacturer's specifications.
- ❑ Certification of Excavation Inspection: Inspector certifies that the excavation has achieved all the appropriate grades, grade transitions, and wet pond geometry as shown on the approved plans.

Landscaping Plan and Stabilization

- ❑ Exposed soils on pond side slopes above permanent pool elevation are stabilized with specified seed mixtures, stabilization matting, mulch, etc., in accordance with approved plans.
- ❑ Appropriate number and spacing of plants are installed and protected on the aquatic bench and pond buffer in accordance with the approved plans.
- ❑ All erosion and sediment control practices have been removed.
- ❑ Follow-up inspection and as-built survey/certification has been scheduled.
- ❑ GPS coordinates have been documented for the wet pond installation.

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5.4.3 Vegetated Swale (Water Quality Swale)

Description: Designed to manage runoff primarily by reducing its velocity for increased treatment efficiency by a downstream practice, vegetated surfaces provide water quality pretreatment through filtering, biological uptake mechanisms, and subsoil cation exchange capacity. Subsoil can also provide a relatively small amount of runoff volume reduction especially when check dams are used. These attributes, in addition to low installation and maintenance costs, make the vegetated swale preferable to the traditional system of curb and gutter, storm drains, and pipes for managing stormwater runoff.

Figure 1: Roadside channel in Spokane, WA.

Site Constraints:

- **Depth to water table:** variable
- **Steep slopes:** longitudinal slope ≤ 4%
- **Soils:** C/D may require compost
- **Hotspots:** typically OK
- **Karst**

Key Design Criteria:

- Contributing drainage area ≤ 5 acres
- Longitudinal slope ≤ 4%
- Side slopes 3:1 (H:V) or flatter
- Bottom width of channel should be between 4 and 8 ft wide
- Flow velocities in channel must be:
  - less than 1 fps during a 1" storm event, and
  - non-erosive during the 2-year and 10-year design storm events.
- 10-year design flow must be contained within the channel which must have a 6" minimum freeboard.
- Dense vegetation capable of withstanding relatively high flow velocities and alternating dry and wet periods
- Check dams and compost material can be added to maximize pollutant capture and stormwater infiltration, respectively.

Maintenance:

- Monitor sediment accumulation and remove as necessary
- Inspect channel and repair any eroding surfaces or damaged vegetation
- Ensure vegetation is well established
- Remove debris from any inlet and outlet structures

Advantages:

- Provides pretreatment when used as part of runoff conveyance system
- Provides partial infiltration of runoff in pervious soils
- Less expensive than typical curb and gutter
- Wildlife habitat potential
- Reduces thermal effects of impervious surfaces

Disadvantages:

- Minimal runoff volume and pollutant reduction
- May allow sediment re-suspension
- Poor design may lead to standing water and mosquito problems

Design Checklist:

- ❑ Identify management goal(s)
- ❑ Review site constraints
- ❑ Review design criteria
- ❑ Protect site resources
- ❑ Size channel for site conditions
- ❑ Submit plans for review

1. Design

1.1 Suggested Applications

Vegetated swales are well suited as pretreatment structures for a volume reducing BMP such as upstream of an infiltration trench or bioretention area. They can also be used to convey water downstream from an SCM. The linear form factor of *vegetated swales* makes them well-suited to treat highway runoff or to be placed in road and highway shoulders and medians. However, *vegetated swales* can also be used in residential, commercial, or institutional developments along parking lot edges or islands, around buildings, or along driveways. *Vegetated swales* should be applied in linear configurations parallel to the contributing impervious cover, such as roads and small parking areas to allow for level spreading and not concentrating flow at one inlet and similarly to prevent a bottleneck or clogging at said single inlet. *Vegetated swales* are not recommended when residential density exceeds more than 4 dwelling units per acre due to lack of available land, the frequency of driveway crossings along the channel, and in order to avoid safety hazards and nuisance conditions.

Standard vegetated swales may or may not have storage capacity, depending on design needs and the use of internal check dams or other structures. Water quality swales are differentiated from standard swales with the use of layered media below the vegetation, which acts like a bioretention cell to filter and infiltrate water. Water quality swale design must include design details on internal baffles or check dams. Sizing of water quality swales follows the protocol for bioretention (see section 5.4.6). As storage in water quality swales fills, overflow occurs along the swale. Sizing of swale dimensions above the storage layers follows in water quality swales follows that of standard vegetated swales. Adequate overflow and spillway design must be in place to protect the surface and vegetation in water quality swales.

1.2 Site Constraints

Contributing Drainage Area: The development density of the contributing drainage area (CDA) affects peak runoff rates and the amount of land available for the footprint of the practice. Also note that the CDA for a single *Vegetated swale* must be 5 acres or less to reduce the occurrence of channel failure due to erosive velocities. When *vegetated swales* treat and convey runoff from drainage areas greater than 5 acres, the velocity and flow depth through the channel become too great to treat runoff or prevent channel erosion.

Note: The footprint required will likely be greater than that of a typical conveyance channel (TDOT or equivalent). However the benefit of the runoff reduction may reduce the footprint requirements for stormwater management elsewhere onsite.

Slopes: *Vegetated swales* are most effective on grades less than 5%. *Vegetated swales* should be designed on areas allowing for longitudinal slopes less than 4%. Slopes greater than 4% create rapid runoff velocities that can cause erosion and do not allow enough contact time for filtering or infiltration unless check dams are used. However, terracing a series of *Vegetated swale* cells may work on slopes from 5% to 10%. The drop in elevation between check dams should be limited to 18 inches in these cases, and the check dams should be armored on the downslope side with properly sized stone to prevent erosion.

Longitudinal slopes less than 2% are ideal and may eliminate the need for check dams. Channels having longitudinal slopes less than 1% must be monitored carefully during construction to ensure a continuous grade to avoid flat areas holding pockets of standing water, i.e. mosquitos.

Soils: *Vegetated swales* can be used in all hydrologic soil groups, but soil amendments may be required to enhance performance in C or D soils. *Vegetated swales* should not be used on soils with infiltration rates less than or equal to 0.5” per hour if infiltration of small runoff flows is intended. In these cases, *vegetated swales* situated on HSG C or D soils will require compost amendments to facilitate acceptable performance conditions.

In areas of fill, soil slips can result from saturating sections of different soil types. While *Vegetated swales* are not necessarily designed to infiltrate runoff, they can attenuate flows so as to encourage infiltration where soils allow. *Vegetated swales* can be used in cut or fill. However, a clear note should address proper fill material preparation in order to minimize any differential soil conditions. *Vegetated swales* depend on dense vegetation to promote filtering and abstraction. Construction of *vegetated swales* in fill material or in a disturbed soil profile may require soil amendments in order to establish vegetation to achieve basic performance. A soil test should be done to evaluate the organic content and fertilization requirements.

Depth to Water Table: Vegetated swale bottoms should lie completely above the water table above an elevation that allows for infiltration of the target reduction volume. This is modeled using soil input data in the TNRRAT. Otherwise, soil texture infiltration must be justified to account for volume reduction.

Utilities and Setbacks: Tennessee One Call (811) must be contacted before onsite digging begins. Typically, utilities can cross vegetated swales if they are protected (e.g. double casing) or located below the channel invert, but designers should consult their local utility provider(s) for guidance concerning the horizontal and vertical clearances between utilities and channels.

As a general rule vegetated swales should be at least 10 feet down-gradient from building foundations, 50 feet from septic system fields, and 100 feet from private wells. Vegetated swales should also be located outside the limits of the mapped 100 year flood plain unless a waiver is obtained from the local authority. However, consult local ordinances and design criteria to determine minimum setbacks from property lines, structures, utilities and wells.

Hotspots: Vegetated swales can typically be used to convey runoff from stormwater hotspots. Vegetated swales are not recommended to treat stormwater hotspots due to the potential for the infiltration of hydrocarbons, trace metals, and other toxic pollutants into groundwater.

1.3 Design Criteria and Calculations

Section 1.3 provides a comprehensive process for designing vegetated swales including recommended calculations, relevant site constraints, and required design objectives. Alternative methods may be used so long as no constraints are violated and all goals are achieved.

Design Constraint:

- ❍ The Contributing Drainage Area to a single channel must be ≤ 5 ac.

1.3.1 Runoff Volume

Swales provide both runoff reduction and pollutant removal. Sizing these practices as part of a stormwater management system of SCMs is accomplished using the TNRRAT. If alternative sizing methods are used, then it is up to the designer to justify the appropriate use of the selected method and provide adequate design calculations to support runoff reduction and pollutant removal.

Water quality swale sizing is efficiently accomplished in the TNRRAT as well. See Section 5.4.6 (Bioretention) for detailed design specifications.

1.3.2 Practice Dimensions

Design Flow Rate: The primary design criterion for Vegetated swales is flow rate. For relatively steeper slopes (2% - 4%), check dams may be necessary in order to meet the allowable max flow velocities. Vegetated swales should generally be aligned adjacent to and the same length (minimum) as the adjacent edge of the contributing drainage area. The minimum length may be achieved with multiple channel segments connected by culverts with energy dissipaters.

Channel Dimensions: The dimensions of a Vegetated swale must convey the required flow at a velocity that is non-erosive. A channel should be sized to convey the 10-yr 24-hr storm (or 10-yr peak runoff if using the rational method) for channel sizing unless an alternate path for high flows is available. It is recommended that the velocity not exceed 1 fps unless supporting calculations are provided to demonstrate that erosive conditions will not occur through the use of turf reinforcement matts (TRMs) or other methods.

Design Constraints:

- ❍ Longitudinal slope ≤ 4% (≤ 10% if terracing is used)
- ❍ Side slopes 3:1 (H:V) or flatter
- ❍ Flow velocities in channel must be less than 1 fps during a 1” storm event and non-erosive during the 2-year and 10-year design storm events.
- ❍ 10-year design flow must be contained within the channel which must have a 6” minimum freeboard.

Determining channel dimensions can be an iterative process, the flow capacity of a vegetated channel is a function of the longitudinal slope, resistance to flow (Manning's n) and cross sectional area. The flow depth should not exceed 4". The channel bottom width is calculated based on Manning's equation for open channel flow:

$$Q = 1.49 / n \, A \, R^{1.67} \, S^{0.5}$$

where

Q = flow rate cfs

n = Manning's roughness coefficient (unitless: assume 0.15 for grass, 0.20 for dense vegetation)

A = cross sectional area of flow (sf)

R = hydraulic radius (ft) = area / wetted perimeter

S = longitudinal slope (ft/ft).

The first step is to estimate the channel bottom width. For shallow flow depths in channels, channel side slopes are negligible and the channel bottom width is estimated as:

$$B = Q \, n / 1.49 \, y^{1.67} \, s^{0.5}$$

where

B = bottom width of channel (ft)

Q = design flow rate (cfs)

n = Manning's roughness coefficient (unitless: assume 0.15 for grass, 0.20 for dense vegetation)

y = design flow depth (ft)

s = slope (ft/ft)

If the bottom width is less than 2 ft, adjust the flow depth. If the bottom width is more than 10 ft (or allowable width per site conditions) it may be necessary to limit the flow rate or adjust the slope if feasible.

If the bottom width is between 2 ft and 10 ft, the second step is to determine the flow velocity:

$$V = Q / A$$

where

V = design flow velocity (fps)

Q = design flow rate (cfs)

A = cross sectional area (ft^2) determined by:

A = by + zy

where

b = bottom width of channel (ft)

y = design flow depth (ft)

z = side slope (ft/ft)

If the velocity exceeds 2 fps or the channel bottom width is less than 2 ft or more than 10 ft, the designer must modify the proposed dimensions until the design criteria are met.

Channels must have a min of 4 inches of freeboard without creating erosive velocities.

An underdrain system is used in channels with check dams to ensure that water moves through the system when the native soil infiltration rate is not high enough to empty excess ponded water, or if infiltration is not feasible. If water does not exit the channel quickly enough, the system will backup and flood adjacent properties. It is not recommended that surface water remain visible in residential areas for more than 24 hrs. All underdrain systems must discharge the water quality volume between 48 and 72 hrs. Underdrain systems must be included in the design if native soils infiltration is less than 0.1 inch per hour.

Check Dams: Check dams are used to create shallow pools of water that reduce the velocity of runoff through the channel while also promoting infiltration. Check dams may measure 4 to 12 inches in height and extend the full width of the channel. Quantity and placement of check dams depend on the slope and required storage volume. Earthen check dams created by excavation rather than by placement of fill are recommended. Stone is recommended for constructed check dams.

Flows through a stone check dam vary based on stone size, flow depth, flow width, and flow path length through the dam. Flow through a stone check dam can be calculated using the following equation:

Design Checklist:

- ✔ Velocity less than 1 fps for 1 in event and non-erosive for 10-yr event
- ✔ Freeboard of at least 4 in for 10-yr event
- ✔ Check dams sized to handle flow-through velocity

$$q = h^{1.5} / (L / D + 2.5 + L2)^{0.5}$$

where

q = flow rate exiting check dam (cfs/ft)

h = flow depth (ft)

L = length of flow (ft)

D = average stone diameter (ft) (more uniform gradations are preferred)

For low flows, check dam geometry and channel width are actually more influential on flow than stone size. The average flow length through a check dam as a function of flow depth can be determined by the following equation:

$$L = (ss) \times (2d - h)$$

where

s = check dam side slope (max 3:1) (side slope is entered as rise over run so 3:1 is entered as 3)

d = height of dam (ft)

h = flow depth (ft).

When channel flows overwhelm the flow through capacity of a stone check dam, the top of the dam should act as a standard weir (use standard weir equation, although principal spillway 6icnches below the height of the dam may also be required depending on flow conditions). If the check dam is designed to be overtopped, appropriate selection of aggregate will ensure stability during flooding events. In general, one stone size is recommended for ease of construction. However two or more stone sizes may be sued provided a larger stone is placed on the downstream side since flows are concentrated at the exit channel of the weir. Several feet of smaller stone (e.g. AASHTO #57) can then be placed on the upstream side. Smaller stone may also be more appropriate at the base of the dam for constructability purposes.

1.4 Typical Details

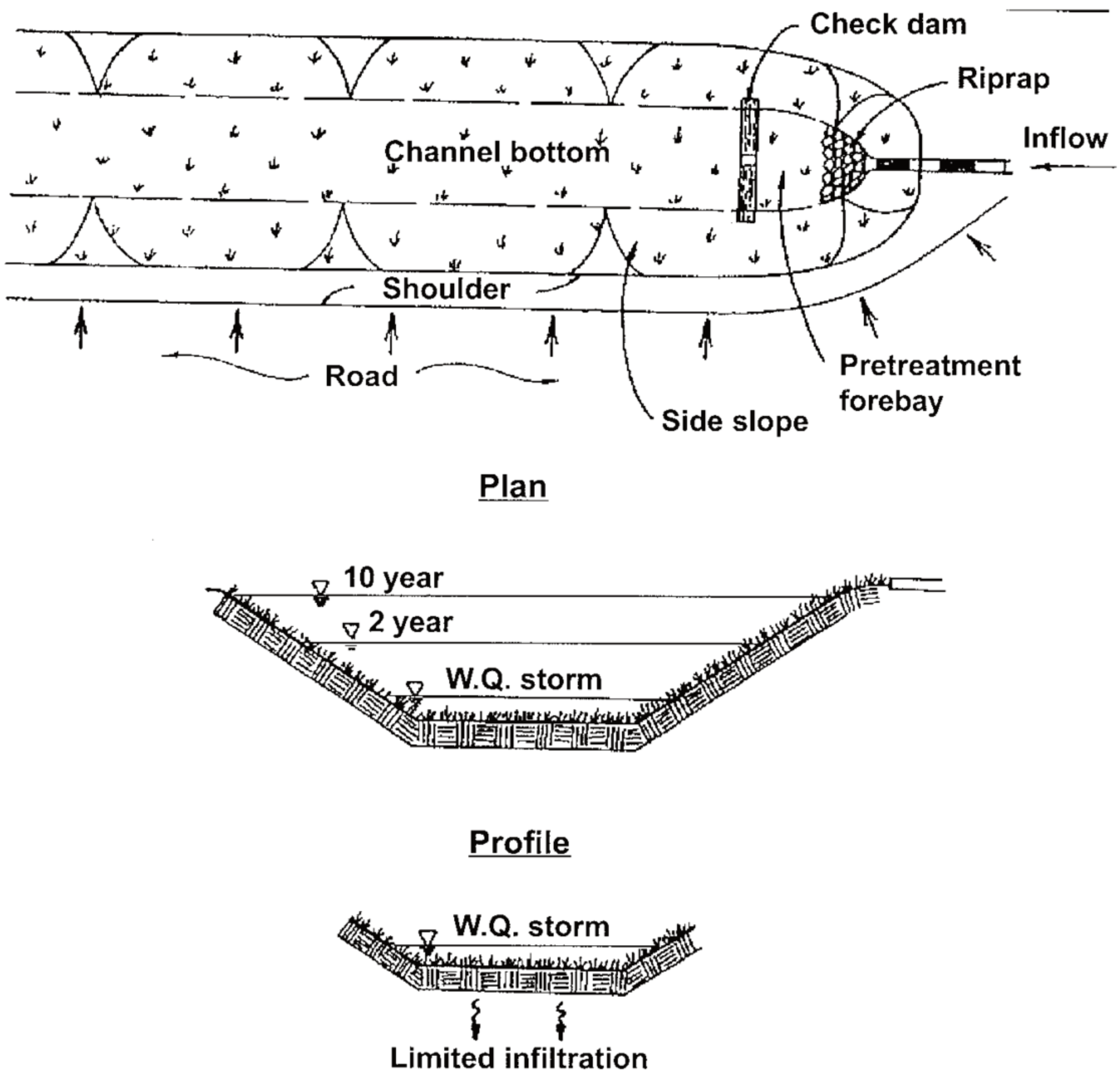

Figure 2: Grass channel – Typical plan, profile, and section (Source: Virginia).

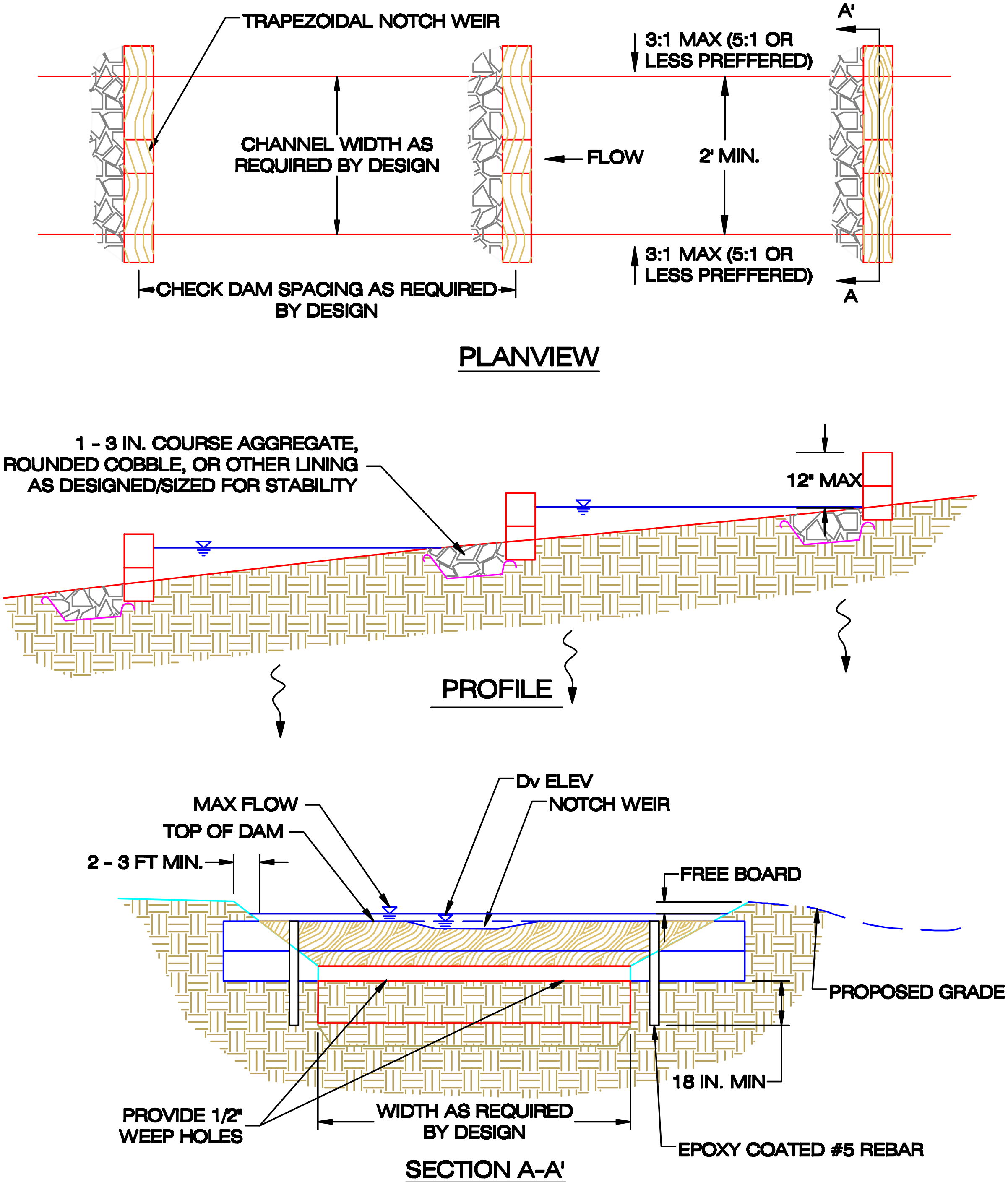

Figure 3: Grass swale with check dams – typical plan, profile, and section (Source: West Virginia).

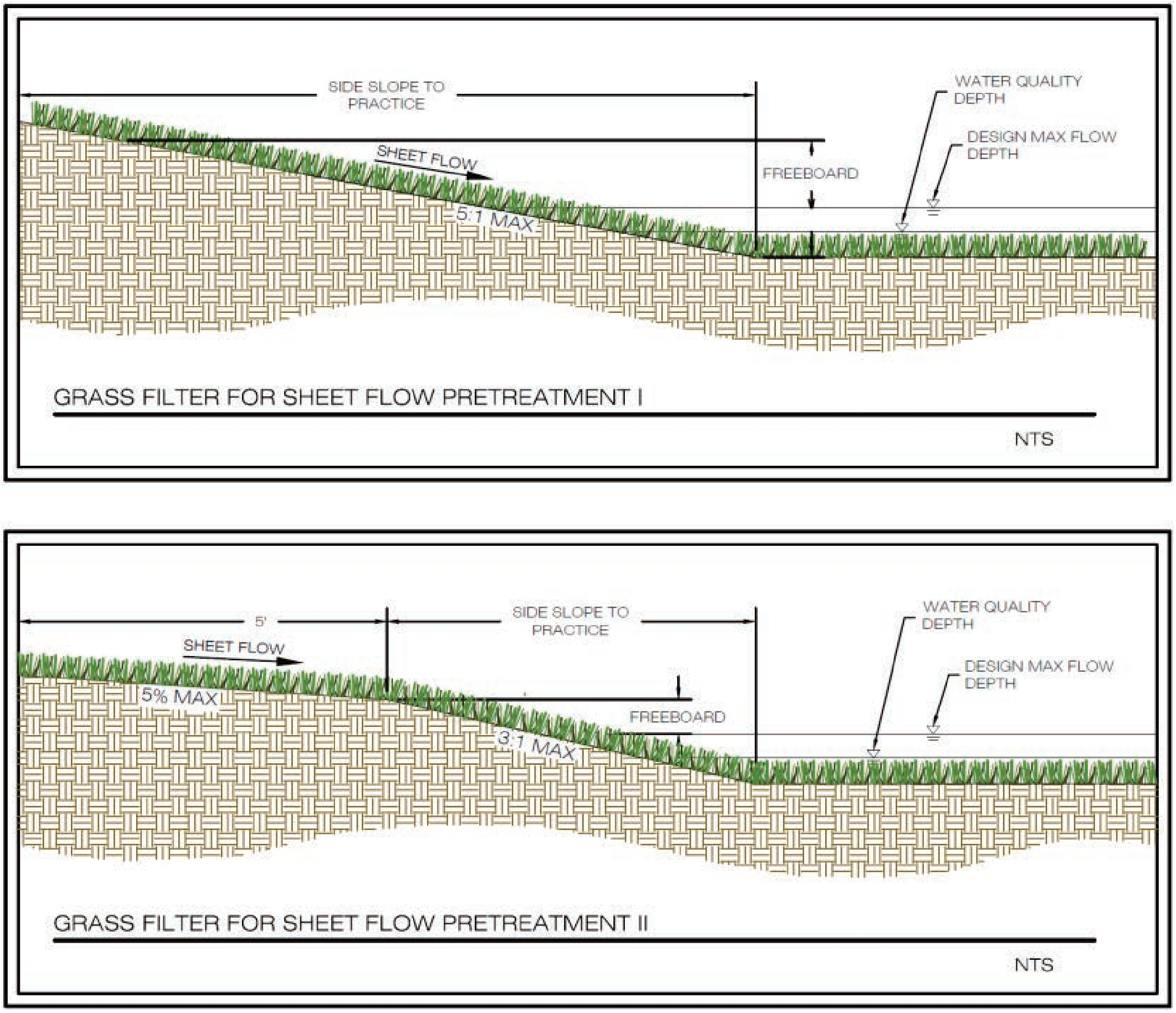

Figure 4: Pretreatment I and II – Grass filter for sheet flow (Source: West Virginia).

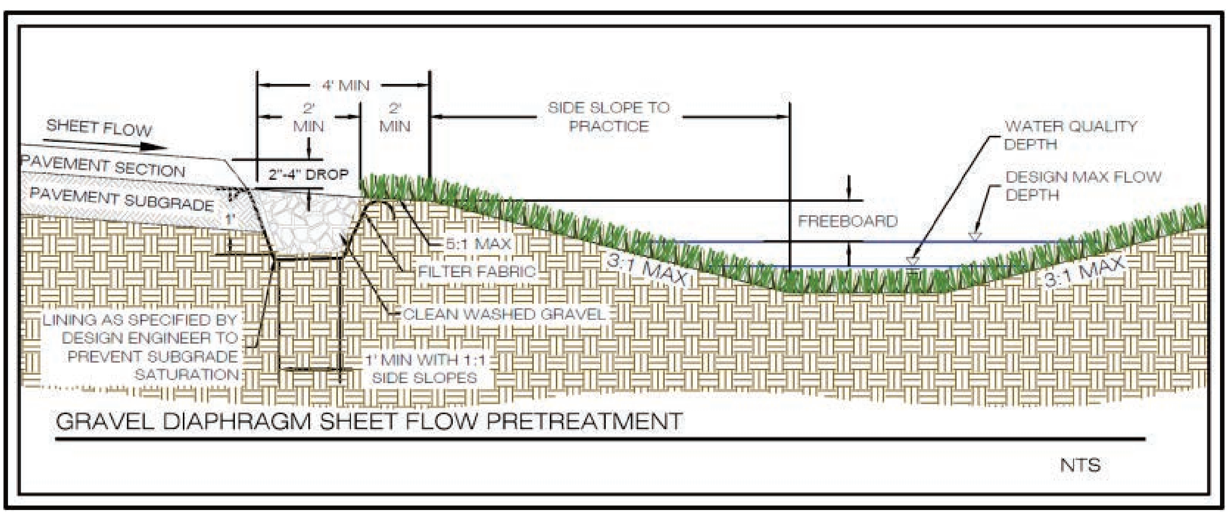

Figure 5: Pretreatment – gravel diaphragm for sheet from impervious or pervious surface (Source: West Virginia).

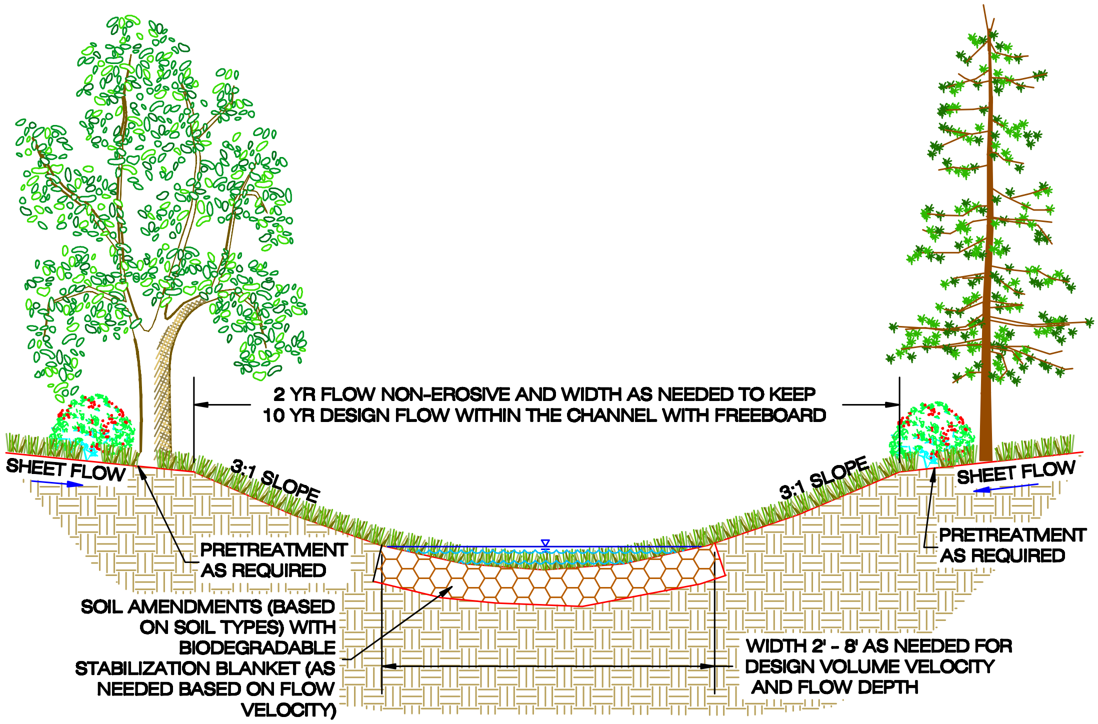

Figure 6: Grass swale with compost amendments – sections (Source: West Virginia).

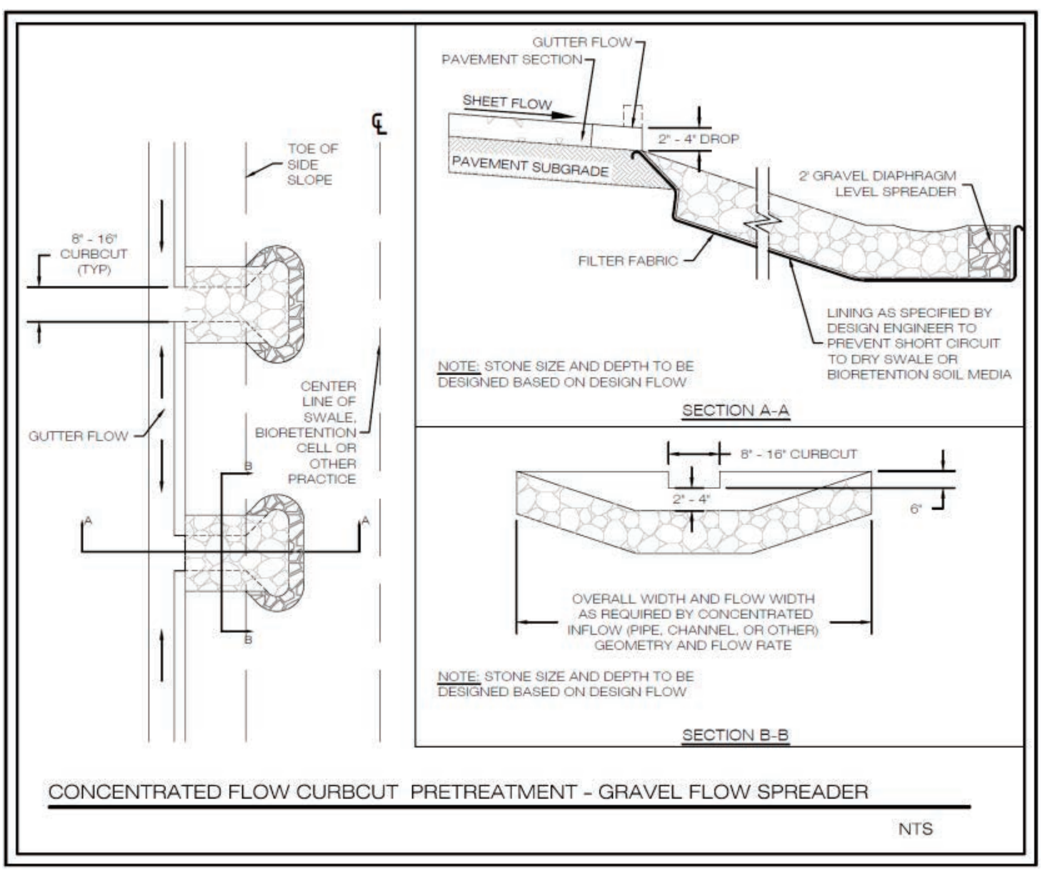

Figure 7: Pretreatment – Gravel from spreader for concentrated flow (Source: Virginia).

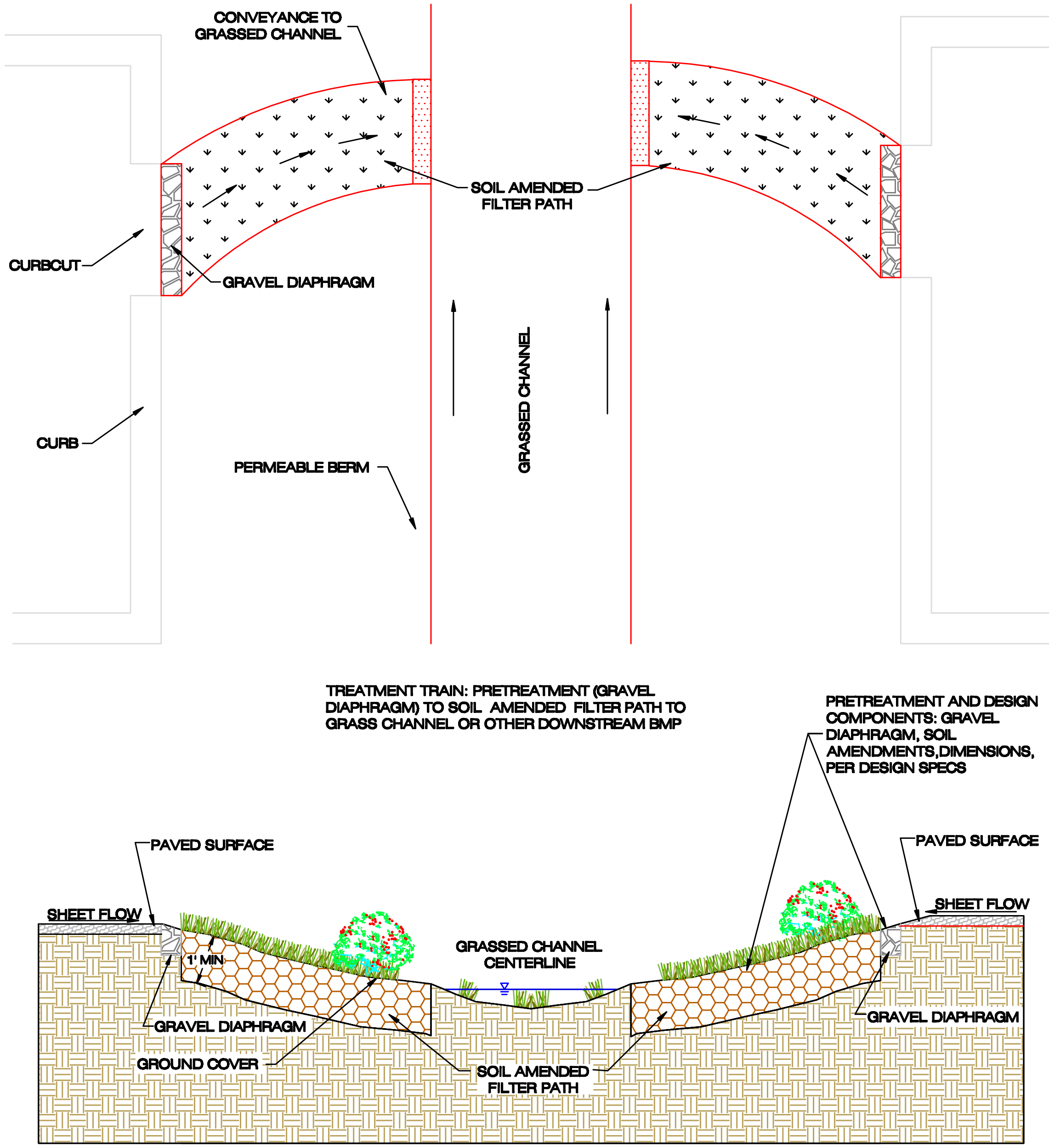

Figure 8: Filter path to grass channel (Source: Virginia).

2. Construction

The following is a typical construction sequence to properly install a grass channel, although steps may be modified to reflect different site conditions. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation.

2.1 Pre-Construction

Site Assessment: Determine whether any site characteristics conflict with the feasibility requirements for successfully implementing the vegetated swale(s) listed below (and discussed in Section 1.1):

- Contributing Drainage Area
- Slopes
- Soils

- Depth to Water Table
- Utilities and Setbacks
- Hotspots

If there are any conflicts, revise the site plan or select another practice.

Protect Resources: Set aside undisturbed portions of the site or areas conducive to vegetated swale installation before construction begins. Place restorative practices onsite (conceptually or physically) to determine the availability of land for the vegetated swale(s).

Ideally, vegetated swales should remain outside the limit of disturbance during 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, temporary EPSC such as dikes, silt fences and other erosion control measures should be integrated into the channel design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric should be used to protect the channel.

Stabilize Contributing Drainage Area: Vegetated swale installation may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross-section. EPSC for construction of the vegetated swale should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the vegetated swale until the bottom and side slopes are fully stabilized.

For best success channels should not be installed until site construction is complete and site stabilization has occurred. Vegetated channels completed before site stabilization must be protected from receiving sediment laden runoff. Runoff should be directed around the completed vegetated channel until site stabilization has occurred. Sediment laden water should not be allowed to enter channels.

2.2 Construction

Grade Channel: Grade the vegetated swale to the final dimensions shown on the plan. Do not compact or subject existing subgrade in vegetated channels to excessive construction equipment traffic. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock. Rough grade the vegetated channel. Excavating equipment should operate from the side of the channel and never on the bottom. If excavation leads to substantial compaction of the subgrade (where an infiltration trench is not proposed) 18 inches shall be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth. At the very least, topsoil shall be thoroughly deep plowed into the subgrade in order to penetrate the compacted zone and promote aeration and the formation of macropores. Following this, the area should be disked prior to final grading of topsoil. Halt excavation and notify the engineer immediately if evidence of sinkhole activity, unanticipated bedrock or groundwater, or other site conditions are encountered that may affect infiltration bed design or performance.

Install Necessary Treatment Structures: Install check dams, driveway culverts, and internal pre-treatment features as shown on the plan. Fill material used to construct check dams should be placed in 8- to 12-inch lifts and compacted to prevent settlement. The top of each check dam should be constructed level at the design elevation.

Install overflow structure and other stormwater structures: close and secure all inlets, pipes, trench drains, and other structures to prevent runoff from entering the vegetated channel prior to completion and site stabilization. Maintain drainage overflow pathways during construction while the vegetated channel is closed to provide for drainage during storm events.

Add Necessary Soil Amendments: Till the bottom of the channel to a depth of 1 foot and incorporate compost amendments as needed.

Vegetate Channel: Hydro-seed the bottom and banks of the grass channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to soil stabilization blanket and matting requirements found in MA–1 of the Tennessee Erosion and Sediment Control Handbook. Prepare planting holes for any trees and shrubs, then plant materials as shown in the landscaping plan and water them weekly in the first two months. The construction contract should include a 'Care and Replacement Warranty' to ensure vegetation is properly established and survives during the first growing season following construction.

2.3 Inspections

Notify the engineer when the site is fully vegetated and the soil mantle is stabilized. The engineer shall inspect the vegetated channel drainage area at his / her discretion before the area is brought online and sediment control devices are removed. Conduct the final construction inspection and develop a punch list for facility acceptance.

During Construction

Inspections during construction are needed to ensure that the grass channel is built in accordance with these specifications. Some common pitfalls can be avoided by careful post-storm inspection of the grass channel:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side-slopes.
- Inspect check dams and pre-treatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- Make sure outfall protection/energy dissipation at concentrated inflows are stable.

The real test of a grass channel occurs after its first big storm. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets or realignment of outfalls and check dams).

As-Built

Conduct as-built inspection to determine success of installation and installed channel characteristics. After the grass channel has been constructed, an as-built certification of the grass channel should be prepared by a registered Professional Engineer and submitted to the local stormwater program. The as-built certification verifies that the SCM was installed as designed and approved. The following components should be addressed in the as-built certification:

1. The channel must be adequately vegetated.
2. The water quality channel flow velocity must not exceed 1.0 foot per second.
3. A mechanism for overflow for large storm events must be provided.

3. Maintenance

3.1 Agreements

The requirements for the maintenance may include the execution and recording of an inspection and maintenance agreement, a declaration of restrictions and covenants, and the development of a long term maintenance plan by the design engineer (See Appendix F for examples).

3.2 Schedules

A properly designed and installed vegetated channel will require relatively little maintenance. While vegetation is being established pruning and weeding may be required. Detritus may also need to be removed approximately twice per year. Perennial grasses can be cut down or mowed at the end of the growing season. Inspect vegetated channels annually for sediment buildup, erosion, vegetative conditions etc. Inspect for pools of standing water, dewater and discharge to a sanitary sewer at an approved location. Mow and trim vegetation according to maintenance schedule to ensure safety aesthetics and proper channel operation or to suppress weeds and invasive species. Dispose of cuttings in a local composting facility. Mow only when channel is dry to avoid rutting. Inspect for uniformity in cross section and longitudinal slope and correct as needed. The following should only be done as needed: plant alternate grass species in the event of unsuccessful establishment. Reseed bare areas and install appropriate erosion control measures when native soil is exposed or erosion is observed. Rototill and replant channel if drawdown time is less than 48 hours. Inspect and correct check dams when signs of altered water flow (channelization, obstructions, etc.) are identified.

Once established, vegetated swales have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover. Maintenance requirements for vegetated swales include the following:

1. Maintain grass height of 3 to 4 inches.
2. Remove sediment build up in channel bottom when it accumulates to 25% of original total channel volume.
3. Ensure that rills and gullies have not formed on side slopes. Correct if necessary.
4. Remove trash and debris build up.
5. Replant areas where vegetation has not been successfully established.

All vegetated swales must be covered by a drainage easement to allow inspection and maintenance. If a vegetated swale is located in a residential private lot, the existence and purpose of the vegetated swale shall be noted on the deed of record.

REFERENCES

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5.4.4 Managed Vegetated Areas

URBAN FOREST, GRASSLANDS AND RIPARIAN BUFFERS

Variations: Prairie, no-mow lawn area, woodland, buffers

Figure 1: Managed vegetated area in native perennial grasses and shrubs in Athens, TN (Source: SMART Center).

Managed Vegetated Areas are those that sustain a determinant amount of vegetated cover such that it intercepts rainfall and covers the soil surface as well as has an established root matrix in the soil. Managed Vegetated Areas may be planted in native plants or non-native plants; however, there are many advantages to selecting and maintaining a native vegetation stand. Native plants are plants that evolved in place over geologic time and are distributed across the landscape largely in response to climatic episodes and adaptation to site conditions related to land formation. Natives are generally defined as plants that occurred in North America before European settlement. Native soil and vegetation retention is the single most effective strategy to reduce stormwater impacts on-site, and has the added benefit of enhancing baseflow in streams and recharge of aquifers [Lacey, 2010].

Key Design Criteria:

- Preserve open spaces and create healthy stands of vegetation
- Develop landscape plan using native materials when possible
- Protect areas during construction

Site Constraints:

- **Hotspots, Karst, or Run-on Volume:** Not suitable for hotspot area nor approved to accept run-on volume. Encouraged management around known karst (undisturbed).
- Water table to bedrock depth: N/A
- Soils: Vegetation should match soil types
- Slope: up to 1:1
- Max. drainage area: N/A

Limitations:

- Establishment period requires more intensive maintenance, such as weeding and watering

Advantages:

- **Facilitates evapotranspiration**
- **May reduce use of pesticides and fertilizers.** Native plants have adapted to local conditions, so they are more resistant to pest problems.
  - Saves time and money
  - Improves water quality
- **Improved air quality.**
- **Improved soil conditions** through organic material and macropore formation
- **Carbon sequestration**
- **Enhanced infiltration**
- **Settling and filtering of pollutants**
- **Groundwater recharge**

1. Design

The use of Managed Vegetated Areas (MVAs) is generally limited to two goals: 1) providing the desired use and aesthetic of a site, and 2) minimizing the amount of runoff generated. The design of MVAs relies solely on establishing a stand of vegetation, which can be characterized in terms of capacity to protect soil surface. The Soil Conservation Service (SCS) Curve Number method is the most widely accepted method for predicting runoff from surfaces with a consistent management (or cover). The effects of management are translated into the TNRRAT approach through adjusting the infiltration capacity of soils based on vegetative cover. To establish and maintain a stand of specific vegetated cover, see section 5.3 for Management Techniques that will assist in preparing a site for establishment. Also utilize local nursery and growers instructions for establishing and maintaining specific ornamental and nonnative vegetation stands. The remainder of this section will focus on establishing native vegetation as well as using managed vegetated areas to balance the stormwater runoff generated from impervious surfaces of a site.

1.1 Benefits of Selecting Native Vegetation

Using native plants to vegetate an area is an effective method of improving the quality and reducing the volume of site runoff. Native plants significantly change the soil medium by adding carbon, decreasing bulk density, and increasing infiltration rates by as much as a factor of 10 or more, even in clay soils (see Bharati, et.al, 2002 and Fuentes, et.al, 2004). Native species are generally described as those existing in a given geographic area prior to European settlement. Over time, native vegetation does not typically require significant chemical maintenance by fertilizers and pesticides. This results in additional water quality benefits. Native species are typically more tolerant and resistant to pest, drought, and other local conditions than non-native species. Landscape architects and ecologists specializing in native plant species are usually able to identify a wide variety of plants that meet these criteria anywhere in the state.

In addition to chemical applications, minimum maintenance also means minimal mowing and irrigation in established areas. Native grasses and other herbaceous materials that do not require mowing or intensive maintenance are preferred. Because selecting such materials begins at the concept design stage, this BMP can generally result in a site with reduced runoff volume and rate, as well as significant nonpoint source load reduction/prevention.

A complete elimination of traditional lawns as a site design element can be a difficult SMC to implement, given the extent to which the lawn as an essential landscape design feature is embedded in current national culture. Instead, the landscape design should strategically incorporate areas of native plantings – surrounding limited turf grass areas – to act as buffers that will capture and filter stormwater flowing off of turf grasses or pavements.

Native species have more extensive root systems (Figure 2). Dense root system increases ability to retain and store water which help reducing the amount of CO_2 in the atmosphere by taking in CO_2 and storing the carbon in the body of the plants, roots and soil.

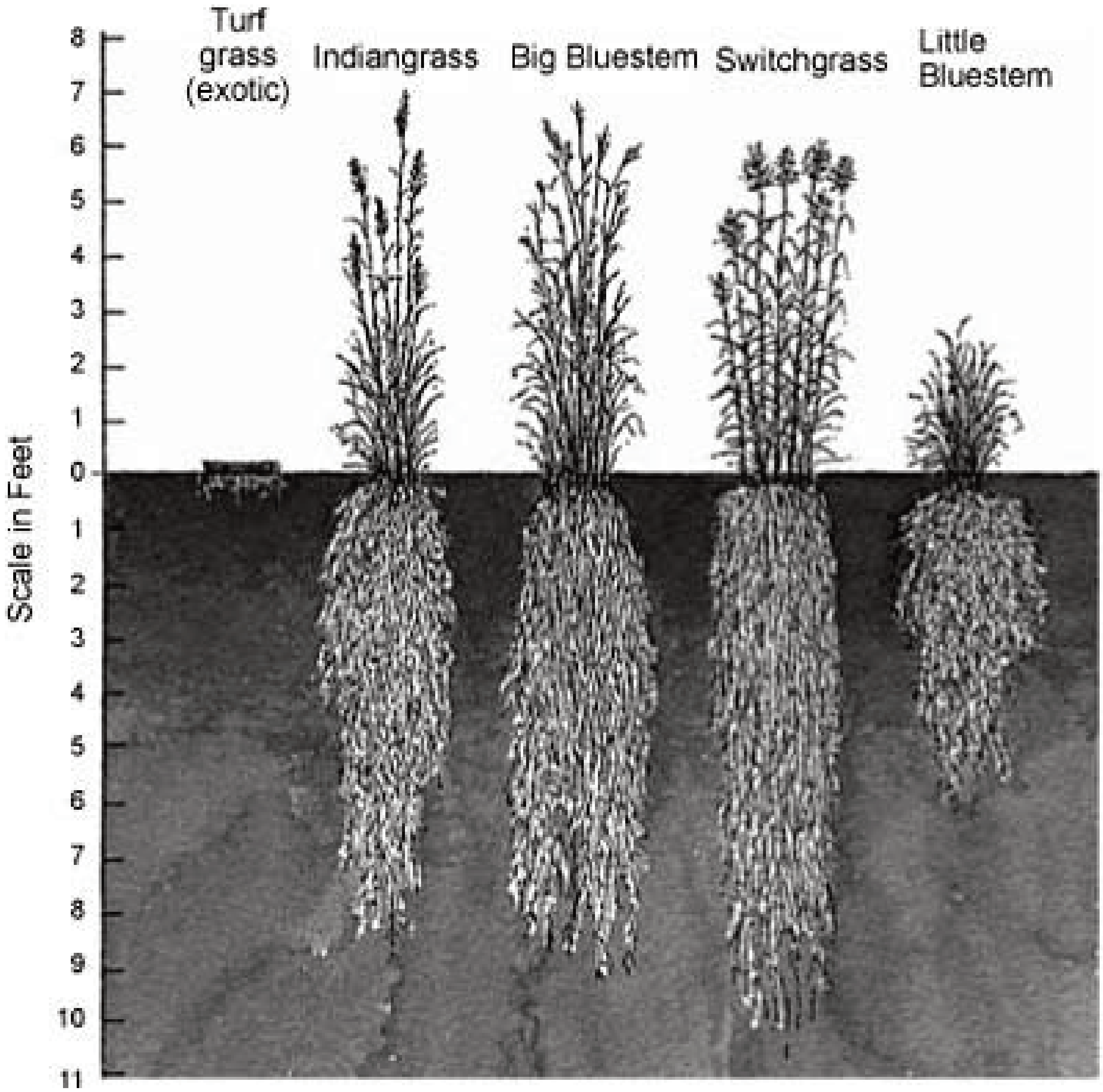

Figure 2: Native meadow species compared to turf grass (Source: TVA).

1.2 Variations

Species selection for any native landscape should be based on function, availability, and level of appropriateness for site conditions. Native species plantings can achieve variation in landscape across a variety of characteristics, such as texture, color, and habitat potential.

Properly selected mixes of flowering prairie species can provide seasonal color; native grasses offer seasonal variation in texture. Seed production is a food source for wildlife and reinforces habitat. In all cases, selection of native species should strive to achieve species variety and balance, avoiding creation of single-species or limited species "monocultures" which pose multiple problems. In sum, many different aspects of native species planting reinforce the value of native landscape restoration, typically increasing in their functional value as species grow and mature over time. Examples include:

- **Prairie** – Install Big Bluestem, Little Bluestem, Indian Grass, Switchgrass and others that resemble the Native Americans grassland. Prairies have a tendency to establish and regain function rather quickly (3-10 years), and can provide lower-growing vegetation with highly attractive native grasses and wildflowers.
- **No-mow lawn area** – Install low-growing native grasses that are used as a substitute for lawn or cool-season grass plantings.

- **Woodland** – Install a balance of native trees, shrubs, forbs, grasses, and sedges. Woodlands will provide shade, vertical structure, and a high level of rainfall interception in the long term. It typically requires a significant amount of time to mature.
- **Constructed wetlands** – Historic drained wetlands or existing artificial low areas may be planted with wetland species that will thrive in standing water or saturated conditions.
- **Buffer areas** – Bands of re-established native vegetation occurring between impermeable surfaces, lawns, or other non-native land uses and existing natural areas.
- **Replacement lawn areas** – Existing turf lawns may be converted to native prairies, wetlands, or woodlands to minimize maintenance while increasing stormwater benefits and wildlife habitat.

Figure 3: Tennessee native no-mow lawn and woodland (Source: S.R.).

Figure 4: Managed Vegetated Areas of fescue lawn and wet meadow adjacent to the parking area in this mixed-use/industrial zone in Asheville, NC.

1.3 Applications

1.3.1 New / Retrofit Development

- **Residential** – Native landscapes can be incorporated into common areas of residential developments. Additionally, individual homeowners may incorporate native landscapes into their own properties. Native revegetation should also be used to provide buffers around any existing natural areas that are undisturbed within the residential development.
- **Commercial** – Common areas and open spaces within commercial developments may be planted with native species, as well as any created detention/retention basins or artificial water ways. Native revegetation should also be used to provide buffers around any existing natural areas that are undisturbed within the commercial development.
- **Ultra Urban** – Use of native revegetation is limited in ultra-urban settings because of the lack of available green space. Wherever possible, however, native species should be incorporated.
- **Industrial** – Use of native revegetation in industrial settings is very similar to that in commercial settings.
- **Retrofit** – Established turf grass may be converted into prairie, woodland, or wetland.
- **Highway/Road** – Native plants may be established in rights-of-way to minimize long-term maintenance while establishing linear habitat corridors.

1.3.2 Preserving Native Vegetation

Preserving native vegetation should be the first priority wherever feasible. Native vegetation preservation and restoration areas should be incorporated to the maximum extent practical and where most effective (i.e., where there is intact native vegetation and soils and/or unconcentrated flows from developed areas). The goals for native vegetation preservation/retention are as follows:

- Large lot development: 65%
- Low density residential (0-4 dwelling units/acre): 50%
- Low-density residential (3-6 du/acre): 50%
- Medium density (6-12 du/acre): maximum practical extent
- High density (>6-20 du/acre): maximum practical extent. [Lacey, 2010].

1.3.3 Selecting Preservation Areas

Selection of areas for natural vegetation preservation should be made in consultation with a landscape architect. Native vegetation and soil protection areas should be prioritized by location and type as follows:

1. Large tracts of riparian areas, that connect, create or maintain contiguous protected riparian areas
2. Large tracts of critical and wildlife habitat area , that connect, create or maintain contiguous protected areas
3. Tracts that create common open space areas among or within developed sites
4. Protection areas on individual lots
5. Protection areas on individual lots that connect to protection areas on adjacent lots [Lacey, 2010].

1.4 Materials

Whenever practical, native species should be from the same ecoregion as the project area. When necessary, species may be used from adjacent ecoregions for aesthetic or practical purposes. Additional information relating to Tennessee native species and their use in landscaping is available from TVA and Southeast Exotic Pest Plant Council (TVA and SE-EPPC).

Developments should use native trees for replacement in areas separate from residential lots, or storm drainage areas adjacent to roadway or parking lots. Species selection should be based on the underlying soils and the historic, native indigenous plant community type for the site, if existing conditions can support the plant community.

Requirements for trees selected for replacement purposes are listed below:

- The trees must be free from injury, pests, diseases, and nutritional disorders.
- The trees must be fully branched and have a healthy root system
- Coniferous and broad leaf evergreen trees shall be no less than 3 feet in height at time of planting.
- Deciduous trees shall be a minimum of 5 feet in height or have a minimum caliper size of 1 inch at time of planting.
- Avoid the use of a single species of tree for replacement purposes. No individual species of replacement tree should exceed 50 percent of the total, and no individual species should be less than 10 percent of the total.

1.5 Calculation

Managed vegetation will lower runoff volume and peak rates by lowering the runoff coefficient (i.e., curve number). Runoff reduction requirements can be met through a site-wide mass balance of square feet of trees, shrubs, or grass and impervious surface. Proposed trees and shrubs to be planted under the requirements of these SCMs are assigned a curve number (CN) reflecting the condition of a stand, either in "good" condition, "fair" condition, or "poor" condition. These conditions are quantified based on plant cover density and described in detail below. The amount of rainfall attenuated is based on this curve number, which decreases in attenuation capacity in the preceding list. This is a function of vegetation characteristics that help retain rainfall, such as soil coverage with foliage canopy and root density. While this practice is not approved to accept run-on water volumes, implementing managed vegetated areas will minimize the overall site generation of runoff.

- Good condition
  - o ≤ 200 ft^2 / tree, or expected full canopy cover
  - o ≤ 25 ft^2 / shrub
  - o > 90% turf cover, with no continuous bare areas
  - o Trees or shrubs with lush undergrowth, with > 90% of surface under either canopy or ground cover
- Fair condition
  - o 200 - 350 ft^2 / tree, or expected canopy cover > 75%
  - o 25 - 40 ft^2 / shrub
  - o > 75% turf cover, with no contiguous bare area > 50 ft^2
  - o Trees or shrubs with fair undergrowth, with > 75% of surface under either canopy or ground cover
- Poor condition
  - o 350 - 500 ft^2 / tree, or expected canopy cover > 50%
  - o 40 - 60 ft^2 / shrub
  - o > 50% turf cover, with no contiguous bare area > 75 ft^2
  - o Trees or shrubs with some undergrowth, with > 50% of surface under either canopy or ground cover

- Below these recommended targets, it is not considered an adequate measure to claim credit, due to very limited infiltration capacity and potential to serve as a source of TSS.
- Minimum seeding/planting will receive “poor” credit, while optimize seeding/planting will receive “fair” credit. “Good” credit can only be achieved when optimized seeding/planting is followed by maintenance practice.

1.6. Design Process

Existing native vegetation is a good starting point for determining what can thrive on a given site. However, the designer should also consider and balance various factors in developing a successful plant list. The hydrologic patterns set the stage for where along the moisture continuum plants will be most successful (easily found in native plant resource guides).

> The basis for native revegetation design scheme begins with assessing the site for:
>
> - Existing native vegetation
> - Soil texture and pH
> - Hydrologic regimes
> - Sun exposure
> - Aesthetics

1. **Analyze site’s physical conditions**

   The most important physical conditions of the site are the topography, hydrology, and soil, each of which will guide protection activities and plant selection. Evaluate the soil using the USDA soil survey to determine important soil characteristics such as flooding potential, seasonal high water table, soil pH, soil moisture, and other characteristics. Evaluate the topography based on USGS maps or a topographical survey of the site.

2. **Analyze site’s vegetative features**

   Existing vegetation present at the site should be examined to determine the overall strategy for vegetation restoration and establishment. Strategies will differ whether pre-existing conditions are pasture, overgrown abandoned field, mid succession forest, or another type of setting. An effort to inventory existing vegetation for protection and to determine type of presettlement vegetation should be made to guide efforts.

   a. **Identify desirable species:** Use native tree and shrub species that thrive in local habitats in Tennessee. These species should be identified in the restoration site and protected. Several native vines and shrubs can provide an effective ground cover during establishment of the area, though they should be controlled to prevent herbaceous competition.

   b. **Identify undesirable species:** Control invasive plants prior to planting new vegetation.

   c. **Identify sensitive species:** Because many areas are rich in wildlife habitat and could potentially harbor wetland plant species, be aware of any rare, threatened, or endangered plant or animal species. Take care to protect sensitive species during restoration activities.

3. **Map the site**

   Prepare an existing conditions sketch of the site that denotes important features, including stream width, length, stream bank condition, adjacent land uses, stream activities, desired width of buffer, discharge pipes, obstructions, etc.

4. **Create a design that meets multiple stakeholder objectives**

   a. Landowner objectives: Consider the current use of the existing vegetation, especially if the area will be protected by the landowner in perpetuity. Determine how the revegetated area will complement or conflict with existing and probable future uses of the property.

   b. Community objectives: Consider linking the revegetated area to an existing or planned green infrastructure system, which may include trails, parks, preserves, and wildlife habitat corridors. Evaluate how the new vegetation could help achieve local recreation goals.

   c. Watershed objectives: Examine the local watershed plan to identify goals related to establishing native plants. Have goals related to water quality been emphasized, or is wildlife habitat of primary concern? If no watershed plan has been prepared, examine other regional resource or recreation plans for reference to native plantings.

5. **Amend soil**

   In those sites where soils have been disturbed, restore compromised soils by subsoiling and/or adding a soil amendment, such as compost. This will help in reestablishing its long-term capacity for infiltration and pollution removal.

6. **Limit the development footprint** as much as possible, preserving natural site features, such as vegetation and topography. In contrast to turf, "natural forest soils with similar overall slopes can store up to 50 times more precipitation than neatly graded turf." (Arendt, Growing Greener, pg. 81) If lawns are desired in certain areas of a site, they should be confined to those areas with slopes less than six percent.

7. **Prairie restoration can reduce turf or create a buffer between turf and forest.** Meadow buffers along forests help reduce off-trail trampling and direct pedestrian traffic in order to avoid "desire-lines" which can further concentrate stormwater. Prepare the site for a prairie planting by weeding well before planting and during the first year. Perennial weeds may require year-long smothering, repeated sprayings with herbicides, or repeated tillage with equipment that can uproot and kill perennial weeds.

   The site should be sunny, open, and well-ventilated, as prairie plants require at least a half a day of full sun. Erosion prone sites should be planted with a nurse crop (such as annual rye or seed oats) for quick vegetation establishment to prevent seed and soil loss. Steep slopes (25 percent or steeper) and areas subject to water flow should be stabilized with erosion blankets, selected to mitigate expected runoff volumes and velocities. Hydro-seeding is generally not recommended for native species. There is tremendous variation among seed suppliers; choose seeds with a minimum percent of non-seed plant parts. Native seed should also be PLS (Pure Live Seed) tested by a third party to gauge seed viability.

8. Converting turf grass areas to prairie requires that all turf be killed or removed before planting, and care taken to control weeds prior to planting.

9. Forest restoration includes planting of tree species, 12-18 inches in height, and shrubs at 18-24 inches, with quick establishment of an appropriate ground cover to stabilize the soil and prevent colonization of invasive species. Trees and shrubs should be planted on eight-foot centers, with a total of approximately 430 trees per acre.

   Reforestation can be combined with other volume control SCMs such as retentive berming, vegetated filter strips and swales. Plant selection should mimic the surrounding native vegetation and expand on the native species already found on the site. A mixture of native trees and shrubs is recommended and should be planted once a ground cover is established.

10. Ensure adequate stabilization, since native grasses, meadow flowers, and woodlands establish more slowly than turf. Stabilization can be achieved for forest restoration by establishing a ground cover before planting of trees and shrubs. When creating meadows, it may be necessary to plant a fast growing nurse crop with meadow seeds for quick stabilization. Annual rye can be planted in the fall or spring with meadow seeds and will establish quickly and usually will not present a competitive problem. Erosion prone sites should be planted with a nurse crop and covered with weed-free straw mulch, while steep slopes and areas subject to runoff should be stabilized with erosion control blankets suitable for the expected volume and velocity of runoff.

11. Prepare a landscape maintenance plan that identifies weeding plans, mowing goals, irrigation needs, and trimming of herbaceous perennials or key tree specimens, as needed.

2. Construction

2.1 Conversion of Previously-Developed Surfaces to Native Vegetation

Conversion of a previously developed surface to native vegetated landscape or restoration of disturbed areas required to be native vegetation requires the removal of impervious surface and ornamental landscaping, de-compaction of soils, and the planting of native trees, shrubs, and ground cover in compost-amended soil according to all of the following specifications:

1. Existing impervious surface and any underlying base course (e.g., crushed rock, gravel, etc.) must be completely removed from the conversion area(s).
2. Underlying soils must be broken up to a depth of 18 inches. This can be accomplished by excavation or ripping with either a backhoe equipped with a bucket with teeth, or a ripper towed behind a tractor.
3. At least 4 inches of well-decomposed compost must be tilled into the broken up soil as deeply as possible. The finished surface should be gently undulating and must be only lightly compacted.
4. The area of native vegetated landscape must be planted with native species, trees, shrubs, and ground cover. Species should be selected as appropriate for the site shade and moisture conditions, and in accordance with the following requirements:
   a. Trees: a minimum of two species of trees should be planted, one of which is a conifer. Conifer and other tree species should cover the entire landscape area.
   b. Shrubs: a minimum of two species of shrubs shall be planted. Space plants to cover the entire landscape area, excluding points where trees are planted.
   c. Groundcover: a minimum of two species of ground cover should be planted. Space plants so as to cover the entire landscape area, excluding points where trees or shrubs are planted.

Note: For landscape areas larger than 10,000 square feet, planting a greater variety of species than the minimum suggested above is strongly encouraged. For example, an acre could easily accommodate three tree species, three species of shrubs, and two or three species of groundcover [Lacey, 2010].

3. Maintenance

3.1 Management Plan

Native vegetation and soil protection areas serve as stormwater control measures and should be managed as are other stormwater control measures. The Maintenance Plan for the SCM shall include a written vegetation management plan and protection mechanisms as necessary to maintain the benefit of these areas over time (Appendix F).

3.2. Monitoring the Survival Rate, Weed Control, and Soil Amendment.

Maintenance of native vegetation restoration areas should include monitoring the survival of planted species, weed control and soil amendment as necessary to ensure the establishment of the native vegetation. A minimum 80 percent survival of all planted vegetation at the end of two years should be required. Ongoing maintenance shall include weeding and watering for a minimum of three years from installation.

If during the 2-year period survival of planted vegetation falls below 80 percent, additional vegetation should be installed as necessary to achieve the required survival percentage. The likely cause of the high rate of plant mortality should also be determined and corrective actions taken to ensure plant survival. If it is determined that the original plant choices are not well suited to site conditions, these plants should be replaced with plant species that are better suited to the site. [Lacey, 2010]

3.3 Applying Carefully Selected Herbicides

Applying a carefully selected herbicide (Roundup or similar glyphosate herbicide) around the protective tree shelters/tubes may be necessary, reinforced by selective cutting/manual removal, if necessary. This initial maintenance routine is often necessary for the first two to three years of growth and may be needed for up to five years until tree growth and tree canopy form, naturally inhibiting weed growth (once shading is adequate, growth of invasive species and other weeds will be naturally prevented, and the woodland becomes self-maintaining). Survey the new woodland intermittently to determine if replacement trees should be provided (some modest rate of planting failure is usual).

3.4 Prairie Management

Prairie management is somewhat more straightforward. A seasonal mowing or burning may be required, although care must be taken to make sure that any management is coordinated with essential reseeding and other important aspects of meadow reestablishment. In addition, burning needs to be coordinated with the local fire marshal and follow local regulations. In the first year, weeds should be carefully controlled and consistently mowed back to four to six inches tall when they reach 12-18 inches in height. In the second year, continue to monitor and mow weeds and hand-treat perennial or rhizomatous weeds with herbicide. Weeds should not be sprayed with herbicide if the drift from the spray may kill large patches of desirable plants, allowing weeds to move in to these new open areas. If necessary, controlled spot herbicide applications may be used to treat invasive plants if the treatments can be completed without damage to off target vegetation.

3.5 Prescribed Burn

A prescribed burn should be conducted at the end of the second or beginning of the third growing season. If burning is not possible, the prairie should be mowed very closely to the ground instead. If possible or practical, the mowed material should be removed from the site to expose the soil to the sun. This helps encourage rapid soil warming which favors the establishment of “warm season” plants over “cool season” weeds. Long-term maintenance should incorporate burning or mowing on a two to five year cycle to minimize woody species growth while encouraging development of the native prairie species.

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5.4.5 Filter Strips

Description: Filter strips are areas of dense vegetation located between runoff pollutant sources and other SCMs or receiving water bodies. Filter strips may be constructed of turf, meadow grasses, or other vegetation such as landscape plantings. Filter strips act to impede the velocity of stormwater runoff (thereby allowing sediment to settle out), to reduce the impacts of temperature, and to encourage infiltration. Filter strips are a water quality SCM to slow the rate of runoff, reduce peak flows, and to allow for infiltration to a lesser extent.

Figure 1: Filter strip along highway (Source: Virginia).

Site Constraints:

- Receiving area slopes must be shallow enough to not cause runoff
- Contributing area cannot be a hotspot without pretreatment

Key Design Criteria:

- Contributing drainage area
- Velocity of inflow
- Vegetation of receiving area

Maintenance:

- Watering, fertilizing, and weeding, especially in the first 2 years while plants are becoming established
- Repair erosion and vegetation as necessary
- Aerate soil as particulates accumulate to promote growth

Advantages:

- Provides flow rate reduction
- Wildlife habitat potential
- Excellent retrofit capability
- Cost effective
- Improve aesthetics

Disadvantages:

- Maintenance must be clearly defined to avoid mowing (e.g. signage)
- Salt use may adversely affect vegetation
- Vegetation and soils must be protected from damage and compaction

Design Checklist:

- ❑ Identify management goal(s)
- ❑ Review site constraints
- ❑ Review design criteria
- ❑ Protect site resources
- ❑ Size channel for site conditions
- ❑ Submit plans for review

1. Design

1.1 Suggested Applications

Filter strips are vegetated areas that treat sheet flow delivered from adjacent areas by slowing runoff velocities and allowing sediment and attached pollutants to settle and/or be filtered by vegetation. Impervious areas are disconnected and runoff is routed over a level spreader to sheet flow over adjacent vegetated areas. This slows runoff velocities, promotes infiltration, and allows sediment and attached pollutants to settle and/or be filtered by the vegetation.

Filter Strips may also be used as pretreatment for another stormwater practice such as a grass channel, bioretention, or infiltration areas. If 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.

Some areas on a new or redevelopment site where filter strips can be used include:

- Better suited for less densely developed locations on a site due to surface area requirements
- Used in combination with other SCMs (especially when treating runoff from highly impervious areas)
- Pretreatment or overflow discharge point for other SCMs (such as infiltration channel or bioretention area)
- To receive runoff from roof leaders or as divisions between individual lots
- Placement in underutilized areas of parks or other open space to receive runoff from compacted pervious areas
- Road and highway shoulders and medians
- Parking edges
- Riparian buffers

1.2 Site Constraints

Location and Capture Area

- Maximum contributing area < 5,000 sf (recommended)
- Contributing area flow path length for impervious areas <= 100 ft (recommended)
- Contributing area flow path length for pervious areas <= 150 ft (recommended)
- Maximum contributing drainage area slope = 6%

Filter strips are best suited to treat runoff from small segments of impervious cover (usually less than 5,000 sf) adjacent to road shoulders, small parking lots, and rooftops. Human activity, slopes, and soil type influence the location of filter strips. Select a location to prevent vegetation damage and soil compaction from pedestrian traffic or unintended vehicle compaction. Optimum filter strip locations are often located to the side or downhill of high-volume vehicle or pedestrian traffic areas. Filter strips are generally most effective when used to manage a small capture area, or in conjunction with other SCMs.

Consider locating filter strips in places that are generally not used such as road/highway shoulders and medians; between parked cars in parking lots; along edges of public playgrounds, school yards, plazas, and courtyards; and in place of traditional landscape planting areas around buildings and structures. Select locations where existing maintenance is difficult. Although locating filter strips on slopes will reduce the ability for infiltration, converting traditional lawn to a denser vegetative cover can provide significant stormwater benefits. Avoid placing filter strips in locations that will disturb existing forest or meadows. Such areas should be addressed by protective SCMs. Locate filter strips to prevent future conflicts for space, and provide public access if necessary.

Filter strips are appropriate for all soil types, except fill soils. The runoff reduction rate, however, is dependent on the underlying Hydrologic Soil Groups and whether soils receive compost amendments. Filter strips should not receive hotspot runoff, since the infiltrated runoff could cause groundwater contamination.

Entrance/Flow Conditions: It is important for entrance conditions or distributed flow into a filter strip to be as sheet flow. Concentrated flows of runoff should always be avoided to prevent erosion, gully formation, and preferential flow paths through a filter strip. When runoff travels across a surface for long distances, flows can begin to concentrate. For pervious contributing areas, flow path lengths greater than 150 feet should be avoided. For impervious contributing areas, flow path lengths greater than 100 feet should be avoided. The upstream edge of a filter strip should be level and directly abut the contributing drainage area. A gravel trench level spreader can be used for this purpose.

Contributing Flow Path to Filter: Filter strips are used to treat very 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 100 feet of flow length for impervious surfaces, and 150 feet for pervious surfaces. When flow concentrates, it moves too rapidly to be effectively treated by a Filter Strip, unless an engineered level spreader is used. When the existing flow at a site is concentrated, a grass channel or a water quality swale should be used instead of a Filter Strip (Lantin and Barrett, 2005).

Filter Slopes and Widths: Maximum slope for filter strips is 6%, in order to maintain sheet flow through the practice. In addition, the overall contributing drainage area must likewise be relatively flat to ensure sheet flow draining into the filter. Where this is not possible, alternative measures, such as an engineered level spreader, can be used.

Proximity of Underground Utilities: Underground pipes and conduits that cross the Filter Strip are acceptable.

1.3 Design Criteria

Filter strips should be planted at such a density to achieve a 90% grass/herbaceous cover after the second growing season. Performance has been shown to fall rapidly as vegetative cover falls below 80%. Filter strips should be seeded, not sodded, whenever possible. Seeding establishes deeper roots, and sod may have muck soil that is not conducive to infiltration (Storey et. al., 2009). The filter strip vegetation may consist of turf grasses, meadow grasses, other herbaceous plants, shrubs, and trees, as long as the primary goal of at least 90% coverage with grasses and/or other herbaceous plants 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.

Stormwater must enter the filter strip or conserved open space as sheet flow. If the inflow is from a pipe or channel, an engineered level spreader must be designed in accordance with the criteria contained herein to convert the concentrated flow to sheet flow.

Diaphragms, Berms, and Level Spreaders

Gravel Diaphragms: A pea gravel diaphragm at the top of the slope is required for Filter Strips that receive sheet flow. The pea 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 (clean bank-run gravel that meets TDOT #57 grade) should be used in the diaphragm.

Permeable Berm: 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 down gradient 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.

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 ensure non-erosive sheet flow into the vegetated area. **Figure 3** represents a configuration that includes a bypass structure that diverts the design storm to the level spreader, and bypasses the larger storm events around the filter strip through an improved channel. An alternative approach involves pipe or channels discharging at the landward edge of a floodplain. The entire flow is directed through a stilling basin energy dissipater and then a level spreader such that the entire design storm for the conveyance system (typically a 10-year frequency storm) is discharged as sheet flow through the floodplain.

Key design elements of the engineered level spreader, as provided in **Figures 2 and 3**, include the following:

- High Flow Bypass provides safe passage for larger design storms through the filter strip. The bypass channel should accommodate all peak flows greater than the water quality design flow.
- A Forebay should have a maximum depth of 3 feet and gradually transition to a depth of 1 foot at the level spreader lip (**Figure 2**). The forebay is sized such that the surface area is 0.2% of the contributing impervious area. *(A forebay is not necessary if the concentrated flow is from the outlet of an extended detention basin or similar practice).*
- 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 consisting of native grasses or thick ground cover.
  - 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 shall be determined using the Rational Equation with an intensity of 1-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.
- The level spreader should be placed 3 to 6 inches above the downstream natural grade elevation to avoid turf buildup. In order to prevent grade drops that re-concentrate the flows, a 3-foot long section of course aggregate, underlain by filter fabric, should be installed just below the spreader to transition from the level spreader to natural grade.

Vegetated receiving areas down-gradient from the level spreader must be able to withstand the force of the flow coming over the lip of the device. It may be necessary to stabilize this area with temporary or permanent materials in accordance with the calculated velocity (on-line system peak, or diverted off-line peak) and material specifications, along with seeding and stabilization in conformance with the Tennessee Erosion and Sediment Control Handbook.

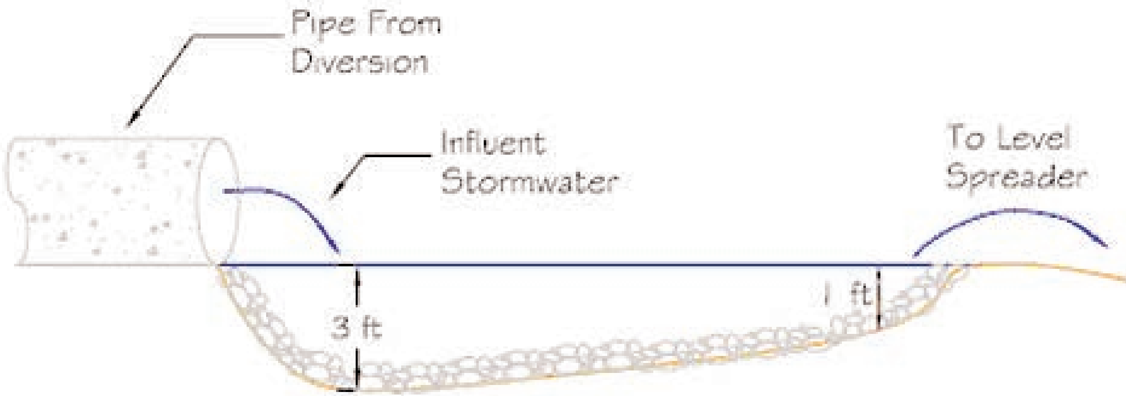

Figure 2: Level Spreader Forebay (Hathaway and Hunt 2006).

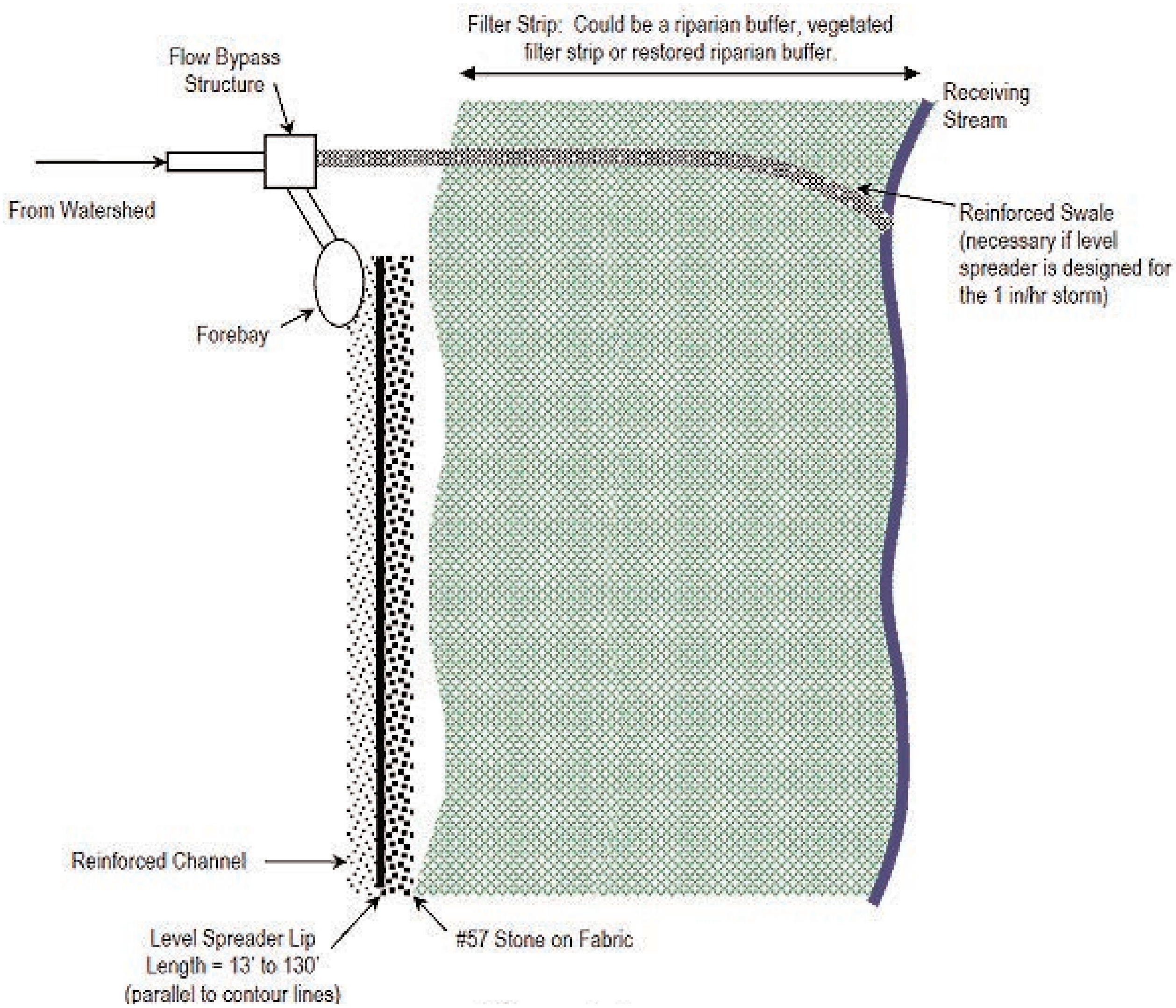

Figure 3a: Engineered Level Spreader (ELS) Plan (Hathaway 2006).

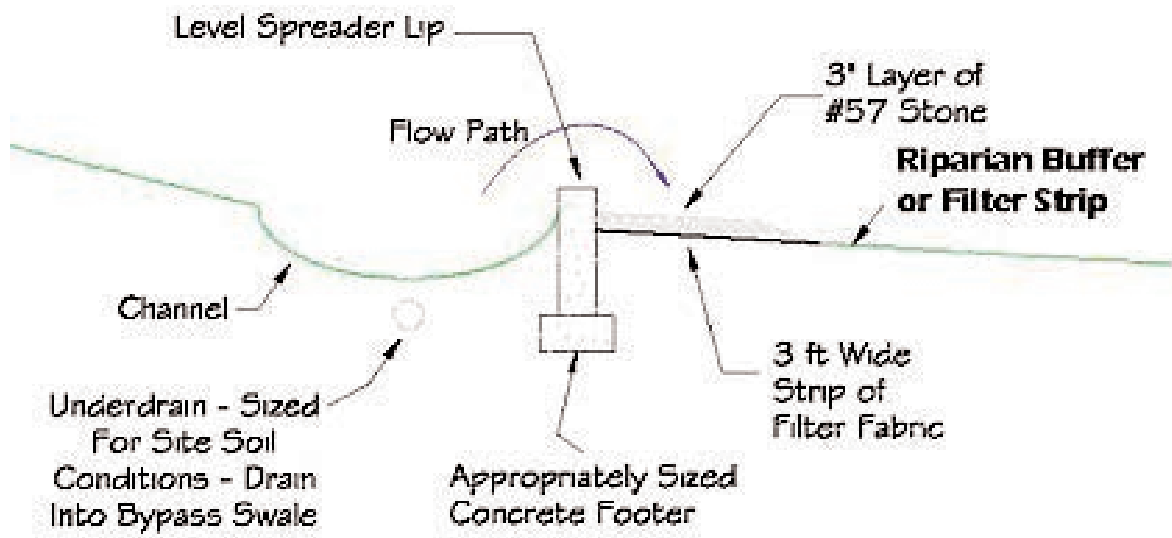

Figure 3b: Cross Section of Engineered Level Spreader (ELS) (Hathaway 2006).

Table 1: Vegetated Filter Strip Materials Specifications.

Material	Specification	Quantity
Gravel Diaphragm	Pea Gravel (#8 or ASTM equivalent) or where steep (6%+); use clean bank-run TDOT #57 or ASTM equivalent (1-inch maximum).	Diaphragm should be 2 feet wide, 1 foot deep, and at least 3 inches below the edge of pavement.
Permeable Berm	40% excavated soil, 40% sand, and 20% pea gravel to serve as the media for the berm.	
Geotextile	Needled, non-woven, polypropylene geotextile meeting the following specifications: Grab Tensile Strength (ASTM D4632): > 120 lbs. Mullen Burst Strength (ASTM D3786): > 225 lbs./sq. in. Flow Rate (ASTM D4491): > 125 gpm/sq. ft. Apparent Opening Size (ASTM D4751): US #70 or #80 sieve	
Engineered Level Spreader	Level Spreader lip should be concrete, metal, timber, or other rigid material; reinforced channel on upstream of lip. *See Hathaway and Hunt (2006).*	
Erosion Control Fabric or Matting	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats that are durable enough to last at least 2 growing seasons.	
Topsoil	If existing topsoil is inadequate to support dense turf growth, imported topsoil (loamy sand or sandy loam texture), with less than 5% clay content, corrected pH at 6 to 7, a soluble salt content not exceeding 500 ppm, and an organic matter content of at least 2% shall be used. Topsoil shall be uniformly distributed and lightly compacted to a minimum depth of 6 to 8 inches.	
Compost	Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program.	

Table 2: Filter Strip Design Criteria.

Design Issue	Conserved Open Space	Vegetated Filter Strip
Soil and Vegetative Cover	Undisturbed soils and native vegetation	Amended soils and dense turf cover or landscaped with herbaceous cover, shrubs, and trees
Overall Slope and Width (perpendicular to the flow)	0.5% to 3% Slope – min. 35 ft. width 3% to 6% Slope – min. 50 ft. width The first 10 ft. of filter must be 2% or less in all cases[2]	1%[1] to 4% Slope – min. 35 ft. width 4% to 6% Slope – min. 50 ft. width The first 10 ft. of filter must be 2% or less in all cases
Sheet Flow	Max. flow length of 150 ft. from adjacent pervious areas; max. flow length of 100 ft. from adjacent impervious areas	
Concentrated Flow	Length of ELS[4] Lip = 13 lin. ft. per each 1 cfs of inflow if area has 90% cover Length = 40 lin. ft. per 1 cfs for[3] forested or re-forested areas (ELS[4] length = 13 lin. ft. min.; 130 lin. ft. max.)	Length of ELS[4] Lip = 13 lin. ft. per each 1 cfs of inflow (13 lin. ft. min.; 130 lin. ft. max.)
Construction Stage	Located outside the limits of disturbance and protected by ESC controls	Prevent soil compaction by heavy equipment
Typical Applications	Adjacent to stream or wetland buffer or forest conservation area	Treat small areas of impervious cover (e.g., 5,000 sf) close to source
Compost Amendments	No	Yes (B, C, and D soils)
Boundary Spreader	GD[4] at top of filter	GD[4] at top of filter PB[4] at toe of filter

1 A minimum of 1% is recommended to ensure positive drainage.

2 For Conservation Areas with a varying slope, a pro-rated length may be computed only if the first 10 ft. is 2% or less.

3 Where the Conserved Open Space is a mixture of native grasses, herbaceous cover and forest (or re-forested area), the length of the ELS6 Lip can be established by computing a weighted average of the lengths required for each vegetation type.

4 ELS = Engineered Level Spreader; GD = Gravel Diaphragm; PB = Permeable Berm.

Runoff sheet flows across vegetation. It is important to provide uniform sheet flow conditions at the interface of the filter strip and the adjacent land cover. Filter strips are well suited as pretreatment for other volume-reducing SCMs (such as infiltration bed). Filter strips are part of a “treatment train” approach for SCMs. They are designed to decrease the velocity of runoff from small storms and improve water quality. For best performance, contributing capture areas should be small and localized. Maximum contributing drainage area slope is generally less than 5 percent, unless energy dissipation is provided. They should have a minimum slope of 1 percent, maximum slope of 8 percent, target slope of 2 to 5 percent. Filter strip length is influenced by the slope, soil type, and vegetation type (see Figures 4 through 9). The minimum recommended length of a filter strip is 25 feet (in the direction of flow); however, shorter lengths provide some water quality benefits as well, especially adjacent to SCMs such as rain gardens (small bioretention areas). Filter strip width should always consider the width of the contributing drainage area. It is important to avoid conditions that create concentrated flow. Concentrated flow should not be discharged directly onto a filter strip. Construction of filter strip shall entail as little disturbance to existing vegetation and soils at the site as possible. See Appendix D for list of acceptable filter strip vegetation. Filter strips should never be mowed to less than 4 inches in height.

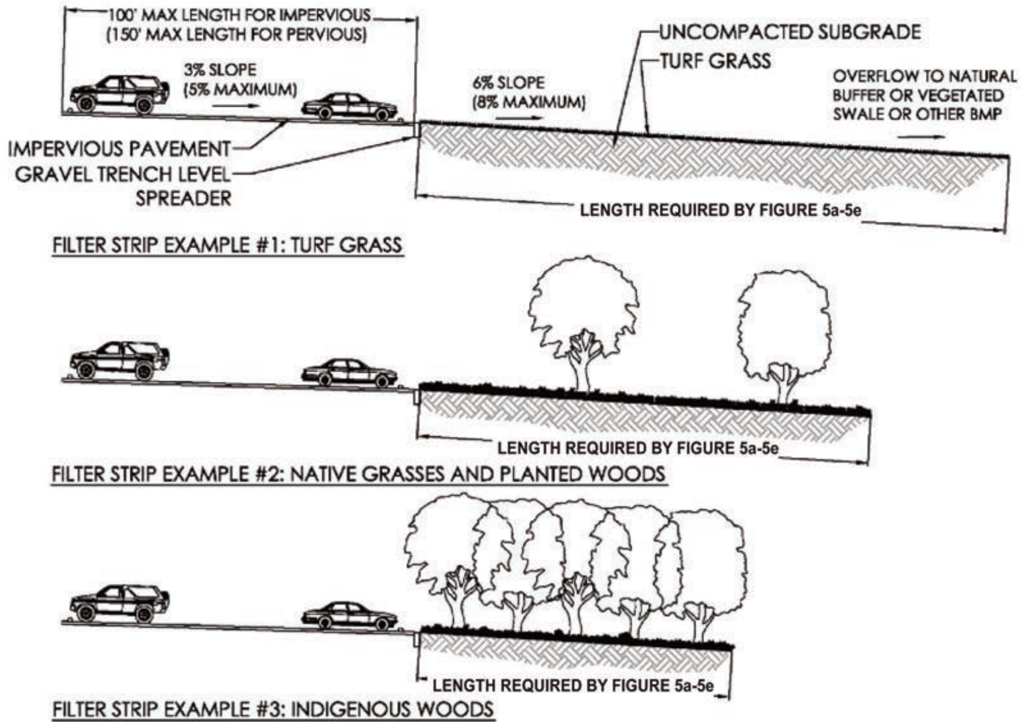

Figure 4: The width of a vegetative filter strip is determined by the slope, soil type, and vegetation type. For example, more densely vegetated strips are shorter in length than grass strips (Source: CHCRPC).

Drainage Area - Hydrologic Soil Group A & Soil Type = Sand

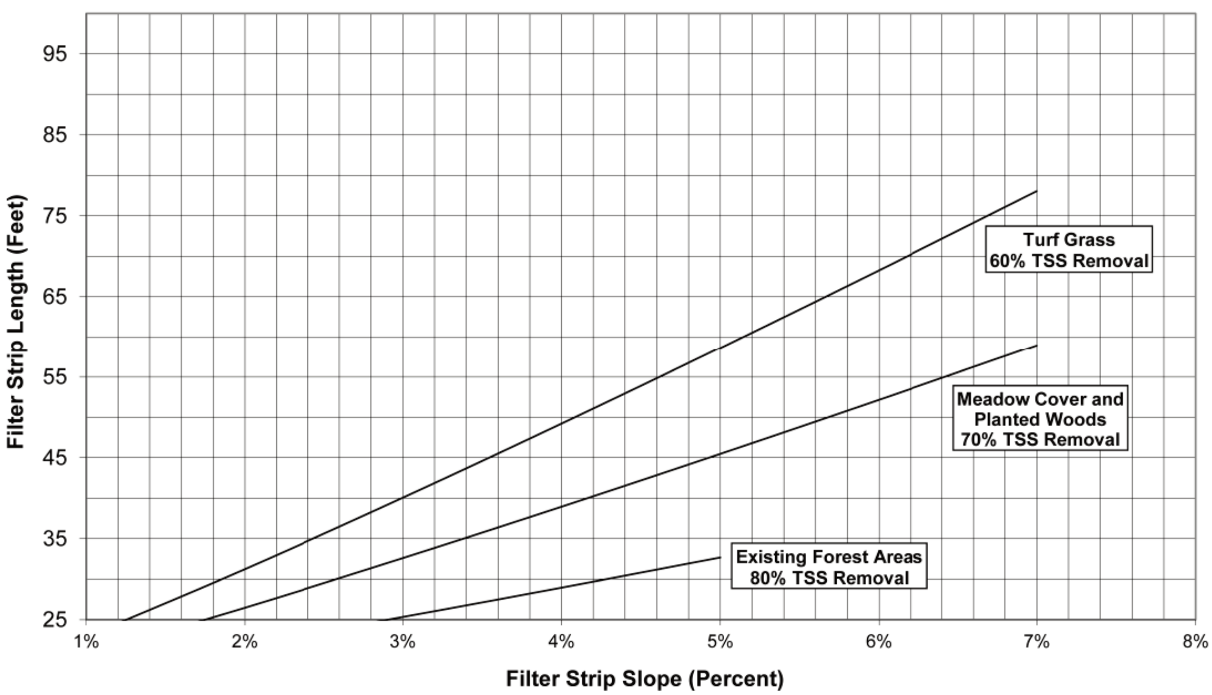

Figure 5: Graph may be used to estimate filter strip width based on soils, slope, and vegetation (Adapted from New Jersey Stormwater Management Practices Manual, Chapter 9, 2004).

Drainage Area - Hydrologic Soil Group A & Soil Type = Sandy Loam

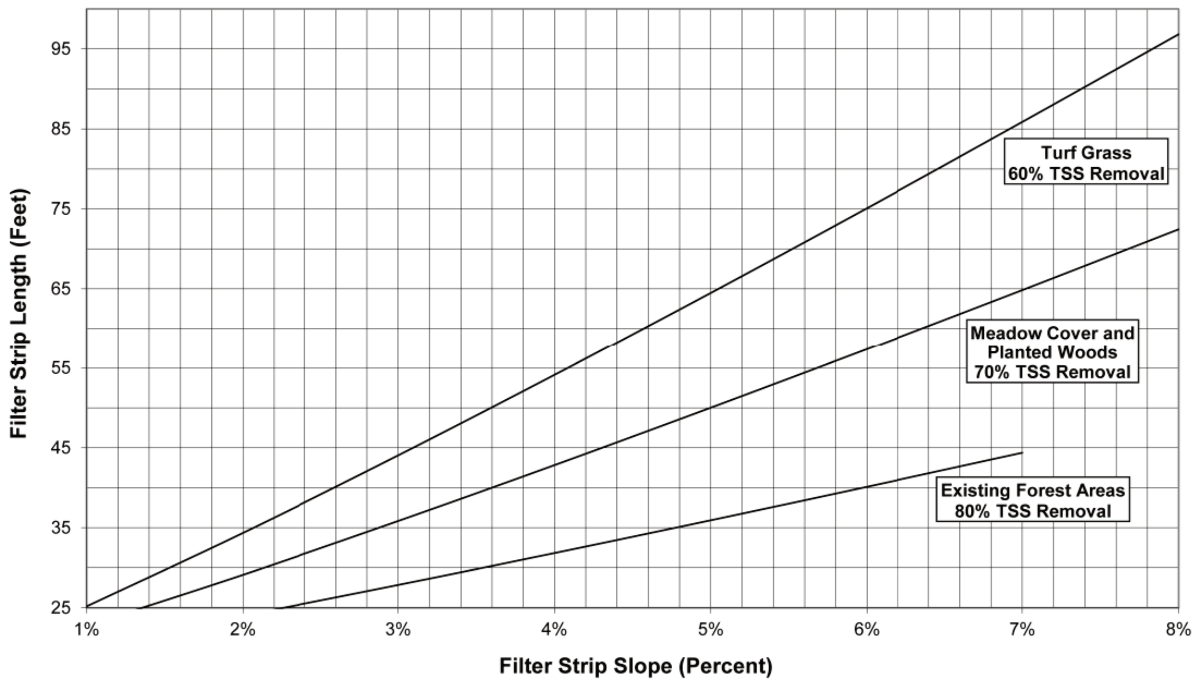

Figure 6: Graph may be used to estimate filter strip width based on soils, slope, and vegetation (Adapted from New Jersey Stormwater Management Practices Manual, Chapter 9, 2004).

Drainage Area - Hydrologic Soil Group B & Soil Type = Loam, Silt Loam

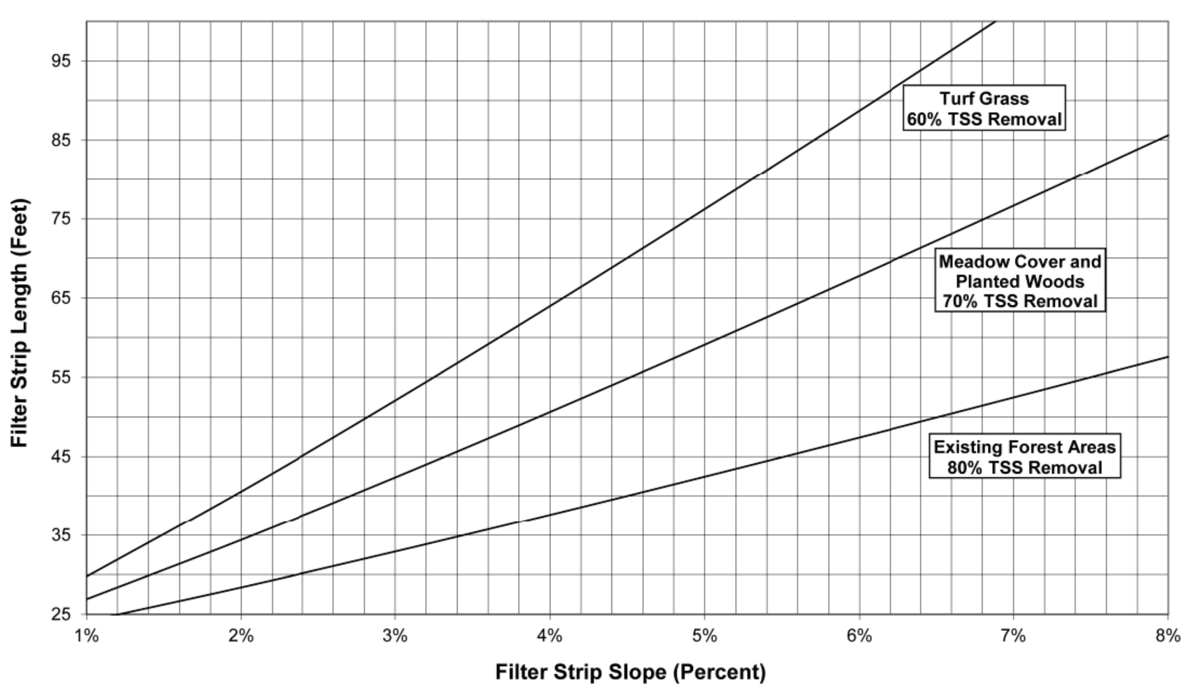

Figure 7: Graph may be used to estimate filter strip width based on soils, slope, and vegetation (Adapted from New Jersey Stormwater Management Practices Manual, Chapter 9, 2004).

Drainage Area - Hydrologic Soil Group C & Soil Type = Sandy Clay Loam

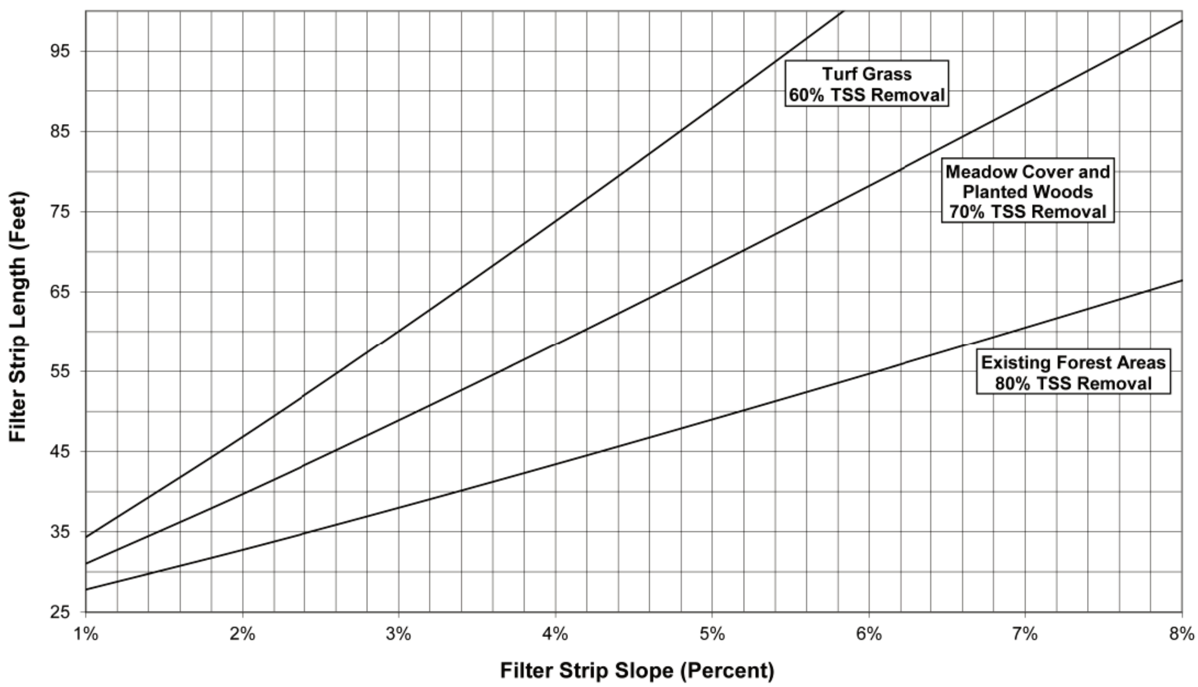

Figure 8: Graph may be used to estimate filter strip width based on soils, slope, and vegetation (Adapted from New Jersey Stormwater Management Practices Manual, Chapter 9, 2004).

Drainage Area - Hydrologic Soil Group D & Soil Type = Clay Loam, Silty Clay, Clay

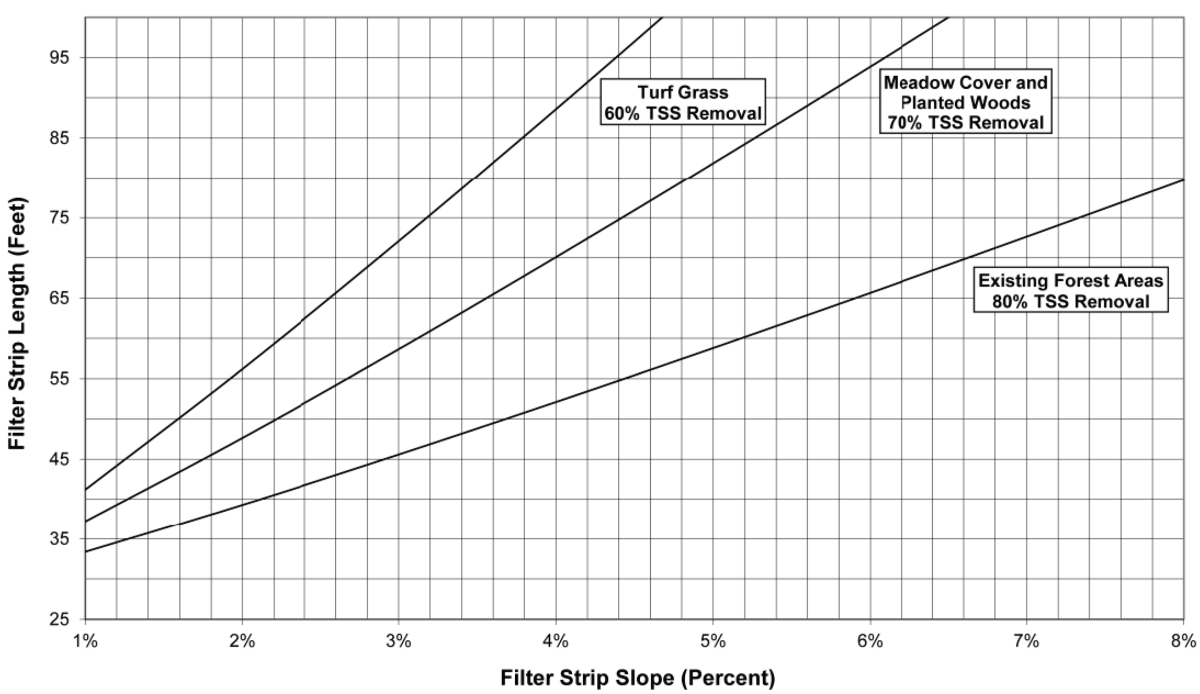

Figure 9: Graph may be used to estimate filter strip width based on soils, slope, and vegetation (Adapted from New Jersey Stormwater Management Practices Manual, Chapter 9, 2004).

Access and protection: If necessary, provide for pedestrian passage or maintenance access. Use structures, barriers, and plantings to limit access and prevent damage to soils and vegetation. Low fences, curbs, and woody vegetation are examples. Identify large filter strips on maintenance plans and with signage. This is especially important since vegetated filter strips can easily be overlooked or forgotten over time. As a result, maintenance personnel may inadvertently mow or remove vegetation.

Compost Soil Amendments: Compost soil amendments will enhance the runoff reduction capability of a vegetated filter strip when located on hydrologic soil groups B, C, and D, subject to the following design requirements:

- The compost amendments should extend over the full length and width of the filter strip.
- The amount of approved compost material and the depth to which it must be incorporated is outlined in Appendix C.
- The amended area will be raked to achieve the most level slope possible without using heavy construction equipment, and it will be stabilized rapidly with perennial grass and/or herbaceous species.
- If slopes exceed 3%, a protective biodegradable fabric or matting should be installed to stabilize the site prior to runoff discharge.
- Compost amendments should not be incorporated until the gravel diaphragm and/or engineered level spreader are installed.

1.4 Typical Details

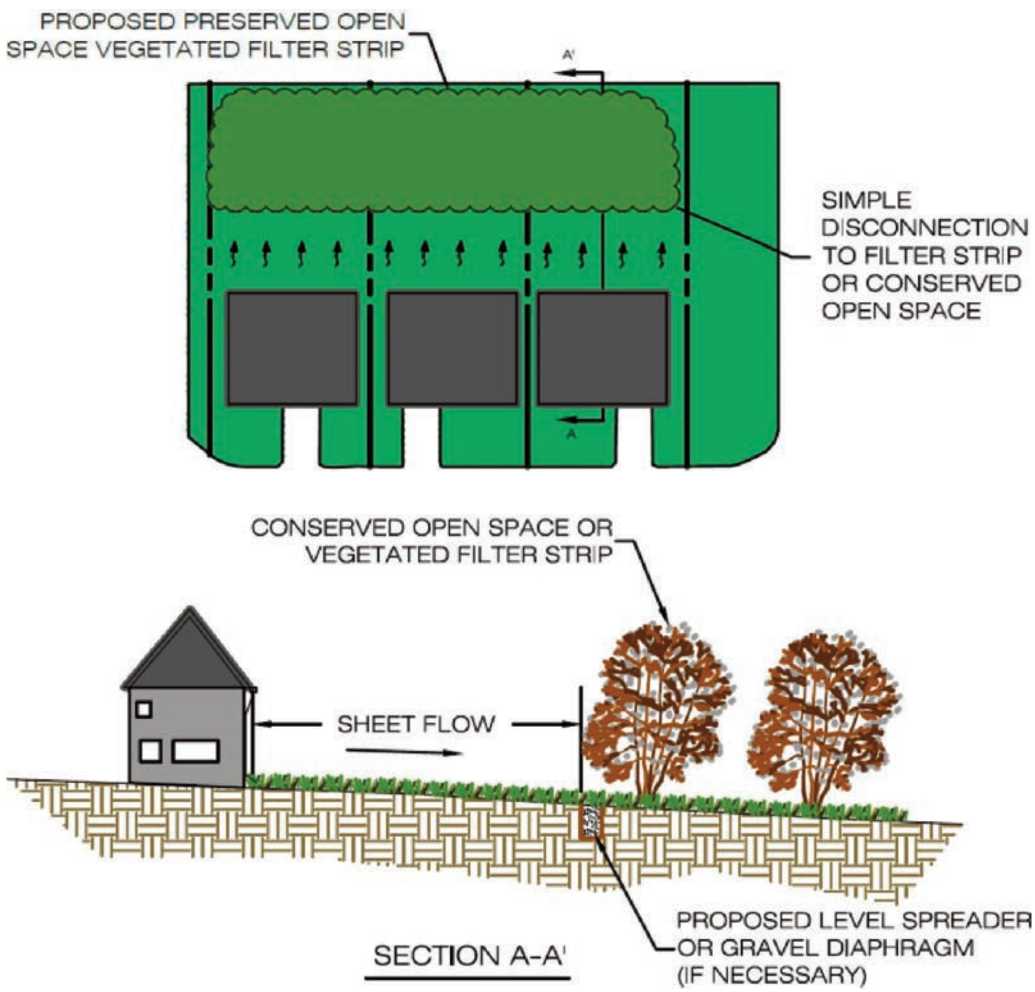

Figure 10: Simple disconnection to downstream preserved open space or vegetated filter strip (Source: Virginia, 2001).

2. Construction

2.1 Pre-Construction

For best success, filter strip areas should be protected during construction and should not be installed until site construction is complete and site stabilization has occurred. Before site work begins, filter strip boundaries should be clearly marked.

2.2 Construction

Filter strips can be within the limits of disturbance during construction. The following procedures should be followed during construction:

Step 1 Excavate Strip

a. Existing subgrade in vegetated filter strips shall not be compacted or subject to excessive construction equipment traffic. Protect areas from vehicle traffic during construction with construction fence, silt fence, or compost sock.

b. Clear and grub site as needed. Disturb as little existing vegetation as possible and avoid compaction.

Step 2 Install Vegetated Filter Strip

a. Rough grade the filter strip area, including the berm at the toe of the slope, if included. Use the lightest, least disruptive equipment possible to avoid excessive compaction and/or land disturbance.

b. Construct level spreader device at the up gradient edge of the strip. For level spreaders and other gravel trenches, do not compact subgrade *(follow construction sequence for infiltration trench).*

c. Fine grade vegetated filter strip area to line, grade, and elevations indicated. Accurate grading is essential for filter strips. Even the smallest nonconformities may compromise flow conditions.

d. If testing indicates that the soil infiltration rate has been compromised (by excessive compaction), rototill the area prior to establishment of vegetation. *Note: tilling will benefit only the top 12 to 18 inches of topsoil.*

e. Seed and vegetate according to plans, and stabilize topsoil. Plant the strip at a time of the year when successful establishment without irrigation is most likely. Temporary irrigation may be needed in periods of little rain or drought. Vegetation should be established as soon as possible to prevent erosion and scour.

f. Concurrently with step "e," stabilize seeded filter strips with appropriate temporary or permanent soil stabilization methods, such as erosion control matting or blankets. Erosion control for seeded filter strips should be required for at least the first 75 days following the first storm event of the season. If runoff velocities are high, consider sodding the filter strip or diverting runoff until vegetation is fully established.

g. Protect vegetated filter strip from sediment at all times during construction. Hay bales, diversion berms, and/or other appropriate measures shall be used at the toe of slopes that are adjacent to vegetated filter strips to prevent sediment from washing into these areas during site development.

h. When the site is fully vegetated and the soil mantle stabilized, the engineer should be notified and should inspect the filter strip drainage area at his/her discretion before the area is brought online and sediment control devices removed.

Other considerations for installation of vegetative filter strips include:

- Only vehicular traffic used for filter strip construction should be allowed within 10 feet of the filter strip boundary.
- If existing topsoil is stripped during grading, it shall 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 shall not commence until the contributing drainage area has been stabilized and perimeter EPSC has 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.

2.3 Construction Inspection

Construction inspection is critical to obtain adequate spot elevations, to ensure the gravel diaphragm or engineered level spreader is completely level, on the same contour and constructed to the correct design elevation. As-built certification should be required to ensure compliance with design standards. Inspectors should evaluate the performance of the filter strip after the first big storm to look for evidence of gullies, outflanking, undercutting or sparse vegetative cover. Spot repairs should be made, as needed.

AS-BUILT REQUIREMENTS: After the filter strip has been constructed, the developer should have an as-built certification of the filter strip conducted by a registered professional engineer. The as-built certification verifies that the SCM was installed as designed and approved. The following components should be addressed in the as-built certification:

1. Ensure level spreader is properly installed to create sheet flow.
2. Ensure vegetated filter strip or open space that receives sheet flow has minimal slope.
3. Ensure paved area drains towards pervious area.
4. Ensure the proper vegetation has been established or protected.
5. If using amended soils ensure proper installation by digging a test pit to verify the depth of mulch, amended soil and scarification.

3. Maintenance

3.1 Maintenance Document

The filter strip should be covered by a drainage easement to allow inspection and maintenance and be included in the site's maintenance document. The requirements for the maintenance document include the execution and recording of an inspection and maintenance agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer *(See Appendix F for examples).* The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities.

3.2 Maintenance Inspections

A properly designed and installed filter strip requires relatively little maintenance, much of which may overlap with standard landscaping requirements. Annual inspections are used to trigger maintenance operations such as sediment removal, spot re-vegetation and level spreader repair. Ideally, inspections should be conducted in the non-growing season when it easier to see the flow path. Inspectors should check to ensure that:

- Flows through the Filter Strip do not short-circuit the overflow control section;
- Debris and sediment does not build up at the top of the filter strip;
- Foot or vehicular traffic does not compromise the gravel diaphragm;
- Scour and erosion do not occur within the filter strip;
- Sediments are cleaned out of level spreader forebays and flow splitters; and
- Vegetative density exceeds a 90% cover in the boundary zone or grass filter.
- While vegetation is being established, pruning and weeding may be required.
- Detritus may need to be removed approximately twice per year. Perennial grasses can also be cut down or mowed at the end of the growing season.

- Inspect for pools of standing water; dewater and discharge to an approved location.
- Regrading may also be required. If a filter strip exhibits signs of poor drainage and/or vegetative cover, periodic soil aeration may be required. In addition, depending on soil characteristics, the strip may require periodic liming.
- Mow and trim vegetation to a minimum height of 4 to 6 inches.
- Mowing and maintenance must occur to ensure safety, aesthetics, and proper filter strip operation, or to suppress weeds and invasive species; dispose of cuttings in a local composting facility; mow only when filter strip is dry to avoid rutting. Fall mowing should be kept to a grass height of 6 inches to provide adequate winter habitat for wildlife.

3.3 Ongoing Maintenance

Once established, filter strips have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the strip and a dense, healthy grass cover. Filter strips that consist of grass/turf cover should be mowed at least twice a year to prevent woody growth.

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5.4.6 Bioretention

Description: Bioretention areas are vegetated, shallow surface depressions that use the interaction of plants, soil, and microorganisms to store, treat, and reduce runoff volume, and to reduce the flow rate of stormwater runoff. Bioretention areas are generally flat and include engineered or modified soils that allow drainage of stormwater through soils. During storms, runoff temporarily ponds 6 to 12 inches above the mulch layer and then rapidly filters through the bed.

Figure 1: Bioretention capture water from parking lot in Powell, TN (Source: The SMART Center).

Key Design Criteria:

- Min. filter media depth: 18-24 inches. Recommended maximum: 36 inches
- Ponding depth: 6-12 inches
- Length of shortest flow path/length: 0.3

Site Constraints:

- **Depth**: 2 feet to water table / bedrock
- Steep slopes: <20% or terraced to slow flow.
- **Media permeability**: ≤ 0.5in/h or needs underdrain
- **Hotspots**: Needs to use impermeable bottom liner and an underdrain system.
- **Min. distance requirement from**:
  Water supply wells: 100 feet
  Surface water: 30 feet

Maintenance:

- Monitor sediment accumulation and remove as necessary
- Inspect channel and repair any eroding surfaces or vegetation
- Ensure vegetation is well established
- Remove debris from any inlet and outlet structures.

Advantages:

- Reduces runoff volume, peak discharge rate, TSS, pollutant, and runoff temperature.
- Creates habitat and improves aesthetic.
- Flexible dimensions to fit conditions
- Excellent retrofit capability.

Disadvantages:

- Built on areas that are generally level (or graded level).
- Steep slopes may require larger footprint to create level grading.
- Vegetation and soils must be protected from damage and compaction.
- Maintenance is required to maintain both performance and aesthetics.

Design Checklist:

- Determine whether an Infiltration or filtration Design is best for the site based on permeability or other site limitations.
- Check bioretention sizing guidance.
- Design bioretention in accordance with design criteria and typical details.
- Submit plans for review.

1. Design

1.1 Suggested Applications and Scale

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed. Consider locating bioretention areas in places that are generally "not used" such as traffic islands; between parked cars in parking lots; along edges of public playgrounds, school yards, and plazas; in courtyards; and in place of traditional landscape planting areas. The following site-specific conditions should be considered:

- Select location to prevent vegetation damage and soil compaction from pedestrian traffic or unintended vehicle compaction. Ideal locations are often located to the side or downhill of high vehicle or pedestrian traffic areas. If necessary, provide for pedestrian passage and maintenance access.
- Locate bioretention areas:
  - Close to the source of runoff.
  - To capture runoff from impervious areas and highly compacted pervious areas such as athletic fields and lawns.
  - To capture smaller drainage areas. If necessary, use several connected bioretention areas to address larger areas.

The most important design factor to consider when applying bioretention to development sites is the scale at which it will be applied, as follows:

- ***Micro-Bioretention or Rain Gardens.*** These are small, distributed practices designed to treat runoff from small areas, such as individual rooftops, driveways and other on-lot features in single-family detached residential developments. Inflow is typically sheet flow, or can be concentrated flow with energy dissipation, when located at downspouts.
- ***Bioretention Basins.*** These are structures treating parking lots and/or commercial rooftops, usually in commercial or institutional areas. Inflow can be either sheetflow or concentrated flow. Bioretention basins may also be distributed throughout a residential subdivision, but ideally they should be located in common areas or within drainage easements, to treat a combination of roadway and lot runoff.
- ***Urban Bioretention.*** These are structures such as expanded tree pits, curb extensions, and foundation planters located in ultra-urban developed areas such as city streetscapes.

Figures 2 & 3: roof leaders are directly connected to the bed. Bioretention that manages runoff from a parking lot (Source: The SMART Center).

1.2 Major Design Elements

Table 1: Bioretention major design elements.

Contributing Drainage Area (CDA)	Bioretention cells work best with smaller CDAs, where it is easier to achieve flow distribution over the filter bed. Typical drainage area size for traditional Bioretention areas can range from 0.1 to 2.5 acres and consist of up to 100% impervious cover. Drainage areas to smaller bioretention practices (Urban Bioretention, Residential Rain Gardens) typically range from 0.5 acre to 1.0.
Slopes	Bioretention can be used for sites with a variety of topographic conditions, but is best applied when the grade of the area immediately adjacent to the bioretention practice (within approximately 15 to 20 feet) is greater than 1% and less than 5%. For sites with steep grades, Bioretention should be split into multiple cells with adequate conveyance between the cells to take advantage of relatively flat and/or areas in cut sections (rather than fill).
Soils	Soil conditions do not typically constrain the use of bioretention, although they do determine whether an underdrain is needed. Underdrains are needed if the measured permeability of the underlying soils is less than 0.5 inches per hour. When designing Bioretention practices without underdrains and with drainage areas greater than 0.5 acre, designers should verify soil permeability by using the on-site soil investigation methods provided in Appendix A of the manual (Infiltration and Soil Texture Testing Methods).
Depth to Water Table	Bioretention should always be separated from the water table to ensure that groundwater does not intersect the filter bed. Mixing can lead to possible groundwater contamination or failure of the bioretention facility. A separation distance of 2 feet is required between the bottom of the excavated Bioretention area and the seasonally high ground water table.
Available Hydraulic Head	Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the Bioretention area into the storm drain system). In general, 4 to 5 feet of elevation above this invert is needed to accommodate the required ponding and filter media depths. For infiltration designs, the available head is less important.
Floodplains	Bioretention areas should be constructed outside the limits of the 100-year floodplain unless it is approved by local program, but must meet minimum distances identified in site constraints.
Utilities and Setbacks	Interference with underground utilities should be avoided whenever possible, particularly water and sewer lines. Approval from the applicable utility company or agency is required if utility lines will run below or through the Bioretention area. Conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service. Additionally, designers should ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead utility lines.

Setbacks	To avoid the risk of seepage, do not allow bioretention areas to be hydraulically connected to structure foundations or pavement. Setbacks to structures and roads vary, based on the scale of the bioretention design. At a minimum, bioretention basins should be located a horizontal distance of 100 feet from any water supply well (50 feet if the bioretention is lined), 50 feet from septic systems (25 feet if the bioretention is lined), and at least 5 feet from down-gradient wet utility lines. Dry utility lines such as gas, electric, cable and telephone may cross under bioretention areas if they are double-cased.
No Irrigation or Baseflow	The planned bioretention area should not receive baseflow, irrigation water, chlorinated wash-water or other such non-stormwater flows that are not stormwater runoff.
Hotspot Land Uses	Runoff from hotspot land uses should not be treated with infiltrating bioretention (i.e., constructed without an underdrain) unless pretreatment has been provided. An impermeable bottom liner and an underdrain system must be employed when bioretention is used to receive and treat hotspot runoff.

1.3 Design Criteria

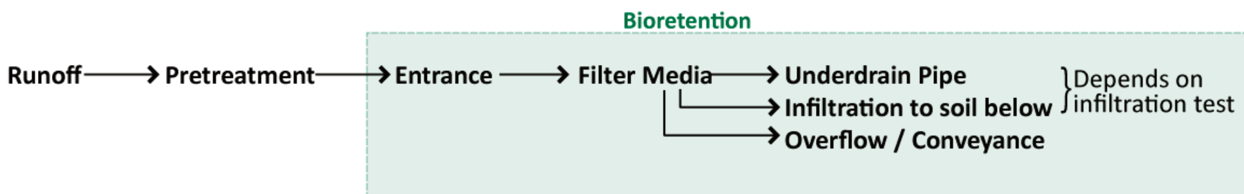

Figure 4: Flow diagram.

1.3.1 Pre-treatment

Pre-treatment of runoff entering bioretention areas is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Pre-treatment measures must be designed to evenly spread runoff across the entire width of the bioretention area. Several pre-treatment measures are feasible, depending on the scale of the bioretention practice and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. The following are appropriate pretreatment options:

- **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 consists of an energy dissipater sized for the expected rates of discharge. It has a storage volume equivalent to at least 15% of the total Treatment Volume (inclusive) with a 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen or rock 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 extend from the edge of pavement to the bottom of the bioretention basin at a 5:1 slope or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) slope and 3:1 or flatter side slopes on the bioretention basin (see Figure 6).
- **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 2 to 4 inch drop. The stone must be sized according to the expected rate of discharge. (See Figure 6)
- **Gravel or Stone Flow Spreaders** (concentrated flow). The gravel flow spreader is 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 a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the basin (see Figure 7).

- **Innovative or Proprietary Structure**: An approved proprietary structure with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pre-treatment.

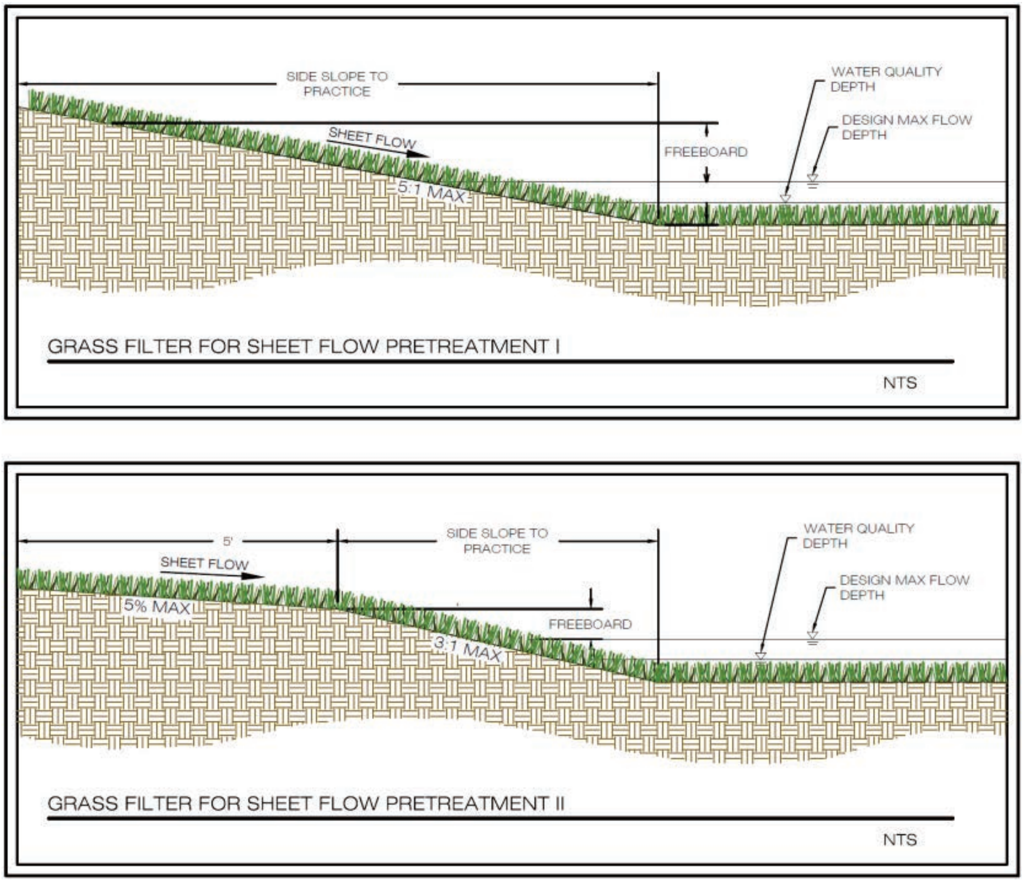

Figure 5: Pretreatment option – grass filter for sheet flow (Source: VADCR).

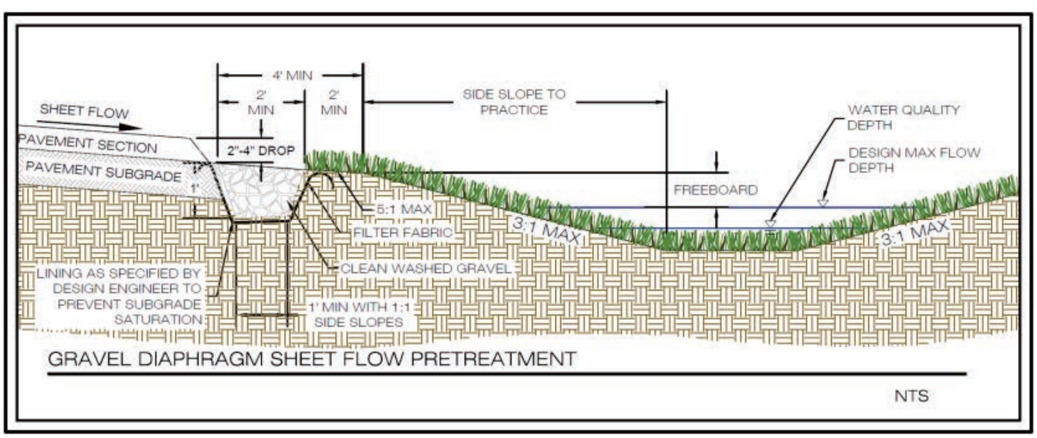

Figure 6: Pretreatment option – gravel diaphragm for sheet flow (Source: VADCR).

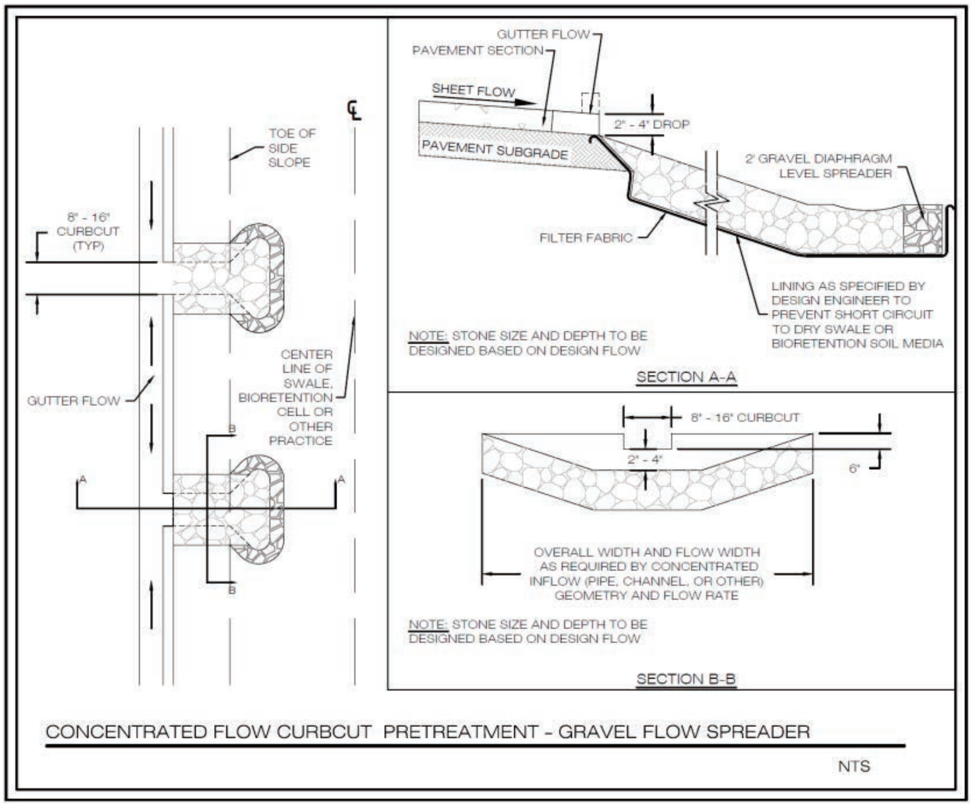

Figure 7: Pretreatment option – gravel flow spreader for concentrated flow (Source: VADCR).

1.3.2 Entrance/Flow conditions

Captured runoff may enter a bioretention area in one of three ways:

a) **Through dispersed surface flow** such as along a depressed curb, lawn area, or edge of pavement as shown in Figures 8 and 9. Careful grading is essential to prevent concentrated flow points and potential erosion. For bioretention adjacent to existing impervious pavement, such as in a retrofit installation or modification to an existing site, it is recommended that the adjacent pavement be milled and repaved/replaced to provide a uniform edge and dispersed sheet flow into the bioretention area.

Figure 8: bioretention to capture sheet flow from neighborhood in Knoxville TN (Source: The SMART Center).

Figure 9: bioretention to capture runoff from a parking lot in Powell TN (Source: The SMART Center).

b) Through a concentrated discharge location such as a trench drain, outlet pipe, or curb cut. Bioretention soils and mulch are highly erosive. Entrance velocities should not exceed 1 fps unless designed with entrance measures to prevent erosion, such as:
   - Cobble splash blocks
   - Small level spreaders
   - Turf reinforcement materials

Supporting entrance velocity calculations are required for all concentrated surface discharges into bioretention areas.

c) Via a direct connection (such as a pipe) into the underlying stone storage bed. This is a good option for "clean" runoff discharging at high velocities. For example, a roof leader may be connected directly to a stone storage bed (see Figure 10).

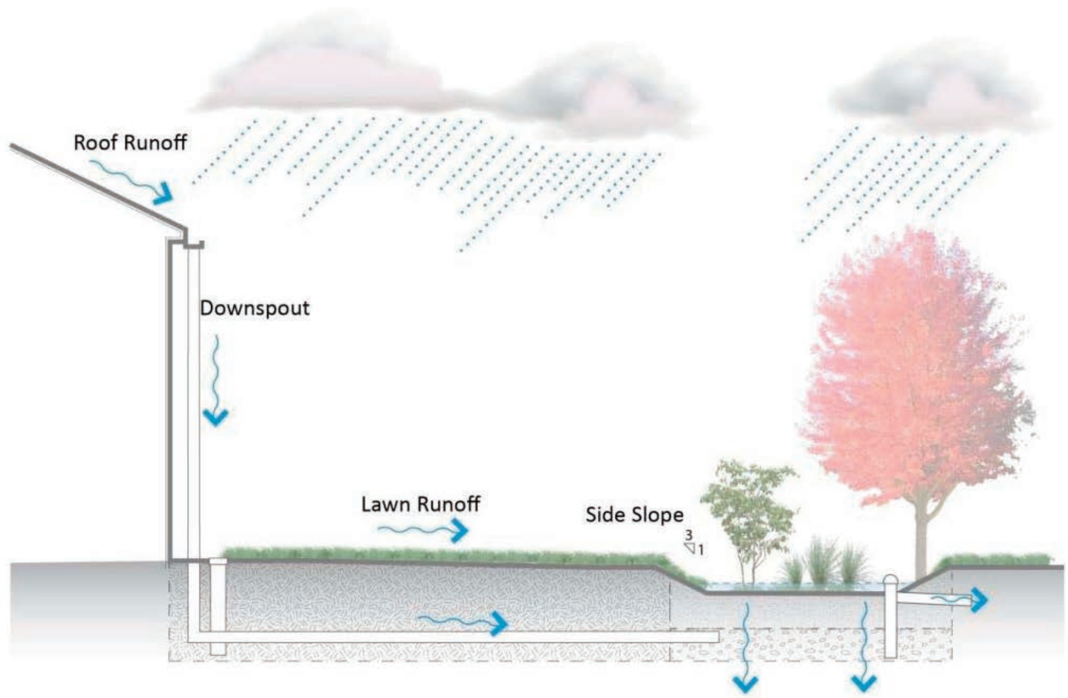

Figure 10: Roof leaders can convey high-velocity flows from the roof directly into the stone bed to prevent erosive conditions (Source: CHCRPC).

1.3.3 Filter Media and Surface Cover

The filter media and surface cover are the two most important elements of a bioretention facility in terms of long-term performance. The following are key factors to consider in determining an acceptable soil media mixture.

- General Filter Media Composition. The recommended bioretention soil mixture is generally classified as a loamy sand on the USDA Texture Triangle, with the following composition:
  - 85% to 88% sand;
  - 8% to 12% soil fines; and
  - 3% to 5% organic matter.

It may be advisable to start with an open-graded coarse sand material and proportionately mix in topsoil that will likely contain anywhere from 30% to 50% soil fines (sandy loam, loamy sand) to achieve the desired ratio of sand and fines. An additional 3% to 5% organic matter can then be added. (The exact composition of organic matter and topsoil material will vary, making particle size distribution and recipe for the total soil media mixture difficult to define in advance of evaluating the available material.)

- **P-Index.** The P-Index provides a measure of soil phosphorus content and the risk of that phosphorus moving through the soil media. The risk of phosphorus movement through a soil is influenced by several soil physical properties: texture, structure, total pore space, pore-size, pore distribution, and organic matter. A soil with a lot of fines will hold phosphorus while also limiting the movement of water. A soil that is sandy will have a high permeability, and will therefore be less likely to hold phosphorus within the soil matrix. A primary factor in interpreting the desired P-Index of a soil is the bulk density. Saxton et. al. (1986) estimated generalized bulk densities and soil-water characteristics from soil texture. The expected bulk density of the loamy sand soil composition described above should be in the range of 1.6 to 1.7 g/cu. cm. Therefore, the recommended range for bioretention soil P-index of between 10 and 30 corresponds to a phosphorus content range (mg of P to kg of soil) within the soil media of 7 mg/kg to 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, since it also holds cations like the clays.
- **Infiltration Rate.** The bioretention soil media should have a minimum infiltration rate of 0.5 inches per hour (a proper soil mix will have an initial infiltration rate that is significantly higher).
- **Depth.** The standard minimum filter should be 24 inches for grass cells and 36 inches for shrub cells, and 18 to 24 inches for rain gardens or micro-bioretention. If trees are included in the bioretention planting plan, tree planting holes in the filter bed must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees. Use turf, perennials or shrubs instead of trees to landscape shallower filter beds.
- **Filter Media for Tree Planting Areas.** A more organic filter media is recommended within the planting holes for trees, with ratio of 50% sand, 30% top soil and 20% acceptable leaf compost.
- **Mulch.** A 2 to 3 inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter media. Shredded, aged hardwood bark mulch makes a very good surface cover, as it retains a significant amount of nitrogen and typically will not float away. The use of woodchips, which may "float" should be prohibited.
- **Alternative to Mulch Cover.** In some situations, designers may consider alternative surface covers such as turf, native groundcover, erosion control matting (coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, cost and maintenance. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water holding capacity.
- **Media for Turf Cover.** One adaptation is to design the filter media primarily as a sand filter with organic content only at the top. Leaf compost tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of compost may be reduced.

1.3.4 Soil Infiltration Rate Testing

In order to determine if an underdrain will be needed, one must measure the infiltration rate of subsoils at the invert elevation of the bioretention area. The infiltration rate of subsoils must exceed 0.5 inch per hour in order to dispense with the underdrain requirement. Soil testing is not needed where an underdrain is used.

1.3.5 Underdrain and Underground Storage Layer

The depth of the storage layer will depend on the target treatment and storage volumes needed to meet water quality. However, the bottom of the storage layer must be at least 2 feet above the seasonally high water table. The storage layer should consist of clean, washed #57 stone or an approved infiltration module.

All bioretention basins should include observation wells. The observation wells should be tied into any T's or Y's in the underdrain system, and should extend upwards to be flush with the surface, with a vented cap. In addition, cleanout pipes should be provided if the contributing drainage area exceeds 1 acre.

1.3.5.1 Internal Water Storage Zones (IWS)

An Internal Water Storage Zone (IWS) can be created by the addition of an elbow in the underdrain piping at a 90º angle vertically perpendicular to the horizontal underdrain, either in retrofit conditions or in new installations. This up-turned elbow on underdrains can force water to remain longer in the bottom of the cell, creating a saturated internal water storage zone (IWS). If this zone remains saturated long enough, anaerobic conditions are created, promoting denitrification and increased N removal (Passeport et al., 2009).

There are several benefits to using upturned elbows and IWS. The IWS works for both pollutant and peak flow reduction as anaerobic conditions can be created to increase nitrogen removal. It also allows more water to infiltrate into the surrounding soils. If an upturned elbow is installed correctly in sufficiently permeable soils, it may only rarely generate outflows. The use of upturned elbows and an IWS is especially beneficial in the areas where surrounding sandy soils can be ideal for infiltration, reducing outflows and surface water runoff. There can be a thermal benefit to IWS use as water is pulled from the coolest zone at the bottom of the cell. This is especially beneficial for temperature reductions in trout waters. Finally, there is often a cost benefit for using upturned elbows, both for new installations and retrofits. In new installations, there is a cost-savings associated with installation since the invert of the outlet is not as deep. Often with IWS there can be less trenching and fewer materials associated with using it. In retrofits, upturned elbows can be cheaply added to existing Bioretention cells where increased N & P removal rates are needed. Additionally, cells with IWS can be added as retrofits even in areas with restricted outlet depth.

In order for an internal water storage zone to work correctly, the underlying soils must have some permeability. In general, if the underlying soils are Group A or B soils with a low clay content, then the IWS will be effective. If soils are too compacted, water will not infiltrate and may stagnate in the lower portion, causing problems for the BMP. Media depth above the bottom gravel and underdrain layer must be at least 3 feet. The top of IWS should be separated from the outlet and bowl surface by at least 12, but ideally 18 inches (see Figure 11).

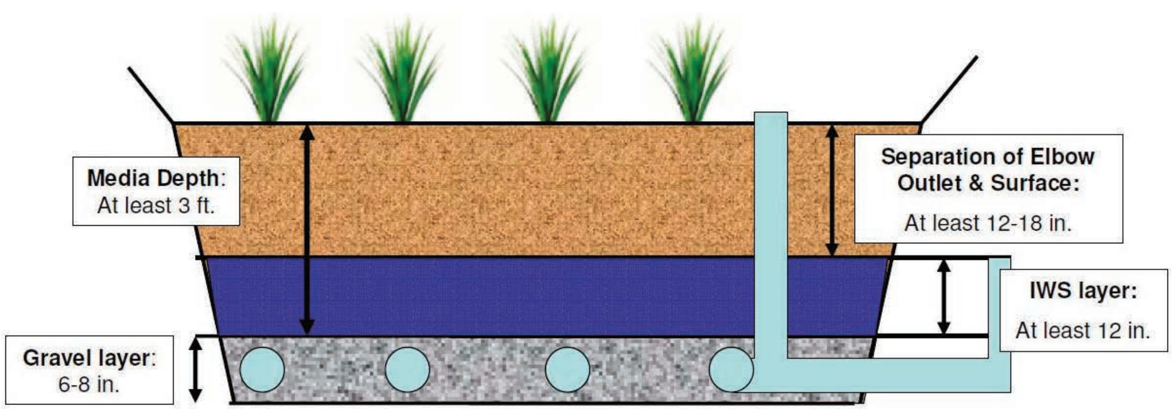

Figure 11: Bioretention cell showing IWS zones (Source: NCDENR).

1.3.6 Overflow/Conveyance

For On-line bioretention:

An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the bioretention area. The following criteria apply to overflow structures:

- The overflow associated with the 2 and 10 year design storms should be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).
- Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum water surface elevation of the bioretention area, which is typically 6 to 12 inches above the surface of the filter bed (6 inches is the preferred ponding depth).
- The overflow capture device (typically a yard inlet) should be scaled to the application – this may be a landscape grate inlet or a commercial-type structure.
- The filter bed surface should generally be flat so the bioretention area fills up like a bathtub.

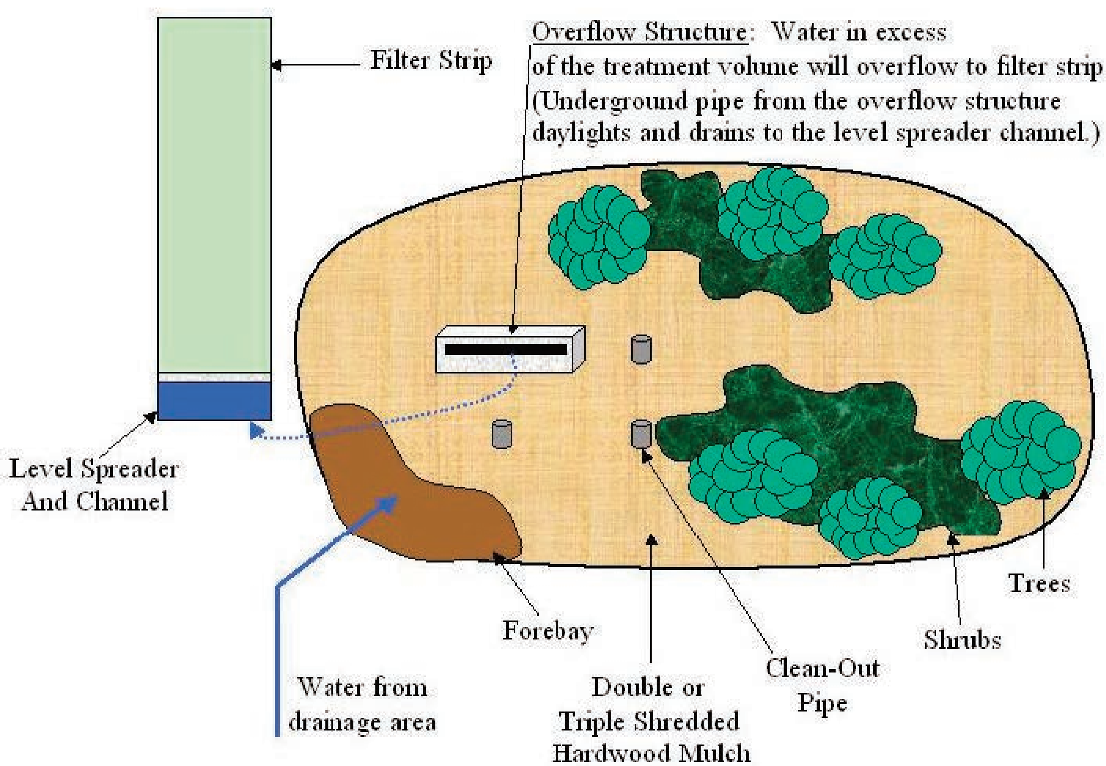

Figure 12: Bioretention units can be designed using an overflow device so that water in excess of the treatment volume overflows to a filter strip. This example shows a filter strip, though it is not required for every design (Source: NCDENR).

Off-line bioretention:

Off-line designs are preferred (see Figure 13). One common approach is to create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filtrates through the soil media.

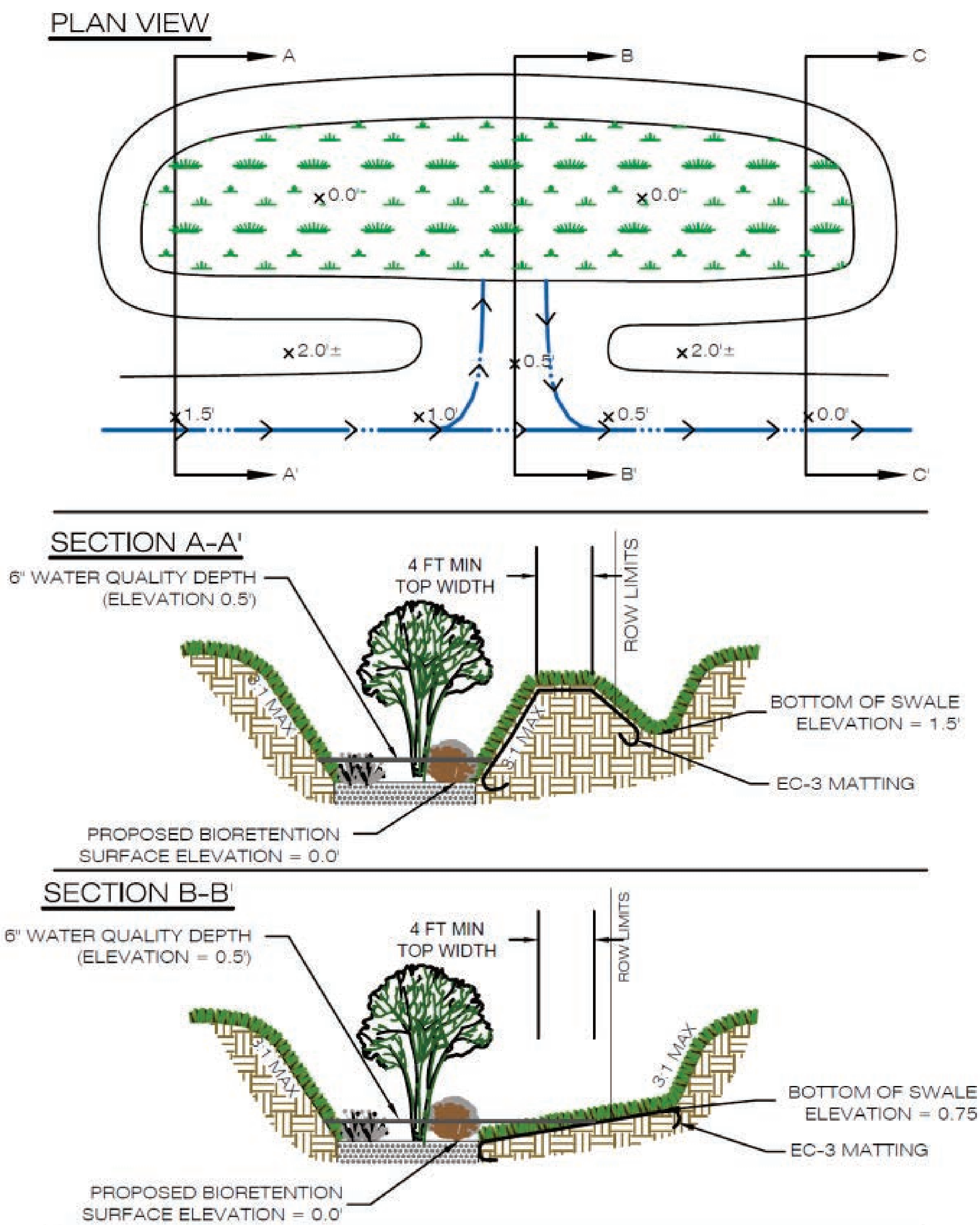

Figure 13: Typical Details for Off-Line Bioretention (Source: VADCR).

1.3.7 Freeboard

It is recommended that bioretention areas include a minimum of 6 inches of freeboard above the overflow route.

1.3.8 Bioretention Planting Plans

A landscaping plan must be provided for each bioretention area. Minimum plan elements shall include the proposed bioretention 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 qualified landscape architect, in order to tailor the planting plan to the site-specific conditions. Tennessee 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 D. The six most common bioretention templates are as follows:

- **Turf.** This option is typically restricted to on-lot micro-bioretention applications, such as a front yard rain garden. Grass species should be selected that have dense cover, are relatively slow growing, and require the least mowing and chemical inputs (e.g., fine fescue, tall fescue).
- **Perennial garden.** This option uses herbaceous plants and native grasses to create a garden effect with seasonal cover. It may be employed in both micro-scale and small scale bioretention applications. This option is attractive, but it requires more maintenance in the form of weeding.
- **Perennial garden with shrubs.** This option provides greater vertical form by mixing native shrubs and perennials together in the bioretention area. This option is frequently used when the filter bed is too shallow to support tree roots. Shrubs should have a minimum height of 30 inches.
- **Tree, shrub and herbaceous plants.** This is the traditional landscaping option for bioretention. It produces the most natural effect, and it is highly recommended for bioretention basin applications. The landscape goal is to simulate the structure and function of a native forest plant community.
- **Turf and tree.** This option is a lower maintenance version of the tree-shrub-herbaceous option where the mulch layer is replaced by turf cover. Trees are planted within larger mulched islands to prevent damage during mowing operations.
- **Herbaceous meadow.** This is another lower maintenance approach that focuses on the herbaceous layer and may resemble a wildflower with Joe Pye Weed, Ironweed, sedges, grasses, etc.). The goal is to establish a more natural look that may be appropriate if the facility is located in a lower maintenance area (e.g., further from buildings and parking lots). Shrubs and trees may be incorporated around the perimeter. Erosion control matting can be used in lieu of the conventional mulch layer.

1.3.9 Material Specifications

Table 2: Bioretention material specifications.

Material	Specification	Notes
Filter Media Composition	Filter media to contain: • 85%-88% sand • 8%-12% soil fines • 3%-5% organic matter in the form of leaf compost	The volume of filter media based on 110% of the plan volume, to account for settling or compaction.
Filter Media Testing	P-Index range = 10-30, OR between 7 and 21 mg/kg of P in the soil media. CECs greater than 10	The media must be procured from approved filter media vendors.
Mulch Layer	Use aged, shredded hardwood bark mulch	Lay a 2 to 3 inch layer on the surface of the filter bed.
Alternative Surface Cover	Use river stone or pea gravel, coir and jute matting, or turf cover.	Lay a 2 to 3 inch layer of cover to suppress weed growth.
Top Soil for Turf Cover	Loamy sand or sandy loam texture, with less than 5% clay content, pH corrected to between 6 and 7, and an organic matter content of at least 2%	3 inch surface depth.
Geotextile/Liner	Use a non-woven geotextile fabric with a flow rate of > 110 gal./min./sq. ft.	Apply only to the sides and above the underdrain. For hotspots and certain karst sites only, use an appropriate liner on bottom.
Choking Layer	Lay a 2 to 4 inch layer of sand over a 2 inch layer of choker stone (typically #8 or #89 washed gravel), which is laid over the underdrain stone	
Stone Jacket for Underdrain and/or Storage Layer	1 inch stone should be double-washed and clean and free of all fines (e.g., TDOT #57 stone).	12 inches for the underdrain; 12 to 18 inches for the stone storage layer, if needed
Underdrains, Cleanouts, and Observation Wells	Use 6 inch rigid schedule 40 PVC pipe (or equivalent corrugated HDPE for micro-bioretention), with 3/8-inch perforations at 6 inches on center; position each underdrain on a 1% or 2% slope located no more than 20 feet from the next pipe.	Lay the perforated pipe under the length of the bioretention cell, and install non-perforated pipe as needed to connect with the storm drain system. Install T's and Y's as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys. Use elbow outlet pipe to provide Internal Water Storage (IWS).
Plant Materials	• Plant one tree per 250 square feet (15 feet on-center, minimum 1 inch caliper). • Shrubs a minimum of 30 inches high planted a minimum of 10 feet on-center. • Plant ground cover plugs at 12 to 18 inches on-center; Plant container-grown plants at 18 to 24 inches on-center, depending on the initial plant size and how large it will grow.	Establish plant materials as specified in the landscaping plan and the recommended plant list. In general, plant spacing must be sufficient to ensure the plant material achieves 80% cover in the proposed planting areas within a 3-year period. If seed mixes are used, they should be from a qualified supplier, should be appropriate for stormwater basin applications, and should consist of native species (unless the seeding is to establish maintained turf).

1.3.10 Overview

Table 3: Bioretention design criteria.

	Micro-bioretention (rain garden). Max CDA: 0.5 acres, 25% impervious cover.	Bioretention filter & basin area. Max CDA: 2.5 acres.
Sizing	Filter surface area (sq. ft.) = 3% of the contributing drainage area (CDA).	Surface Area (sq. ft.) = Total runoff volume – the volume reduced by an upstream SCM(s)/Storage Depth[1]
Maximum Ponding Depth	6 inches	6 - 12 inches[2]
Filter Media Depth	Min: 18 inches; max: 24 inches	Min: 24 inches for grass; 36 inches for shrubs; max: 6 feet
Media / surface cover	Mixed on-site or supplied by vendor. Media mix tested for an acceptable phosphorus index (P-Index) of between 10 and 30, OR Between 7 and 21 mg/kg of P in the soil media	
Sub-soil testing	Not needed if an underdrain is used; Min infiltration rate > 0.5 inch/hour in order to remove the underdrain requirement.	Not needed if an underdrain used; Min infiltration rate ≥ 2 inch/hour in order to remove the underdrain requirement.
Underdrain	Corrugated HDPE or equivalent	Schedule 40 PVC with clean-outs
Clean-outs	Not needed	Needed
Inflow	Sheet flow or roof leader	Sheet flow, curb cuts, trench drains, or concentrated flow.
Geometry		Length of shortest flow path/Overall length = 0.3
Pretreatment	External (leaf screens, grass filter strip, energy dissipater, etc.)	A pretreatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.
Building setbacks[3]	10 feet down-gradient; 25 feet up-gradient from building	0 to 0.5 acre CDA = 10 feet if down-gradient from building; 50 feet if up-gradient. 0.5 to 2.5 acre CDA = 25 feet if down-gradient from building; 100 feet if up-gradient.
Planting Plan		A planting template to include turf, herbaceous vegetation, shrubs, and/or trees to achieve surface area coverage of at least 80% within 3 years.

1. *Storage depth is the sum of the Void Ratio (Vr) of the soil media and gravel layers multiplied by their respective depths, plus the surface ponding depth. .*
2. *A ponding depth of 6 inches is preferred. Ponding depths greater than 6 inches will require a specific planting plan to ensure appropriate plant selection.*
3. *These are recommendations for simple building foundations. If an in-ground basement or other special conditions exist, the design should be reviewed by a licensed engineer. Also, a special footing or drainage design may be used to justify a reduction of the setbacks noted above.*

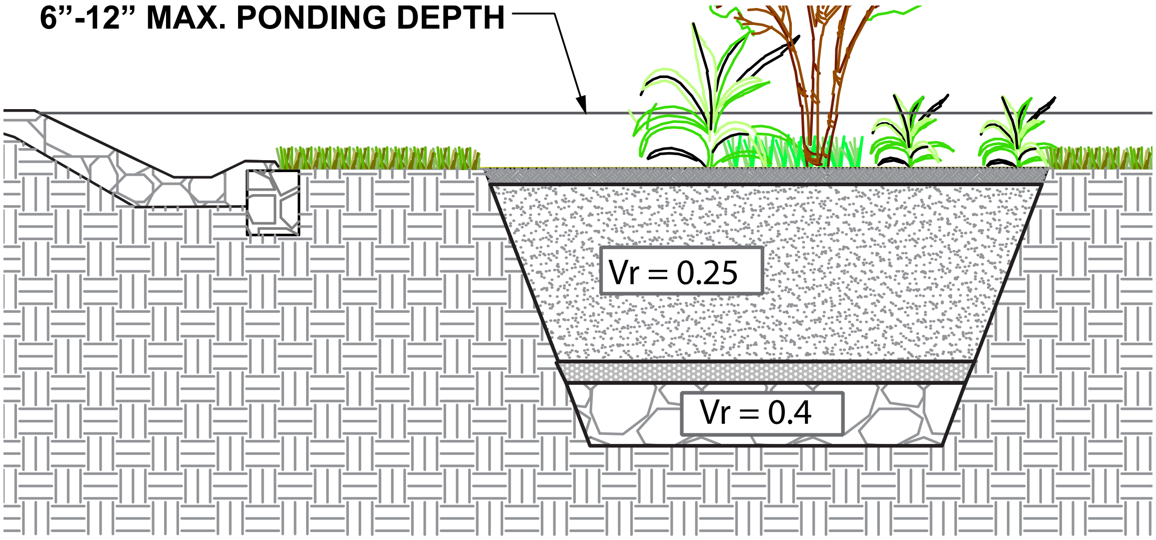

Figure 14: Typical bioretention section with void ratios for volume computations (Source: CHCRPC).

1.4 Calculations

1.4.1 Practice Dimensions using TNRRAT

Sizing the practice dimension can be done using the Tennessee Stormwater Runoff Reduction Assessment Tool (TNRRAT). The tool allows users to iteratively size their SCM(s) to meet the goal of 1-inch runoff reduction and 80% pollutant removal. The inputs needed for the tool are:

- Location
- Area per management types and surface management types (such as impervious, bare soil, good forest, bioretention, etc)
- Soil texture
- Depth surface to restrictive layer
- Type of layer materials
- Depth of layer materials

1.4.2 Practice Dimensions using other method

Although using the TNRRAT is recommended, designer and engineers are welcomed to use other methods to size bioretention and other SCMs.

1.4.2.1 Runoff Volume

Use standard engineering methods to calculate runoff volume.

1.4.2.2 Surface Area

The size and surface area of a bioretention system may be a function of the drainage area that will discharge to the bioretention system. It is important not to concentrate too much flow in one location. A basic rule-of-thumb is to design a bioretention system with a surface area that is a ratio of the impervious and compacted pervious areas draining to it. A 1:10 ratio of surface area to impervious drainage area base on design rainfall depth can be used to estimate a bioretention area.

Inputs needed for calculation:

- Location
- Size of CDA
- Cover type
- Approximation of practice surface area and practice depth
- Void ratio values

1.4.2.3 Design Depth

With an estimate of the required bioretention area and runoff volume, the designer can estimate the depth of water, soil, and stone storage.

The recommended depths for surface water storage, soil storage, and stone storage are:

- Surface Water Storage Depth:
  - 6 inches maximum in high-use areas (along streets, at schools, in public landscapes, etc.)
  - 12 inches in less used areas (away from frequent public access)
- Bioretention Soil Depth: Between 12 and 36 inches
- Gravel storage Depth: Between 12 and 36 inches

Void ratios (V_r) are generally:

- 0.20 for bioretention soils
- 0.40 for clean-washed aggregate such as AASHTO No.3
- 0.85 to 0.95 for manufactured storage units depending on manufacturer

Storage depth:

[Soil depth x Soil media V_r] + [Gravel depth x Gravel V_r] + [Surface storage depth x surface storage]
(Equation 1)

Example: (2 ft. x 0.25) + (1 ft. x 0.40) + (0.5 x 1.0) = 1.40 ft.

1.4.2.4 Practice Volume

Storage Volume (ft^3) = Surface Water Volume + Soil Storage Volume + Stone Storage Volume
(Equation 2)

Where:

- **Surface Water Volume:** Available surface water storage between soil surface and overflow structure (always equal to or less than 12 inches). The designer should consider the bed side slopes when estimating volume. **Surface water volume = Surface water area (ft^2) x Surface water depth (ft) x Void Ratio**
- **Soil Storage Volume (ft^3)** = Soil Area (ft^2) x Soil depth (ft) below overflow x Void ratio
- **Gravel Storage Volume (ft^3)** = Gravel area (ft^2) x Gravel Depth (ft) below overflow x Void Ratio

Storage volume has to be ≥ runoff volume

1.4.3 Design Geometry

Bioretention basins must be designed with internal flow path geometry such that the treatment mechanisms provided by the bioretention are not bypassed or short-circuited. Examples of short-circuiting include inlets or curb cuts that are very close to outlet structures (see Figure 15) or incoming flow that is diverted immediately to the underdrain through stone layers. Short-circuiting can be particularly problematic when there are multiple curb cuts or inlets.

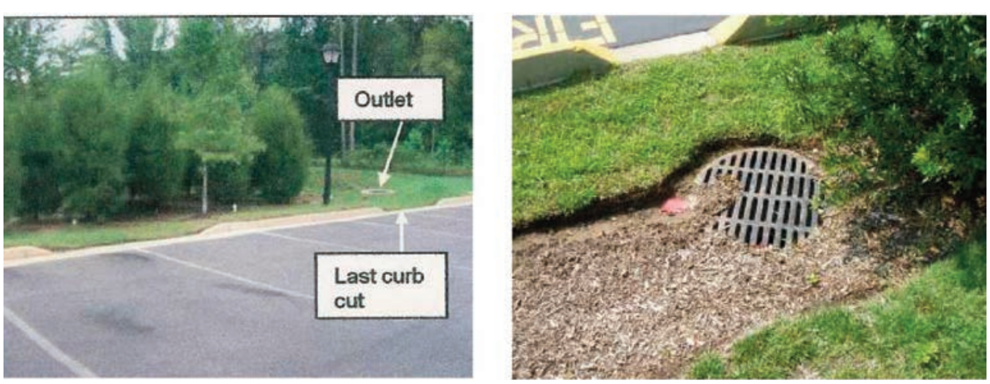

Figure 15: Short circuiting in bioretention (Source: VADCR).

In order for these bioretention areas to have an acceptable internal geometry, the "travel time" from each inlet to the outlet should be maximized, and incoming flow must be distributed as evenly as possible across the filter surface area. One important characteristic is the length of the shortest flow path compared to the overall length, as shown in Figures 16 and 17. In this figure, the ratio of the shortest flow path to the overall length is represented as:

Ratio of Shortest Flow Path to Overall Length:

SFP / L

Where:

SFP = length of the shortest flow path

L = length from the most distant inlet to the outlet

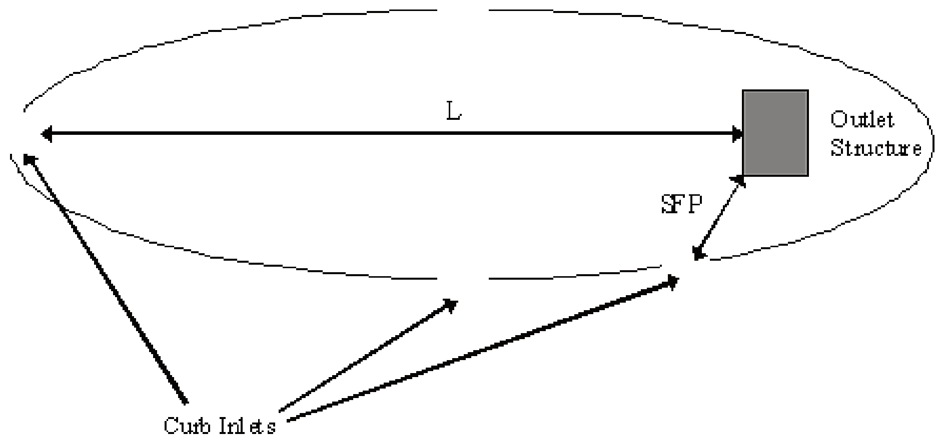

Figure 16: Flow path ratio.

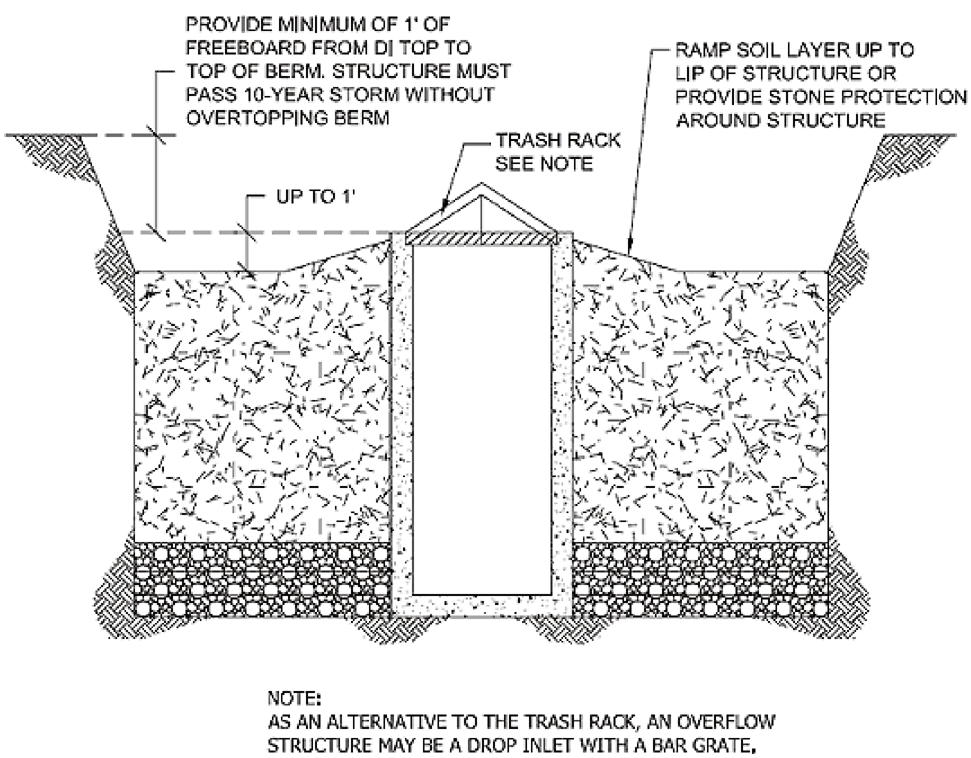

Figure 17: Typical Detail of how to prevent bypass or short-circuiting around the overflow structure (Source: VADCR).

1.5 Typical Details

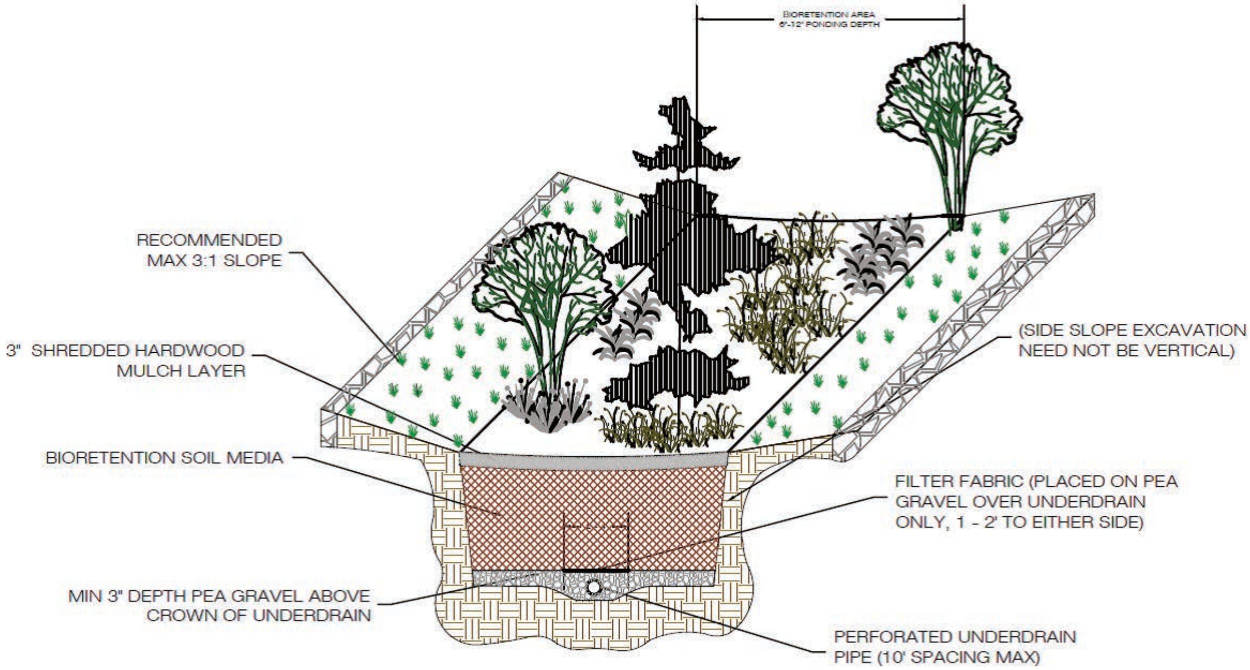

Figure 18: Typical section with underdrain (Source: VADCR).

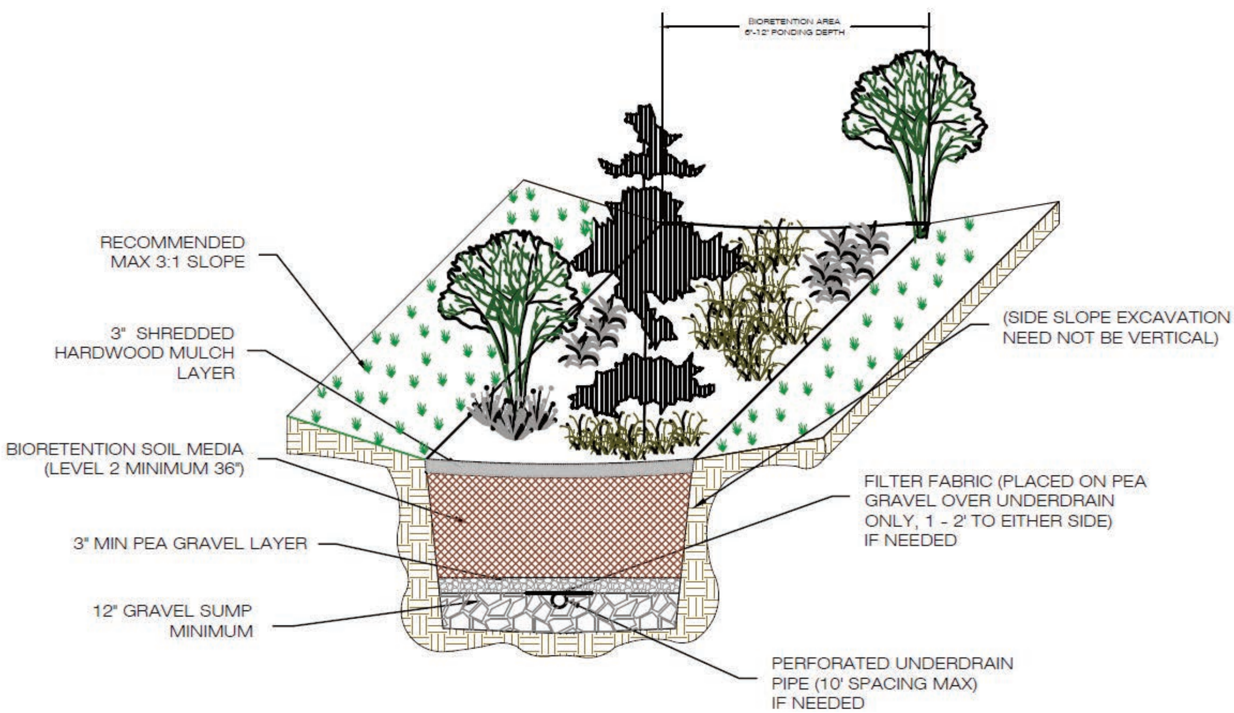

Figure 19: Typical section with underdrain (Source: VADCR).

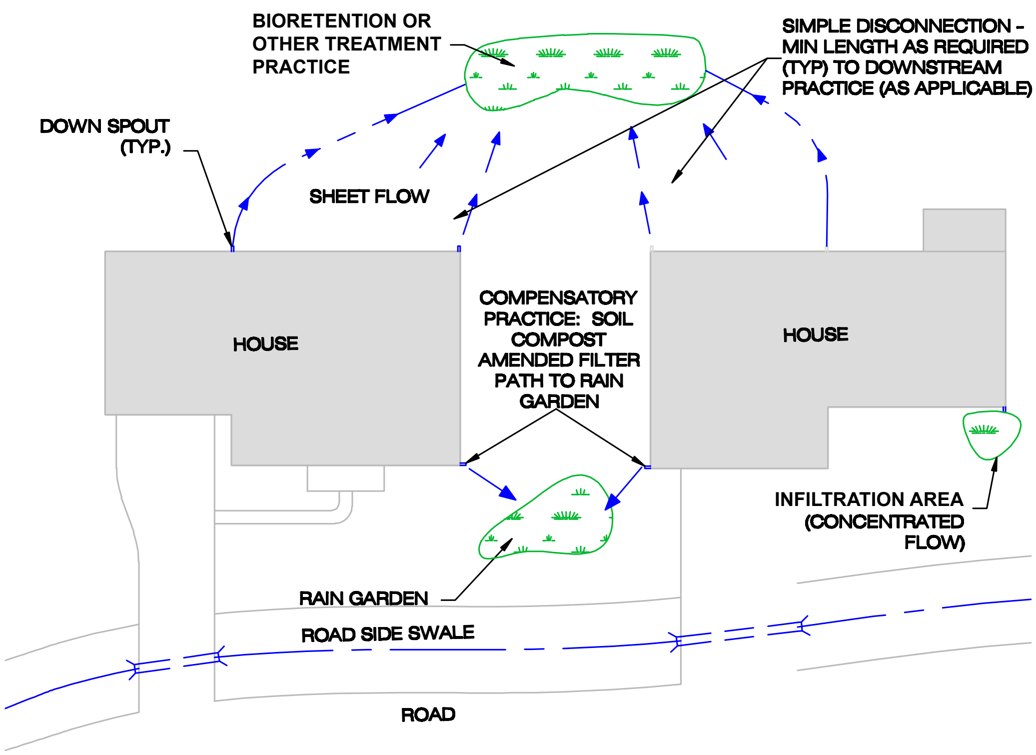

Figure 20: Residential Rooftop Treatment – Plan View (Source: WVDEP).

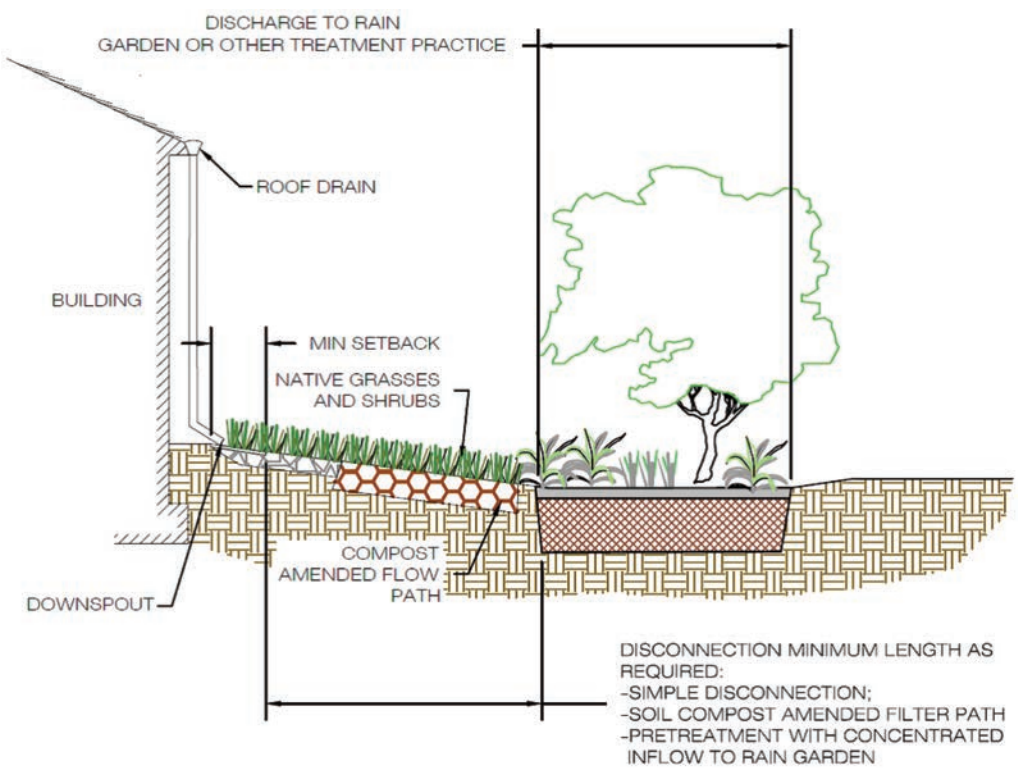

Figure 21: Residential Rooftop Disconnection to downstream raingarden – Bioretention without an underdrain (Source: VADCR).

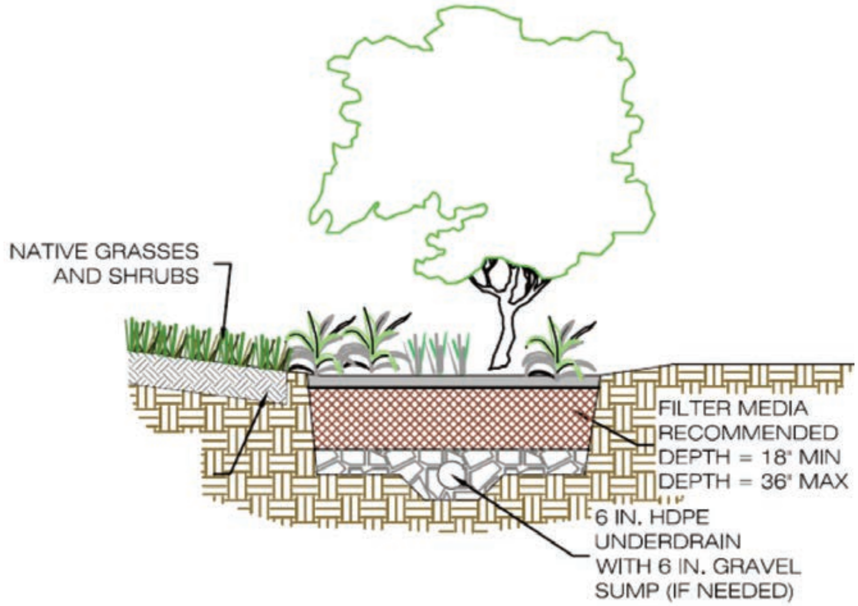

Figure 22: Bioretention with an underdrain (Source: VADCR).

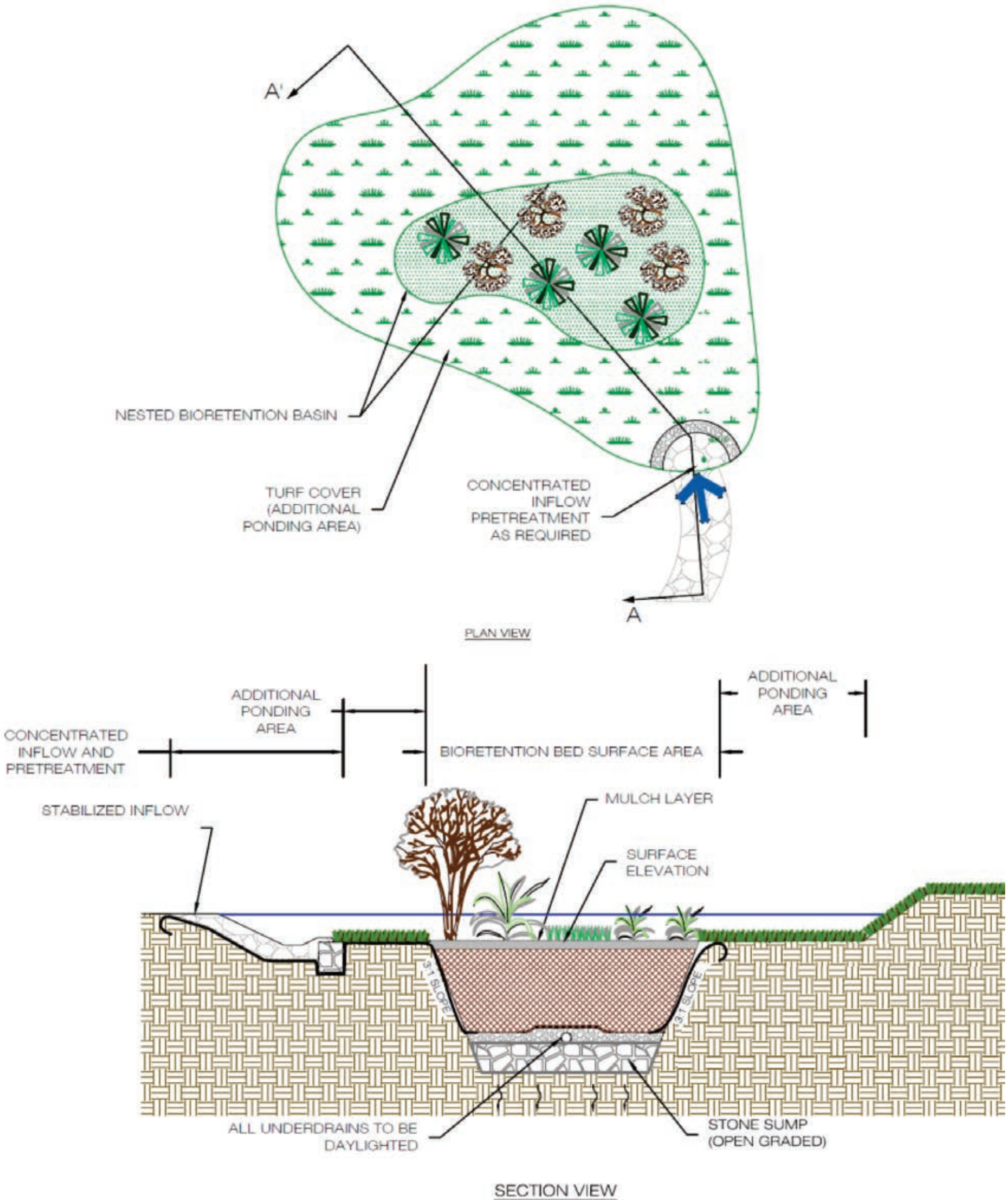

Figure 23: Typical Detail of bioretention with additional surface ponding (Source: VADCR).

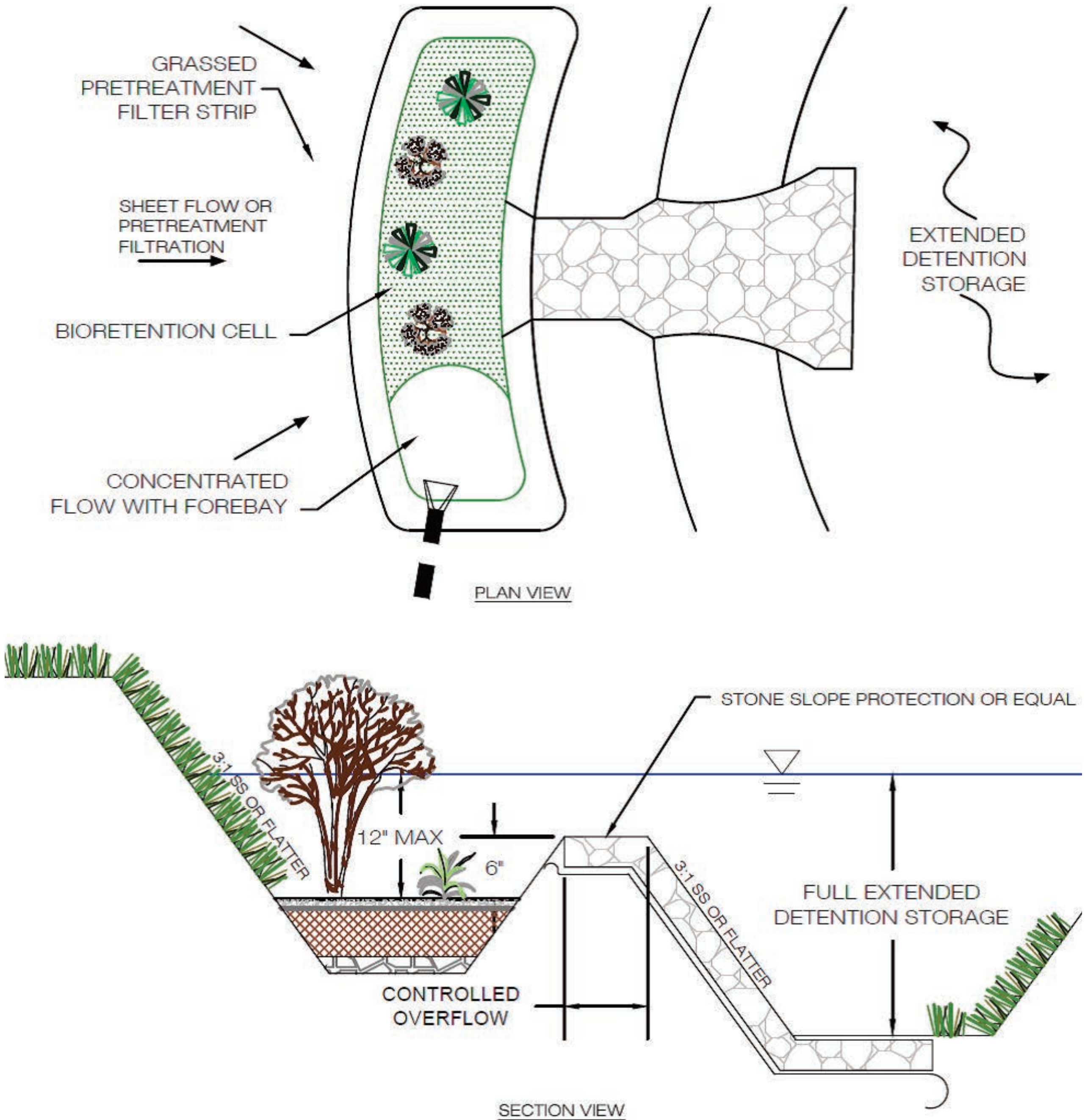

Figure 24: Typical Detail of bioretention with the upper shelf of an extended detention storage (Source: VADCR).

1.6 Variation – Bioretention Cells on Steep Slopes

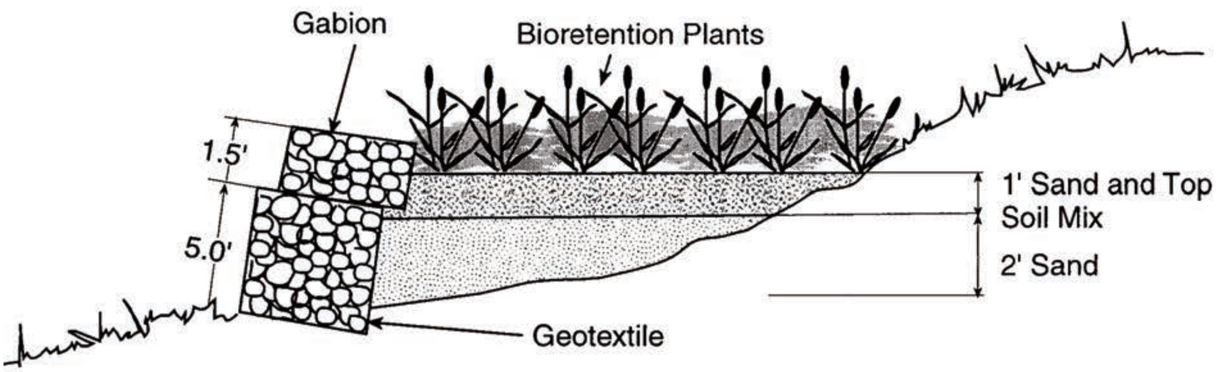

Figure 25: Bioretention suitable for use on slopes 10-20% (Source: NCDENR).

Figure 25 depicts a bioretention terrace that can be used in sloping terrain (for 10-20% slopes). An impermeable or very low permeability geomembrane must be used against the gabions or similar retaining structure to prevent flow from leaving the treatment unit through that surface. An underdrain could be placed at the low point of the filter if the native soil that the unit is built against will not provide adequate infiltration capacity.

2. Construction

The following is a typical construction sequence to properly install a bioretention, although steps may be modified to reflect different site conditions. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation.

2.1 Pre-Construction

Micro-bioretention and small-scale bioretention areas should be fully protected by silt fence or construction fencing, particularly if they will rely on infiltration (i.e., have no underdrains). Ideally, bioretention should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Bioretention basin locations may be used as small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the EPSC plan specifying that (1) the maximum excavation depth at the construction stage must be at least 1 foot above the post-construction installation, and (2) the facility must contain an underdrain. The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent bioretention facility, including dewatering, cleanout and stabilization.

2.2 Construction

The following is a typical construction sequence to properly install a bioretention measure. The construction sequence for micro-bioretention is more simplified. These steps may be modified to reflect different bioretention applications or expected site conditions:

- **Step 1**. Construction of the bioretention area may only begin after the entire contributing drainage area has been stabilized with vegetation. It may be necessary to block certain 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 area. 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 E&S controls are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the construction process.
- **Step 4**. Any pre-treatment cells should be excavated first and then sealed to trap sediments.
- **Step 5**. Excavators or backhoes should work from the sides to excavate the bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the bioretention area. Contractors should use a cell construction approach 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 the bottom soils to a depth of 8 to 12 inches to promote greater infiltration.
- **Step 7**. Place geotextile fabric on the sides of the bioretention area with a 6-inch overlap on the sides. If a stone storage layer will be used, place the appropriate depth of #57 stone on the bottom, install the perforated underdrain pipe, pack #57 stone to 3 inches above the underdrain pipe, and add approximately 3 inches of choker stone/pea gravel as a filter between the underdrain and the soil media layer. If no stone storage layer is used, start with 6 inches of #57 stone on the bottom, and proceed with the layering as described above. If IWS is desired, use 6" solid pipe for the up-turned elbow.
- **Step 8**. Deliver the soil media from an approved vendor, and 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 area is achieved. Wait a few days to check for settlement, and add additional media, as needed, to achieve the design elevation.
- **Step 9**. Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.
- **Step 10**. Place the surface cover in both cells (mulch, river stone or turf), depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (Step 9), and holes or slits will have to be cut in the matting to install the plants.
- **Step 11**. Install the plant materials as shown in the landscaping plan, and water them during weeks of no rain for the first two months.
- **Step 12**. Conduct the final construction inspection. Then log the GPS coordinates for each bioretention facility and submit them for entry into the local maintenance tracking database.

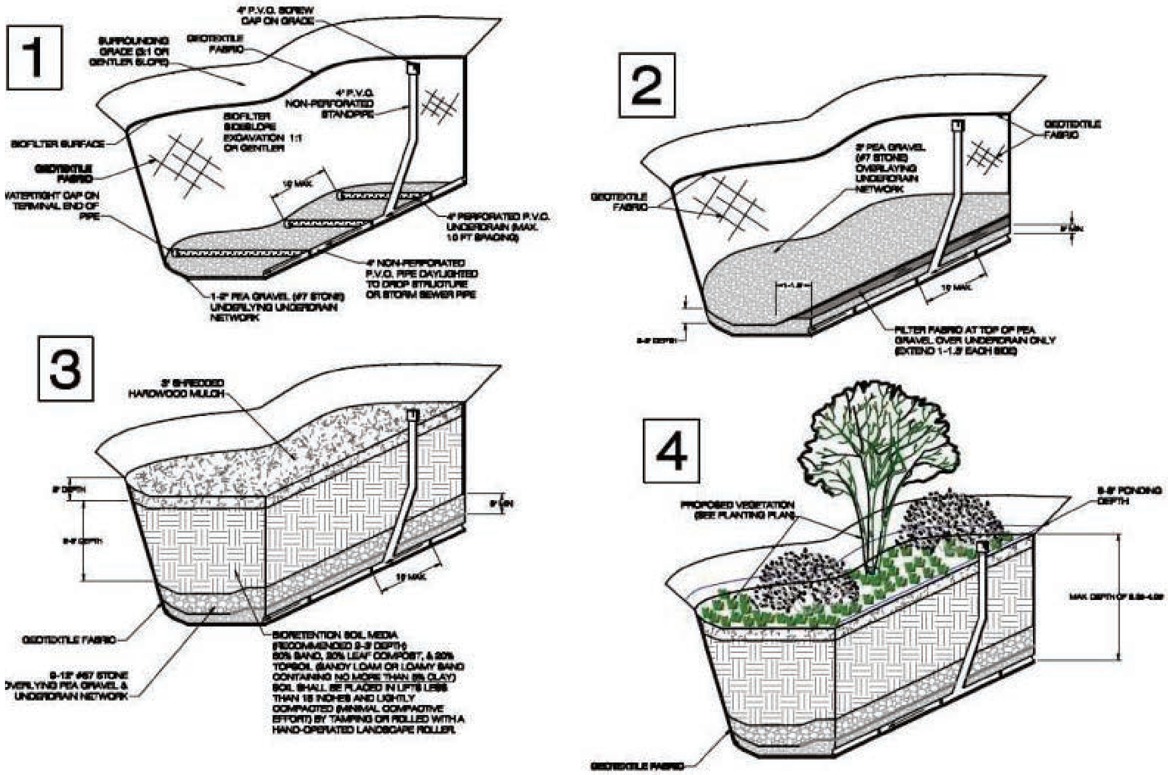

Figure 26: Typical bioretention construction sequence (Source:VADCR).

3. Maintenance

3.1 Agreements

Examples of maintenance documents can be found in Appendix F. They may include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities.

3.2 First Year Maintenance Operations

Successful establishment of bioretention areas requires that the following tasks be undertaken in the first year following installation:

- **Initial inspections.** For the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 0.5 inch of rainfall.
- **Spot reseeding.** Inspectors should look for bare or eroding areas in the contributing drainage area or around the bioretention area, and make sure they are immediately stabilized with grass cover.
- **Fertilization.** One-time, spot fertilization may be needed for initial plantings.
- **Watering.** Depending on rainfall, watering may be necessary once a week during the first 2 months, and then as needed during first growing season (April-October), depending on rainfall.
- **Remove and replace dead plants.** Since up to 10% of the plant stock may die off in the first year, construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction. The typical thresholds below which replacement is required are 85% survival of plant material and 100% survival of trees.

3.3 Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each bioretention area. The following is a list of some of the key maintenance problems to look for:

- Check to see if 75% to 90% cover (mulch plus vegetative cover) has been achieved in the bed, and measure the depth of the remaining mulch.
- Check for sediment buildup at curb cuts, gravel diaphragms or pavement edges that prevents flow from getting into the bed, and check for other signs of bypassing.
- Check for any winter- or salt-killed vegetation, and replace it with hardier species.
- Note presence of accumulated sand, sediment and trash in the pre-treatment cell or filter beds, and remove it.
- Inspect bioretention side slopes and grass filter strips for evidence of any rill or gully erosion, and repair it.
- Check the bioretention bed for evidence of mulch flotation, excessive ponding, dead plants or concentrated flows, and take appropriate remedial action.
- Check inflow points for clogging, and remove any sediment.
- Look for any bare soil or sediment sources in the contributing drainage area, and stabilize them immediately.
- Check for clogged or slow-draining soil media, a crust formed on the top layer, inappropriate soil media, or other causes of insufficient filtering time, and restore proper filtration characteristics.

3.4 Routine and Non-Routine Maintenance Tasks

Maintenance of bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides. A customized maintenance schedule must be prepared for each bioretention facility, since the maintenance tasks will differ depending on the scale of bioretention, the landscaping template chosen, and the type of surface cover. A generalized summary of common maintenance tasks and their frequency is provided in Table 4.

The most common non-routine maintenance problem involves standing water. If water remains on the surface for more than 48 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter (try the easiest things first, as listed below):

- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be snaked.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 8 to 12 inches of soil.
- Install sand wicks from 3 inches below the surface to the underdrain layer. This reduces the average concentration of fines in the media bed and promotes quicker drawdown times. Sand wicks can be installed by excavating or augering (using a tree auger or similar tool) down to the gravel storage zone to create vertical columns which are then filled with a clean open-graded coarse sand material (ASTM C-33 concrete sand or similar approved sand mix for bioretention media). A sufficient number of wick drains of sufficient dimension should be installed to meet the design dewatering time for the facility.
- Remove and replace some or all of the soil media.

Table 4: Suggested Annual Maintenance Activities for Bioretention.

Maintenance Tasks	Frequency
• Mowing of grass filter strips and bioretention turf cover	At least 4 times a year
• Spot weeding, erosion repair, trash removal, and mulch raking	Twice during growing season
• Add reinforcement planting to maintain the desired vegetation density • Remove invasive plants using recommended control methods • Stabilize the contributing drainage area to prevent erosion	As needed
• Spring inspection and cleanup • Supplement mulch to maintain a 3 inch layer • Prune trees and shrubs	Annually
• Remove sediment in pre-treatment cells and inflow points	Once every 2 to 3 years
• Replace the mulch layer	Every 3 years

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Chattanooga Hamilton County Regional Planning Commission (CHCRPC). "Bioretention." Rainwater Management Guide. Chattanooga: 2012.

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5.4.6a Urban Bioretention

Variations: Planter box, Extended tree pits, Stormwater curb extensions.

Figure 1: Urban planter box (Source: The SMART Center).

Description: Urban bioretention SCM are similar in function to regular bioretention practices except they are adapted to fit into “containers” within urban landscapes. Typically, urban bioretention is installed within an urban streetscape or city street right-of-way, urban landscaping beds, tree pits and plazas, or other features within an Urban Development Area. Urban bioretention is not intended for large commercial areas. Rather, urban bioretention is intended to be incorporated into small fragmented drainage areas such as shopping or pedestrian plazas within a larger urban development.

Urban bioretention features hard edges, often with vertical concrete sides, as contrasted with the more gentle earthen slopes of regular bioretention. These practices may be open-bottomed, to allow some infiltration of runoff into the sub-grade, but they generally are served by an underdrain.

1. Design

1.1 Suggested Applications

Potential applications include capturing roof runoff directly adjacent to buildings, within or along parking lots, adjacent to parking stalls on roadways, sidewalks and paths, plazas, playgrounds, and athletic fields and courts.

Figure 2: Street side planter boxes. runoff enters the planter boxes through curb cuts (Source: The SMART Center).

Figure 3: Curb extension (Source: WVDEP).

Figure 4: Institutional planter box (Source: The SMART Center).

Figure 5: Parking lot planter box (Source: CHCRPC).

1.1.2 Variations

- **Curb Extensions/Curb Bump-Out**

  Large planter boxes constructed within and along a street are also referred to as "curb extensions" or "curb bump-outs." These are sometimes constructed within over-wide drive aisles to capture stormwater as well as to provide traffic calming. Curb extensions function in the same way as planter boxes in that they are curbed vegetated areas with soil and potentially stone for stormwater storage. Curb cuts allow the entry of roadway and sidewalk runoff to sheet flow into the system.

  Curb bump-outs and curb extensions must be structurally designed with consideration of the traffic loads both during and after construction.

- **Stormwater Planters** (also known as vegetative box filters or foundation planters) take advantage of limited space available for stormwater treatment by placing a soil filter in a container located above ground or at grade in landscaping areas adjacent to buildings and/or between buildings and roadways. The small footprint of the planter is typically contained in a precast or cast-in-place concrete vault. Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. They generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation.

- **Extended Tree Boxes** are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree pit is increased and used for stormwater treatment. 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.

1.2 Site Constraints

Contributing Drainage Area. Urban bioretention is classified as a micro-bioretention practice and is therefore limited to 2,500 sq. ft. of drainage area to each unit. However, this is considered a general rule; larger drainage areas may be allowed with sufficient flow controls and other mechanisms to ensure proper function, safety, and community acceptance. The drainage areas in these urban settings are typically considered to be 100% impervious. While multiple units can be installed to maximize the treatment area in ultra-urban watersheds, urban bioretention is not intended to be used as treatment for large impervious areas (such as parking lots).

Adequate Drainage. Urban bioretention practice elevations must allow the untreated stormwater runoff to be discharged at the surface of the filter bed and ultimately connect to the local storm drain system.

Available Hydraulic Head. In general, 3 to 5 feet of elevation difference is needed between the downstream storm drain invert and the inflow point of the urban bioretention practice. This is generally not a constraint, due to the standard depth of most storm drains systems.

Setbacks from Buildings. If an impermeable liner and an underdrain are used, no setback is needed from the building. Otherwise, the standard 10 foot down-gradient setback applies.

Proximity to Underground Utilities. Urban bioretention practices frequently compete for space with a variety of utilities. Since they are often located parallel to the road right-of-way, care should be taken to provide utility-specific horizontal and vertical setbacks. However, conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Overhead Wires. Designers should also check whether future tree canopy heights achieved in conjunction with urban bioretention practices will interfere with existing overhead telephone, cable communications and power lines.

Minimizing External Impacts. Because urban bioretention practices are installed in highly urban settings, individual units may be subject to higher public visibility, greater trash loads, pedestrian use traffic, vandalism, and even vehicular loads. 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 vegetation. The urban landscape context may feature naturalized landscaping or a more formal deign. 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, grates or other measures to prevent damage from pedestrian short-cutting across the practices.

1.3 Design Criteria and Calculations

Sizing	Surface area = Runoff volume / storage depth (refer to main Bioretention section 1.4.2.3 Equation 1)
Underdrain	Schedule 40 PVC with clean-outs
Maximum Drainage Area	2,500 sq. ft.
Maximum Ponding Depth	6 inches
Filter media depth minimum	Min: 18 inches; max: 24 inches
Gravel layer depth minimum	6 inches
Media and Surface Cover	Refer to the Main Bioretention Design Criteria
Sub-soil testing	Refer to the Main Bioretention Design Criteria
Inflow	Sheetflow, curb cuts, trench drains, roof drains, concentrated flow, or equivalent

1.3.1 Practice Dimensions
Sizing the practice dimension can be done using the Tennessee Runoff Reduction Assessment Tool (TNRRAT).

1.3.2 Practice Dimensions using other methods
Although using TNRRAT is recommended, designers and engineers can use other methods to size urban bioretention and other SCMs.

1.3.2.1 Runoff Volume
Use standard engineering method to calculate runoff volume.

1.3.2.2 Practice Dimensions

The required surface area of the urban bioretention is calculated by dividing the Runoff Volume by storage depth as described in the main Bioretention section 1.4.2.3 Equation 1. The equivalent storage depth is computed as the depth of media, gravel, or surface ponding (in feet) multiplied by the accepted void ratio.

Surface area = Runoff volume / Storage depth
(Equation 1)

1.4 Design Elements

Design of urban bioretention should follow the general guidance presented in this Bioretention design specification. The actual geometric design of urban bioretention is usually dictated by other landscape elements such as buildings, sidewalk widths, utility corridors, retaining walls, etc. Designers can divert fractions of the runoff volume from small impervious surfaces into urban bioretention that is integrated with the overall landscape design. Inlets and outlets should be located as far apart as possible. The following is additional design guidance that applies to all variations of urban bioretention:

- All urban bioretention practices should be designed to fully drain within 24 hours.
- Any grates used above urban bioretention areas must be removable to allow maintenance access

1.4.1 Pre-treatment

Pre-treatment options overlap with those of regular bioretention practices. However, the materials used may be chosen based on their aesthetic qualities in addition to their functional properties. For example, river rock may be used in lieu of rip rap. Other pretreatment options may include one of the following:

- A trash rack between the pre-treatment cell and the main filter bed. This will allow trash to be collected from one location.
- A trash rack across curb cuts. While this trash rack may clog occasionally, it keeps trash in the gutter, where it can be picked up by street sweeping equipment.
- A pre-treatment area above ground or a manhole or grate directly over the pre-treatment area.

1.4.2 Entrance/flow conditions

The inlet(s) to urban bioretention should be stabilized using course aggregate stone, splash block, river stone or other acceptable energy dissipation measures. The following forms of inlet stabilization are recommended:

- 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 under sidewalks from the curb or from downspouts (if the bioretention area is outside of the ROW).
- Grates or trench drains that capture runoff from the sidewalk or plaza area.

1.4.3. Filter Media and Surface Cover

- The ground surface of the urban bioretention cell should slope 1% towards the outlet, unless a stormwater planter is used.
- The soil media depth should be a minimum of 18 inches.
- If large trees and shrubs are to be installed, soil media depths should be minimum 4 feet.

1.4.4 Conveyance and Overflow

Overflows can either be diverted from entering the bioretention cell or dealt with via an overflow inlet.

Optional methods include the following:

- Size curb openings to capture only the Treatment Volume and bypass higher flows through the existing gutter.

- Use landscaping type inlets or standpipes with trash guards as overflow devices.
- Use a pre-treatment chamber with a weir design that limits flow to the filter bed area.

1.4.5 Material Specification

The unique components for urban bioretention may include the inlet control device, a concrete box or other containing shell, protective grates, and an underdrain that daylights to another stormwater practice or connects to the storm drain system. The underdrain should:

- Consist of slotted pipe greater than or equal to 4 inches in diameter, placed in a layer of washed (less than 1% passing a #200 sieve) TDOT #57 stone.
- Have a minimum of 2 inches of gravel laid above and below the pipe.
- Be laid at a minimum slope of 0.5 %.
- Extend the length of the box filter from one wall to within 6 inches of the opposite wall, and may be either centered in the box or offset to one side.
- Be separated from the soil media by non-woven, geotextile fabric or a 2 to 3 inch layer of either washed TDOT #8 stone or 1/8 to 3/8 inch pea gravel.

1.5 Specific Design Issues

Planter Box

Since stormwater planters are often located near building foundations, waterproofing by using a watertight concrete shell or an impermeable liner should be required to prevent seepage.

Expanded Tree Pits

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- Expanded tree pits designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.
- Installing a tree pit grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.
- Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a drop off from the pavement to the urban bioretention cell.
- A removable grate capable of supporting typical H-20 axel loads may be used to allow the tree to grow through it.
- Each tree needs a minimum of 400 cubic feet of shared root space.

Curb Extensions

Roadway stability can be a design issue where stormwater curb extensions are installed. Consult design standards pertaining to roadway drainage. It may be necessary to provide a barrier to keep water from saturating the road’s sub-base and demonstrate it is capable of supporting H-20 axel loads.

1.6 Planting and Landscaping Considerations

The degree of landscape maintenance that can be provided will determine some of the planting choices for urban bioretention areas. The planting cells can be formal gardens or naturalized landscapes.

In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a “turf and trees” landscaping model. Spaces for herbaceous flowering plants can be included. This may be attractive at a community entrance location. Native trees or shrubs are preferred for urban bioretention areas, although some ornamental species may be used. As with regular bioretention, the selected perennials, shrubs, and trees must be tolerant of salt, drought, and inundation. Additionally, tree species should be those that are known to survive well in the compacted soils and polluted air and water of an urban landscape.

1.7 Typical Details

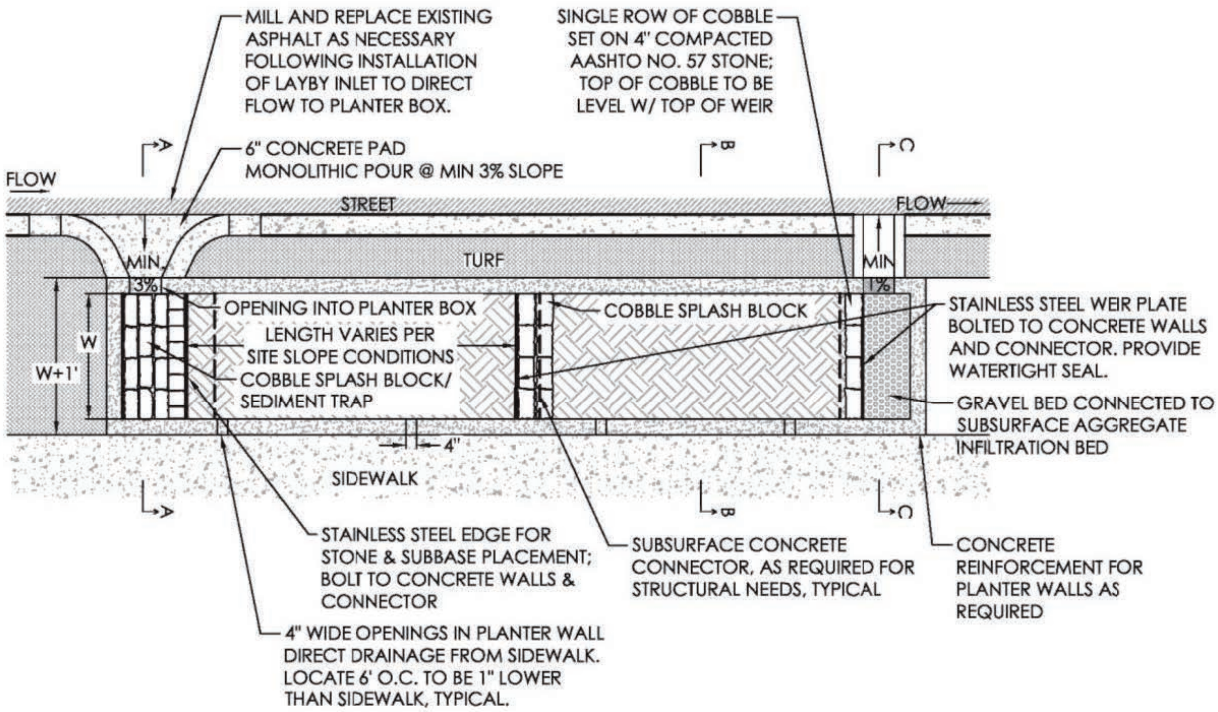

Figure 6: Example of streetside planter box (slopes <5%) with infiltration bed plan view (Source: CHCRPC).

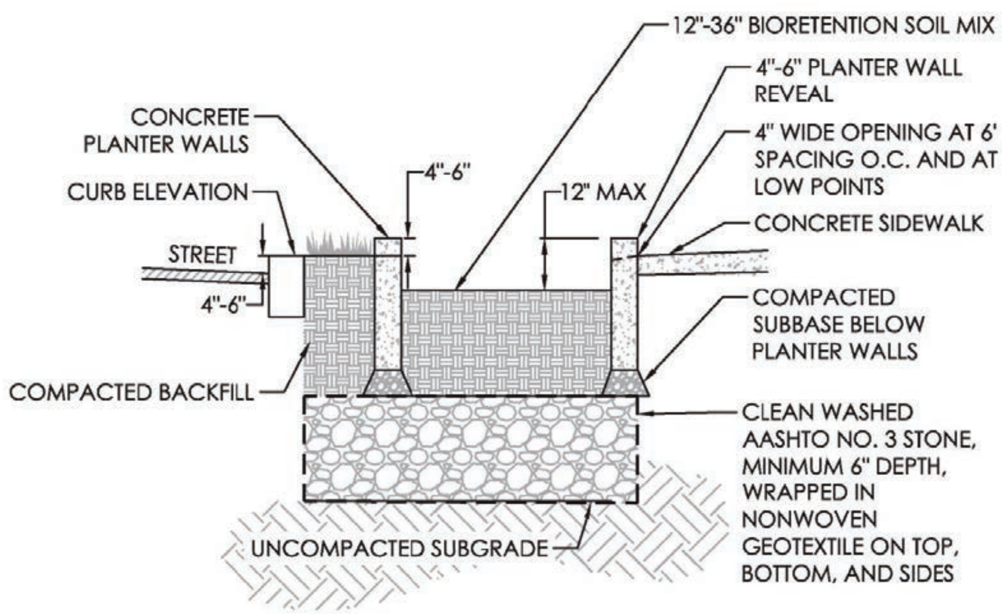

Figure 7: Example of stone splash block / sediment trap detail (Source: CHCRPC).

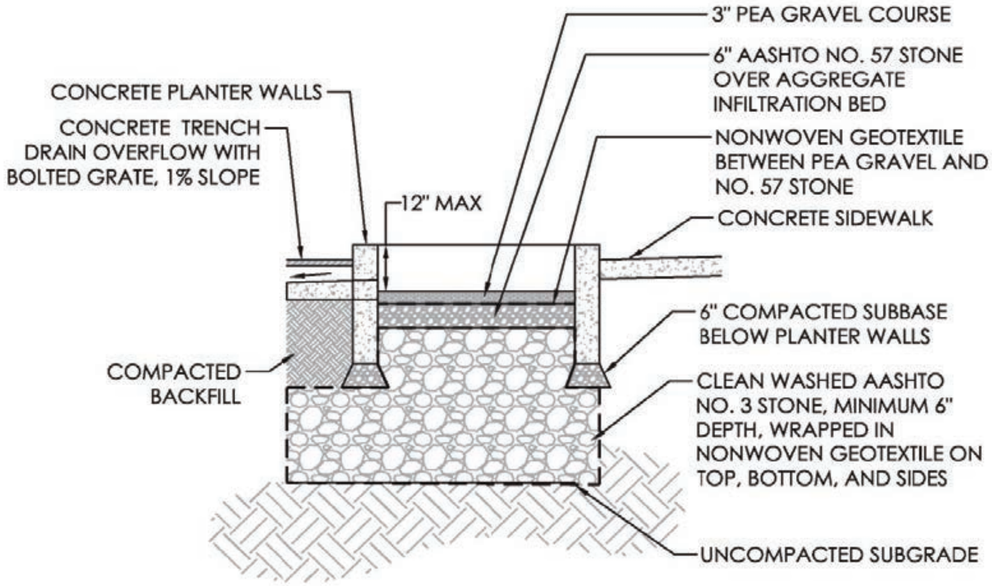

Figure 8: Overflow from streetside planter box (Source: NCDENR).

2. Construction

The construction sequence and inspection requirements for urban bioretention are generally the same as micro-bioretention practices. In cases where urban bioretention is constructed in the road or right-of-way, the construction sequence may need to be adjusted to account for traffic control, pedestrian access and utility notification. Urban bioretention areas should only be constructed after the drainage area to the facility is completely stabilized. The specified growth media should be placed and spread by hand with minimal compaction, in order to avoid compaction and maintain the porosity of the media. The media should be placed in 8 to 12 inch lifts with no machinery allowed directly on the media during or after construction. The media should be overfilled above the proposed surface elevation, as needed, to allow for natural settling. Lifts may be lightly watered to encourage settling. After the final lift is placed, the media should be raked (to level it), saturated, and allowed to settle for a few days prior to installation of plant materials.

3. Maintenance

Routine operation and maintenance are essential to gain public acceptance of highly visible urban bioretention areas. Weeding, pruning, and trash removal should be done as needed to maintain the aesthetics necessary for community acceptance. During drought conditions, it may be necessary to water the plants, as would be necessary for any landscaped area. To ensure proper performance, inspectors should check that stormwater infiltrates properly into the soil within 24 hours after a storm. If excessive surface ponding is observed, corrective measures include inspection for soil compaction and underdrain clogging. Consult the maintenance guidance outlined in the main part of this design specification.

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5.4.7 Infiltration Areas

Description: Infiltration areas are properly sized engineered vegetated areas designated to receive runoff from disconnected roof downspouts, driveways, parking lots, and other impervious areas. Infiltration areas are low cost and have been proven to reduce the volume and flows associated with stormwater runoff.

Figure 1: Roof downspout is directed to an infiltration area (Source: The SMART Center).

Key Design Criteria: (NC, 2014)

- Must provide adequate sheet flow.
- **Vegetated cover:** dense lawn with no clumping species.

Site Constraints:

- **Setback from building foundations:** 5 feet
- **Setback from water supply wells:** none
- **Soil type:** any
- **Maximum slope:** 7 percent with land graded to promote sheet flow for B, C, and D soils, 15% for A soil
- **Seasonal high table requirement:** none
- **Hotspots:** shall not be used to treat stormwater hotspot

Advantages:

- Cost effective
- Promotes infiltration, reducing runoff volume & peak discharge
- Vegetated areas for infiltration provide aesthetics

Disadvantages:

- For appreciable volume and peak discharge reduction, must be applied broadly
- Requires owner buy-in and maintenance to ensure proper drainage
- May require large on-lot pervious areas
- Must avoid causing foundation flooding or ice hazards
- Difficult to regulate and oversee, especially for subdivision grading permit projects

Maintenance:

- Should be accessible by mowing equipment
- Remove sediment and debris from contributing impervious surfaces.
- Repair any areas that are eroding or where vegetation has died.
- Re-grade the soil if necessary to remove the gully and re-seed and water until it is established.

Design Checklist:

- ❑ Ensure acceptable conditions for construction
- ❑ Design the Drainage and Outlet System
- ❑ Design infiltration area in accordance with design criteria and typical details
- ❑ Submit plans for review

1. Design

1.1 Description

An infiltration area is a vegetated area that is sized and graded to receive discharges runoff from built-upon area (usually a roof or a paved surface) to reduce runoff and pollutants. Much of the development across the state has been designed as **connected impervious surface**; that is, draining to pipes and ditches that rapidly convey stormwater without runoff reduction or treatment. Infiltration areas can only work if **impervious surfaces are disconnected** and runoff is routed to it. Using infiltration area and **Disconnected Impervious Surface (DIS)** technique can help restore the hydrology of streams and reduce pollutant loadings.

There are two types of DIS discussed in this chapter: rooftop downspout disconnection and pavement disconnection.

Rooftop Downspout Disconnection

Table 1: Simple Rooftop Disconnection Design Criteria (NCDENR, 2014).

Design Factor	Simple Disconnection
Maximum impervious (Rooftop) area treated	300 sq. ft. per disconnection
Longest flow path (roof/gutter)	75 feet
Infiltration area length	Equal to longest flow path, but no less than 40 feet [1]
Infiltration area slope	< 2%, or < 5% with turf reinforcement [2]
Distance from buildings or foundations	Extend downspouts 5 ft. [3] (15 ft. in karst areas) away from building *if grade is less than 1%*
Type of pretreatment	External (leaf screens, etc)

1 *An alternative runoff reduction practice must be used when the disconnection length is less than 40 feet.*

2 *Turf reinforcement 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 TDEC.*

3 *Note that the downspout extension of 5 feet is intended for simple foundations. The use of a dry well or French drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.*

Pavement Disconnection

Table 2: Pavement Disconnection Design Criteria (NCDENR, 2014).

Design Factor	Simple Disconnection
Maximum run of the flow on the pavement	100 feet
Maximum slope of the pavement	7%
Infiltration area length	Min. 10 feet
Infiltration area slope	Max. 7%
A gravel verge or other transition shall be provided between the edge of the paved surface and the infiltration area.	

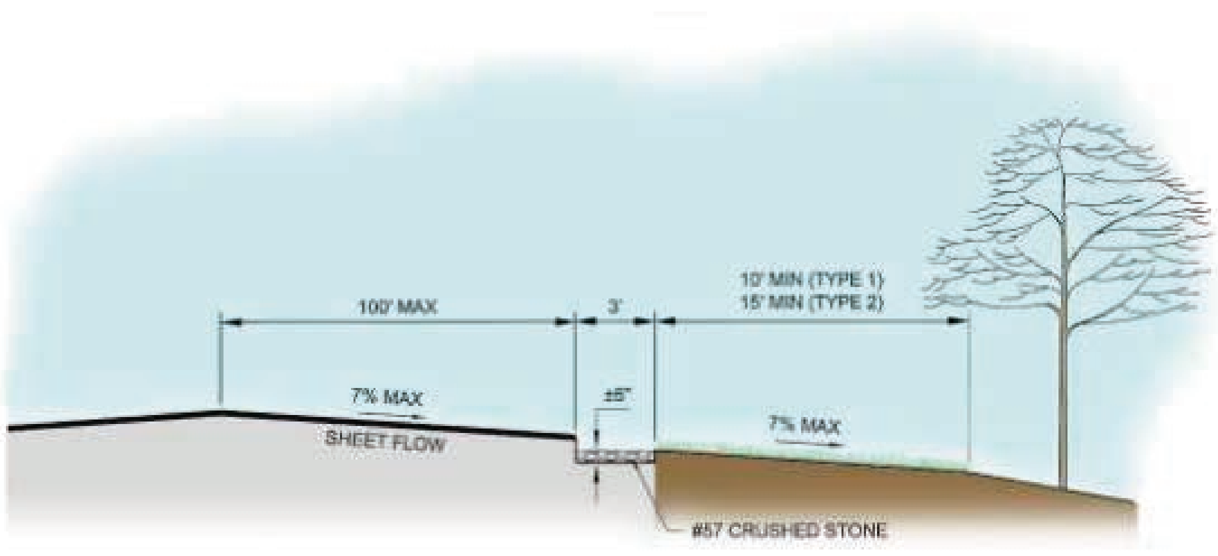


Figure 2: Schematic Cross Section of a Disconnected Paved Area (Source: NCDENR, 2014).

1.2 Major Design Elements

Table 3: Major Design Elements for Infiltration Area (NCDENR, 2014).

1. The infiltration area shall not include any impervious surface.
2. The infiltration area shall have a maximum slope of 7% for B, C and D soils and 15% for A soils with land graded to promote diffuse flow in all directions. Vegetative cover shall establish a dense lawn with no clumping species.
3. If the infiltration area is established on fill soils that are less permeable than the in-situ soils, then the soil type for crediting purposes shall be based on the fill soils. However, if the fill soils are more permeable than the in-situ soils, then the soil type for crediting shall reflect the in-situ soil type.
4. The vegetated cover shall be established dense lawn with no clumping species.
5. All sites built within the past fifty years shall be tilled to eight inches prior to vegetation establishment.
6. Recommended: There should be a minimum 5-foot distance between building foundation and infiltration area.

1.3 Siting and Feasibility

Table 4: Siting and Feasibility Considerations for Infiltration Areas (NCDENR, 2014).

Installation Size	The size of disconnected roof areas is limited to a maximum of 300 square feet per downspout. Paved areas are limited to a 100-foot run of pavement; however, there is no limit to the length of pavement that may be disconnected. This will allow most standard roadway cross-sections to be disconnected provided that there is an adequate width of infiltration area in the right-of-way.
Proximity to building foundations & utilities	As a precaution, at least five feet of setback from building foundations should be allowed for downspout disconnection. The limit of 300 square feet for each downspout makes it unlikely that foundations or underground utilities will be adversely affected by infiltration area.

Proximity to water supply wells	No setback from water supply wells is required for infiltration areas.
Status of the site as high or low density	Infiltration areas can be used on either high or low density sites. On high density sites, infiltration areas can reduce required SCM volumes. However, they may be impractical on highly built-out sites that do not have vegetated areas available to receive stormwater runoff. On low density sites, as much impervious surface as possible can be treated as infiltration area if flow rate is low.
Soil type	Infiltration areas may be used on any soil type, although the credit will vary.
Site slopes	In B, C and D soils, the vegetated areas associated with infiltration areas shall have a slope of seven percent or less. In A soils, the slope may not exceed 15 percent. It may not be cost-effective to meet the requirement for gently sloping vegetated surface on a steep site.
Seasonal high water table	There are no seasonal high water table requirements associated with infiltration area.
Stormwater hotspots	Infiltration areas shall not be used to treat stormwater hotspots – areas where concentrations of pollutants such as oils and grease, heavy metals and toxic chemicals are likely to be significantly higher than in typical stormwater runoff.
Redevelopment sites	Care should be taken when implementing infiltration areas at redevelopment sites. Stormwater shall not be infiltrated into contaminated soils because this can cause dispersion of toxic substances. If contaminated soils are present or suspected, the state recommends that the designer consult with an appropriately licensed TN professional.
Maintenance access	Because its performance depends on maintenance, infiltration areas should be accessible by mowing equipment

1.4 Design

The design standards for Infiltration Area are based on providing a minimum loading ratio of 7:1 for (rooftop area: vegetated area) or 10:1 for (pavement area: vegetated area). These loading ratios ensure a significant level of infiltration for stormwater and significant pollutant reductions.

1.4.1 Design Step 1: Ensure Acceptable Conditions for Construction

Before pursuing an infiltration area beyond the conceptual stage, the designer shall verify site feasibility and meet with the owner to explain the installation, construction and maintenance requirements of the proposed infiltration area. These costs are likely lower than other SCMs, but it is important to integrate maintenance requirements into the owner's planning for site operations.

1.4.2 Design Step 2: Design the Drainage and Outlet System

For disconnected roofs, the gutter system shall be designed so that no more than 300 square feet of roof flows to each downspout if the downspout releases at a single point as shown in Figure 3. If the flow is distributed evenly across the infiltration area via a spreading device such as a level spreader, then up to 500 square feet of rooftop may flow to the downspout. Most designs require the use of a converter joint as shown in Figure 3.

Figure 3: Disconnected downspouts on the left and a converter joint on the right (Source: Carmen, NCSU).

Figure 4 shows two potential problems with downspout disconnection. In Figure 4 (left), the converter joint was omitted and instead the four-inch corrugated plastic pipe was split. This weakens the structure and the pipe will most likely continue to split over time. In Figure 4 (right), the downspout releases onto a sidewalk instead of vegetated area. Additionally the sidewalk is graded to collect water.

Figure 4: Poorly designed and installed downspout disconnections (Source: Carmen, NCSU).

There are many possible outlet configurations for a disconnected downspout. Figure 5a-c shows a variety of possibilities. All outlet configurations should be designed with maintenance in mind. As mentioned above, outlet configurations that are equipped with a durable means of spreading the flow evenly across the vegetated filter strip shall be able to serve a larger rooftop area.

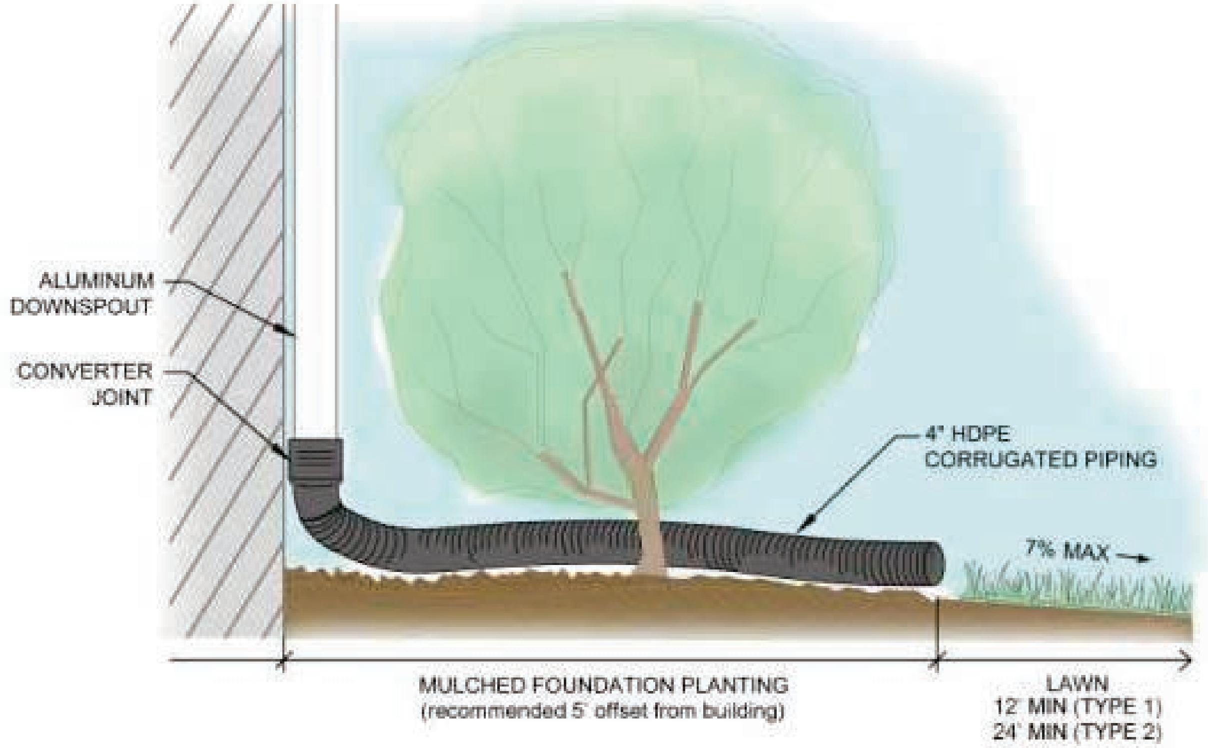


Figure 5a: Outlet configuration with a foundation planting (Source: Carmen, NCSU).

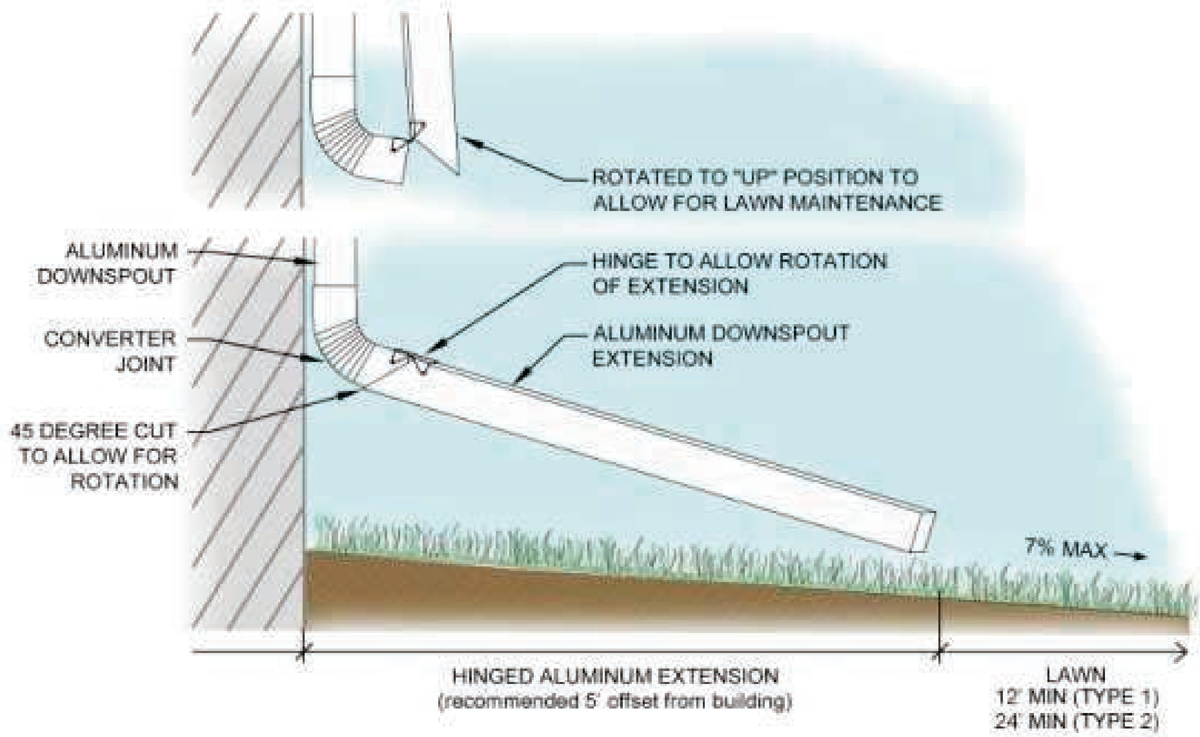


Figure 5b: Hinged outlet configuration (Source: Carmen, NCSU).

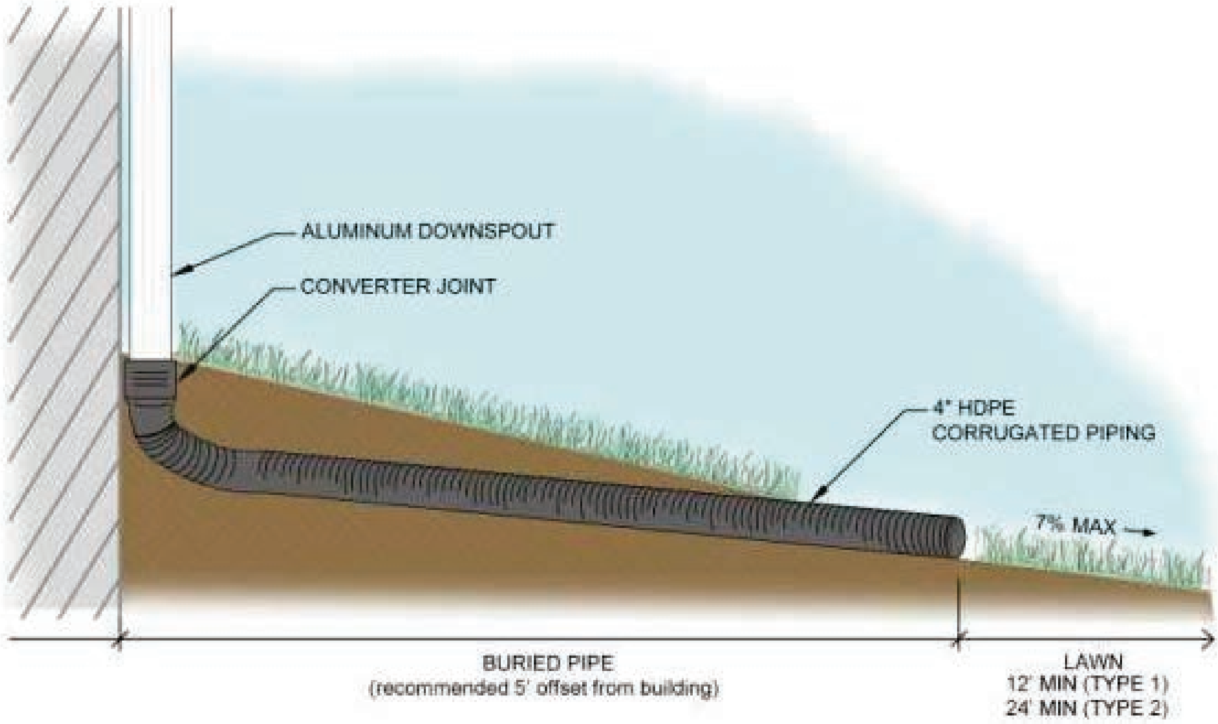


Figure 5c: Buried pipe outlet configuration (Source: Carmen, NCSU).

For disconnected pavement, a stone verge or concrete edge restraint should be used between contributing pavement and receiving vegetated area.

1.4.3 Design Step 3: Design the Infiltration Area

Disconnected downspouts and pavement shall be directed to appropriately sized infiltration areas based on Tables 1 and 2. In B, C and D soils, the vegetated receiving area shall have a uniform slope that does not exceed 7 percent. In A soils, the slope of the infiltration area may be increased up to 15 percent. The infiltration area may be graded to achieve this slope, but shall have additional positive grade at the end of the infiltration area for possible runoff to be directed offsite and not cause ponding.

If appropriate vegetation is not already established on site, then seed blend application is recommended. Seed blends should be selected based on shade/sun exposure of the infiltration area and regional climate within Tennessee. A non-clumping species should be selected. Sod should not be grown in a clay base or otherwise should be washed. Forested areas are not recommended as infiltration areas because uneven micro-topography often causes channelization, which reduces surface area exposed to stormwater.

1.4.3.1 Practice Dimensions using TNRRAT

Sizing the practice dimension can be done using the Tennessee Runoff Reduction Assessment Tool (TNRRAT). The tool allows users to iteratively size their SCM(s) to meet the goal of 1-inch runoff reduction and 80% pollutant removal. The inputs needed for the tool are:

- Location
- Management types (such as good, fair, poor forest, turf, and natural grasses)
- Soil texture
- Depth surface to restrictive layer
- Type of materials

1.4.3.2 Practice Dimensions using other method

Although using TNRRAT is recommended, designer and engineers are welcomed to use other methods to size the infiltration area. Refer to tables 2-3, and section 1.4 for more guidance.

1.5 Typical Details

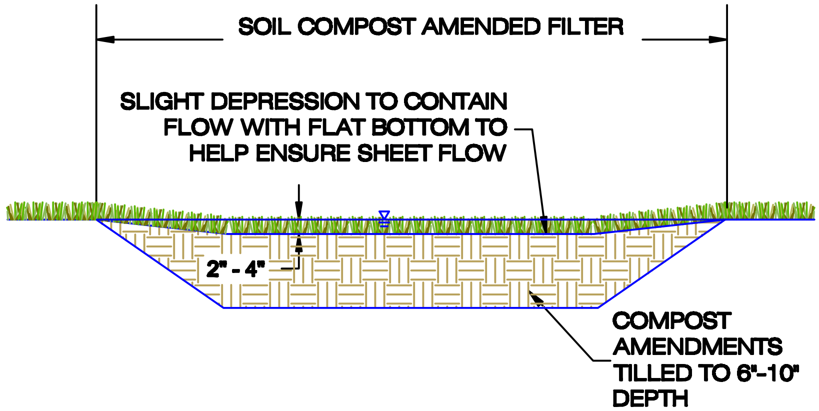


Figure 6: Disconnection: Soil Compost Amended Filter Path (Source: VADCR, 2011).

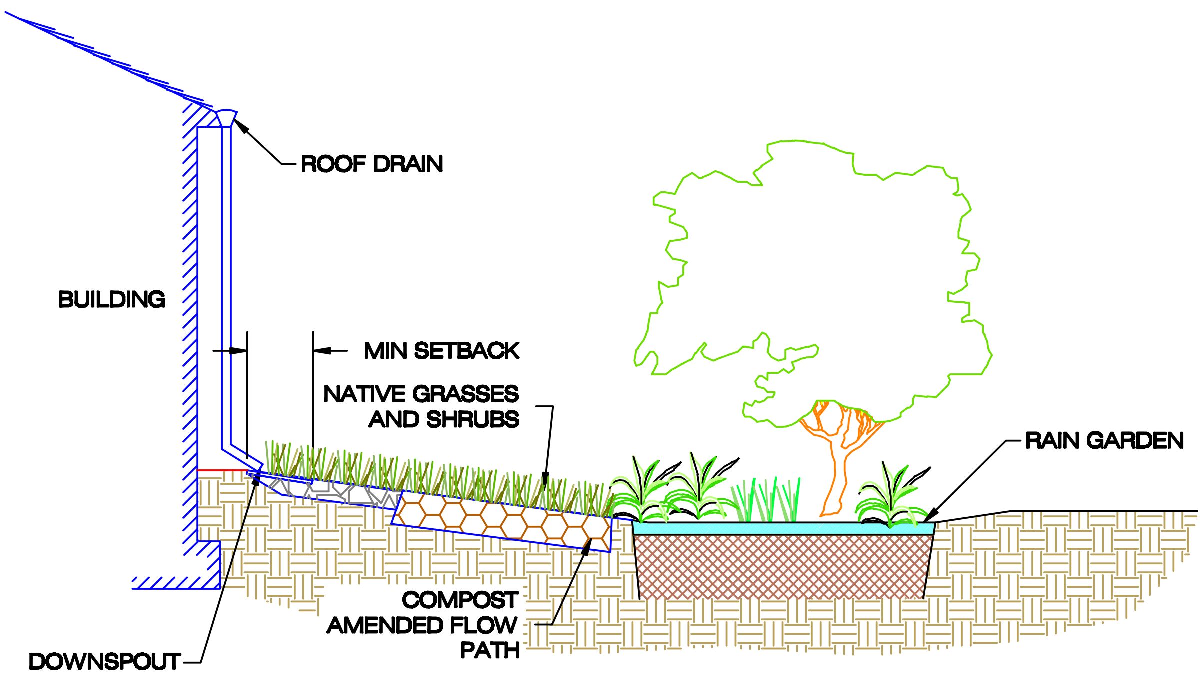


Figure 7: Rooftop Disconnection – Section View: Simple disconnection to downstream bioretention (Source: VADCR, 2011).

2. Construction

For an existing home, downspouts can be disconnected easily with minimum effort and expense if there is already an appropriately sized, sloped and vegetated area on the lot. For a new construction project, a preconstruction meeting is highly recommended to ensure contractors understand the locations and function of the infiltration area. Contractors will need to understand the need to construct the site drainage system according to the plans. Also, contractors shall grade and till the vegetated receiving areas as one of the last steps in the site construction process. A preconstruction meeting is also an opportunity to discuss other unique construction considerations for infiltration areas.

2.1 Construction Step 1: Ensure Acceptable Conditions for Construction

Do not construct infiltration areas until:

- Impervious areas that will drain to the infiltration areas are completed.
- Areas of the site adjacent to the infiltration area are stabilized with vegetation, mulch, straw, seed, sod, fiber blankets or other appropriate cover.
- The forecast calls for a window of dry weather to prevent smearing and compaction if grading the vegetated receiving area is necessary subgrade.
- The forecast calls for extremely hot or cold temperatures, which can hinder establishment of vegetation.

2.2 Construction Step 2: Install the Downspout System (If Applicable)

The downspout system shall be installed per the plans. In the field, verify that the downspout system has been installed correctly and that the drainage areas do not exceed the allowable design standards.

2.3 Construction Step 3: Grade, Prepare and Plant the Vegetated Receiving Area

It is important to ensure that the vegetated receiving areas are uniformly graded with no gullies, low spots or lateral slopes. Soils should be tilled to a depth of 8 inches unless this is an existing site that was built more than 50 years ago. When the sod is brought to the site, inspect it to be certain that it does not have a clay base or has been washed. A one-time fertilizer application and regular watering should be conducted to establish the vegetation in an infiltration area.

For a downspout disconnection system, the vegetated receiving area shall be kept offline until vegetation has been established. For disconnected pavement, soils should be stabilized with temporary means such as straw or matting until the permanent vegetative cover has taken root.

2.4 Construction Step 4: As-Built Inspection

After installation, an appropriately licensed Tennessee design professional shall perform a final as-built inspection and certification that includes:

- Ensuring that the infiltration area is installed per the plans and specifications.
- Checking that the vegetated receiving areas are sized correctly and that the vegetated receiving areas are stabilized with vegetation.
- Checking that the impervious surfaces are free from sediment and debris.

Any deficiencies found during the as-built inspection shall be promptly addressed and corrected.

3. Maintenance

Infiltration areas require maintenance to provide long-term stormwater benefits. Regular inspections will determine whether the impervious surface and the vegetated receiving area are draining and functioning as intended.

3.1 Directions for Maintenance Staff

Communication with maintenance staff is important in maintaining DIS. Maintenance staff shall:

- Not regrade infiltration areas or cover them with impervious surfaces such as a shed or patio.
- Not stockpile soil, sand, mulch or other materials on the infiltration area.
- Immediately repair any areas that are eroding or where vegetation has died.
- Immediately remove sediment and debris from contributing impervious surfaces.

3.2 Required Operation and Maintenance Provisions

After the infiltration area is constructed, it shall be inspected once a quarter. The inspector shall check each component and address any deficiencies in accordance with Table 5. The person responsible for maintaining the infiltration area shall keep a signed and notarized Operation and Maintenance Agreement and inspection records. These records shall be available upon request.

At all times, the roof area shall be maintained to reduce the debris and sediment load to the system. Excess debris can clog the system and lead to bypass of the design storm and reduced infiltration and pollutant removal.

To ensure proper operation as designed, a licensed Professional Engineer, Landscape Architect or other qualified professional shall inspect the system annually. The system components will be repaired or replaced whenever they fail to function properly.

Table 5: Inspection Process and Required Remedies for Infiltration Area (Source: NCDENR, 2014).

SCM Elements	Potential problem	How to remediate the problem
The contributing impervious area	Excess debris or sediment is present on the rooftop or impervious surface	Remove the debris or sediment as soon as possible.
The gutter system (if applicable)	Gutters are clogged or water is backing up out of the gutter system.	Unclog and remove the debris. May need to install gutter screens to prevent future clogging.
	Rooftop runoff is not flowing into the gutter system	Correct the positioning or installation of the gutters. Replace if necessary to capture the roof runoff.
Roadways & parking lots (if applicable)	Runoff flows to the pervious area as concentrated flow	Remove any sediment or obstructions at the pavement-vegetate area interface.
	The aggregate transition area or concrete edge restraint is cracked, settled, undercut, eroded or otherwise damaged.	Repair or replace the transition area or concrete edge restraint.
The pervious area	Areas of bare soil and/or erosive gullies have formed.	Regrade the soil if necessary to remove the gully and re-seed and water until it is established. Provide lime and a one-time fertilizer application.
	Trees or shrubs have begun to grow	Remove them.
	Vegetation is too short or too long.	Maintain vegetation at a height of approximately three to four inches.

REFERENCES

Carmen, N.B., W.F. Hunt, and A.R. Anderson. "Evaluating Residential Disconnected Downspouts as Stormwater Control Measures." 6th International Low Impact Development Conference. St. Paul, MN. (2013)

Metro Water Service, Metropolitan Government of Nashville and Davidson County. "Downspout Disconnection" Volume 5 Low Impact Development Stormwater Management Manual. 2012.

NCDENR. "24. Disconnected Impervious Surface (DIS)." NCDENR Stormwater BMP Manual. 2014.

VADCR. "Virginia DEQ Stormwater Specification No. 1: Rooftop (Impervious Surface) Disconnection." Virginia Stormwater Management Handbook. 1.9 ed. 2011.

5.4.8 Permeable Pavement

Variations: permeable interlocking pavers, concrete grid pavers, plastic reinforced grid pavers.

Description: Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. Porous paving systems have several design variants. The four major categories are: 1) pervious concrete; 2) modular block systems; 3) porous asphalt and 4) grass and gravel pavers. All have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric installed on the bottom.

Figure 1: Parking lot of St. John Lutheran church, Knoxville, TN (Source: SMART Center).

Key Design Criteria:

- **Contributing area:** External drainage area should generally not exceed twice the surface area of the permeable pavement.
- **Pavement slope:** ≤ 6%

Site Constraints:

- **Hotspots:** Not suitable
- **High loading situation**: Not intended to treat sites with high sediment or trash/debris loads.
- **Water table:** min. 2 feet
- Setbacks from:
  - Water supply well: min. 100 feet
  - Septic systems: min. 50 feet min.
  - Dry or wet utility lines: min. 5 feet down-gradient.
- **Soil:** No constraint, except soil C or D usually requires an underdrain.
- **Limitations:** It should not be used for high speed road

Maintenance:

- Inspect the surface of the pavement for evidence of sediment deposition, organic debris, staining or ponding that may indicate surface clogging.
- Vacuum sweeping regularly
- Inspect the structural integrity of the pavement surface,
- Check inlets, pretreatment cells and any flow diversion structures for sediment buildup
- Inspect the condition of the observation well

Advantages:

- Can increase aesthetic value
- Provides water quality treatment
- Dual use for pavement structure and stormwater management
- Meet partial or full storage requirements for local stormwater detention standards
- Retrofit existing developed areas, especially highly impervious areas

Disadvantages:

- Cost
- Maintenance
- Limited to low traffic areas with limited structural loading
- Potential issues with handicap access
- Infiltration can be limited by underlying soil property
- Not effective on steep slopes

Design Checklist:

- ❑ Check feasibility for site
- ❑ Check permeable pavement sizing guidance and make sure there is an adequate footprint (can be split to multiple areas)
- ❑ Calculate design volume
- ❑ Design Permeable Pavement in accordance with design criteria and typical details
- ❑ Submit plans

1. Design

1.1 Application

1.1.1 Types

The pavement course should be selected based on the project's budget and desired appearance as well as the types of loadings that will be applied to the permeable pavement. Designers may propose other types of pavement courses but they will be responsible for showing that their proposed design will function well both hydraulically and structurally in both short and long term. See Table 1 for a summary of the most commonly used pavement courses and some of the pros and cons of each.

Table 1: Types of permeable pavement.

Permeable Interlocking Concrete Pavers (PICP)	PICPs are a type of unit paver system that maintains drainage through gaps between the pavers filled with small, uniformly graded gravel. The pavers are bedded on a gravel layer that provides uniform support and drainage. **Pros:** Well suited for plazas, patios, small parking areas, parking stalls and residential streets. PICP is easy to renovate if it becomes clogged. As compared to PC and PA, PICP is easier and less costly to renovate if it becomes clogged. The Interlocking Concrete Pavement Institute offers a PICP Specialist Certification program for contractors. **Cons:** PICP often has the highest initial cost for materials and installation. The regular maintenance of PICP is more expensive than PC and PA because of the need to refill the gravel after street sweeping and the greater occurrence of weeds.	  Parking lot of St. John Lutheran church, Knoxville, TN (Source: SMART Center)
Pervious Concrete (PC)	PC is produced by reducing the fines in a conventional concrete mix to maintain interconnected void space for drainage. Pervious concrete has a coarser appearance than standard concrete. **Pros:** PC is the most structurally sound permeable course, making it a good choice for travel lanes or larger vehicles in addition to parking areas, patios and residential streets. The regular maintenance costs are lower than PICP and CGP. PC has a design guide, construction specification and a contractor certification program managed by independent organizations (American Concrete Institute and National Ready Mixed Concrete Association). **Cons:** Mixing and installation must be done correctly or the PC will not function properly. It may be difficult to restore permeability to the PC after a significant loss of initial permeability without removing it and installing a new course.	  Hallsdale PUD parking lot, Powell, TN (Source: SMART Center)

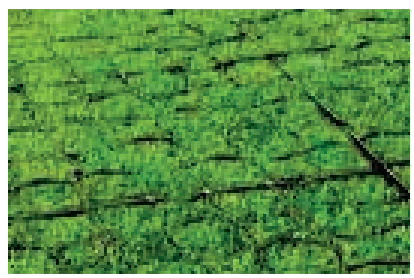
Pervious Asphalt (PA)	Porous asphalt is very similar to standard asphalt except that the fines have been removed to maintain interconnected void space. PA may not be approved unless the designer shows that the design provides equal or better performance than PICP and PC. **Pros:** May be more economical in initial cost than PC for large scale operations (greater than 100,000 square feet). **Cons:** PA does not offer the structural strength of PC and it has a much shorter design life, typically less than 15 years. There are also concerns about unknowingly using asphalt sealants or overlays that would eliminate the permeability of the PA. Mixing and installation must be done correctly or the PA will not function properly.	
Concrete Grid Pavers (CGP)	CGPs are an "older cousin" to PICPs and have relatively larger open areas that are filled with gravel, sand, or even a loamy sand top soil. CGPs may not be approved for vehicular loads unless the designer shows that the design provides equal or better performance than PICP and PC. **Pros:** CGP is a somewhat less expensive paver option than PICP. **Cons:** The vast majority of sites observed exhibited problems with waviness (differential settling) or clogging caused by soil and vegetation in the grids (or both). CGP should only be used for non-travel purposes or occasional use (fire lanes, police cut through lanes, etc).	
Plastic Turf Reinforcing Grid (PTRG)	PTRG, also called geocells, consist of flexible plastic interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turf grass. PTRG is well suited to provide for emergency vehicle access over lawn areas. For other uses, PTRG may not be approved unless the designer shows that the design provides equal or better performance than PICP and PC. **Pros:** Reduces expenses and maximizes lawn area. **Cons:** PTRG has less structural strength than the other pavement course options, especially if used under wet conditions. Also, the use of soil and vegetation between the grids makes it prone to clogging.	

Table 2: Comparative properties of 3 major permeable pavement types.

Design Factor	Porous Concrete (PC)	Pervious Asphalt (PA)	Permeable interlocking concrete pavers (PICP)
Scale of application	Small and large scale paving applications	Small and large scale paving applications	Micro, Small and large scale paving applications
Pavement thickness[1]	5 to 8 inches	3 to 4 inches	3 inches[1,8]
Bedding layer[1,8]	None	2 inches of No. 8 stone	2 inches of No. 8 stone over 3 to 4 inches of No. 57
Construction properties[2,8]	Cast in place, seven day cure, must be covered	Cast in place, 24 hour cure	No cure period; manual or mechanical installation of pre-manufactured units, over 5000 sf/day per machine
Design permeability[4]	10 feet/day	6 feet/day	2 feet/day
Construction cost[5]	$2.00 to $6.50/sq. ft.	$0.50 to $1.00/ sq. ft.	$5.00 to $10.00/ sq. ft.
Min. batch size	500 sq. ft.		NA
Longevity[6]	20 to 30 years	15 to 20 years	20 to 30 years
Overflow	Drop inlet or overflow edge	Drop inlet or overflow edge	Surface, drop inlet or overflow edge
Temperature reduction	Cooling in the reservoir layer	Cooling in the reservoir layer	Cooling at the pavement surface & reservoir layer
Colors/texture	Limited range of colors and textures	Black or dark grey color	Wide range of colors, textures, and patterns
Traffic bearing capacity[7]	Can handle all traffic loads, with appropriate bedding layer design		
Surface clogging	Replace paved areas or install drop inlet	Replace paved areas or install drop inlet	Replace permeable stone jointing materials
Other issues	Avoid seal coating		Snowplow damage
Design reference	American Concrete Institute # 522.1.08	Jackson (2007); NVRA (2008)	Smith (2006); ICPI (2008)

1 Individual designs may depart from these typical cross-sections, due to site, traffic and design conditions.
2 Reservoir storage may be augmented by corrugated metal pipes, plastic arch pipe, or plastic lattice blocks.
3 ICPI (2008)
4 NVRA (2008)
5 WERF 2005 as updated by NVRA (2008)
6 Based on pavement being maintained properly, Resurfacing or rehabilitation may be needed after the indicated period.
7 Depends primarily on on-site geotechnical considerations and structural design computations.
8 Stone sizes correspond to ASTM D 448: Standard Classification for Sizes of Aggregate for Road and Bridge Construction

1.1.2 Design Scales

Permeable pavement can be installed at the following three scales:

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

Table 3: Three design scales for permeable pavement.

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

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

1.2 Major Design Elements

Table 4: Pervious Pavement Design Elements.

Available Space	A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.
Soils	Soil conditions do not constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Groups (HSG) C or D usually require an underdrain, whereas HSG A and B soils often do not. In addition, permeable pavement should never be situated above fill soils unless designed with an impermeable liner and underdrain. If the proposed permeable pavement area is designed to infiltrate runoff without under drains, it must have a minimum infiltration rate of 0.5 inches per hour. Initially, projected soil infiltration rates can be estimated from USDA-NRCS soil data, but they must be confirmed by an on-site infiltration measurement. Native soils must have silt/clay content less than 40% and clay content less than 20%. Designers should also evaluate existing soil properties during initial site layout, and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of HSG A or B soils shown on NRCS soil surveys should be considered as primary locations for all types of infiltration.
External Drainage Area	Any external drainage area contributing runoff to permeable pavement should generally not exceed twice the surface area of the permeable pavement, and it should be as close to 100% impervious as possible. Some field experience has shown that an up gradient drainage area (even if it is impervious) can contribute particulates to the permeable pavement and lead to clogging (Hirschman, et al., 2009). Therefore, careful sediment source control and/or a pre-treatment strip or sump (e.g., stone or gravel) should be used to control sediment run-on to the permeable pavement section.
Pavement Slope	The surface of the permeable pavement must have a slope of ≤ 6%. The surface of the subgrade must have a slope of ≤ 0.5%. Terraces and baffles may be installed to achieve flat subgrades under sloping pavement surfaces.
Water Table	A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.
Design Storm	Permeable pavement must be designed to treat the Runoff Reduction Volume and to provide safe conveyance of the 10-year, 24-hour storm event via infiltration, bypass or detention and release.
Setbacks	Permeable pavement should not be hydraulically connected to structure foundations, in order to avoid harmful seepage. Setbacks to structures and roads vary, based on the scale of the permeable pavement installation (see Table 3). At a minimum, small- and large-scale pavement applications should be located a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines. Setbacks can be reduced at the discretion of the local program authority for designs that use underdrains and/or liners.

Installation	For **PICP, CGP, PRTG, and PRP,** follow manufacturer recommendations and industry standards to ensure lasting effectiveness. Some of the manufacturer requirements that must be considered include designing the bedding course and specifying jointing materials. Any manufacturer requirements should be implemented in addition to (and NOT instead of) the design requirements in this manual. For **PC and PA,** it is crucial to specify the proper mix design. For pervious concrete, the mix design shall be in accordance with the latest version of ACI 522.1 Specification for Pervious Concrete. If installing PC or PICP, it is preferable to use contractors that are certified and use the applicable design guides.
Subgrade	A washed aggregate base must be used. The surface of the subgrade must be scarified, ripped or trenched to maintain the pre-construction subgrade infiltration rate. The subgrade for the permeable pavement must be graded in the dry. The aggregate base and permeable course should be completed as soon as possible to reduce the chance of compaction of the subgrade.
Run On	Permeable pavement may be designed to receive runoff from adjacent impervious surfaces such as roofs and conventional pavement (if the soils are adequate). The design must provide storage for the runoff volume, and there must be a well-designed distribution system. Runoff from adjoining pervious areas, such as grassed slopes and landscaping, must be prevented by grading the landscape away from the site except for instances when draining pervious areas to pavement is unavoidable, such as parking lot islands.
Installation	Permeable pavement must not be installed until the upslope and adjoining areas are stabilized. After installations, barriers must be installed to prevent construction traffic from driving on the pavement.
Hydraulic Head	The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head may be needed to drive flows through underdrains. Flat terrain may affect proper drainage of permeable pavement designs, so underdrains should have a minimum 0.5% slope.
Observation Well	A minimum of one observation well shall be provided at the low point in the system unless the subgrade is terraced; in that case, there shall be one well for each terrace.
Edge Restraints	Edge restraints must be provided around the perimeter of permeable pavement systems (except for pervious concrete) as well as anywhere permeable pavement (of any type) is adjacent to conventional pavement.
Maintenance	The property owner should clearly understand the unique maintenance responsibilities inherent with permeable pavement, particularly for parking lot applications. The owner should be capable of performing routine and long-term actions (e.g., vacuum sweeping) to maintain the pavement's hydrologic functions, and avoid future practices (e.g., winter sanding, seal coating or repaving) that diminish or eliminate them.
High Loading Situations	Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail.
Hotspot	Infiltration of runoff from designated hotspots is highly restricted or prohibited.
High Speed Roads	Permeable pavement should not be used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes and roadway shoulders.
Floodplains	Permeable Pavement should be constructed outside the limits of the 100-year floodplain, unless a waiver is obtained from the local authority.
Signage	Permeable pavement signage must be clearly and permanently posted to prevent use by inappropriate vehicles, and the deposition and storage of particulate matter (except for single family residences, where signage is optional).

1.3 Calculations

1.3.1 Structural Design

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

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

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

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

TDOT Roadway Design Guidelines (REV. August 8, 2014)
http://www.tdot.state.tn.us/chief_Engineer/assistant_engineer_design/design/DesGuide.htm

AASHTO Guide for Design of Pavement Structures (1993)
http://www.transportation.org/

AASHTO Supplement to the Guide for Design of Pavement Structures (1998)
http://www.transportation.org/

1.3.2 Hydraulic Design

Permeable pavement is typically sized to store the complete runoff reduction volume or another design storm volume in the reservoir layer. Modeling has shown that this simplified sizing rule approximates an 80% average rainfall volume removal for subsurface soil infiltration rates up to one inch per hour. More conservative values are given because both local and national experience has shown that clogging of the permeable material can be an issue, especially with larger contributing areas carrying significant soil materials onto the permeable surface.

The infiltration rate typically will be less than the flow rate through the pavement, so that some underground reservoir storage will usually be required. Designers should initially assume that there is no outflow through underdrains, to determine the depth of the reservoir layer, assuming runoff fully infiltrates into the underlying soil.

Design recommendations:

- For design purposes, the native soil infiltration rate (i) should be the field-tested soil infiltration rate divided by a factor of safety of 2. The minimum acceptable native soil infiltration rate is 0.5 inches/hr.
- The porosity (n) for No. 57 stone = 0.40
- Max. drain time for the reservoir layer should be not less than 48 or more than 72 hours.

1.3.2.1 Runoff Volume

The first step in designing permeable pavement SCM is to identify the size of the CDA. Once the CDA is identified, the soil and cover type(s) must then be identified to determine the net runoff volume for the appropriate design storm. Using the cover type(s) to determine the CN for the CDA, the net runoff volume can be calculated from the regionally-specific design storm using Tennessee Runoff Reduction Assessment Tool (TNRRAT). This net runoff volume (or some smaller fraction if another practice will be used to handle the remaining volume) is the target volume to be handled by the Pervious Pavement SCM.

1.3.2.2 Practice Dimensions

Sizing the practice dimension can be done using the TNRRAT, otherwise manual calculation needs to be used.

Inputs needed:

- Location
- Size of CDA
- Cover type
- Approximation of practice surface area and storage depth

Ponding time (T)

An infiltrating permeable pavement system shall be capable of infiltrating the rainfall depth associated with the Runoff Reduction Volume within 48 to 72 hours. The equation for estimating ponding time is provided below.

Equation 1: Ponding Time (T)

$$T = \frac{\mathrm{P}(1+\mathrm{R})}{24 * \mathrm{SF} * \mathrm{i}}$$

Where:

T = Ponding time (days)
P = Depth of the design storm (inches)
R = Aa/Ap, the ratio of the CDA to the permeable pavement area (between 0 and 1)
SF = Safety factor (0.2)
i = Measured in-situ soil infiltration rate (in/hr)

If the ponding time exceeds 72 hours, then the designer can reduce the amount of CDA that drains to the permeable pavement and see if this decreases ponding time to less than 72 hours. Otherwise, the site requires a detention system. It shall be designed to detain the stormwater for a 48 to 72 hour period.

Equation 2: Aggregate Depth for the Runoff Reduction Volume (RRV)

The aggregate depth shall be determined based on the assumption that no infiltration occurs during the design storm. The formula for RRV is as follows:

$$RRV = \frac{P(1+\mathrm{R})}{\mathrm{n}}$$

Where:

RRV = Depth of aggregate needed to treat the runoff reduction volume (inches)
P = Rainfall depth for the design storm (inches)
R = Aa/Ap, the ratio of the CDA to the permeable pavement area (between 0 and 1)
n = porosity of reservoir layer (0.4)

Please note that the bedding layer of aggregate in a PICP system may not be used to provide storage for the runoff reduction volume.

Equation 3: Design for Safe Conveyance of the 10-year, 24-hour Storm

Permeable pavement designs shall include a mechanism for safely conveying the 10- year, 24-hour storm, which may be accomplished through infiltration, bypass, or detention. The permeable pavement can also be designed to meet local requirements for peak attenuation and volume control for larger storms using the same design process described below for the 10-year, 24-hour storm.

$$D_{10} = \frac{P_{10}(1+R) - d * i * SF}{\mathrm{n}}$$

Where:

- D_{10} = Aggregate depth to infiltrate the 10-year, 24-hour storm (inches)
- P_{10} = Rainfall depth for the 10-year, 24-hour storm (inches)
- R = Aa/Ap, the ratio of the CDA to the permeable pavement area (between 0 and 1)
- d = Storm duration (24 hours)
- i = Soil infiltration rate (in./hr)
- SF = Safety factor (0.2)
- n = porosity of reservoir layer (0.4)

1.4 Design Criteria

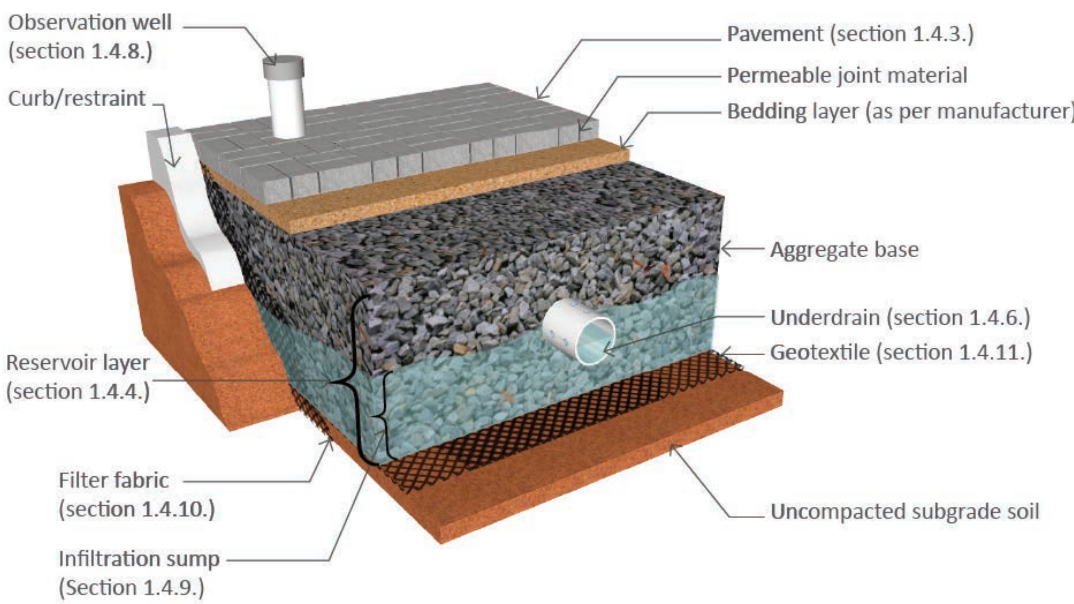


Figure 2: Schematic profile of permeable pavement.

1.4.1 Soil Infiltration Rate Testing

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

1.4.2 Drainage System and Pre-treatment

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

To avoid pavement clogging, pervious areas (such as lawns and landscaping) on the site may not drain to permeable pavement except for instances when this is unavoidable, such as parking lot islands. The site plan must show pervious areas graded to flow away from the pavement or include conveyances to route runoff from pervious surfaces elsewhere. These conveyances should be designed for non-erosive flow during the 10- year, 24-hour storm event or the local conveyance design standard, whichever is larger.

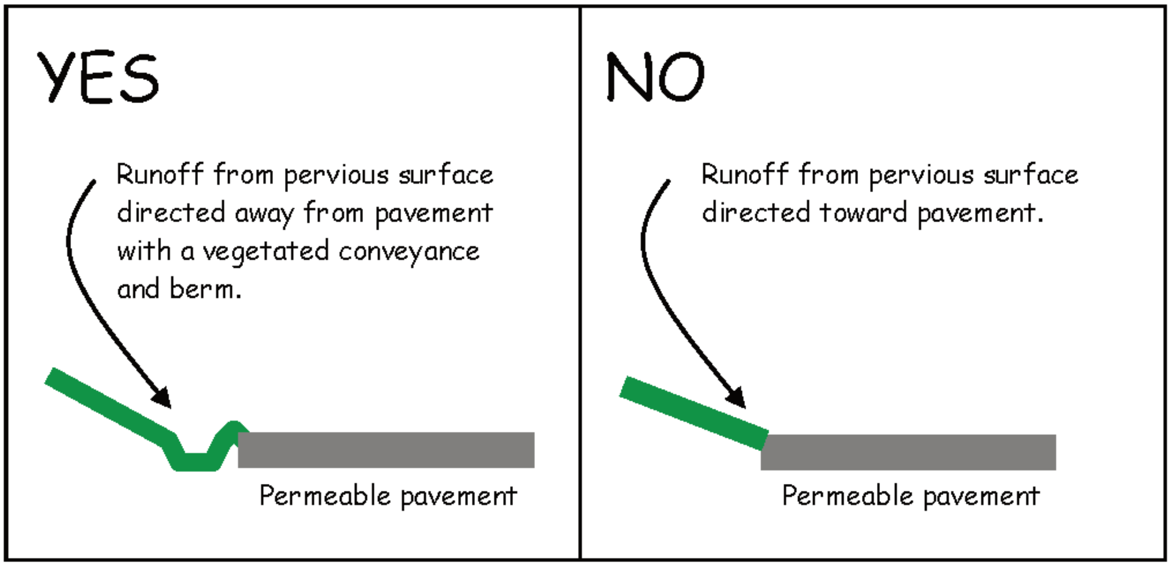


Figure 3: Draining Pervious Areas Adjacent to Permeable Pavement Schematic (Source: NCDENR).

Impervious areas are allowed to drain to the permeable pavement with proper design of the pavement system per this chapter. Examples of areas that may be easily diverted onto the permeable pavement include: travel lanes in parking lots, sidewalks, and roof drains. Roof leaders may be directed to the permeable pavement surface, but it is the designer's responsibility to ensure that these leaders are of a sufficient number and spacing to prevent nuisance flooding. It is recommended that no more than 1000 square feet of impervious area drain to a single point. The additional built-upon area (BUA) draining to the pavement may not exceed the area of the pavement itself (in other words, a maximum 1:1 ratio pavement area to other BUA).

1.4.3 Type of Surface Pavement

The type of pavement should be selected based on a review of the factors in Table 1, and designed according to the product manufacturer's recommendations.

1.4.4 Sub-base Reservoir Layer

The thickness of the reservoir layer is determined by RRV and D_{10} (see Equations 2 and 3). A professional should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The storage layer may consist of clean washed No. 57 stone, although No. 2 stone is preferred because it provides additional storage and structural stability.
- The bottom of the reservoir layer should be completely flat (less than 0.5% slope) so that runoff will be able to infiltrate evenly through the entire surface. A flat subgrade is needed to provide optimal storage capacity within the aggregate base. Terraces and baffles or graded berms can be used in the subgrade design to store stormwater at different elevations so that it can be treated. See Figure 4 for a schematic of how terraces and baffles can be configured in the subgrade. The plan set should include a separate subsurface (subgrade) grading plan, especially for sites with baffles/berms/terraces/bays/cells.

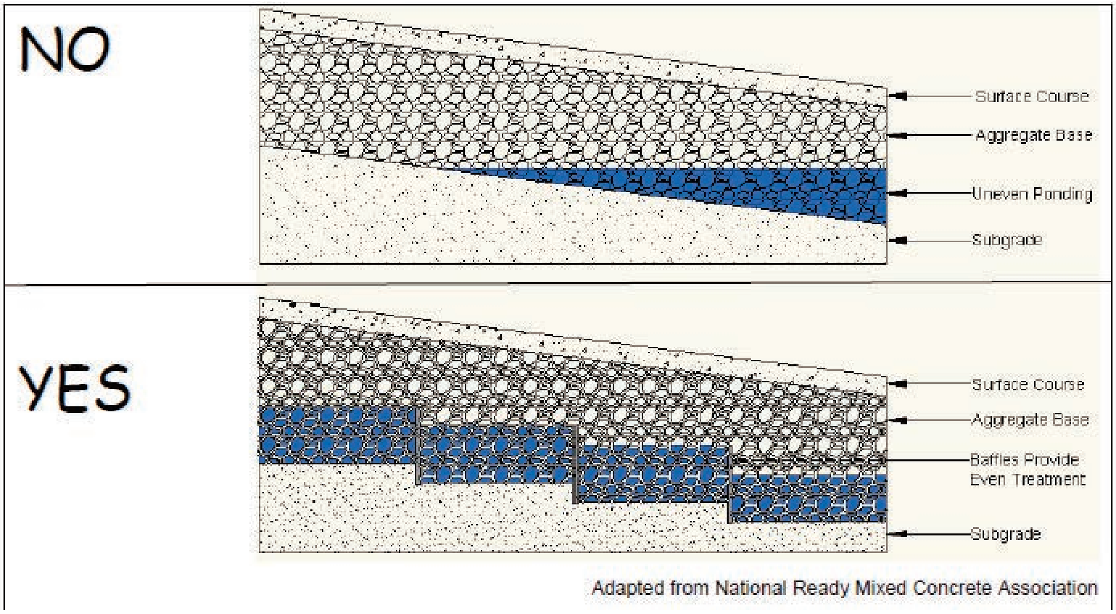


Figure 4: Terraces and baffles under permeable pavement (Source: NCSU-BAE).

1.4.5 Internal Geometry and Drawdowns

- **Elevated Underdrain.** To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain should be installed with a stone jacket that creates a 12 to 18 inch deep storage layer below the underdrain invert.
- **Rapid Drawdown.** When possible, permeable pavement should be designed so that the target runoff reduction volume stays in the reservoir layer for at least 48 hours before being discharged through an underdrain.
- **Conservative Infiltration Rates.** Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.

1.4.6 Underdrains

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

- An underdrain(s) should be placed within the reservoir and encased in 8 to 12 inches of clean, washed stone.
- An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.
- Underdrains should be used in accordance with the following:
  - Minimum 0.5% slope
  - Located 20 feet or less from the next pipe when using multiple pipes
  - Perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center
  - Encased in a layer of clean, washed No.57 stone
  - Include an adjustable outlet control design such as an orifice and weir wall housed within an adjacent manhole or other structure that is easily accessed for maintenance and inspections
  - Outlet control design should ensure that the stone reservoir drains slowly (recommended > 48 hours); however, it must completely drain within 72 hours.

- Infiltration designs can be fitted with an underdrain(s) and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.
- Underdrain cleanouts should be provided if the pavement surface area exceeds 1,000 ft^2.

• Underdrains must be used in locations in which bedrock is encountered less than 2 feet beneath the planned invert of the reservoir layer.

1.4.7 Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms of 10-yr, 24 hour to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place a perforated pipe horizontally near the top of the reservoir layer to pass excess flows after water has filled the base. The placement and/or design should be such that the incoming runoff is not captured (e.g., placing the perforations on the underside only).
- Increase the thickness of the top of the reservoir layer by as much as 6 inches (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system (typically in remote areas). The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.
- Route excess flows to another detention or conveyance system that is designed for the management of extreme event flows. Figures 5 through 9 detail possibilities of safe conveyance of the 10-year, 24 hour storm.

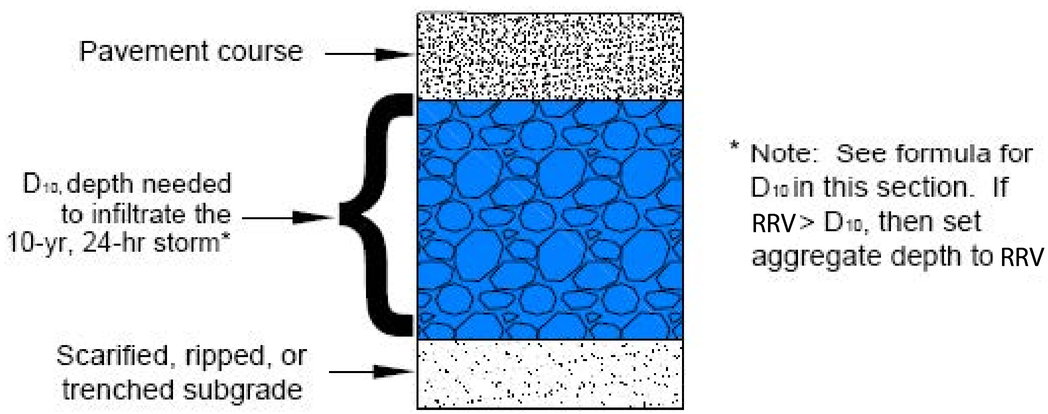


Figure 5: Infiltrate the 10-yr, 24-hr storm (Source: NCSU-BAE).

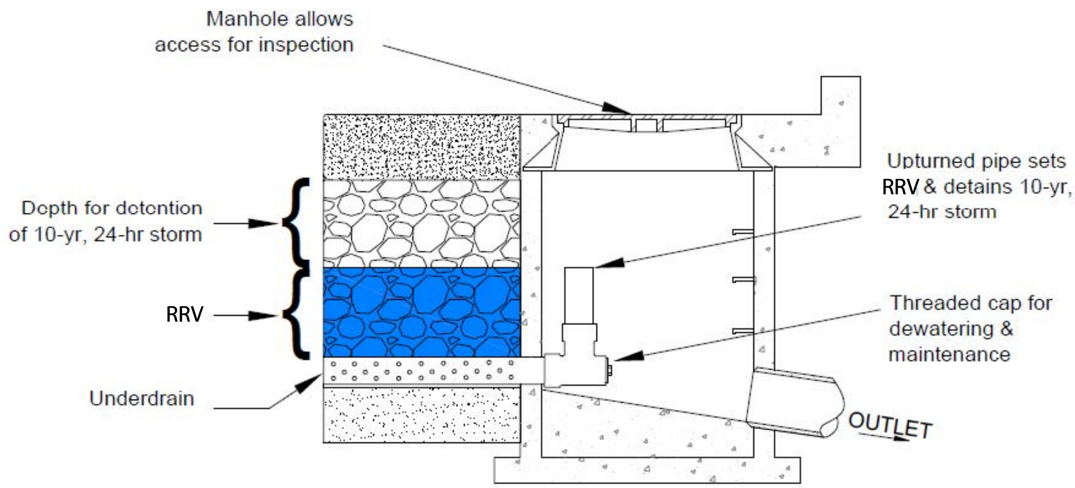


Figure 6: Detail via underdrain with upturned elbow (Source: NCSU-BAE).

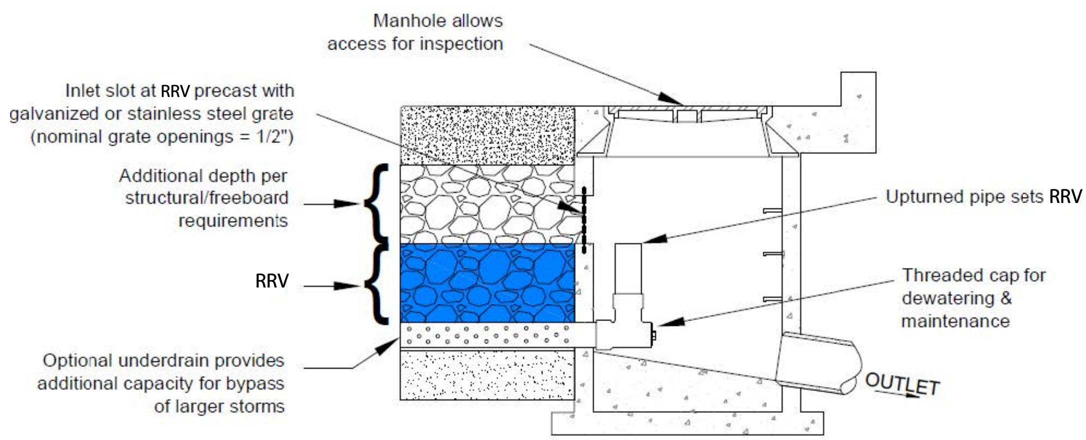


Figure 7: Bypass via subsurface openings in manhole structures (Source: NCSU-BAE).

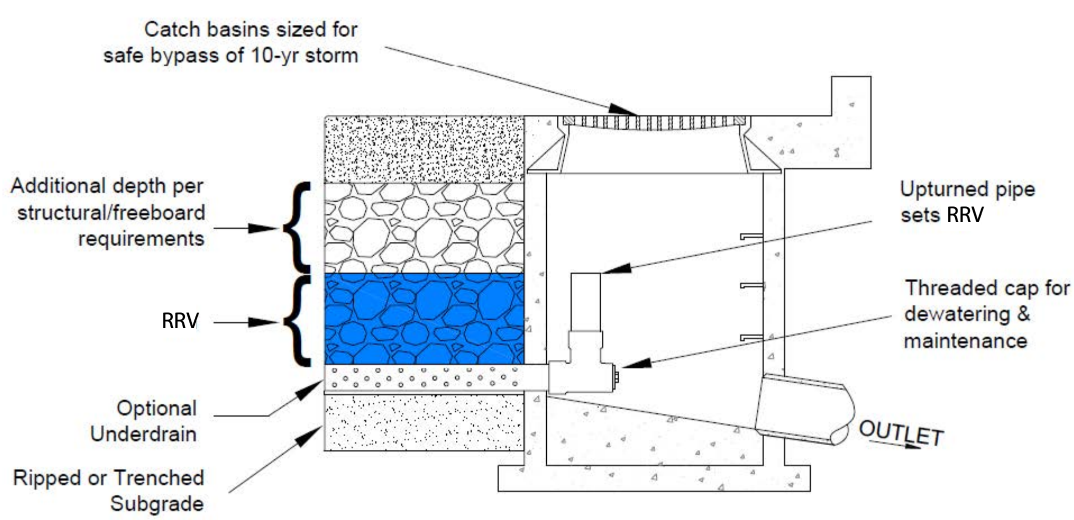


Figure 8: Bypass via catch basin (PC & PA only) (Source: NCSU-BAE).

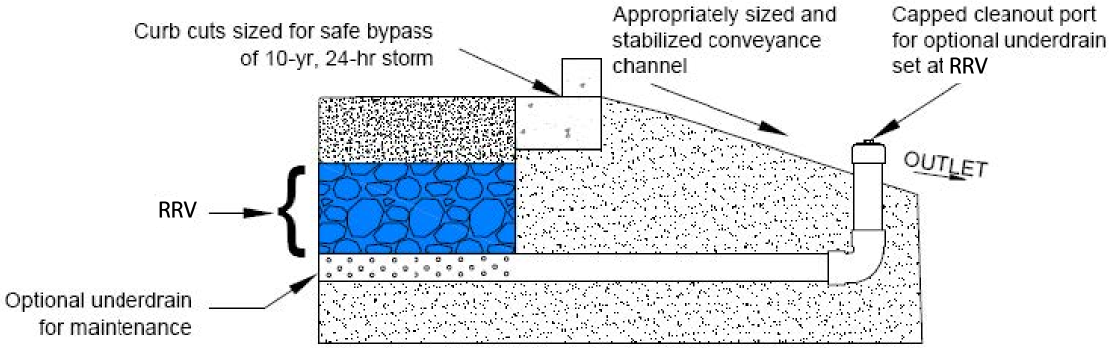


Figure 9: Bypass via curb cut and conveyance (PC only) (Source: NCSU-BAE).

1.4.8 Observation Well

Observations wells measure the elevation of standing water at the subgrade of the permeable pavement system. They are required for all commercial applications and for any residential system exceeding 10,000 square feet. If the subgrade is not terraced, then the observation well should be placed at the lower end of the subgrade slope. If the subgrade is terraced, then one observation well should be built into the lower end of each terrace.

Observation wells should be fitted with a cap installed flush with the pavement surface to facilitate quarterly inspection and maintenance. Observations of the water depth throughout the estimated ponding time (T) provide an indication of how well the water is infiltrating.

The observation well should be placed near the center of the pavement and shall consist of a rigid 4 to 6 inch perforated PVC pipe. This should be capped flush with or below the top of pavement elevation and fitted with a screw or flange type cover.

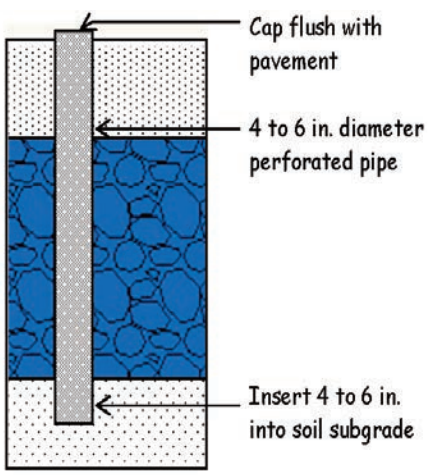


Figure 10: An observation well enables inspection of water infiltration (Source: NCDENR).

1.4.9 Infiltration Sump

The infiltration sump consists of the same stone material as the reservoir layer. The depth of this layer is sized so that the Runoff Reduction Volume of the sump can infiltrate into the subsoil in a 48 to 72 hour period. The bottom of infiltration sump must be at least 2 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

1.4.10 Filter Fabric (optional)

Filter fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of filter fabric beneath Permeable Pavements since it may become a future plane of clogging within the system. Designers should evaluate the paving application and refer to AASHTO M288-06 for an appropriate fabric specification. AASHTO M288-06 covers six geotextile applications: Subsurface Drainage, Separation, Stabilization, Permanent Erosion Control, Sediment Control and Paving Fabrics. However, AASHTO M288-06 is not a design guideline. It is the engineer's responsibility to choose a geotextile for the application that takes into consideration site-specific soil and water conditions. Fabrics for use under permeable pavement should at a minimum meet criterion for Survivability Classes (1) and (2).

1.4.11 Bottom of the Reservoir Layer Protection

There are two options to protect the bottom of the reservoir layer from intrusion by underlying soils. The first method involves covering the bottom with nonwoven, polypropylene geotextile that is permeable, although some practitioners recommend avoiding the use of filter fabric since it may become a future plane of clogging within the system. Permeable filter fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. The second method is to form a barrier of choker stone and sand. In this case, underlying native soils should be separated from reservoir base/subgrade layer by a thin 2 to 4 inch layer of clean, washed, choker stone (ASTM D 448 No. 8 stone) covered by a layer of 6 to 8 inches of course sand.

1.4.12 Impermeable Liner

This material should be used where deemed necessary by a geotechnical investigation; such as in fill applications, karst, adjacent to building foundations, etc. Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

1.4.13 Curb/Edge Restraints and Intersections of Permeable and Impermeable Pavements

Figure 11: Edge restraint (Source: NCDENR).

Edge restraints are an essential element to the structural longevity of a PICP pavement system. Without edge restraints, pavers can "unravel" over time, resulting in movement of pavers. As pavers move, the joints open and unit pavers become damaged. PC pavement systems provide adequate structural edge support and do not require perimeter edge restraints.

Concrete edge restraints (cast-in place or precast curbs) are recommended. Flexible, plastic or metal edging supported with spikes is not recommended for vehicular use. Edge restraints must:

- Extend below the frost line.
- Be flush with the pavement or somewhat higher than the pavement surface. Edge restraints that are higher than the pavement surface help keep the stormwater on the pavement and prevent stormwater run-on from clogging the permeable pavement.

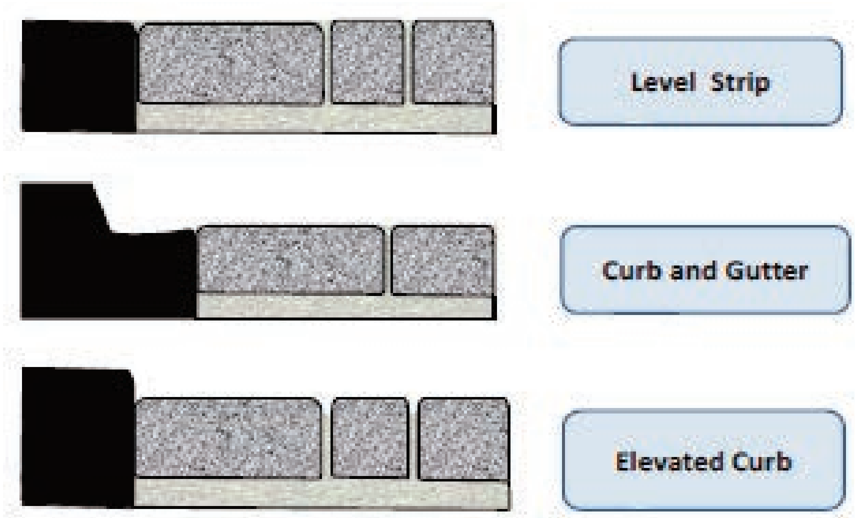


Figure 12: Examples of perimeter edge restraints (Source: NCDENR).

At intersections between permeable pavement and conventional concrete, a geomembrane barrier should be provided to contain the stormwater under the permeable pavement and protect the subgrade under the conventional concrete. There should be a seam between the pavement surfaces for maintenance purposes.

At intersections between permeable pavement and conventional asphalt, a concrete curb that extends below the frost line should be provided to protect the subgrade under the conventional asphalt. The concrete curb will also provide a larger separation between the pavement courses, which will be helpful when the conventional asphalt is resurfaced.

In addition to concrete edge restraints, it is important to consider the boundary between permeable and conventional pavement. The design will differ depending on whether the permeable pavement is adjacent to conventional concrete or conventional asphalt as shown in Figure 13.

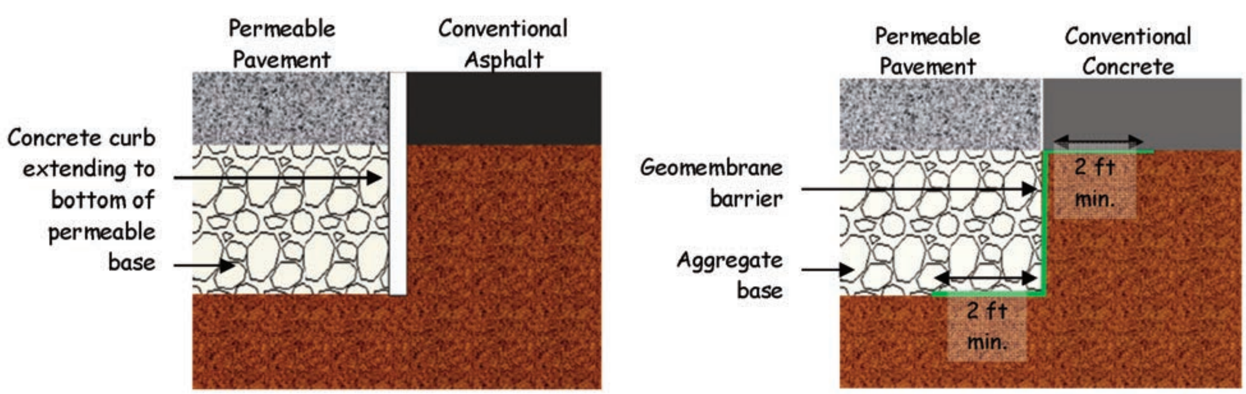


Figure 13: Detail of separation between permeable and conventional pavement (Source: NCDENR).

1.4.14 Signage

Because permeable pavements will be maintained and managed differently than traditional pavements, signage at permeable pavement installations is required. This will promote its prolonged effectiveness and prevent conventional pavement management from damaging the system.

Figure 14 is an example of a sign for a permeable pavement system. The design is based on a 24 by 18 inch standard size for sign production. Even though this graphic is in color, color images are not required. Large permeable pavement applications may require numerous signs.

Figure 14: Example of permeable pavement signage (Source: NCDENR).

1.4.15 Material Specifications

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

Table 5: Material Specifications for Underneath the Pavement Surface.

Material	Specification	Notes
Bedding Layer	PC: None PA: 2 in. depth of No. 8 stone PICP: 2 in. depth of No. 8 stone, over 3 to 4 inches of No. 57	ASTM D448 size No. 8 stone (e.g. 3/8 to 3/16 inch in size). Should be double-washed and clean and free of all fines.
Reservoir Layer	PC: No. 57 stone PA: No. 2 stone PICP: No. 57 stone	ASTM D448 size No. 57 stone (e.g. 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be double-washed and clean and free of all fines.
Underdrain	Use 4 to 6 inch diameter perforated PVC (AASHTO M 252) pipe, with 3/8-inch perforations at 6 inches on center; each underdrain installed at a minimum 0.5% slope located 20 feet or less from the next pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications). Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Filter Layer	The underlying native soils should be separated from the stone reservoir by a thin, 2 to 4 inch layer of choker stone (e.g. No. 8) covered by a 6 to 8 inch layer of coarse sand (e.g. ASTM C 33, 0.02-0.04 inch).	The sand should be placed between the stone reservoir and the choker stone, which should be placed on top of the underlying native soils.

Material	Specification	Notes
Filter Fabric *(optional)*	Use a needled, non-woven, polypropylene geotextile with Grab Tensile Strength equal to or greater than 120 lbs (ASTM D4632), with a Mullen Burst Strength equal to or greater than 225 lbs./sq. in. (ASTM D3786), with a Flow Rate greater than 125 gpm/sq. ft. (ASTM D4491), and an Apparent Opening Size (AOS) equivalent to a US # 70 or # 80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" Soil subgrade, using FHWA or AASHTO selection criteria.	
Impermeable Liner	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd.2 non-woven geotextile. NOTE: THIS IS USED ONLY FOR KARST REGIONS.	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface.	

Table 6: Different Permeable Pavement Specifications.

Material	Specification	Notes
Permeable Interlocking Concrete Pavers	*Surface open area:* 5% to 15% *Thickness:* 3.125 inches for vehicles *Compressive strength:* 55 Mpa *Open void fill media:* aggregate	Must conform to ASTM C936 specifications. Reservoir Layer required to support the structural load.
Concrete Grid Pavers	*Open void content:* 20% to 50% *Thickness:* 3.5 inches *Compressive strength:* 35 Mpa *Open void fill media:* aggregate, topsoil and grass, coarse sand	Must conform to ASTM C1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	*Void content:* depends on fill material *Compressive strength:* varies, depending on fill material *Open void fill media:* aggregate, topsoil and grass, coarse sand	Reservoir layer required to support the structural load.
Pervious Concrete	*Void content:* 15% to 25% *Thickness:* typically 4 to 8 inches *Compressive strength:* 2.8 to 28 Mpa *Open void fill media:* None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt	*Void content:* 15% to 20 %. *Thickness:* typically 3 to 7 in. (depending on traffic load) *Open void fill media:* None	Reservoir layer required to support the structural load.

1.5 Typical Details

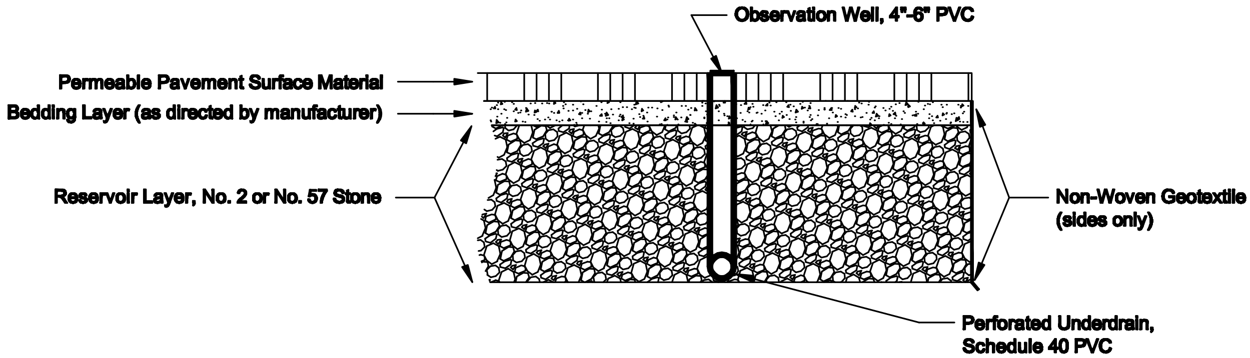


Figure 15: Cross section of a basic permeable pavement design (Source: WVDEP).

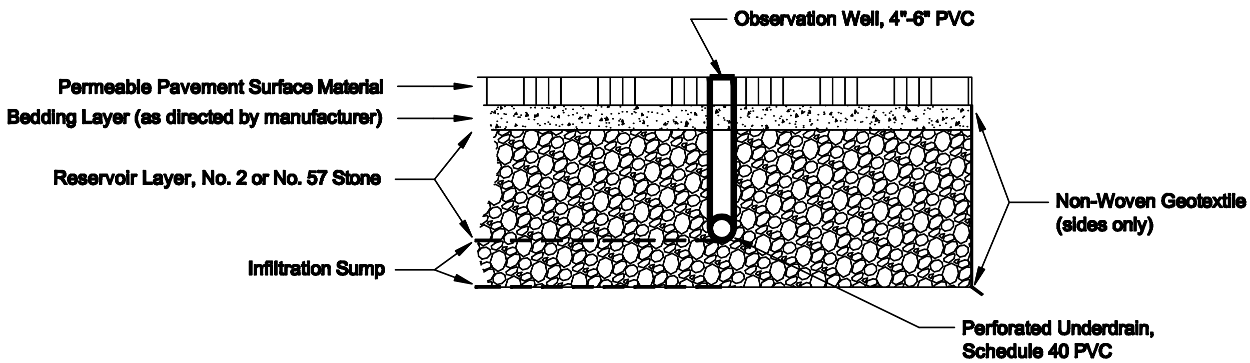


Figure 16: Cross section of a basic permeable pavement design with infiltration sump (Source: WVDEP).

2. Construction

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

2.1 Necessary Erosion & Sediment Controls

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

2.2. Permeable Pavement Construction Sequence

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

Step 1: Stabilize drainage area

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: Install temporary erosion and sediment control

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

Figure 17: *Where possible, excavate soil from the sides of the pavement area to minimize subgrade compaction from equipment (Source: NCSU-BAE).*

Step 3: Excavate the pavement area

Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For micro-scale and small-scale pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction).

Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500 to 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so that cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

The final subgrade slope may not exceed 0.5%.

Figure 18: *Ripping the soil subgrade increases its infiltration rate (Source: Tyner).*

Step 4: Scarified the native soil

The native soils along the bottom and sides of the permeable pavement system should be scarified or tilled to a depth of 6 to 9 inches prior to the placement of the filter layer or filter fabric. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity. (NOTE: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design.)

To rip the subgrade, use a subsoil ripper to make parallel rips six to nine inches deep spaced three feet apart along the length of the permeable pavement excavation. In silty or clayey soils, clean coarse sand must be poured over the ripped surface to keep it free-flowing (Brown and Hunt 2010).

An alternative to ripping is trenching. If trenching is chosen, then parallel trenches 12 inches wide by 12 inches deep shall be made along the length of the permeable pavement excavation. Excavate trenches every 6 feet (measured from center to center of each trench) and fill with ½ inch of clean course sand and 11.5 inches of #57 stone aggregate (Brown and Hunt 2010).

Figure 19: *Trenching used to increase the soil infiltration rate (Source: Tyner).*

Step 5: Install filter fabric

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

Figure 20: *Filter fabric is installed on bottom and sides of reservoir layer (Source R.K.).*

Step 6: Install the underdrain and observation well

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

Figure 21: *Installation of upturned underdrain and observation well (NC 2012, p:27).*

Step 7: Place aggregate base

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

Step 8: Install curb restraints and pavement barriers

Edge restraints and barriers between permeable and impervious pavement shall be installed per design. Before moving on to the next step, be certain that the design and installation are consistent.

Step 9: Install the bedding layer

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

- **Pervious Concrete:** No bedding layer is used.
- **Porous Asphalt:** The bedding layer for porous asphalt pavement consists of 2 inches of clean, washed ASTM D 448 No.8 stone. The filter course must be leveled and pressed (choked) into the reservoir base with at least four (4) passes of a 10-ton steel drum static roller.
- **Interlocking Pavers:** The bedding layer for open-jointed pavement blocks should consist 2 inches of washed ASTM D 448 No.8 stone over 3 to 4 inches of No. 57. The thickness of the bedding layer is to be based on the block manufacturer's recommendation or that of a qualified professional.

Figure 22: *A dump truck deposits aggregate directly into excavated area for spreading (Source: NCSU-BAE).*

Figure 23: *Compacting the open-graded aggregate base (Source: NCSU-BAE).*

Figure 24: *A 2 in. thick bedding course of aggregate is being screed smooth prior to placing the concrete pavers (Source: NCSU-BAE).*

Step 10: Install pavement

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

Figure 25: Alternative way of installing the permeable pavement (Source: R.K.).

Step 11: Protect the pavement through project completion

It is preferable to have the permeable pavement installed at the end of the site construction timeline. If that is not possible, it is important to protect the permeable pavement through project completion. This may be done by:

- Route construction access through other portions of the site so that no construction traffic passes through the permeable pavement site. Install barriers or fences as needed.
- If this is not possible, protect the pavement per the construction documents. Protection techniques that may be specified include mats, plastic sheeting, barriers to limit access, or moving the stabilized construction entrance
- Schedule street sweeping during and after construction to prevent sediment from accumulating on the pavement.

2.3 Construction Inspection

Inspections before, during and after construction are needed to ensure that permeable pavement is built in accordance with these specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intent. Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.
- Check the aggregate material to confirm that it is clean and washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the permeable pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 to 72 hours.
- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.

- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

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

2.4 As-Built Requirements

After installation, an appropriately licensed professional in Tennessee must perform a final as-built inspection and certification that includes:

- Ensuring that the installation remains in good condition and the surface is free of fines.
- Checking that all pervious surfaces are draining away from the pavement and that the overall site is stabilized.
- Verifying that the pavement was installed per the design.
- Preparing the as-built plans that include any changes the underdrains, observation well locations, terrace layouts, aggregate depth or storage structures, any revised calculations, etc.
- Testing the permeability of the pavement surface using an appropriate test such as ASTM C1701 Standard Test Method for Infiltration Rate of In-Place Pervious Concrete.

2.5 Special Case Design Adaptations

2.5.1 Karst Terrain

Permeable pavement infiltration and Infiltration Sump Designs are not recommended in any area with a moderate or high risk of sinkhole formation. A geotechnical investigation and recommendations should be reviewed to consider whether an impermeable bottom liner is necessary. In general, small-scale applications of Permeable Pavement (drainage areas not exceeding one-half acre) are preferred in karst areas in order to prevent possible sinkhole formation.

2.5.2 Steep Slopes

Permeable Pavement can be used on sites with steep slopes; provided the paved areas are terraced and maintain maximum slopes. A geotechnical evaluation should also evaluate the need for impermeable liner on the sides of the stone reservoir to minimize saturation of soils adjacent to steep slopes.

2.5.3 Cold Climate and Winter Performance

The prevalence of sanding and salting operations create additional hazards for Permeable Pavement installations. Since the pavement itself is the pretreatment mechanism for the stone reservoir and infiltration design, precautions such as signage near the entrances to the pavement should specifically warn against applying sand or other grit to the pavement.

Research at the University of New Hampshire Stormwater Center (UNHSC) indicates that Permeable Pavement has a higher frictional resistance than standard pavements and therefore requires less sand and/or salt to maintain braking distance and safety. Further, the internal thermal convection of subsurface ground temperatures serves to warm the permeable pavement section faster than regular pavement, thereby minimizing the need to apply chemicals or salt to accelerate melting (Roseen et al., 2006).

Finally, UNHSC research on Permeable Pavement's durability in cold weather is ongoing with positive results. Properly constructed Permeable Pavements structural durability is comparable to traditional pavement materials (Roseen and Ballestero, 2008). Design variations may include extending the stone reservoir to below the frost line.

2.5.4 Stormwater Retrofitting

Permeable pavement is a versatile retrofitting practice that can be applied in any situation where the existing pavement may require repair or replacement. Considerations include determining if there is enough hydraulic head available to tie underdrains into an existing drainage structure or to daylight.

For more information on retrofitting, see the Center for Watershed Protection's manual, Urban Stormwater Retrofit Practices (Schueler et al., 2007).

3. Maintenance

3.1 Recommended Maintenance Tasks

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.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging

Table 7: Recommended maintenance tasks for permeable pavement practices (WV, 2012, p:27).

Maintenance Tasks	Frequency[1]
• For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.	After installation
• Mow grass in grid paver applications	At least 1 time every 1-2 months during the growing season
• Stabilize the CDA 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 pre-treatment cells and inflow points	Once every 2 to 3 years
• Conduct maintenance using a regenerative street sweeper • Replace any necessary joint material	If clogged

1 Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use

3.2. Winter maintenance

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 partially treated before they reach the Permeable Pavement.
- Sand or cinders should not be applied for winter traction over Permeable Pavement or areas of standard (impervious) pavement that drain toward Permeable Pavement, since it will quickly clog the system. If applied, the materials must be removed by vacuuming in the spring.
- 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, pervious concrete and permeable interlocking concrete pavers can be plowed similar to traditional pavements, using similar equipment and settings.
- Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater. Salt can be applied but environmentally sensitive deicers are recommended. Permeable Pavement applications will generally require less salt application than traditional pavements.

Maintenance agreements must be executed between the owner and the local authority. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not preformed.

All permeable pavement areas must be covered by a drainage easement to allow inspection and maintenance by local authority staff. When Permeable Pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a 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 Appendix F.

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5.4.9 Green Roofs

Description: A green roof consists of vegetated cover used to mimic the hydrologic performance of surface vegetation rather than the surface of an impervious roof. They are effective in reducing the volume of runoff from a roof as well as the rate at which runoff leaves a rooftop. Green roofs help to minimize thermal impacts to downstream receiving waters. They may be designed to accommodate functions ranging from solely rainfall management to more complex systems that integrate rainfall management with livable/usable space.

Figure 1: Greenroof on top of Hallsdale Powell Utility District, TN (Source: SMART Center).

Site Constraints:
- Load capacity of roof
- Roof pitch
- Roof access

Key Design Criteria:
- Load capacity of roof
- Inclusion/exclusion of various layers
- Media composition
- Plant selection

Maintenance:
- Watering, fertilizing, and weeding especially in the first 2 years while plants are becoming established

Advantages:
- Provides volume reduction
- Extends life of a conventional roof by up to 20 years
- Provides increased insulation and energy savings
- Wildlife habitat potential
- Provides sound insulation
- Reduces urban heat island effect
- Utilizes otherwise impervious surface for runoff management
- Protects roof structure from weathering

Disadvantages:
- More maintenance than conventional roof
- May require irrigation
- Potential for roof leaks
- Not suited for groundwater recharge purposes

Design Checklist:
- ❑ Identify management goal(s)
- ❑ Review site constraints
- ❑ Review design criteria
- ❑ Protect site resources
- ❑ Size channel for site conditions
- ❑ Submit plans for review

1. Design

Green roofs are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Green roofs capture and temporarily store stormwater runoff in the growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates from the surface or transpires through plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

A green roof is a layer of vegetated media installed on top of a conventional flat or slightly sloped roof that consists of waterproofing material, root permeable filter fabric, growing media, and specially selected plants. There are two different types of green roof systems: intensive green roofs and extensive green roofs:

- Intensive systems have a deeper growing media layer that ranges from 6 inches to 4 feet thick, which is planted with a wider variety of plants including trees and shrubs.
- Extensive systems typically have much shallower growing media (under 6 inches), which is planted with carefully selected drought tolerant vegetation, usually sedums. Extensive green roofs are much lighter and less expensive than intensive green roofs and are recommended for use on most development and redevelopment sites.

Designers may wish to pursue other design objectives for vegetated roofs, such as energy efficiency, green building or LEED points, architectural considerations, visual amenities, and landscaping features, which are often maximized with intensive green roof systems. However, these design objectives are beyond the scope of this specification. This specification is intended for situations where the primary design objective of the green roof is stormwater management and addresses only extensive roof systems.

1.1 Suggested Applications

Green roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites where space for infiltrative practices can be limited. Green roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for green rooftops due to pollutant leaching through the media (Clark *et al,* 2008).

1.2 Site Constraints

- Green roofs typically need to support 15-30 psf more than a conventional roof
- Optimal roof slope = 1-2 % and max roof slope = 25% with baffles
- Roof access door area >= 16 sf with minimum dimension of 2 ft

Structural Capacity of the roof: Designers must not only consider the stormwater storage capacity of the green roof, but also its structural capacity to support the weight of the additional water. A conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot for an extensive green roof. As a result, a structural engineer, architect, or other qualified professional should be involved with all green roof designs to ensure that the building has enough structural capacity to support a green roof.

Roof Slope: Treatment volume is maximized on relatively flat roofs (a slope of 1 to 2%). However, some slope is needed to promote positive drainage and prevent ponding and/or prolonged saturation of the growing media. Green roofs can be installed on rooftops with slopes up to 25% if baffles, grids, or strips are used to prevent slippage of the media. The effective treatment volume, however, diminishes on rooftops with steep slopes (Van Woert et al, 2005).

Roof Access: Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 2 feet. Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane), and how construction materials will be maneuvered and stockpiled in the limited space.

Building Codes: The green roof design should comply with local building codes with respect to roof drains and emergency overflow devices. If the green roof is designed to be accessible to the public, the access must not only be convenient for installation and maintenance purposes, but also must adhere to local building codes and other regulations for access and safety.

Construction Cost: When viewed strictly as stormwater treatment systems, green roofs can cost $12 to $25 per square foot (Moran et al, 2004, Schueler et al 2007). These cost analyses, however, do not include life cycle cost savings relating to increased energy efficiency, higher rents due to green building scores and increased roof longevity. These benefits over the life cycle of a green roof may make it a more attractive investment compared to traditional roof prices.

Risks of Leaky Roofs: Although well designed and installed green roofs have fewer problems with roof leaks than traditional roofs, there is a perception among property managers, insurers, and product fabricators that this emerging technology could have a greater risk of problems. For an excellent discussion on how to properly manage risk in green roof installations, see Chapter 9 in Weiler and Scholz-Barth (2009).

1.3 Design Criteria

Green roofs typically consist of layers which are designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Green roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after initial establishment. Tray systems are also available with removable dividers allowing the media to meld together creating a seamless appearance but with less difficulty in construction.

Green roofs are typically designed to manage the rainfall that falls onto the vegetated area. They also may be sized to manage runoff from other roof areas where vegetation may not be established (e.g., areas of steeply pitched roofs, air conditioning units). Green roofs that receive drainage from more steeply sloped roof areas should include an area for velocity dissipation (i.e., cobbles) prior to runoff flowing onto the vegetated area.

Regardless of the complexity of the system, green roofs may be designed and constructed to meet stormwater management requirements. Green roof plant species generally have shallow root systems, good regenerative qualities, and resistance to direct solar radiation, drought, frost, and wind. In addition to stormwater benefits, green roofs provide benefits in terms of increased longevity of the roofing system (by protecting the roof from temperature extremes) and insulation benefits that may reduce heating or air-conditioning energy costs. Green roofs always include one or more drainage layers, separation fabrics (which may include root barriers), and a waterproofing system. Designs and specifics vary with different manufacturers and designers.

Overall Sizing: Green roof areas should be sized to capture a portion of the treatment volume. The required size of a green roof will depend on several factors, including the porosity and hydraulic conductivity of the growing media and the underlying drainage materials. Site designers and planners should consult with green roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, the following equation can be used to determine the water quality treatment storage volume retained by a green roof:

$$V = (A * D * n)/12$$

where

V = storage volume (cu. ft.)
A = roof area (sq. ft.)
D = media depth (in.)
n = media porosity (usually 0.3, but consult manufacturer specifications)

Structural Capacity of the Roof: Green roofs can be limited by the additional weight of the fully saturated growing medium and plants, in terms of the physical capacity of the roof to bear structural loads. The designer should consult with a licensed structural engineer or architect to ensure that the building will be able to support the additional live and dead structural load and determine the maximum depth of the green roof system and any needed structural reinforcement. In most cases, fully-saturated extensive green roofs have a maximum load of about 30 psf, which is fairly similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For an excellent discussion of green roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E2397, Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems.

Functional Elements: A green roof is composed of up to eight different systems, or layers, listed below from bottom to top, that are combined together to protect the roof and maintain a vigorous cover. Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary green roofing systems, whereas in other cases, the designer or architect must assemble their own system, in which case they are advised to consult Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004).

1. **Deck Layer:** The roof deck is the foundation of a green 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 green roof system. In general, concrete decks are preferred for green roofs, although other materials can be used as long as the appropriate system components are matched to them.

2. **Waterproofing Layer:** All green roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including built up roofs, modified bitumen, single-ply, and liquid-applied methods (see Weiler and Scholz-Barth, 2009 and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the green roof system.

   Depending on the waterproofing materials selected, a supplemental root-fast layer may be required to protect the primary waterproofing membrane from plant roots. Insulation, if included in the roof covering system, may be installed either above or below the primary waterproofing membrane. Most green roof cover systems can be adapted to either roofing configuration.

3. **Insulation Layer (optional):** Many green rooftops contain an insulation layer, usually located above, but sometimes below, the waxcess water from the vegetation root zone. The drainage layer should consist of synthetic or inorganic materials (e.g. gravel, recycled polyethylene, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors and roof leader. The required depth of the drainage layer is governed by both the required stormwater storage capacity and the structural capacity of the rooftop. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.

   The drainage layer below the growth media should be designed to convey the 10-year storm without inundating the growing media. The drainage layer should convey flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the green roof surface. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging.

   Internal building drainage, including provisions to cover and protect deck drains or scuppers, must anticipate the need to manage large rainfall events without inundating the cover. All green roofs must provide a safe way for water to exit the system when large storms generate more stormwater runoff than the media can hold. The inclusion of a positive overflow route ensures that flooding risks, which can cause overloading of the structural capacity of the building and related property damage, are minimized. The positive overflow route is most often via the downspouts and roof gutters normally provided in the building design. Underdrains may be designed as perforated pipes connected to roof gutters or manufactured products that promote positive drainage.

6. **Root-Permeable Filter Fabric:** A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it.
7. **Growing Media:** The next layer is the growing media, which is typically 4 to 6 inches deep. The depth and composition of the media is described in Materials Specification Section below. The recommended growing media for extensive green roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria or other similar materials. The remaining media should contain no more than 15% organic matter, normally well-aged compost. The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media should have a maximum water retention capacity of around 30%. It is advisable to mix the media in a batch facility prior to delivery to the roof. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).
8. **Plant Cover:** The top layer typically consists of slow-growing, shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. An experienced design professional should be consulted to select the plant species best suited to a given installation. Guidance on selecting the appropriate vegetated roof plants for hardiness zones in Tennessee can be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually Sedum species) and accent plants can be used to enhance the visual amenity value of a green roof.

   A planting plan must be prepared for a green roof by a landscape architect, botanist or other professional experienced with vegetated roofs, and it must be reviewed and approved by the local stormwater program. Plant selection for vegetated rooftops is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most vegetated roof installations is a hardy, low-growing succulent, such as Sedum, Delosperma, Talinum, Semperivum, or Hieracium that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006).

   Other vegetation considerations:

   - The species and layout of the planting plan should reflect the building location, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire resistant and able to withstand heat, cold, and high winds.
   - Designers should also match species to the expected rooting depth of the growing media, which can provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on green roof plant selection, consult Snodgrass and Snodgrass (2006).
   - It is also important to note that most green roof plant species will not be native to the Southeast (which is in contrast to native plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
   - Given the limited number of green roof plant nurseries in the region, designers should order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract grown.
   - The planting window extends from the spring to early fall, although it is important to allow plants to root thoroughly before the first killing frost. Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary green roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
   - When appropriate species are selected, most green roofs will not require supplemental irrigation, except as required during the first year that the green roof is being established or during periods of drought. Green roof covers intended to achieve water quality benefits should not be fertilized.
   - The green roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.

- The goal for green roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining and requires minimal mowing, trimming, or weeding.
- May include a wind erosion stabilization system.

USING THE TNRRAT: Upon specifying a design storm, a drainage area, and any media depths, the TNRRAT will output the volume of water captured by the green roof and any volume of water leaving the green roof and potentially needing further treatment.

Material Specifications: Standards specifications for green roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The American Society for Testing and Materials (ASTM) has recently issued several overarching green roof standards, which are described and referenced in Table 1. Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" green roof systems or modules.

Table 1: Extensive Vegetated Roof Material Specifications.

Material	Specification
Roof	Structural Capacity should conform to ASTM E2397-05, *Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems.* In addition, use standard test methods ASTM #2398-05 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems,* and ASTM E2399-05 for *Maximum Media Density for Dead Load Analysis.*
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Roof Barrier (Optional)	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	1 to 2 inch layer of clean, washed granular material, such as ASTM D 448 size No. 8 stone. Roof drains and emergency overflow should be designed in accordance with local Codes.
Filter Fabric	Needled, non-woven, polypropylene geotextile. Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.
Growth Media	85% lightweight inorganic materials and 15% organic matter (e.g. well-aged compost). Media should have a maximum water retention capacity of around 30%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM #2396-05.
Plant Materials	Low plants such as sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems.*

1.4 Typical Details

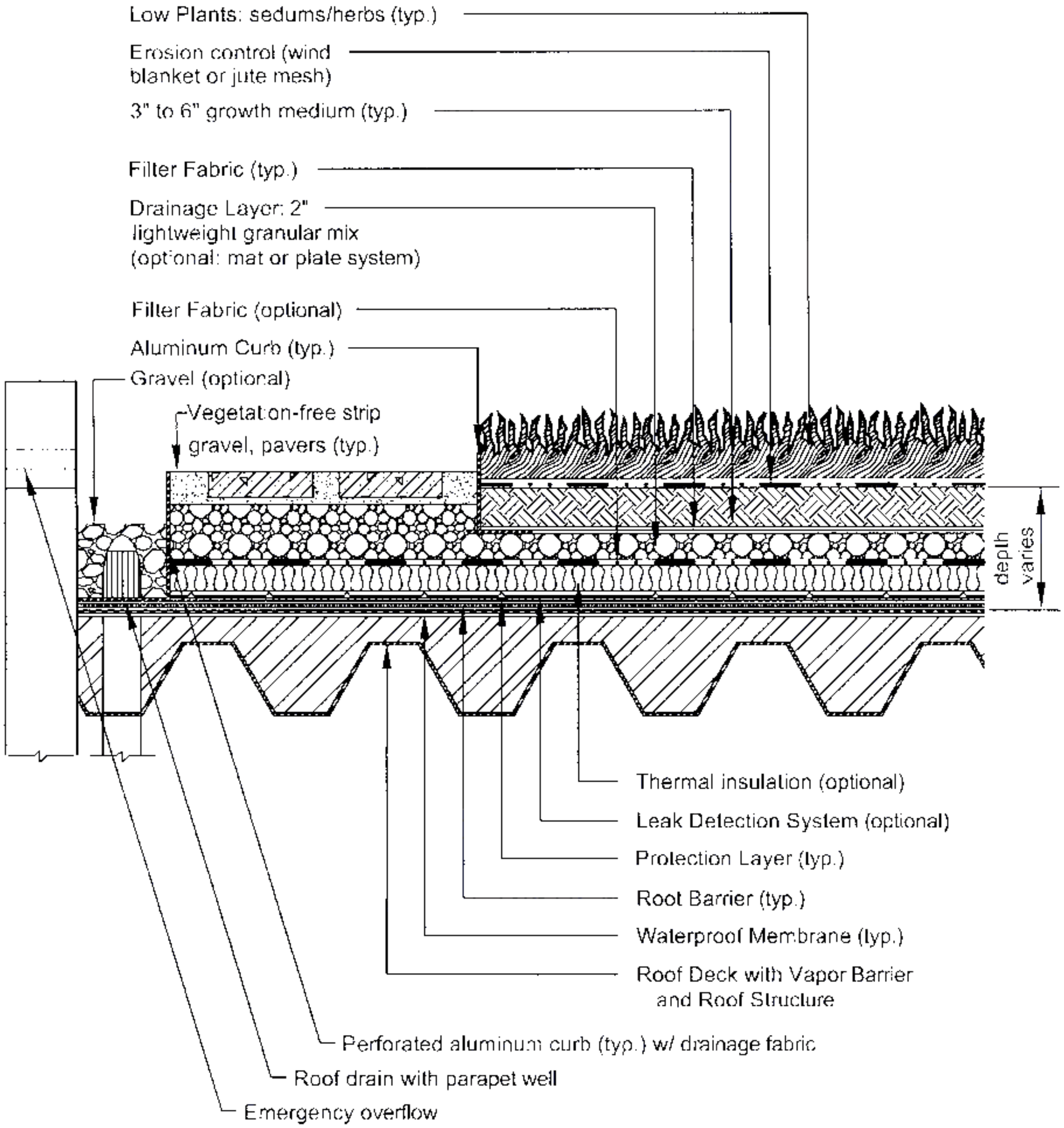

Figure 2: Typical Section – Extensive Vegetated Roof (Source: Northern VA Regional Commission).

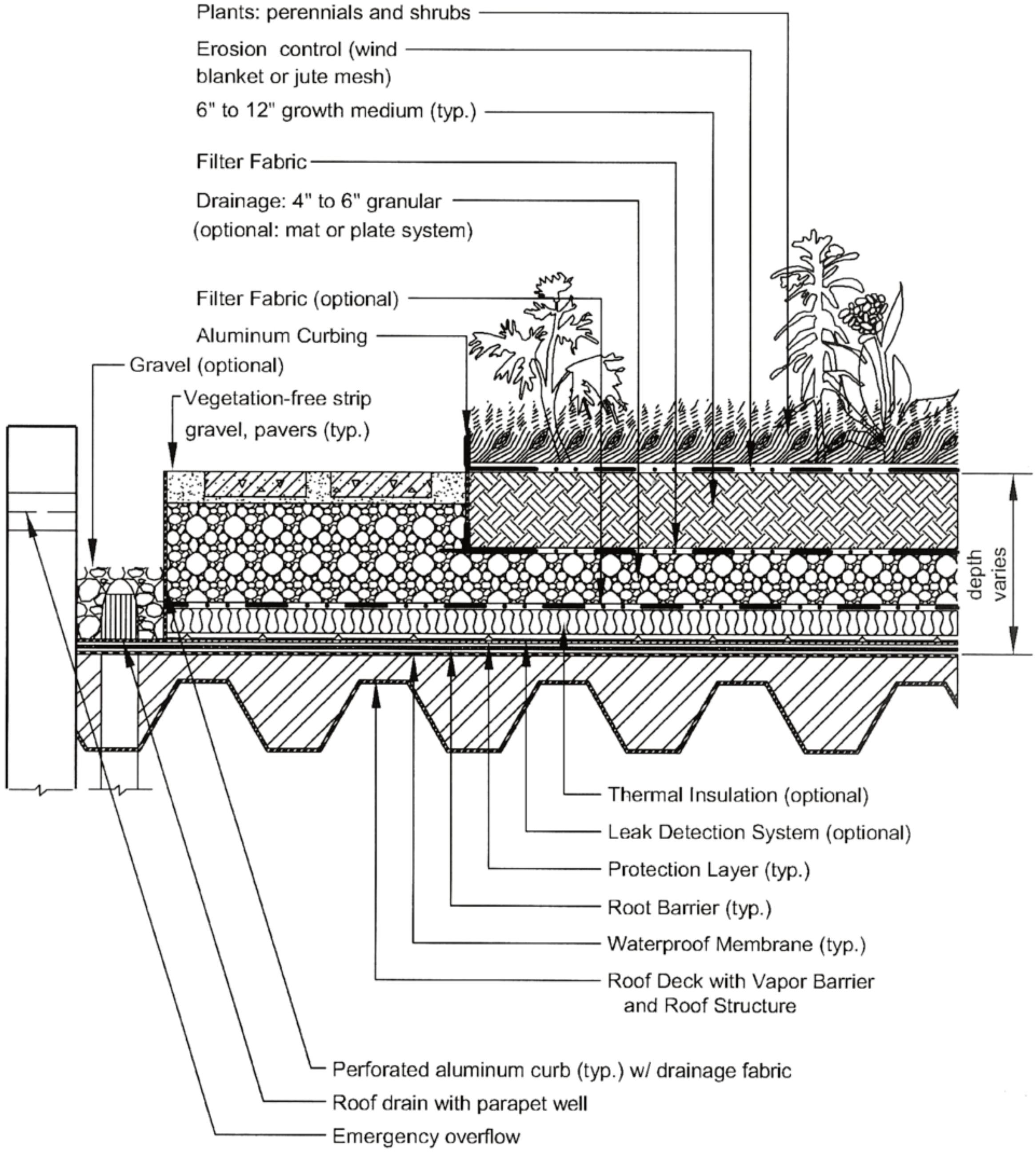

Figure 3: Typical Section – Intensive Vegetated Roof (Source: Northern VA Regional Commission).

Figure 4: Vegetated roof cross-section (Source: NCSU-BAE).

2. Construction

2.1 Pre-Construction

Implement temporary erosion controls, including control measures for dust suppression, during construction until vegetation has been suitably established.

2.2 Construction

An experienced installer should be retained to construct the green roof system. The green roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains.

Given the diversity of extensive green roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer's specifications.
- Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours.
- Add additional system components (e.g., optional insulation, optional root barrier, drainage layer, and interior drainage system, and filter fabric), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.
- The growing media should be moistened prior to planting and then planted with the ground cover and other plant materials, per the planting plan, or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- It generally takes 12 to 18 months to fully establish the green roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. Watering is needed during the first summer. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds).
- Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

2.3 Construction Inspection

Inspections are needed to ensure that the green roof is built in accordance with the design plan and manufacturer's specificiations. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

Careful construction supervision is needed during several steps of green roof installation, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight;
- During placement of the drainage layer and drainage system;
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth;
- Upon installation of plants, to ensure they conform to the planting plan;
- Before issuing use and occupancy approvals.

After the green roof has been constructed, the developer must have an as-built certification of the green roof conducted by a registered professional engineer. The as-built certification verifies that the SCM was installed as designed and approved. The following components are vital components of a properly working green roof and should be addressed in the as-built certification:

1. Protection of vulnerable areas (abutting vertical walls, roof vent pipes, outlets, air conditioning units and perimeter areas) from leakage;
2. Profile view of facility including typical cross-sections with dimensions;
3. Growing medium specification including dry and saturated weight;
4. Filter fabric specification;
5. Drainage layer specification;
6. Waterproof membrane specification, including root barriers;
7. Stormwater piping associated with the site, including pipe materials, sizes, slopes, invert elevations at bends and connections; and
8. Planting and irrigation plan.

3. Maintenance

Examples of the requirements for the Maintenance Document are in Appendix F. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to the local stormwater program.

A green roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns (see Table 2). In addition, the green roof should be hand-weeded to remove invasive or volunteer plants, and plants/media should be added to repair bare areas (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first few years after the green roof is installed. If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the green roof plant communities.

Table 2: Typical Maintenance Activities Associated with Green Roofs.

Activity	Schedule
Water to promote plant growth and survival.	As needed
Inspect the vegetated roof and replace any dead or dying vegetation.	Following Construction
Inspect the waterproof membrane for leaking or cracks.	Semi-annually
Annual fertilization.	As needed
Weeding to remove invasive plants.	As needed
Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris.	Semi-annually
Inspect the green roof for dead, dying or invasive vegetation. Plant replacement vegetation as needed.	As needed

Green roofs designed to integrate human occupancy of roof space should have a maintenance program that includes frequent inspection and removal of accumulated trash and debris.

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5.4.10 Rainwater Harvesting

Description: Rainwater can be used as a resource when it is captured from impervious surfaces, stored in cisterns or rain barrels, and reused as non-potable water. Captured rainwater can be used for landscape irrigation, firefighting needs, toilet flushing, or other grey water uses. Toilet flushing in high-use buildings (i.e., schools, visitor centers) is one of the most effective reuse methods. Roof runoff is generally cleaner and more suitable than runoff from parking lots and roads, which require additional treatment and maintenance to address suspended solids. Runoff capture and reuse reduce the volume and peak flow associated with stormwater runoff).

Figure 1: Cistern in a community garden, Chattanooga (Source: Smart Center).

Site Constraints:
- Contributing area
- Tank location
- Proximity to hotspots
- Roof material

Key Design Criteria:
- Tank size
- Pump or gravity distribution
- Drawdown practice
- Overflow

Maintenance:
- Inspect gutters, downspouts, screens , and filters for debris and remove if necessary
- Inspect tank for leaks and accumulated sediment and address if necessary
- Check flow control components and repair or replace as necessary
- Check all piping and repair or replace as necessary

Advantages:
- Provides volume reduction
- Reduces potable water needed for grey water activities
- Contributes to peak rate reduction

Relative Factors:
- Estimated costs: Moderate
- Runoff reduction: High

Disadvantages:
- Water must be emptied from the cistern to provide volume reduction for the next storm which sometimes requires pump(s)
- Water treatment may be necessary depending on the contaminants in the contributing area and the reuse application.
- Reusing runoff for potable uses is not recommended in the U.S., unless water is treated to all required water quality standards.

Design Checklist:
- ❑ Identify management goal(s)
- ❑ Review site constraints
- ❑ Review design criteria
- ❑ Protect site resources
- ❑ Size channel for site conditions
- ❑ Submit plans for review

1. Design

Cisterns may be above- or below-ground tanks made from a variety of materials including wood, concrete, plastic, or stone. A cistern intercepts, diverts, stores, and releases rainfall for future use. The term cistern is used in this SCM and includes smaller rainwater harvesting systems such as rain barrels (Figures 2 and 3). Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for non-potable water uses and onsite stormwater disposal/infiltration. Non-potable uses may include toilet flushing, irrigation, exterior washing (e.g. car washes, buildings, sidewalks, street sweepers, etc.), cooling tower water, and laundry operations if allowed and approved by local governments.

Figure 2: Set of rain barrels (Source: VADCR, 2011).

Rainwater capture and reuse can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also 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). To enhance their runoff reduction and nutrient removal capability, cisterns can be combined with other rooftop disconnection practices, such as infiltration channels, bioretention cells, or street planter boxes. In this SCM, these down-gradient practices are referred to as “secondary runoff reduction practices.” While the most common uses of captured rainwater are for non-potable purposes, such as those noted above, in some limited cases rainwater can be treated to potable standards.

Figure 3: Residential Nonpotable System – Roanoke VA (Source: VADCR, 2011).

In many instances, rainwater harvesting can be combined with a secondary, down-gradient runoff reduction practice to enhance runoff volume reduction rates and/or provide treatment of overflow from the rainwater harvesting system. Some candidate secondary practices include:

- Filter Strips
- Infiltration Channels
- Bioretention Cells

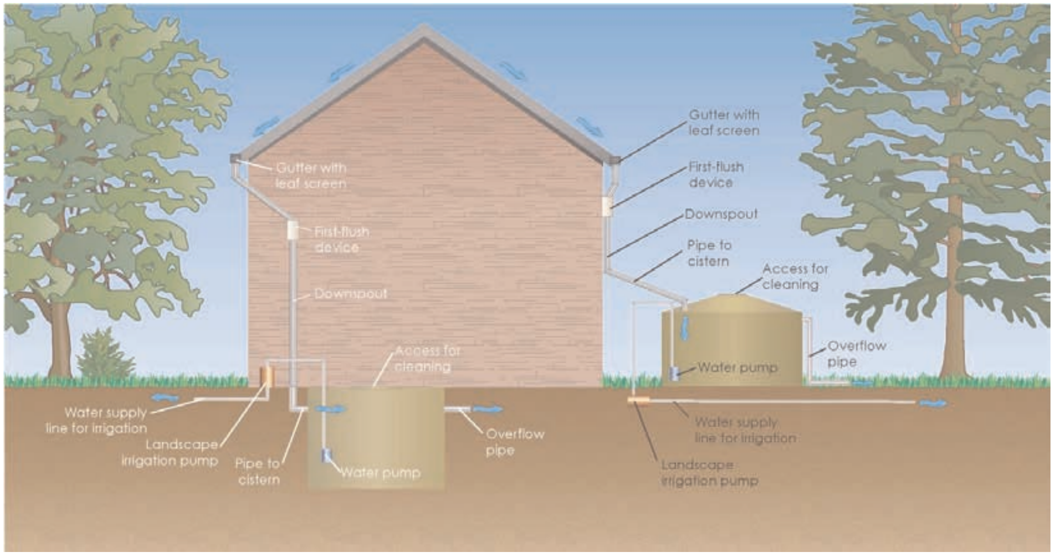


Figure 4: Roof runoff can be captured in cisterns above or below grade and used for irrigation or non-potable water needs (Source: CHCRPC, 2012).

1.1 Suggested Applications

Runoff capture and reuse may be implemented on a variety of sites in urban and suburban environments, on residential, institutional, and commercial properties. Potential applications include office buildings, schools, libraries, multi-family residential buildings, and mixed-use areas for irrigation, fire suppression systems, toilet flushing, or other grey water uses. They can also be used on brownfield sites where the water collected from rooftops is captured and stored before becoming contaminated.

Rainwater harvesting systems can be useful in areas of steep terrain where other stormwater treatments are inappropriate, provided the systems are designed in a way that protects slope stability. Cisterns should be located in level areas where soils have been sufficiently compacted to bear the load of a full storage tank. Harvested rainwater should not be discharged over steep slopes; rather, the rainwater should be used for indoor non-potable applications or outdoor irrigation.

1.2 Site Constraints

A number of site-specific features influence how rainwater harvesting systems are designed and/or utilized. The following 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.

> **NOTE**
>
> Air conditioning condensate (although not a form of stormwater runoff) can also be captured for reuse instead of being discharged to the storm sewer.

1.2.1 Tank Location

Adequate space is needed to house the tank and any overflow structures. Space limitations are rarely a concern with rainwater harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Storage tanks can be placed underground, indoors, on rooftops, within buildings that are structurally designed to support the added weight, and adjacent to buildings.

The bearing capacity of the soil upon which the cistern will be placed should be considered because full cisterns can be very heavy. Storage tanks should only be placed on native soils or on fill in accordance with the manufacturer's guidelines, or in consultation with a geotechnical engineer. This is particularly important for above-ground cisterns since significant settling could cause the cistern to lean or topple. A sufficient aggregate or concrete base may be appropriate depending on the soils.

1.2.2 Contributing Drainage Area

The size of the contributing drainage area(s) must be considered to determine if sufficient runoff will enter cisterns to provide the necessary volume for usage demands. Contributing areas must be evaluated for potential pollutants including metals, fungicides, and herbicides. Often, contributing drainage areas are rooftops. Roofs made of copper or that are treated with fungicides or herbicides should not be used for rainwater capture and reuse. Consideration of roof pitch, roofing materials, and large overhanging trees must be made when evaluating capture and reuse. Pavement areas, such as parking lots, sidewalks, or roadways, may also be captured for irrigation reuse but may require more treatment.

The contributing drainage area to the cistern is the impervious area draining to the tank. In general, only rooftop surfaces should be included in the contributing drainage area. Runoff should be routed directly from rooftops 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. The quality of the harvested rainwater will vary according to the roof material 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, unless new information determines that these materials are sufficient for the intended use and are allowed by your local government. 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).

1.2.3 Elevation Requirement

Site topography and tank location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system. The total elevation drop will be realized beginning from the downspout leaders to the final mechanism receiving gravity-fed discharge and/or overflow from the cistern. These elevation drops will occur along the sloping lengths of the underground roof drains from roof drain leader downspouts at the building all the way to the cistern. A vertical drop occurs within the filter before the cistern. The cistern itself must be located sufficiently below grade and below the frost line, resulting in an additional elevation drop. When the cistern is used for additional volume detention for channel and/or flood protection, a peak-rate-attenuating orifice may be included with a low invert specified by the designer. An overflow having an invert elevation will always be present within the system. Both the orifice (if specified) and the overflow will drain the tank during large storms, routing this water through an outlet pipe, the length and slope of which will vary from one site to another. All these components of the rainwater harvesting system have an elevation drop associated with them. The final invert of the outlet pipe must match the invert of the receiving mechanism (natural channel, storm drain system, conveyance to secondary practice, etc.) that receives this overflow. These elevation drops and associated inverts should be considered early in the design in order to ensure that the rainwater harvesting system is feasible for the particular site.

The required 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, at a sufficiently high elevation, which then serves the internal demands through gravity-fed head. Cisterns can also use gravity to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure. In cases where cisterns are located on building roofs in order to operate under gravity-fed conditions, the roof structure must be designed to provide for the added weight of the rainwater harvesting system and stored water.

Site topography and tank location will also affect the amount of pumping needed. Locating storage tanks in low areas will make it easier to route roof drains from buildings to cisterns. However, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigate areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter roof drains with smaller slopes. However, this will also reduce the amount of pumping needed for distribution. In general, it is often best to locate the cistern close to the building, ensuring that minimum roof drain slopes and enclosure of roof drain pipes are sufficient.

1.2.4 Water Table

Underground storage tanks are most appropriate in areas where the tank can be buried above the water table. The tank should be located in a manner that will not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from "floating"), conducting buoyancy calculations when the tank is empty, etc. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The tank must also be installed according to the tank manufacturer's specifications.

1.2.5 Water Quality

Designers should note that the pH of rainfall in the eastern United States tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from the roof surface, tank lining or water laterals to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Cistern supplies may also need a pH adjustment, since rainwater may be corrosive towards metals in the system if the pH is less than 6.5. Limestone or other materials may be added in the tank to buffer acidity, if desired.

Often, contributing drainage areas are rooftops. Consideration of roof pitch, roofing materials, and large overhanging trees must be made when evaluating capture and reuse. Roofs made of copper or that are treated with fungicides or herbicides should not be used for rainwater capture and reuse. Pavement areas, such as parking lots, sidewalks, or roadways, may also be captured for irrigation reuse but may require more treatment due to the presence of suspended solids.

If runoff contains sediment or other contaminants, additional treatment such as solids settling or UV disinfection may be required prior to using water, depending on usage goal(s) (Metro, 2013). Treatment of water for reuse may be necessary depending on the contaminants in the contributing drainage area. Reusing runoff for potable uses is not recommended, unless the water is treated to meet all required water quality standards. All collection and redistribution of stormwater runoff have the potential to cause human pathogenic issues. All capture and reuse SCMs that involve human contact must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water. Both ultraviolet (UV) and ozone disinfection systems are available for this purpose .

1.2.6 Setbacks and Utilities

Cistern overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. Storage tanks should be designed to be watertight to prevent water damage when placed near building foundations. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation.

Underground utilities or other obstructions should always be identified prior to final determination of the tank location. Before digging, call Tennessee One-Call (811) to get underground utility lines marked. All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems. Underground utilities must be marked and avoided during the installation of underground tanks and piping associated with the system. Appropriate minimum setbacks from septic drain fields should be observed.

1.2.7 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 and should not be fitted with cisterns.

1.2.8 Vehicle Loading

Whenever possible, underground 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.

1.3 Design Criteria

1.3.1 Runoff Volume

Many rainwater harvesting system variations can be designed to meet user demand and stormwater objectives. This SCM focuses on providing a design framework for addressing the design treatment volume. The actual runoff reduction rates for rainwater harvesting systems are based on tank size, configuration, demand drawdown, and use of secondary practices.

The number of rain barrels or the size of the cistern required will be determined by the drainage area, the intended capture goal, and the usage needs of the reuse application. The designer must select a pump of adequate capacity to meet the flow requirements for the reuse system. A rain barrel or cistern provides volume management within the storage device only. The size of the storage device is dependent on the contributing drainage area.

Underground storage tanks must be above groundwater level. Certain roof materials may leach metals or hydrocarbons, limiting potential uses for harvested rainwater. Underground tanks should be set at least 10 feet from building foundations. Cistern overflows should be designed to avoid soil saturation within 10 feet of building foundations. Systems must be designed for consistent drawdown year round. Aboveground storage tanks should be UV resistant and opaque to inhibit algae growth. Underground storage tanks must be designed to support anticipated loads. Hookups to municipal backup water supplies must be equipped with backflow prevention devices.

1.3.2 Primary Components

Cisterns may be above- or below-ground tanks made from a variety of materials such as wood, concrete, plastic, or metal. Storage devices should be sized to store the appropriate runoff volume from the contributing capture area and reuse needs should be adequate to drain the cistern within 72 hours to ensure that sufficient storage is available for subsequent rainfall events. A rain barrel or cistern provides volume management within the storage device only. The size of the storage device is dependent on the contributing drainage area.

There are six primary components of a rainwater harvesting system

- Roof surface
- Collection and conveyance system
- Pre-screening and first flush diverter
- Storage tank(s)
- Distribution system
- Overflow, filter path, or secondary runoff reduction practice

Each of these system components is discussed below.

Roof surface: 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. If the harvested rainwater is selected for uses with significant human exposure (e.g. pool filling, watering vegetable gardens), care should be taken in the choice of roof materials. Some materials may leach toxic chemicals making the water unsafe for humans.

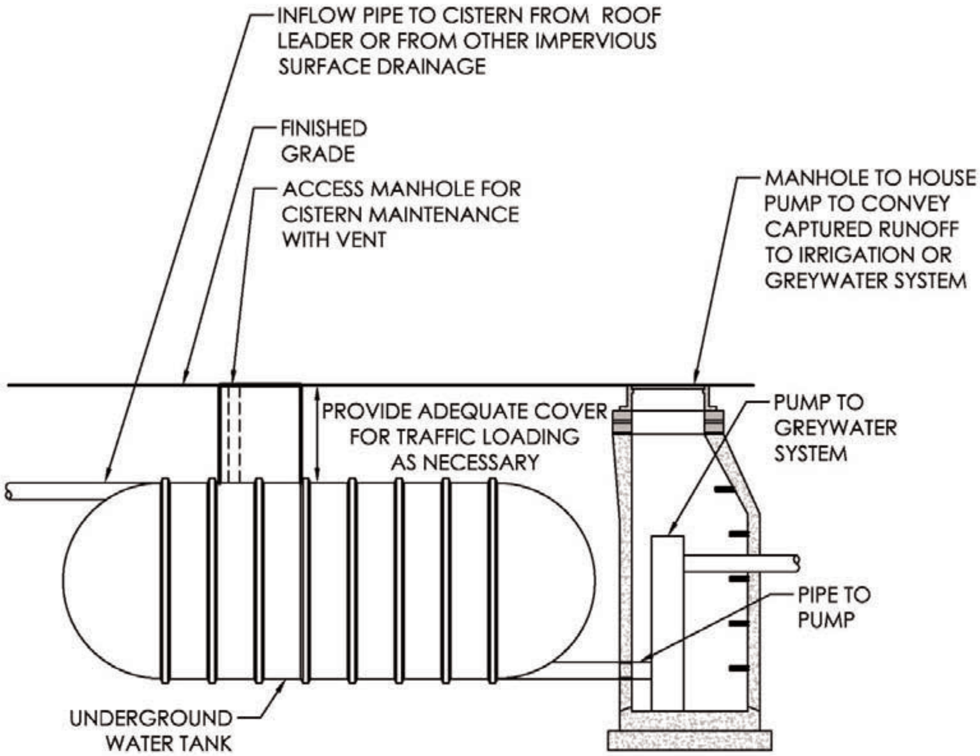


Figure 5: Cross-section of an underground cistern (Source: CHCRPC).

Collection and conveyance system: The collection and conveyance system consists of the gutters, downspouts, and pipes that channel stormwater runoff into storage tanks. 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. Minimum slopes of gutters should be specified. At a minimum, gutters should be sized with slopes specified to contain the 1-inch storm at a rate of 1-inch/hour for treatment volume credit. If volume credit will also be sought for channel and flood protection, the gutters should be designed to convey the 2- and 10-year storm, using the appropriate 2- and 10-year storm intensities, specifying size and minimum slope. In all cases, gutters should be hung at a minimum of 0.5% for 2/3 of the length and at 1% for the remaining 1/3 of the length.

Pipes connecting downspouts to the cistern tank should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. 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. Gutters and downspouts should be kept clean and free of debris and rust.

Pre-screening and first flush diverter: Inflow must be pre-screened to remove leaves, sediment, and other debris. For large systems, the first flush (0.02 – 0.06 inches) of rooftop runoff should be diverted to a secondary treatment practice to prevent sediment from entering the system. Rooftop runoff should be filtered to remove sediment before it is stored. Pre-filtration is required to keep sediment, leaves, contaminants and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices should be low-maintenance or maintenance-free. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources.

When runoff enters a rain barrel or cistern through roof leaders, it should pass through a first-flush diverter that is self-draining with a cleanout. Runoff captured from paved surfaces may enter a subsurface cistern through stormwater structures and piping, or after first passing through a water quality, pretreatment SCM. A first-flush diverter with a cleanout should be a part of the piping system conveying runoff to the cistern.

For larger tank systems, the initial first flush must be diverted from the system before rainwater enters the storage tank. Designers should note that the term "first flush" in rainwater harvesting design does not have the same meaning as has been applied historically in the design of stormwater treatment practices. In this SCM, the term "first flush diversion" is used to distinguish it from the traditional stormwater management term "first flush". The amount can range between the first 0.02 to 0.06 inches of rooftop runoff. The diverted flows (first flush diversion and overflow from the filter) must be directed to an acceptable pervious flow path that will not cause erosion during a 2-year storm or to an appropriate SCM on the property for infiltration. Preferably the diversion will be conveyed to the same secondary runoff reduction practice that is used to receive tank overflows.

Various first flush diverters are described on the following pages. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the storage tank. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the tank at all. A design intensity of 1-inch/hour should be used for the purposes of sizing pre-tank conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA, 2004). If the system will be used for channel and flood protection, the 2- and 10-year storm intensities should be used for the design of the conveyance and pretreatment portion of the system. For the 1-inch storm treatment volume, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion. For the 2- and 10-year storms, a minimum filter efficiency of 90% should be met.

First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. 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. Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred pretreatment method if the water is to be used for indoor purposes. A vortex filter may serve as an effective pre-tank filtration device and first flush diverter.

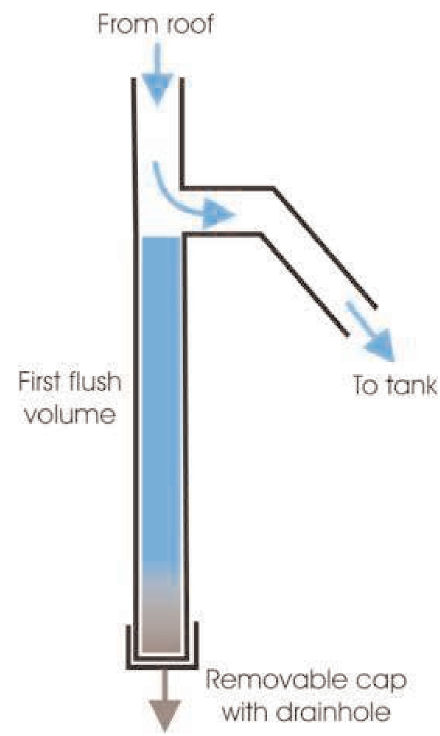


Figure 6: Simple first flush diverters (Source: Boodram and Cox).

Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective. If not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005).

Screens should be used on gutters, inlets, and outlets to limit debris entering the system. A first-flush diverter may be used to prevent leaf litter and other debris from rooftops from entering cisterns. Captured runoff has the potential to collect sediment, metals, dust, bird waste, and other foreign components that may contribute to pathogenic growth, discolor collected water, or add an odor to reused water. These concerns may be minimized by avoiding collection of water from areas with large overhanging trees and installing gutter guards to prevent leaf litter and other large debris from entering the cistern from roofs. Regular inspection and cleaning of both the distribution system and the cistern tank itself will prevent contamination of reuse systems from sediment, trash, and debris.

Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater. 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 (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

For large scale applications, vortex filters can provide filtering of rooftop rainwater from larger rooftop areas.

When runoff enters a rain barrel or cistern through roof leaders, it should pass through a first-flush diverter that is self-draining with a cleanout (see Figure 6). Runoff captured from paved surfaces may enter a subsurface cistern through stormwater structures and piping, or after first passing through a water quality, pretreatment SCM. A first-flush diverter with a cleanout should be a part of the piping system conveying runoff to the cistern.

Storage tank(s): Storage tanks are sized based on consideration of indoor and outdoor water demand, long-term rainfall and rooftop capture area. (Metro, 2013) The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities can range from 250 to over 30,000 gallons. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage onsite as needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Storage tank volumes are calculated to meet the water demand and stormwater treatment volume objectives, as described in this section.

While many of the graphics and photos in this SCM depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped or step vertically to match the topography of a site. The following factors should be considered when designing a rainwater harvesting system and selecting a storage tank:

- Aboveground storage tanks should be UV and impact resistant.
- Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- Underground rainwater harvesting systems should have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point should be secured to prevent unwanted access.
- All rainwater harvesting systems should be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials.
- Storage tanks should be opaque or otherwise protected from direct sunlight to inhibit algae growth and should be screened to discourage mosquito breeding and reproduction.
- Dead storage below the outlet to the distribution system and an air gap at the top of the tank should 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 will 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. Check with your local government for any regulations pertaining to this.

Distribution system: The rainwater harvesting system should be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses. Distribution lines should be installed with shutoff valves and cleanouts, and should be buried beneath the frost line or insulated to prevent freezing. Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary runoff reduction practice. Separate plumbing labeled as non-potable may be required. The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the storage tank 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. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

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, should be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes should be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter. (Metro, 2013)

Overflow, filter path, or secondary runoff reduction practice: The system must be designed with an overflow mechanism to divert runoff when the storage tanks are full. Overflows should discharge to pervious areas set back from buildings and paved surfaces, or to secondary SCMs. All rain barrels and cisterns must provide a safe way for water to exit the system when it is full, such as when large storms generate more stormwater runoff than the storage device is designed to hold. The cistern can be designed to slowly drain to the landscape between storm events to provide capacity. The overflow should convey runoff to an approved discharge point. The size of the overflow device or orifice should be equal in area to the total of all inlet orifices.

An overflow mechanism should be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe should be screened to prevent access to the tank by rodents and birds.

The filter path is a pervious or grass corridor that extends from the overflow to the next runoff reduction practice, the street, an adequate existing or proposed channel, or the storm drain system. The filter path must be graded with a slope that results in sheet flow conditions. If compacted or impermeable soils are present along the filter path, compost amendments may be needed. It is also recommended that the filter path be used for first flush diversions. In many cases, rainwater harvesting system overflows are directed to a secondary runoff reduction practice to boost overall runoff reduction rates.

Backup: When used for grey water reuse (such as toilet flushing), a backup water supply is required to supplement the system during dry periods. Backflow preventers must be installed on water service lines from cisterns. Collection and reuse systems must include an emergency overflow for large storm events.

Area and Dimensions: The number of rain barrels or the size of the cistern required will be determined by the drainage area, the intended capture goal, and the usage needs of the reuse application. If water is to be pumped from the cistern, the designer must select a pump of adequate capacity to meet the flow requirements for the reuse system.

Water Quality: All capture and reuse SCMs must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water. All cisterns should be shaded to the maximum extent possible to help prevent algal growth. Storage tanks should be placed in cool, shaded areas to help prevent algal growth. Cisterns must be watertight, vented, completely covered or screened, composed of non-reactive materials, and be approved for potable water storage, although runoff cannot be used for potable needs without treatment. This includes irrigation water that has any human contact (i.e., sprinklers). If the storage device is open to the air, a screen or other cover is necessary to prevent mosquito breeding. Cistern seams should be checked regularly for leaks.

Design criteria: The rainwater harvesting cistern sizing criteria presented in this section was developed using best estimates of indoor and outdoor water demand, long-term rainfall data, and rooftop capture area data. Rainwater tank sizing is determined by accounting for varying precipitation levels, captured rooftop runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for treatment volume (permanent storage), storage needed for channel protection and flood volume (temporary detention storage), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See Figure 7 for a graphical representation of these various incremental design volumes.

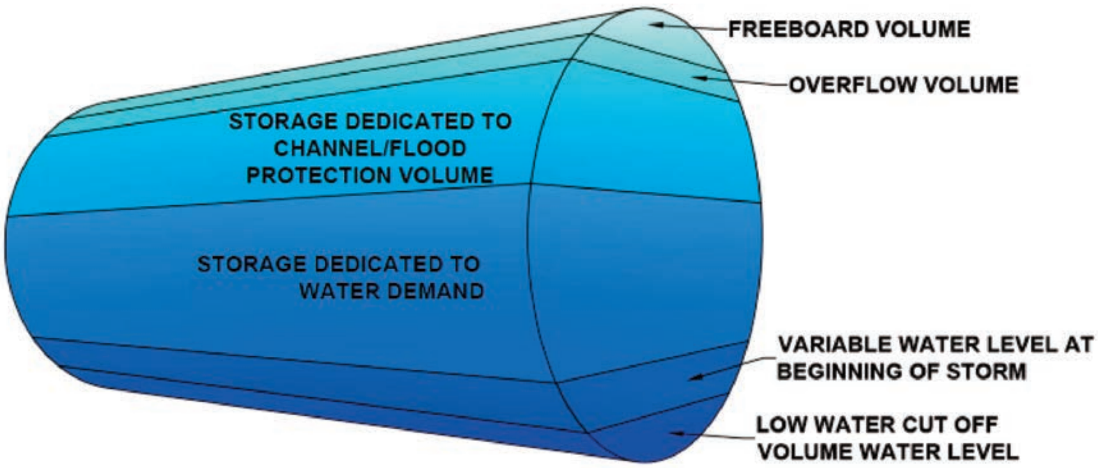


Figure 7: Incremental Design Volumes associated with tank sizing (Adapted from VADCR, 2013, p.24).

The "Storage Associated with the Treatment Volume" is the storage within the tank that is modeled and available for reuse. While the Treatment Volume will remain the same for a specific rooftop capture area, the "Storage Associated with the Treatment Volume" may vary depending on demand and runoff reduction credit objectives. It includes the variable water level at the beginning of a storm and the low water cut-off volume that is necessary to satisfy pumping requirements.

Material specifications: Examples of basic material specifications for rainwater harvesting systems are presented in Table 1. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table 1: Design Specifications for Rainwater Harvesting Systems.

Item	Specification
Gutters and Downspout	Materials commonly used for gutters and downspouts include PVC pipe, vinyl, aluminum and galvanized steel. Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. • The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tanks. • Be sure to include needed bends and trees.
Pre-Treatment	At least one of the following (all rainwater to pass through pre-treatment): • First flush diverter • Vortex filter • Roof washer • Leaf and mosquito screen (1 mm mesh size)
Storage Tanks	• Materials used to construct storage tanks should be structurally sound. • Tanks should be constructed in areas of the site where native soils can support the load associated with stored water. • Storage tanks should be water tight and sealed using a water-safe, non-toxic substance. • Tanks should be opaque to prevent the growth of algae. • Re-used tanks should be fit for potable water or food-grade products. • Underground rainwater harvesting systems should have a minimum of 18 to 24 inches of soil cover and be located below the frost line. • The size of the rainwater harvesting system(s) is determined during the design calculations.

Note: This table does not address indoor systems or pumps.

1.3.3 System Configurations

From a rainwater harvesting standpoint, there are numerous potential configurations that could be implemented. However, in terms of the goal of addressing the design treatment volume, this SCM adheres to the following concepts in order to properly meet the stormwater volume reduction goals:

- Runoff reduction volume credit is only available for dedicated year-round drawdown/demand for the water. While seasonal practices (such as irrigation) may be incorporated into the site design, they are not considered to contribute to the treatment volume credit (for stormwater purposes) unless a drawdown at an equal or greater rate is also realized during non-seasonal periods (e.g. treatment in a secondary runoff reduction practice during non-irrigation months).
- System design is encouraged to use rainwater as a resource to meet onsite demand or in conjunction with other runoff reduction practices (especially those that promote groundwater recharge).
- Pollutant load reduction is realized through reduction of the volume of runoff leaving the site.
- Peak flow reduction is realized through reduced volume and temporary storage of runoff.

Therefore, the rainwater harvesting system design configurations presented in this SCM are targeted for continuous (year-round) use of rainwater through (1) internal use, and (2) irrigation and/or treatment in a secondary practice. Three basic system configurations are described below.

Configuration 1: Year-round indoor use with seasonal indoor and/or outdoor uses (Figure 8). The first configuration is for year-round indoor use. Typical year-round uses include toilet and urinal flushing and laundry. Additional uses include irrigation, cooling towers, and a catch-all category of other uses that may include vehicle washing, street sweepers, and other not yet defined year-round or seasonal uses.

The only runoff reduction volume credit derived from this configuration is the year-round indoor use. While the seasonal uses do not provide an annual credit, they generally use a lot of water (i.e., irrigation) such that the owner may elect to increase the system size to provide for the seasonal demand in order to reduce potable water usage.

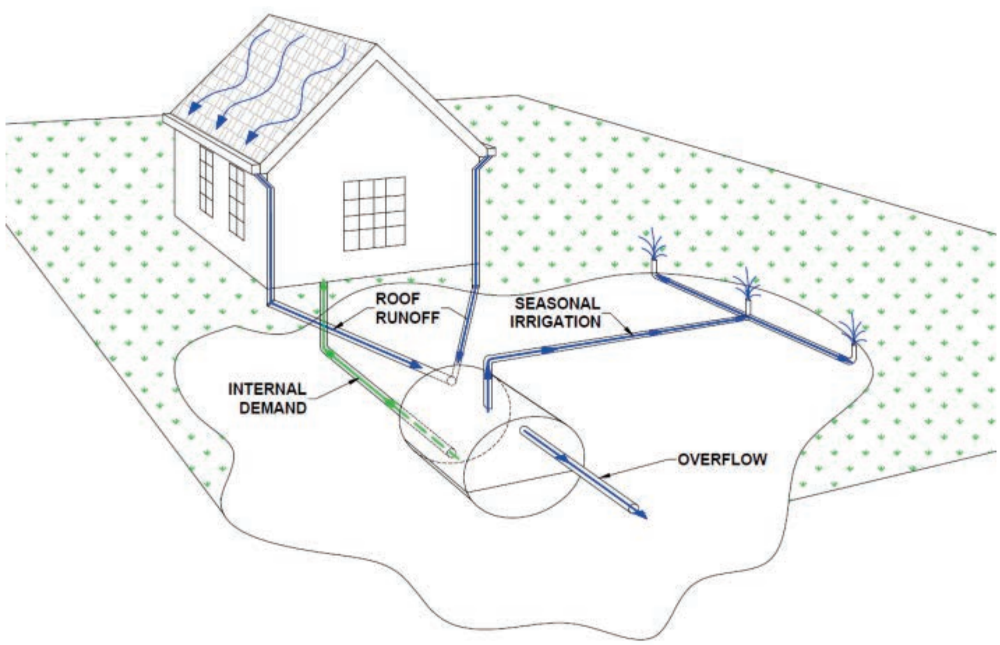


Figure 8. Configuration 1 Year-round indoor use with seasonal indoor and/or outdoor uses (Source: VADCR, 2013).

Configuration 2: Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Figure 9). The second configuration builds upon the first with the addition of a secondary runoff reduction drawdown practice in order to supplement the seasonal uses and establish a runoff reduction volume credit (in addition to the credit based on the year-round indoor uses). Therefore, the system must account for three uses: year-round internal non-potable water demand, a seasonal outdoor use such as automated irrigation system or cooling towers, and an engineered drawdown to a secondary runoff reduction drawdown practice for volume reduction during non-irrigation (or non-seasonal) months.

The cistern acts as a detention system during the non-seasonal months that must be designed to slowly drawdown at a rate comparable to the seasonal use in order to provide storage for the next storm event. In this way, the system achieves a year-round use and a corresponding runoff reduction volume credit. The design and sizing of the secondary runoff reduction drawdown practice is based on a specific drawdown rate, The secondary drawdown practice sizing will also be influenced by the hydraulic properties of the practice and the site conditions, such as soil infiltration rates, surface area, and/or retention capacity. The resulting size and/or storage volume of the secondary runoff reduction drawdown practice will generally be smaller than the stand-alone SCM (e.g., without the up-gradient storage tank).

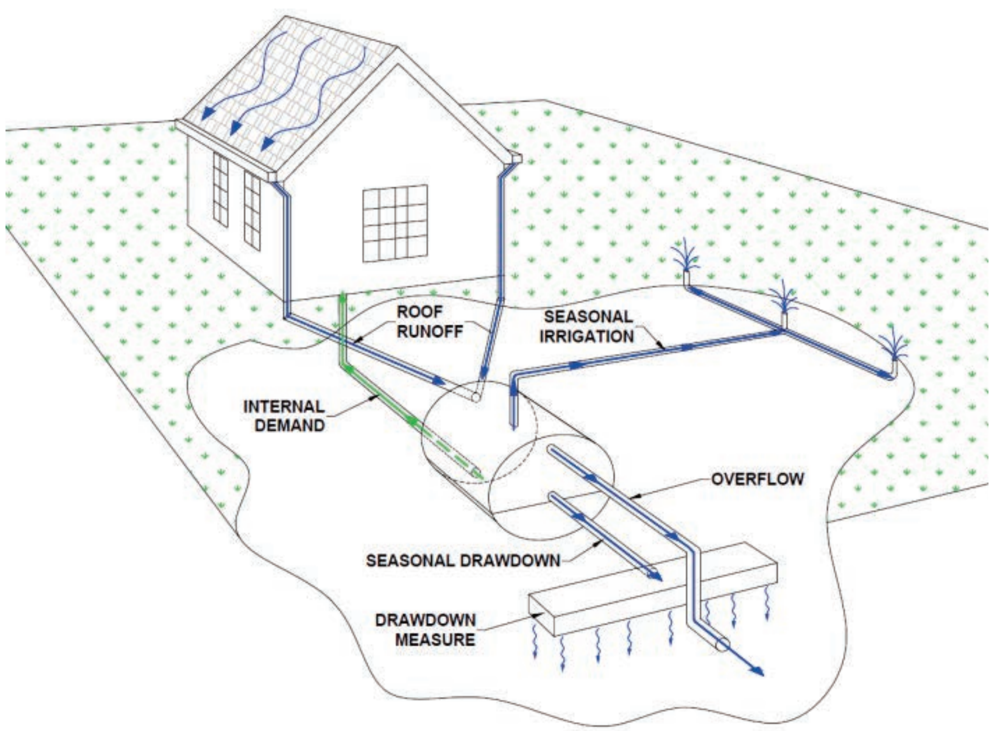


Figure 9: Configuration 2 Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Source: VADCR, 2013).

Configuration 3: Seasonal only indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Figure 10). The third configuration does not have any year-round uses and therefore uses stored rainwater to meet seasonal or intermittent water uses, while utilizing a secondary runoff reduction drawdown practice in order to supplement the seasonal uses and establish a runoff reduction volume credit. In this configuration, the system need only account for two uses: the seasonal outdoor use (automated irrigation system, cooling towers, etc.) and the engineered drawdown to a secondary runoff reduction drawdown practice. Similar to the previous configuration, the tank drawdown rate should be designed to be, at a minimum, comparable to the periodic seasonal use. The drawdown rate and practice sizing may also be influenced by the hydraulic properties of the practice and the site conditions, such as soil infiltration rates, surface area, and/or retention capacity.

In the case of both Configuration 2 and 3, the design of the tank size and drawdown rate and the exfiltration rate and surface area of the drawdown practice may be utilized to establish a hydraulic routing of the system for sizing purposes.

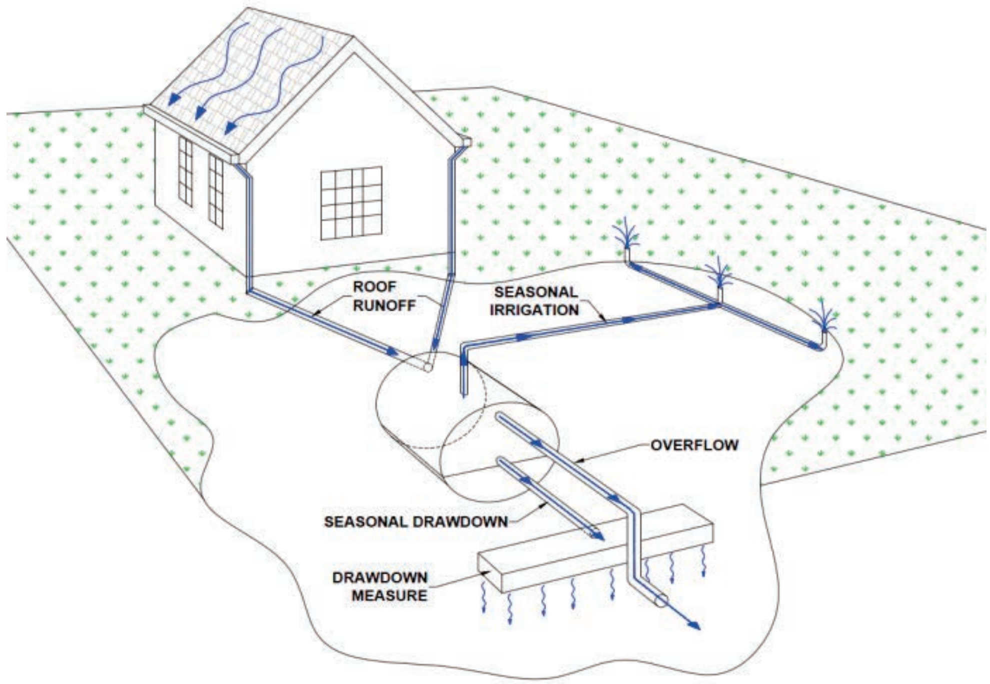


Figure 10: Configuration 3 Seasonal only indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Source: VADCR, 2013).

1.3.4 Tank Configurations

Pre-fabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. There are three basic tank design configurations used to meet the various rainwater harvesting system configurations. (VADCR, 2011)

Tank Design 1. The first tank set-up (Figure 11) maximizes the available tank storage volume for the treatment volume to meet the water demand and achieve the desired runoff reduction volume credit. An emergency overflow exists near the top of the tank. The overflow outlet may be a gravity flow outlet or a pumped outlet. Alternatively, the overflow may be an external control that backs up the flow before the tank thereby diverting any additional inflow.

> **Note:** Figures 11 and 12 are schematic representations of the relative configuration of the storage volume and outlets. If these tanks are configured below grade there would be a mechanical system to pump the required flow to meet the water demand or drawdown, requiring a float switch or other water level sensor to trigger the pump for meeting a variable demand. An above grade system may include a combination of gravity overflow orifices and a pump system to generate adequate pressure for the intended uses. Figure 13 provides a schematic representation of a cistern with a mechanical system included.

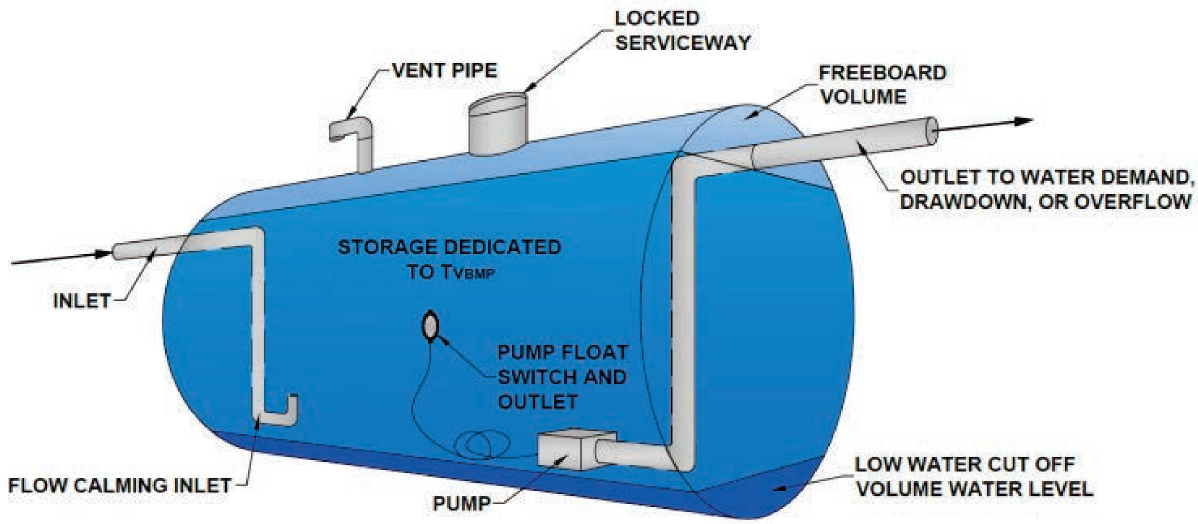


Figure 11: Tank Design 1 Storage Associated with Treatment Volume only (Source: VADCR, 2013).

Tank Design 2. The second tank set-up (Figure 12) uses tank storage to manage the runoff reduction volume objectives as well as using an additional detention volume to also meet some or all of the channel and/or flood protection volume requirements. For an above ground system, the channel and/or flood protection storage outlet orifice is located at the top of the design storage and sized according to the channel and/or flood protection peak flow requirements. Alternatively, a below grade system would rely on a float switch and pump to achieve the same objectives. An emergency overflow is located at the top of the detention volume level.

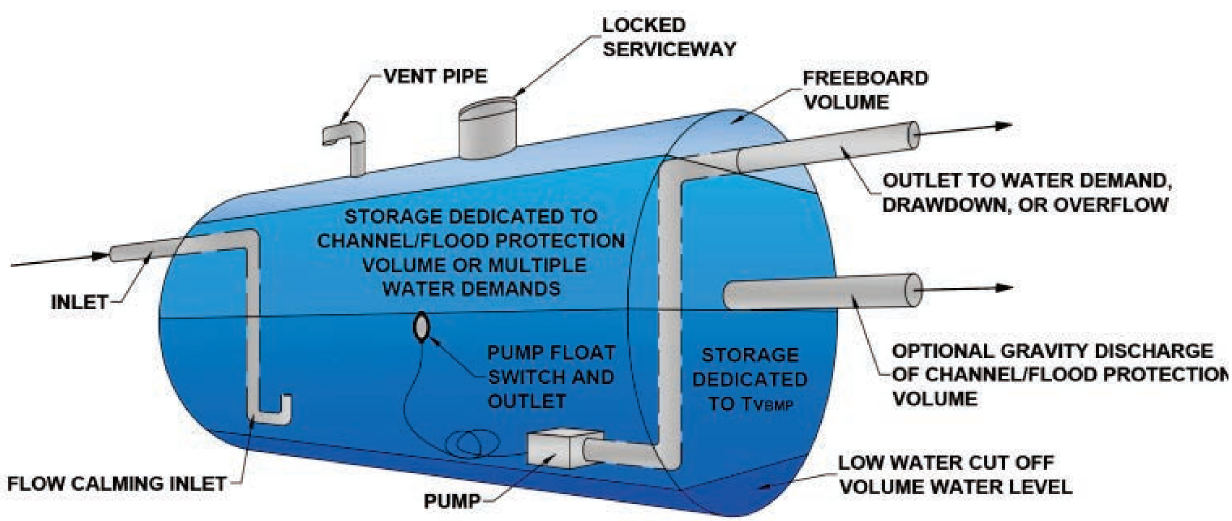


Figure 12: Tank Design 2 Storage Associated with Treatment, Channel Protection and Flood Volume (Source: VADCR, 2013).

1.3.5 Secondary Practices

Recent rainwater harvesting system design materials do not include guidance for onsite stormwater infiltration or "disposal". The basic approach is to provide a dedicated secondary runoff reduction practice onsite that will ensure water within the tank will gradually drawdown at a specified design rate between storm events. Secondary runoff reduction practices may include the following:

- Downspout Disconnection, excluding rain tanks and cisterns. This may include release to a compost-amended filter path.
- Sheet Flow
- Grass Channel
- Infiltration Trench
- Bioretention
- Urban Bioretention. Storage and release in foundation planter.
- Water Quality Swale

The secondary practice approach is useful to help achieve the desired treatment volume when demand is not enough to sufficiently draw down water levels in the tank between storm events. Of course, if demand for the harvested rainwater is relatively high, then a secondary practice may not be needed or desired. Use of a secondary practice may be particularly beneficial for sites that use captured rainwater for irrigation during part of the year, but have no other use for the water during non-irrigation months. During non-irrigation months, credit cannot be realized unless onsite infiltration/treatment or another drawdown mechanism creates a year-round drawdown, since no stormwater benefit would be realized during non-seasonal periods. The design of the secondary practice should account for soil types, ground surface areas, release rates, methods of conveyance (gravity fed or pumped), time periods of operation, and invert elevations to determine the disposal rate and sizing of the practice (both storage volume and surface area).

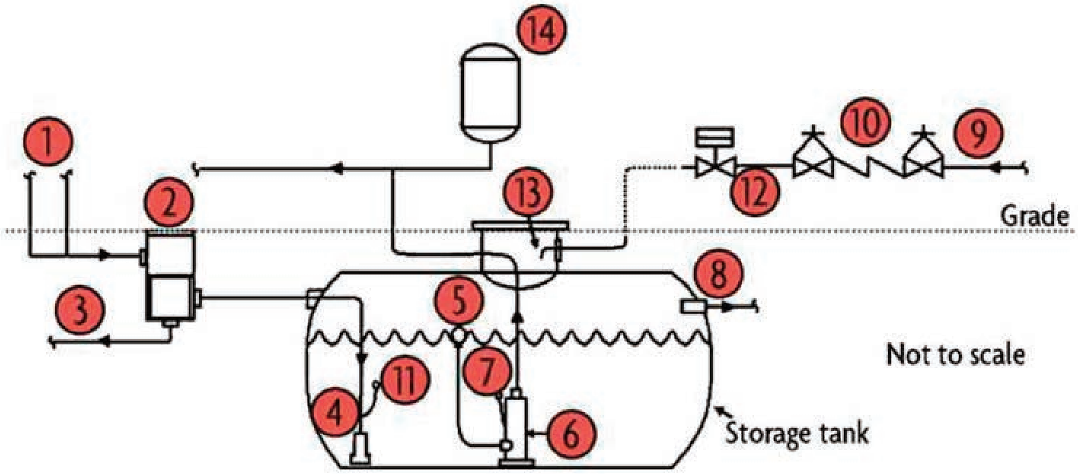
1.3.6 Safety Considerations

All collection and redistribution of stormwater runoff have the potential to cause human pathogenic issues. All capture and reuse SCMs that involve human contact must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water. Both ultraviolet (UV) and ozone disinfection systems are available for this purpose.

Spigots or hose bibs at above-grade cisterns should be labeled "NON-POTABLE" and be equipped with an atmospheric vacuum breaker. Backflow preventers must be installed on water service lines from cisterns. Safety labels should be placed on cisterns stating "NON-POTABLE" and "DROWNING HAZARD." Distribution lines and other system appurtenances must be clearly labeled as non-potable water.

1.4 Typical Details

The components of a rainwater harvesting system may include those illustrated in Figure 13.



1. Rooftop surface and rainwater collection system (roof drains, gutters, etc.)
2. Pre-treatment (screening, first flush diverters, filters, etc.)
3. Discharge of excess or diverted first flush to overflow or downstream practice
4. Flow calming inlet
5. Floating (outlet) filter
6. Submersible pump
7. Low water cut off float switch
8. Overflow to secondary runoff reduction drawdown practice, downstream runoff reduction or pollutant removal SCM, or conveyance system
9. Municipal back-up water supply
10. Back flow preventer
11. Float switch to control water levels
12. Solenoid valve
13. Air gap
14. Pressure tank

Figure 13: Sample rainwater harvesting system detail (Source: VADCR, 2011).

2. Construction

For the purposes of site peak rate control, the designer may adjust the Curve Number value based on the volume managed by the treatment volume during a portion of a 24-hour storm event.

2.1 Pre-Construction

Site Protection: Prior to installing a rain barrel or cistern, clean roofs, gutters, and downspouts and install effective leaf screens.

2.2 Construction

It is advisable to have a single contractor install the rainwater harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. A licensed plumber is required to install the rainwater harvesting system components to the plumbing system. A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions:

- Choose the tank location on the site
- Route all downspouts or roof drains to pre-screening devices and first flush diverters
- Properly install the tank
- Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release)

- Route all pipes to the tank
- Stormwater should not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.
- Install rain barrels and cisterns on level surfaces.
- Consider head required to provide necessary pressure for the designed reuse.

Follow the manufacturer's instructions for rain barrel or cistern installation.

2.3 Inspections

The following items shall be inspected prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Mosquito screens are installed on all 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
- Secondary runoff reduction practice(s) is installed as shown on plans

As-Built: After the cistern has been installed, the developer must have an as-built certification of the cistern conducted by a registered professional engineer. The as-built certification verifies that the SCM was installed as designed and approved. The following components are vital components of a properly working cistern and must be addressed in the as-built certification:

Incorporation of Rainwater Harvesting System into the site Grading and Drainage Plan, as follows:

1. Include a roof plan of the building that will be used to capture rainwater, showing slope direction and roof material.
2. Display downspout leaders from the rooftops being used to capture rainwater.
3. Display the storm drain pipe layout (pipes between building downspouts and the tank) in plan view, specifying materials, diameters, slopes and lengths, to be included on typical grading and utilities or storm sewer plan sheets.
4. Include a detail or note specifying the minimum size, shape configuration and slope of the gutter(s) that convey rainwater

Rainwater Harvesting System Construction Document sheet, to show the following:

1. The Cistern or Storage Unit material and dimensions in a scalable detail (use a cut sheet detail from manufacturer, if appropriate).
2. Include the specific Filter Performance specification and filter efficiency curves. Runoff estimates from the rooftop area captured for 1-inch storm should be estimated and compared to filter efficiencies for the 1-inch storm. It is assumed that the first flush diversion is included in filter efficiency curves. A minimum of 95% filter efficiency should be met for the Treatment Volume credit. If this value is altered (increased), the value should be reported. Filter curve cut sheets are normally available from the manufacturer. Show the specified materials and diameters of inflow and outflow pipes.
3. Show the inverts of the orifice outlet, the emergency overflows, and, if applicable, the receiving secondary runoff reduction practice or on-site infiltration facility.
4. Include a cross section of the storage unit displaying the inverts associated with the various incremental volumes (if requested by the reviewer).

3. Construction

Plans must indicate that sufficient access is provided to allow for regular maintenance activities.

3.1 Agreements

The Tennessee MS4 permit suggest that a maintenance agreement should be executed between the owner and the local stormwater program or local government responsible for stormwater management. The local stormwater program may set forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

Rainwater harvesting systems can be complex and often will include mechanical components and therefore should be inspected and maintained by qualified personnel. The following are suggested minimum requirements for establishing accountability for the system to remain operational when a runoff reduction volume credit is applied to the system:

- Rainwater harvesting systems must include long term maintenance agreements consistent with the provisions of the local stormwater program's regulations, and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- When rainwater harvesting systems are applied on private residential lots, homeowners should be educated regarding their routine maintenance needs by being provided a simple document that explains their purpose and routine maintenance needs. .
- A deed restriction, drainage easement or other mechanism enforceable by the local stormwater program must be in place to help ensure that the rainwater harvesting system is maintained and operational, as well as to pass the knowledge along to any subsequent owners.
- The mechanism should, if possible, grant authority for the local stormwater program staff to access the property for inspection of the tank (if external), the overflow conveyance, and any secondary runoff reduction drawdown practice.
- As an alternative, property owners may document that their system has been inspected and maintained by a qualified third party inspector.

3.2 Schedules

All rainwater harvesting systems components should be inspected by the property owner in the Spring and the Fall each year. A comprehensive inspection by a qualified third party inspector is recommended at least once a year, but at a minimum should occur and be documented at a minimum once every five years. An example maintenance inspection checklist for Rainwater Harvesting can be accessed in Appendix F.

3.3 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 2** describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 2: Suggested Maintenance Tasks for Rainwater Harvesting Systems.

Activity	Frequency
Keep gutters and downspouts free of leaves and other debris	O: Twice a year
Inspect and clean pre-screening devices and first flush diverters	O: Four times a year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately	O: Once a year
Inspect condition of overflow pipes, overflow filter path and/or secondary runoff reduction practices	O: Once a year
Inspect tank for sediment buildup	I: Every third year
Clear overhanging vegetation and trees over roof surface	I: Every third year
Check integrity of backflow preventer	I: Every third year
Inspect structural integrity of tank, pump, pipe and electrical system	I: Every third year
Replace damaged or defective system components	I: Every third year
***Key:* *O* = Owner *I* = qualified third party inspector**	

4. Community and Environmental Concerns

Although rainwater harvesting is an ancient practice, it is enjoying a revival due to the inherent quality of rainwater and the many beneficial uses that it can provide. Some common concerns associated with rainwater harvesting that must be addressed during design include:

- ***Winter Operation:*** Rainwater harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternately, an outdoor system can be used seasonally, or year round if special measures and design considerations are incorporated.
- ***Local Plumbing Codes:*** Designer and plan reviewers should consult local building codes to determine if they explicitly allow the use of harvested rainwater for toilet and urinal flushing. In the cases where a municipal backup supply is used, rainwater harvesting systems are typically required to have backflow preventers or air gaps to keep harvested water separate from the main water supply. Pipes and spigots using rainwater must be clearly labeled as non-potable.
- ***Mosquitoes:*** In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other insects from entering the tanks. 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.
- ***Child Safety:*** Above-grade residential rainwater harvesting systems cannot have unsecured openings large enough for children to enter the tank. For underground cisterns, manhole access should be secured to prevent unwanted access.

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5.4.11 Stormwater Treatment Wetland

Variations: Constructed wetlands

Description: Constructed wetlands, sometimes called stormwater wetlands, are shallow depressions that receive stormwater inputs for water quality treatment. 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. Constructed wetlands are the final element in the roof-to-stream runoff reduction sequence. They should only be considered for use after all other upland runoff reduction opportunities have been exhausted and there is still a remaining water quality or channel protection volume to manage.

Figure 1: Wetland in Blount County, TN (Source: SMART Center).

Key Design Criteria:

- **Space requirement:** typically 3% of the contributing area.
- **Available hydraulic head:** 2'- 4'

Site Constraints:

- **Adequate water balance:** must have enough water supplied from groundwater, runoff, or baseflow.
- **Soils:** Need liner for permeable soils or if karst geology is a concern.
- **Water table:** no constraint but need to be concerned about contaminant transport.
- **Setbacks from:**
  - Property lines : 10 feet
  - Building foundation: 25 feet
  - Septic system fields : 50 feet
  - Private wells: 100 feet

Maintenance:

- Measure sediment accumulation levels in forebays and micropools.
- Monitor the growth and survival of emergent wetlands and tree/shrub species.
- Inspect the condition of stormwater inlets to the wetland for material damage, erosion or undercutting.
- Inspect the condition of the principal spillway and riser for evidence of spalling and joint failure.
- Inspect maintenance access to ensure it is free of woody vegetation.
- Inspect internal and external side slopes of the wetland for evidence of erosion.
- Control invasive species.

Advantages:

- Support wildlife habitat.
- Wetlands have low operating and maintenance expenses and can handle fluctuating water levels.
- Aesthetically pleasing additions to homes and neighborhoods
- They are viewed as an environmentally friendly technology and are generally received by the public.

Disadvantages:

- Not an infiltration practice, therefore other LID practice(s) needs to be used in addition to constructed wetland.
- Requires more land area than other treatment options.
- Attracts mosquitoes and other pests
- Limited to low traffic areas with limited structural loading.
- The performance of wetlands may vary based on usage and climatic conditions.
- There may be a prolonged initial start-up period before vegetation is adequately established.

Design Checklist:

- ❑ Check feasibility for site.
- ❑ Check treatment wetland sizing guidance and make sure there is an adequate footprint on the site.
- ❑ Design treatment wetland in accordance with design criteria and typical details.
- ❑ Submit plans.

1. Design

1.1 Variations

Table 1: Type of wetland.

Description		Application	Picture
Wetland Basin	• Single cell (w/ forebay) • Uniform wetland depth • Mean depth more than 1 foot • Surface area less than 3% of contributing drainage area • Design Volume = 1.0 x Target Treatment Volume	Can be used at the terminus of a storm drain pipe or open channel	 (Source: SMART Center)
Multi-Cell Wetland or Pond/ Wetland Combination	• Multiple cells (w/ forebay) • Variable depths • The depth of temporary ponding allowed above the wetland cell pools to pass the larger design storms or if the wetland cell pools are hydraulically connected to the pond cell. • Temporary storage mean depth less than 1 foot • Surface area more than 3% of contributing drainage area	Effective in moderately-to highly-urban areas where space is a premium and providing adequate surface area or grade drop is difficult.	 (Source: West Virginia)
Subsurface Gravel Wetland	• Cells (w/ forebay) • Saturated gravel layer • Minimum 24” gravel sub-layer • Design and sizing as per UNHSC (2009) and RIDEM (2010)	Sites that require enhanced nutrient removal, especially for nitrogen.	 (Source: Roseen et al, 2012)

1.2 Major Design Elements

Table 2: Design Elements for Stormwater Wetlands.

Adequate Water Balance	The proposed wetland must have enough water supplied from groundwater, runoff or baseflow so that the wetland micropools will not go completely dry after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in Section 1.4.1.
Contributing Drainage Area (CDA)	The contributing drainage area must be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then several dozen acres of drainage area are typically 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 or approving agency is willing to accept periodic wetland drawdown.
Space Requirements	Constructed wetlands normally require a footprint that takes up about 3% of the contributing drainage area, depending on the average depth of the wetland and the extent of its deep pool features.
Available Hydraulic Head	The depth of a constructed wetland is usually constrained by the hydraulic head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because constructed wetlands are typically shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.
Steep Slopes	A modification of the Constructed Wetland (and linear wetland or wet swale system) is the Regenerative Conveyance System (RCS). The RCS can be used to bring stormwater down steeper grades through a series of step pools. This can serve to bring stormwater down the steep slopes where steep drops on the edge of a stream or river receiving system can create design challenges.
Minimum Setbacks	Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, utilities, and wells. As a general rule, the edges of constructed wetlands should be located at least 10 feet away from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from private wells.
Depth to Water Table	The depth to the groundwater table is not a major constraint for constructed wetlands, since a high water table can help maintain wetland conditions. However, designers should keep in mind that high groundwater inputs may reduce pollutant removal rates and increase excavation costs.
Soils	Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. If soils are permeable or karst geology is a concern, it may be necessary to use an impermeable liner.
Use of or Discharges to Natural Wetlands	It can be tempting to construct a stormwater wetland within an existing natural wetland, but this should never be done unless it is part of a broader effort to restore a degraded urban wetland and is approved by the local, state, and/or federal wetland regulatory authority. Constructed wetlands may not be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate local, state, and/or federal regulatory agency. In addition, designer should investigate the status of adjacent wetlands to determine if the discharge from the constructed wetland will change the hydro period of a downstream natural wetland (see Wright et al, 2006 for guidance on minimizing stormwater discharges to existing wetlands).

Regulatory Status	Constructed wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country, but designers should check with their wetland regulatory authorities to ensure this is the case.
Perennial Streams	Locating a constructed wetland along or within a perennial stream is strongly discouraged and will require both a Section 401 and Section 404 permits from the state or federal regulatory authority.
Trout Streams	The use of constructed wetlands in watersheds containing trout streams is generally not recommended due to the potential for stream warming, unless (1) all other upland runoff reduction opportunities have been exhausted, (2) the Channel Protection Volume has not been provided, and (3) a linear/mixed wetland design is applied to minimize stream warming.
Community and Environmental Concerns	Stormwater Wetland designs should strive to address the following: • Aesthetics and Habitat. Stormwater Wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the wetland plant community will evolve over time, since the future plant community seldom resembles the one initially planted. Invasive control is a major concern with the long-term management of Stormwater Wetlands. • Existing Forests. Given the large footprint of a Stormwater Wetland, there is a strong chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout, and may consider creating a wooded wetland. • Safety Risk. Stormwater Wetlands are safer than other types of ponds, although forebays and micropools should be designed with aquatic benches to reduce safety risks. • Mosquito Risk. Mosquito control can be a concern for Stormwater Wetlands if they are under-sized or have a small CDA. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other pond life that prey on mosquito larvae. Few mosquito problems are reported for well designed, properly-sized and frequently-maintained stormwater wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within Stormwater Wetlands, for example, constant inflows, benches that create habitat for natural predators, and constant pool elevations.

1.3 Design Criteria

1.3.2. Design Geometry for Stormwater Wetlands

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. Whenever possible, stormwater wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements should be included for stormwater wetlands:

1.3.2.1 Multiple-Cell Wetlands

Wetland should be divided into at least four internal sub-cells of different elevations: the forebay, at least two wetland cells, and a micro-pool outlet. The first cell (the forebay) is deeper and is used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it evenly into successive wetland cells. The purpose of the wetland cells is to create an alternating sequence of aerobic and anaerobic conditions to maximize nitrogen removal. The fourth wetland cell is located at the discharge point and serves as a micro-pool with an outlet structure or weir.

Each wetland sub-cell can be differentiated by sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas extending as wedges across 95% of the wetland cell width (see Section 1.3.3 on micro-topography). If there are elevation drops greater than 1 foot between cells, then the designer should consider using an earthen berm with a spillway, concrete weir, gabion baskets, or other means that provide adequate freeboard to pass expected peak rates (these approaches are also applicable to the forebay and micro-pool). In addition, stable conveyance between cells should be provided based on the elevation change and expected velocities.

1.3.2.2 Detention Storage Ponding Depth

Where a stormwater wetland basin incorporates detention storage for larger storms, the detention elevation above the permanent pool should be 1 vertical foot or less.

Where a multiple-cell design is used, the detention storage limits are as follows:

- Multi-cell wetlands should be designed so that the water level fluctuation associated with the maximum "Design Volume" storm (a 1-inch rainfall event) is limited to 6 to 8 inches.
- The maximum water level fluctuation during the larger design storm associated with local detention requirements (as applicable) should be limited to 12 inches in the wetland cells. This can be achieved by using a long weir structure capable of passing large flows at relatively low hydraulic head. If this standard cannot be met within the stormwater wetland footprint, the designer should use the pond/wetland combination design or an "off-line" design whereby the wetland receives only flow associated with the design volume, and larger flows are diverted to other detention facilities.
- For the pond/wetland combination, the maximum detention storage depth may be up to 5 feet above the wet pond cell permanent pool (but not the wetland cells).

1.3.2.3 Pool Depths

Wetland designs may have a mean pool depth greater than 1 foot.

1.3.2.4 Deep Pools

Approximately 25% of the wetland design volume should be provided in at least three deeper pools – located at the inlet (forebay), center, and outlet (micro-pool) of the wetland. Approximately 60% of this overall deep pool volume should be allocated to the forebays. Each deep pool should have a depth of 18 to 48 inches. Use this water balance equation in Section 1.4.1 (Eq 1) to calculate the minimum depth of the permanent pool.

1.3.2.5 High Marsh Zone

Approximately 70% of the wetland surface area should exist in the high marsh zone (-6 inches to +6 inches relative to the normal pool elevation).

1.3.2.6 Transition Zone

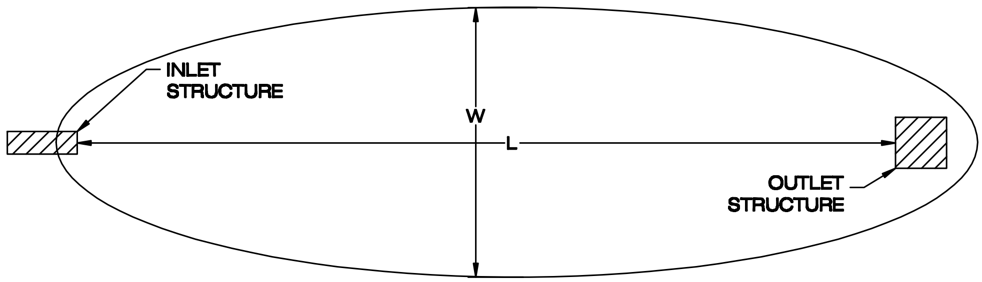
The low marsh zone (-6 to -18 inches below the normal pool elevation) is no longer an acceptable wetland zone, and is only allowed as a short transition zone from the deeper pools to the high marsh zone. In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high 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.

1.3.2.7 Flow Path

In terms of the flow path, there are two design objectives:

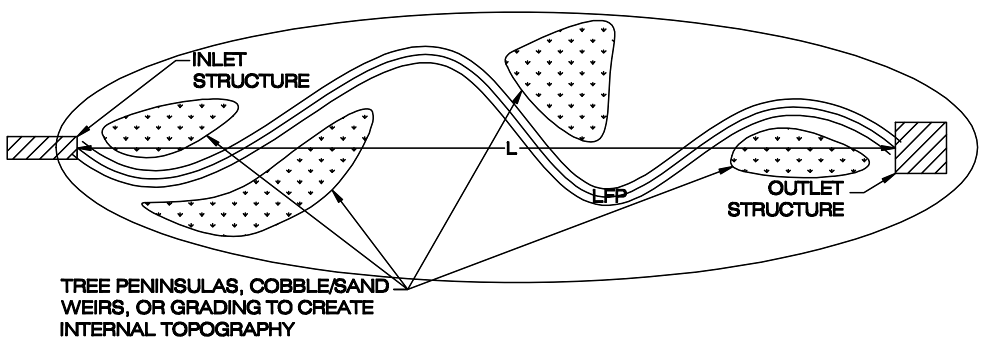
- The overall flow path through the wetland can be represented as the length-to-width ratio and/or the flow path ratio (see Figure 2). At least one of these ratios should be at least 2:1.
- The shortest flow path represents the distance from the closest inlet to the outlet (see Figure 2, bottom). The ratio of the shortest flow path to the overall length should be at least 0.5. 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 drainage area.

LENGTH/WIDTH RATIO GEOMETRY



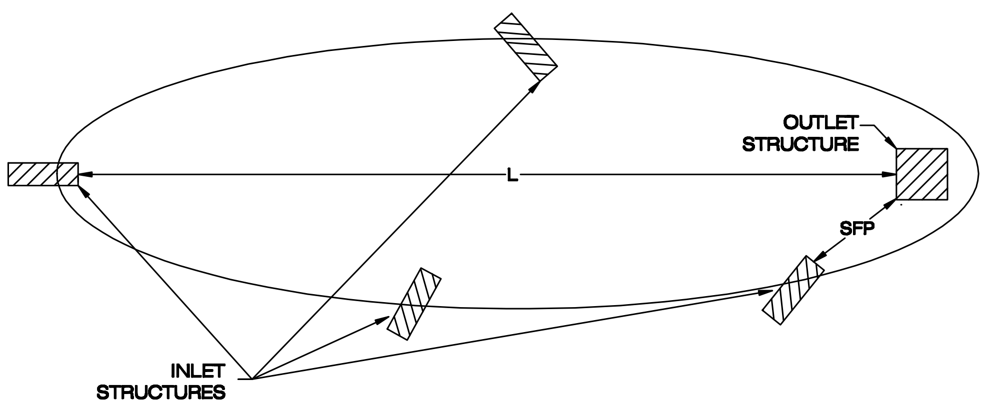
LENGTH/WIDTH RATIO = L/W, WHERE:
L = LENGTH FROM INLET TO OUTLET
W = AVERAGE WIDTH

FLOW PATH GEOMETRY



FLOW PATH RATIO = LFP/L, WHERE:
LFP = LENTH OF FLOW PATH DURING WATER QUALITY STORM EVENT
L = LENGTH FROM INLET TO OUTLET

SHORTEST FLOW PATH GEOMETRY



SHORTEST FLOW PATH RATIO = SFP/L, WHERE:
SFP = LENTGH OF SHORTEST FLOW PATH FROM AN INLET TO
OUTLET
L = OVERALL LENGTH OF FACILITY

Figure 2: Design geometry factors: (1) Length/Width Ratio (top), (2) Flow Path Ratio (middle), and (3) Shortest Flow Path Ratio (Source: VA, 2011).

1.3.2.8 Side Slopes

Side slopes for the wetland should generally have gradients of 4:1 to 5:1. Such mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

1.3.3 Micro-topographic Features

While the slope profile within individual wetland cells should generally be flat from inlet to outlet, Stormwater Wetlands should have internal structures that create variable micro-topography. This is defined as a mix of above-pool vegetation, shallow pools, and deep pools that promote dense and diverse vegetative cover. Designers should incorporate at least two of the following internal design features to meet the microtopography requirements:

- Tree peninsulas, high marsh wedges or rock filter cells configured perpendicular to the flow path.
- Tree islands above the normal pool elevation and maximum detention zone, formed by coir fiber logs.
- Inverted root wads or large woody debris.
- Gravel diaphragm layers within high marsh zones.
- Cobble sand weirs.

1.3.4 Maintenance Reduction Features

The following design criteria will help to avoid significant maintenance problems pertaining to constructed wetlands:

Maintenance Access. Good access is needed so crews can remove sediments, make repairs and preserve wetland treatment capacity).

- Maintenance access must be provided to the forebay, safety benches, and outlet riser area.
- Risers should be located in embankments to ensure easy access.
- Access roads should (1) be constructed of load bearing materials, (2) have a minimum width of 12 feet, and (3) possess a maximum profile grade of 15%.
- Turnaround areas may also be needed, depending on the size and configuration of the wetland.

Clogging Reduction. If the low flow orifice clogs, it can result in a rapid change in wetland water elevations that can potentially kill wetland vegetation. Therefore, designers should carefully design the flow control structure to minimize clogging, as follows:

- A minimum 3-inch diameter orifice is recommended in order to minimize clogging of an outlet or extended detention pipe when it is surface fed. It should be noted, however, that even a 3 inch orifice will be very susceptible to clogging from floating vegetation and debris.
- Smaller openings (down to 1 inch in diameter) are permissible, using internal orifice plates within the pipe.
- All outlet pipes should be adequately protected by trash racks, half-round CMP, or reverse-sloped pipes extending to mid-depth of the micropool.

1.3.5 Wetland Landscaping Plan

An initial wetland landscaping plan should be required for any stormwater wetland and should be jointly developed by the engineer and a wetlands expert or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting. More details on preparing a wetland landscaping plan can be found throughout this section. 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. At a minimum, the plan should contain the following:

- Plan view(s) with topography at a contour interval of no more than1 foot and spot elevations throughout the cell showing the wetland configuration, different planting zones (e.g., high marsh, deep water, upland), micro topography, grades, site preparation, and construction sequence.
- A plant schedule and planting plan specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing. To the degree possible, the species list for the constructed wetland should contain plants found in similar local wetlands.

The local stormwater program will usually establish any more specific vegetative goals to achieve in the wetland landscaping plan. The following general guidance is provided:

- **Use Native Species Where Possible.** Appendix D provides a list of common native shrub and tree species and provides a list of common native emergent, submergent and perimeter plant species, all of which have proven to do well in stormwater wetlands in the mid-Atlantic region and are generally available from most commercial nurseries . Other native species can be used that appear in state-wide plant lists. The use of native species is strongly encouraged, but in some cases, non-native ornamental species may be added as long as they are not invasive. Invasive species such as cattails, Phragmites and purple loosestrife should never be planted.
- **Match Plants to Inundation Zones.** The various plant species shown in Appendix D should be matched to the appropriate inundation zone. The first four inundation zones are particularly applicable to stormwater wetlands, as follows:
  - Zone 1: -6 inches to -12 below the normal pool elevation
  - Zone 2: -6 inches to the normal pool elevation)
  - Zone 3: From the normal pool elevation to + 12 inches above it)

  Zone 4: +12 inches to + 36 inches above the normal pool elevation (i.e., above ED Zone) (Note that the Low Marsh Zone (-6 inches to -18 inches below the normal pool elevation) has been dropped since experience has shown that few emergent wetland plants flourish in this deeper zone.
- **Aggressive Colonizers.** To add diversity to the wetland, 5 to 7 species of emergent wetland plants should be planted, using at least colonizers. Four emergent species designated as aggressive No more than 25% of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each single species “cluster”.

1.3.6. 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 filter fabric for lining banks or berms.

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.

1.4 Calculations

Sizing the practice dimension can be done using the Tennessee Runoff Reduction Assessment Tool (TNRRAT). The inputs needed for the tools are discussed below (need to know what input needed for the tool).

1.4.1 Water Balance: Sizing for Minimum Pool Depth

Initially, it is recommended that there be no minimum drainage area requirement for the system, although it may be necessary to calculate a water balance for the wet pond cell when its CDA is less than 10 acres.

Similarly, if the hydrology for the constructed wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using Equation 1 (Hunt et al., 2007), to assure the deep pools will not go completely dry during a 30 day summer drought.

The Hunt Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland:

DP = RFm* EF * WS/WL – ET – INF – RES (Eq. 1)

Where:

DP = Depth of pool (inches)
RFm = Monthly rainfall during drought (inches)
EF = Fraction of rainfall that enters the stormwater wetland (CDA *Rv)
WS/WL = Ratio of contributing drainage area to wetland surface area
ET = Summer evapotranspiration rate (inches; assume 8)
INF = Monthly infiltration loss (assume 7.2 inches @ 0.01 inch/hour)
RES = Reservoir of water for a factor of safety (assume 6 inches)

Inputs needed:

- Location
- Size of CDA
- Cover type
- Approximation of practice surface area and practice depth for each zone

Using Equation 1, setting the groundwater and (dry weather) base flow to zero and assuming a worst case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows:

Depth of Pool (DP) = 0” (RFm) – 8” (ET) – 7.2” (INF)– 6” (RES) = 21.2 inches

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool should be at least 22 inches (rather than the 18” minimum depth).

1.5 Typical Details

Typical details for the three major constructed wetland variations are provided in Figures 3 to 5.

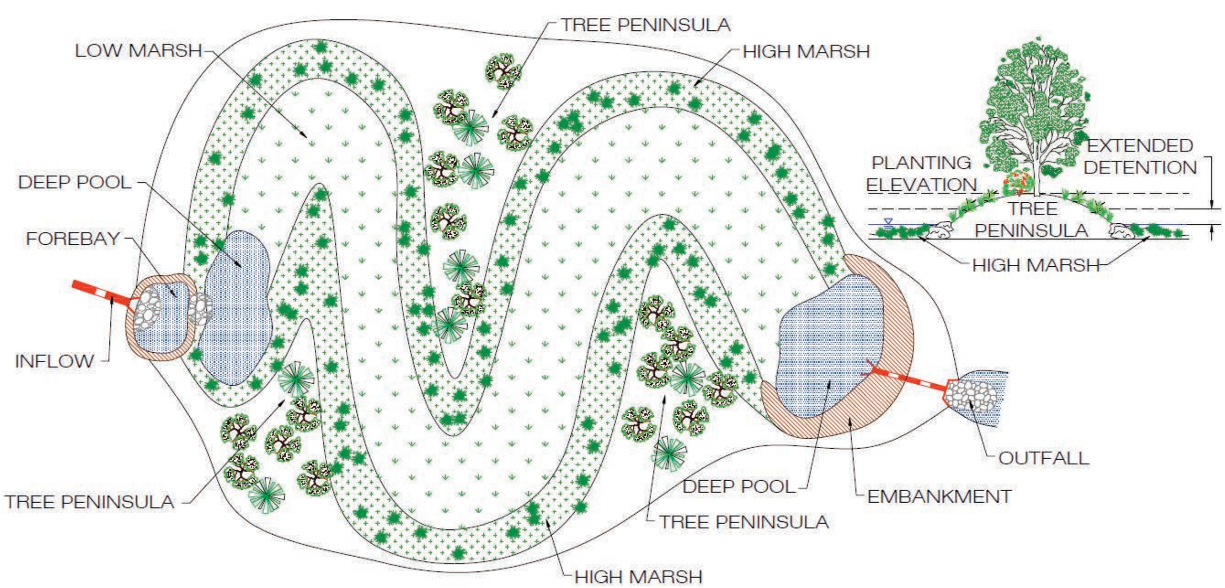


Figure 3: Constructed Wetland with Forested Peninsulas.

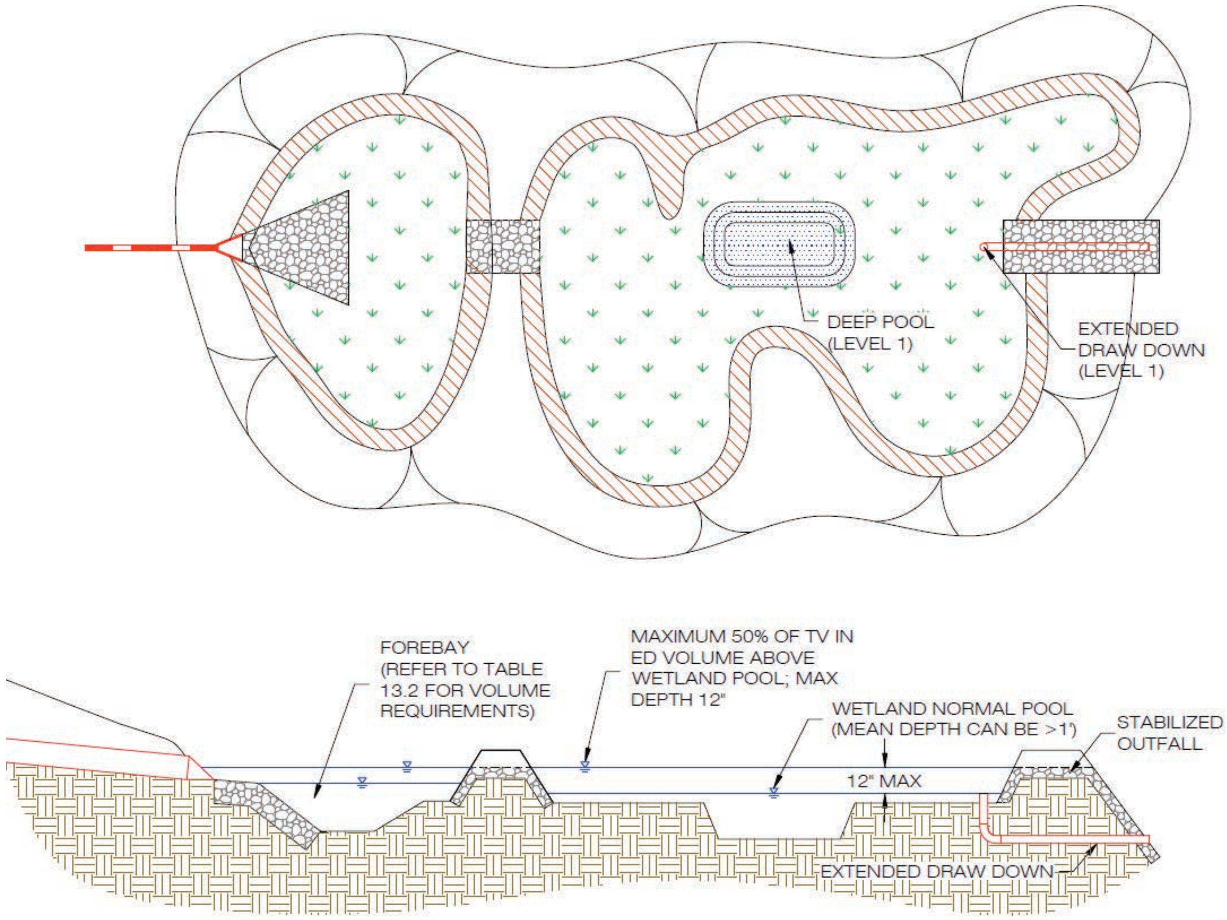


Figure 4: Constructed Wetland Plan and Cross Section.

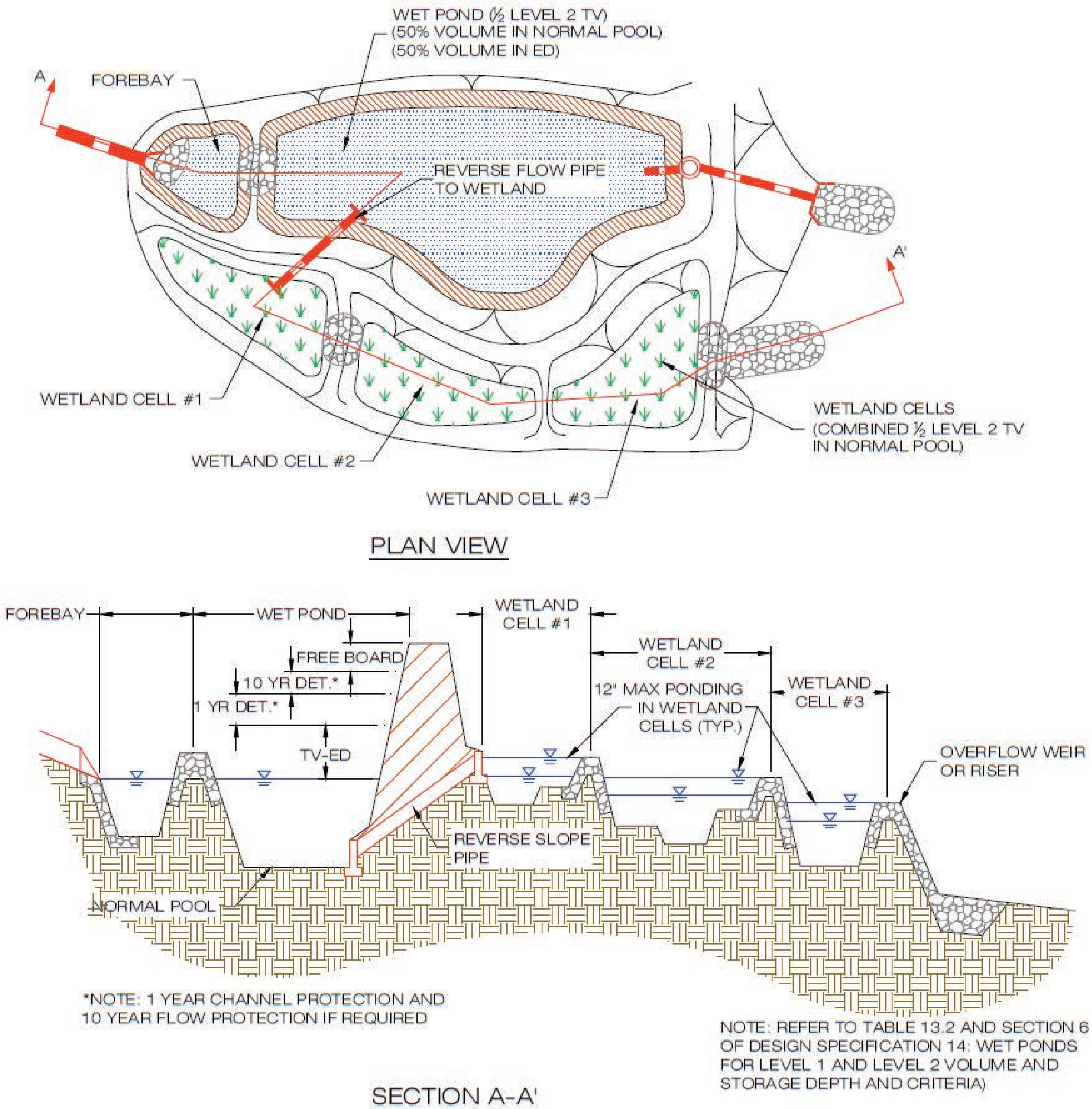


Figure 5: Pond-Wetland Combination – Plan and Section.

1.6 Regional & Special Case Design Adaptations

1.6.1 Karst Terrain

Even shallow pools in karst terrain can increase the risk of sinkhole formation and groundwater contamination. Designers should always conduct geotechnical investigations in karst terrain to assess this risk during the project planning stage. If constructed wetlands are employed in karst terrain, the designer must:

- Employ an impermeable liner.
- Maintain at least 3 feet of vertical separation from the underlying karst layer.
- Shallow, linear and multiple cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system and the ED wetland have limited application in karst terrain.

Table 3: Required Groundwater Protection Liners for Ponds in Karst Terrain (Source: WVDEP, 2006 and VA DCR, 1999).

Situation	Criteria
Not Excavated to Bedrock	24 inches of soil with a maximum hydraulic conductivity of 1 x 10^{-5}cm/sec
Excavated to or near Bedrock	24 inches of clay[1] with maximum hydraulic conductivity of 1 x 10^{-6} cm/sec
Excavated to Bedrock within wellhead protection area, in recharge are for domestic well or spring, or in known faulted or folded area	24 inches of clay[1] with maximum hydraulic conductivity of 1 x 10^{-7} cm/sec and a synthetic liner with a minimum thickness of 60 mil.

1 Plasticity Index of Clay : Not less than 15% (ASTM D-423/424)
Liquid Limit of Clay : Not less than 30% (ASTM D-2216)
Clay Particles Passing : Not less than 30% (ASTM D-422)
Clay Compaction : 95% of standard proctor density (ASTM D-2216)

1.6.2 Steep Terrain – Regenerative Conveyance Systems

Constructed wetlands are not an effective practice at development sites with steep terrain. Some adjustment can be made by terracing wetland cells in a linear manner as with Regenerative Conveyance Systems (RSC). Regenerative stormwater conveyance (RSC) systems are open-channel, sand seepage filtering systems that utilize a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand channel to treat and safely detain and convey storm flow, and convert stormwater to groundwater via infiltration in other areas where grades make traditional practices difficult to implement.

RSC systems combine features and treatment benefits of swales, infiltration, filtering and wetland practices. In addition, they are designed to convey flows associated with extreme floods (i.e., 100 year return frequency event) in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

RCS systems are referred to as Step Pool Storm Conveyance (SPSC) channels in Ann Arundel County, MD where systems have been installed and observed. The physical characteristics of the SPSC 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). Due to their ability to safely convey large flood events, RSC systems do not require flow splitters to divert smaller events for water quality treatment, and reduce the need for storm drain infrastructure in the conveyance system.

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. RSC systems have the added benefit of creating dynamic and diverse ecosystems for a range of plants, animals, amphibians and insects. These ecosystems enhance pollutant uptake and assimilation and provide a natural and native aesthetic at sites. RSC systems are unique in that they can be located on the front or tail end of a treatment system and still provide water quality and groundwater recharge benefits. When located on the front end of a treatment train, they provide water quality, groundwater recharge, and channel protection, while also providing non-erosive flow conveyance that delivers flow to the stormwater quantity practice - a constructed wetland, wet pond, ED Pond, or combination. The Ann Arundel County design specification can be found at:

http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

1.6.3 Cold Climate and Winter Performance

Wetland performance decreases when snowmelt runoff delivers high pollutant loads. Shallow constructed wetlands can freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing wetland performance. Salt loadings are higher in cold climates due to winter road maintenance. High chloride inputs have a detrimental effect on native wetland vegetation and can shift the wetland plant composition to more salt-tolerant but less desirable species, such as cattails. Designers should choose salt-tolerant species when crafting their planting plans and consider specifying reduced salt applications in the contributing drainage area, when they actually have control of this. The following design adjustments are recommended for stormwater wetlands installed in higher elevations and colder climates.

- Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool.
- Plant salt-tolerant wetland vegetation.
- Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage ice formation.
- Locate low flow orifices so they withdraw at least 6 inches below the typical ice layer.
- Angle trash racks to prevent ice formation.
- Over-size the riser and weir structures to avoid ice formation and freezing pipes.
- If road sanding is prevalent in the contributing drainage area, increase the forebay size to accommodate additional sediment loading.

1.6.4 Linear Highway Sites

Wet swales, linear wetland cells and regenerative conveyance systems are particularly well suited and considered preferred practices to treat runoff within open channels located in the highway right of way.

2. Construction

The construction sequence for stormwater wetlands 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 an on-line wetland facility and establishing vigorous plant cover.

2.1 Stage 1 Construction Sequence: Wetland Facility Construction

Step 1: Stabilize Drainage Area. Stormwater 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 they meet design specifications, and prepare any staging areas.

Step 3: Clear and Strip the project area to the desired sub-grade.

Step 4: Install Erosion and Sediment (E&S) Controls prior to construction, including temporary dewatering devices, sediment basins, and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials or other approved methods of soil stabilization. Grass sod is preferred over seed to reduce seed colonization of the wetland. During construction the wetland should be separated from the contributing drainage area so that no sediment flows into the wetland areas. 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 5: Excavate the Core Trench for the Embankment and Install the Spillway Pipe.

Step 6: 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 7: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts and compacted 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. Since most stormwater wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, 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 survival and future wetland coverage are likely if soil amendments are not added (Bowers, 1992). 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 as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Pipes, including the downstream rip-rap apron protection.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw.

2.2 Stage 2 Construction Sequence: Establishing the Wetland Vegetation

Step 13: Finalize the Wetland Landscaping Plan. At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan after the stormwater wetland has been constructed. Several weeks of standing time is needed so that the designer can more precisely predict the following two things:

- Where the inundation zones are located in and around the wetland; and
- Whether the final grade and wetland microtopography will persist over time.

This allows 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.

Step 14: Open Up the Wetland Connection. Once the final grades are attained, the pond and/or contributing drainage area connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the wetland to prevent erosion of unplanted features. Inundation should occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

Step 15: 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. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field, using stakes or flags.

Step 16: Propagate the Stormwater 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, since 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 switchgrass or 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 on Their Own.* The remaining areas of the stormwater wetland will eventually (within 3 to5 years) be colonized by volunteer species from upstream or the forest buffer.

Step 17: 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 criss-cross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 18: Plant the Wetland Fringe and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2-year storm). Consequently, plants in this zone are infrequently inundated (5 to 10 times per year), and must be able to tolerate both wet and dry periods.

2.3 Construction Inspection

Construction inspections are critical to ensure that stormwater wetlands are properly constructed and established. Multiple site visits and inspections are recommended during the following stages of the wetland construction process:

- Pre-construction meeting
- Initial site preparation (including installation of project E&S controls)
- Excavation/Grading (e.g., interim/final elevations)
- Wetland installation (e.g., microtopography, soil amendments and staking of planting zones)
- Planting Phase (with an experienced landscape architect or wetland expert)
- Final Inspection (develop a punch list for facility acceptance)

3. Maintenance

3.1 Maintenance Agreements

A maintenance plan and maintenance agreement must be executed between the owner and the local stormwater program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

It is also recommended that the maintenance agreement include a list of qualified contractors that can perform inspection or maintenance services, as well as contact information for owners to get local or state assistance to solve common nuisance problems, such as mosquito control, geese, invasive plants, vegetative management, and beaver removal.

3.2 First Year Maintenance Operations

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first two years:

- **Initial Inspections.** During the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 1/2 inch of rainfall.
- **Spot Reseeding.** Inspectors should look for bare or eroding areas in the contributing drainage area or around the wetland buffer, and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees 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.

- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, 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.

3.3. Inspections and Ongoing Maintenance

Ideally, maintenance of constructed wetlands should be driven by annual inspections that evaluate the condition and performance of the wetland, including the following:

- Measure sediment accumulation levels in forebays and micropools.
- Monitor the growth and survival of emergent wetlands and tree/shrub species. Record the species and approximate coverage, and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the wetland for material damage, erosion or undercutting.
- Inspect upstream and downstream banks for evidence of sloughing, animal burrows, boggy areas, woody growth or gully erosion that may undermine embankment integrity.
- Inspect the wetland outfall channel for erosion, undercutting, rip-rap displacement, woody growth, etc.
- Inspect the condition of the principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc.
- Inspect the condition of all trash racks, reverse-sloped pipes, and flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and locks can be opened or operated.
- Inspect internal and external side slopes of the wetland for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.
- Cleanups should be scheduled at least once a year to remove trash, debris and floatables.

Managing vegetation is an important ongoing maintenance task at every constructed wetland and for each inundation zone. Following the design criteria above should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the wetland, however, will require some annual maintenance.

3.4. Non-Routine Maintenance

Sediment Removal. Frequent sediment removal from the forebay is essential to maintain the function and performance of a constructed wetland. Maintenance plans should schedule cleanouts approximately every 5 years, or when inspections indicate that 50% of the forebay sediment storage capacity has been filled. The designer should also check to see whether removed sediments can be spoiled on-site or must be hauled away. 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.

Control Invasive Species. Designers should expect significant changes in wetland species composition to occur over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, since 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.

Thinning and Harvesting of Woody Growth. Thinning or harvesting of excess forest growth may be periodically needed to guide the forested wetland into a more mature state. Vegetation may need to be harvested periodically if the constructed wetland becomes 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 and maintenance access areas should be conducted every 2 years.

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5.4.12 Manufactured/Proprietary Treatment Devices

Manufactured or proprietary stormwater control measures are devices that use proprietary settling, filtration, absorption/adsorption, vortex principles, vegetation, and other processes to meet permanent stormwater management requirements. They may be used individually, or with other measures as part of a treatment train. Although there are some proprietary devices that are used to control stormwater quantity such as underground storage and cisterns, the common purpose of proprietary devices is pollutant removal. There are two general types of devices: **hydrodynamic separators and filtering systems.**

Key Design Criteria:
See manufacturer's technical specifications.

Key Considerations:
- Independent performance data must be available to prove a demonstrated capability of meeting stormwater management requirements.
- System or device must be appropriate for use in Tennessee conditions.
- Installation and operations/maintenance requirements must be understood by all parties approving and using the system or device in question.

Maintenance:
See manufacturer's technical specifications.

Advantages:
- Useful for pretreatment/removal of TSS.
- Can be an excellent choice in ultra-urban or other constrained sites.
- Useful for redevelopments and to improve local conditions.
- Longevity can be high with proper maintenance.

Disadvantages:
- Must be sized carefully to achieve design removal efficiencies.
- Efficiency may be affected by size of sediment and rate of sediment loading.
- Must ensure regular maintenance to achieve design removal efficiencies.
- Limited performance data.

1. Description

1.1. Hydrodynamic Separators

- Hydrodynamic separators are designed to meet specific pollutant removal requirements and generally control pollution using the movement of water and water's properties to settle or filter pollutants from the stormwater.
- No outside power source is required, because the energy of the flowing water allows the sediments to efficiently separate.
- Depending on the type of device, separation may be by means of swirl action or indirect filtration.

1.2 Filtering Systems

- Filtering systems typically use a settling chamber and filtering system that removes specific pollutants. The choice of filtering media or cartridges is typically based on the target pollutants.

2. Guidelines for Selection and Use of Proprietary Treatment Devices

In order for use as a limited application control, a proprietary treatment device must have a demonstrated capability of meeting the stormwater management goals for which it is being intended. It is recommended that the system provide:

(1) Independent third-party scientific verification of the ability of the proprietary treatment device to meet pollutant removal objectives;

(2) Proven record of longevity in the field; and,
(3) Proven ability to function in local conditions (e.g., climate, rainfall patterns, soil types, etc.).
(4) Maintainability – Documented procedures for required maintenance including collection and removal of pollutants or debris.

Although local data is preferred, data from other regions can be accepted as long as the design accounts for the local conditions. Local stormwater programs may submit a proprietary system to further scrutiny based on the performance of similar practices. A poor performance record or high failure rate is valid justification for not allowing the use of a proprietary system or device.

Consult your local stormwater program for information related to the selection and use of proprietary stormwater control measures.

3. Maintenance

Maintenance is especially important with these devices, and must be performed in accordance with the manufacturer's technical specifications. Clogging of devices can not only hinder removal of pollutants, but may also create drainage problems. Frequent inspections throughout the first year of installation are recommended. Although the general rule of thumb is that these devices need to be cleaned out once or twice a year, they must be maintained once capacity is reached. Depending on the device, maintenance may include the use of a sump vacuum or vacuum truck.

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Chapter 5.5

Inlets, Outlets, and Flow Control

There are common structural elements of SCMs that are designed to safely route water. Engineered flow control devices are used to effectively route water at a designed flow rate such that energy is dissipated to decrease erosion potential, protect downstream infrastructure, and/or filter particulates or other pollutants of concern. Flow control devices are used to lower the velocity of stormwater, create storage, provide adequate retention/detention time, and release storage at an acceptable rate. Pretreatment devices are used to treat stormwater in order to protect downstream infrastructure like receiving channels or stormwater control measures. It is the responsibility of the designer to incorporate the appropriate inlet and outlet structures as necessitated by the scale of the SCM and the volume of water being handled.

Inlets and Pretreatment

An inlet is the location where water enters a design element or SCM. Here, flow is either routed into storage, dispersed through an area, or routed to an overflow structure. Most likely, the inlet will need to be designed to accomplish all of these flow scenarios. Sediment and other particulate pollutants cause clogging of pore space and surface sealing. Without adequate percolation and infiltration, the full storage capacity of SCMs is not utilized, which results in failure to meet the runoff reduction volume target. Pretreatment is used when there is potential for solids transport to remove a portion of them before stormwater enters a SCM that relies on a designed percolation and/or infiltration rate.

Splash Pads

Splash pads are concrete structures that are used at the end of concentrated flow to dissipate energy, protect the soil surface, and guide water downhill. A splash pad may be used at various scales of measures such as for a simple downspout that discharges into an infiltration zone or at the end a culvert discharging into a bioretention practice.

Rock Aprons (riprap)

Rock aprons are a constructed layer or facing of stone strategically places to prevent erosion, scour, or sloughing of an earthen structure. Riprap is a certain class of very large aggregate, ranging in diameter from 2 to 42 inches. Riprap should be structurally sound (no cracks) and free of finer materials such as soil, weathered shale aggregates, or organic materials. The resistance of riprap to displacement by flowing water is a function of its weight, size, and shape of the stone as well as its orientation with respect to flowing water. Considerations should be made to place stones in a flow-resisting manner such that the stones won't roll or tumble.

Flow Splitters

SCMs can either be placed in-line or off-line. An on-line SCM will receive all stormwater flow regardless of intensity, with the flows beyond the design volume typically passing through an overflow device. An off-line SCM has a flow splitter at the inlet that diverts the design volume into the SCM and bypasses a certain volume of excess flow around the practice. Flow splitters are most often designed as a weir overflow device placed in a vault as shown in Figure 5.8. The elevation of the overflow weir is most often set at the SCM design volume elevation. That will allow the flow up to the design volume enter the SCM, and the flows in excess of the design volume to split and routed through a bypass device. Splitter boxes with an internal wall baffle and inlet and outlets pipes in association with a ponding practice also accomplish the desired result (Figure 5.9).

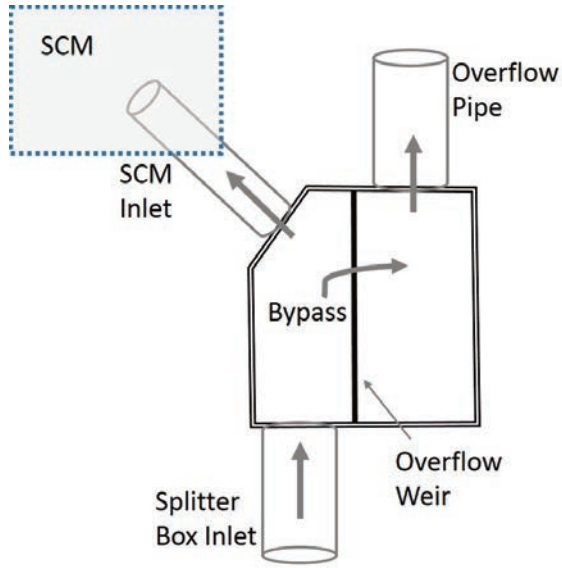

Figure 5.8: Flow splitter box with one inlet, a pipe outfall to the stormwater control measure (SCM) and overflow pipe (Source: MCES, 2001).

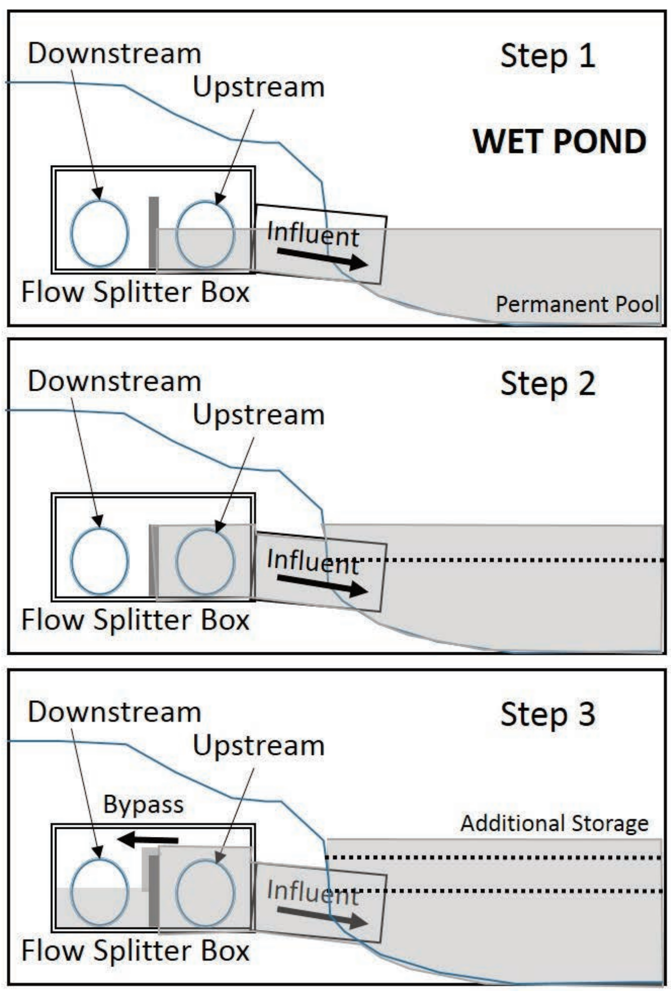

Figure 5.9: Water level progression in flow splitter box leading to a wet pond (Source: MCES, 2001).

The materials in the flow splitting device should be corrosion resistant, such as concrete, aluminum, stainless steel, or plastic. Painted, zinc coated, and galvanized metals should not be used due to their corrosion potential and possible aquatic ecosystem toxicity.

Level Spreaders

A level spreader is a relatively complex structure that can be used at the inlet of an SCM to control inflow as sheet flow and remove particulates for pretreatment. A typical level spreader system consists of pre-treatment (a forebay), principal treatment (e.g., a level spreader with grassed buffer), and emergency treatment (a reinforced grassy swale downslope of spreader). A stilling area such as a forebay is particularly useful upstream of a level spreader, because low energy should be dissipated before the flow enters a level spreader. The forebay will periodically fill with sediment, which must be periodically removed. Level spreaders are preferably made of a non-erodible material (such as poured concrete or wood beams) and must be completely level from one end to the other. The sides and the downstream side of the spreader are of particular concern regarding erosion, so armoring these areas is highly recommended.

Curb Cuts and Diverters

Curb cuts can be used to divert flow from curb-and-gutter type pervious surfaces such as roads and parking lots into a variety of SCMs. The use of a curb cut can avoid the installation of a piped stormwater collection system, however, it does not guarantee sheet flow or proper flow quantity diversion.

Figure 5.10: A curb cut inlet in an ultra-urban setting in downtown Nashville, TN.

Forebays

A forebay is a settling basin at the inlet of an SCM used to dissipate energy of concentrated inflow and settle out large sediments. As deposition is confined to the forebay area, maintenance is simpler and less costly and the life of the SCM is extended. A forebay is required for stormwater treatment wetlands and highly recommended for other practices where sediment loads are a potential concern. Forebay volume should generally be 20% of the total design volume and may be comprised of two zones: 1) a relatively deep inlet area zone for energy dissipation and flow spreading, and 2) a relatively flat and shallow zone for additional settling.

Direct access for maintenance equipment is required and should consist of a hard surface, such as gravel, concrete pavers, etc. The bottom of the forebay should also be a hard surface for ease of finding the bottom during sediment removal. This will minimize the amount of erosion and disturbance to soils and vegetation during maintenance activities. A stage indicator for deposition should be installed to monitor accumulation over time. Sediment should be removed when 25% of the forebay volume is taken up.

A separation structure must be used between the forebay and the remainder of the SCM. This structure may be earthen, rock, rock-filled gabion baskets, or concrete. The forebay should be at a higher elevation than the design volume elevation of the SCM.

Outlets

Outlet devices control the flow of stormwater out of the SCM. The outlet design and elevation are integral to the function of the SCM and/or overall treatment train. Outlets are either the point where outflow leaves a project site or the point to which flow leaves one design element and enters another.

Weirs and Drop Inlets

A weir outlet generally consists of an outlet box of concrete with a free-flowing weir water level control. Weirs can be made of various materials, such as wood, metal, or concrete. Standard weir shapes (v-notch, rectangular, etc.) with given dimensions have a known stage to discharge relationship that can be used to calculate drawdown times and outlet hydrographs.

A drop inlet is a common device for extended detention basins, wetlands, and bioretention cells. A drop inlet allows for the rapid release of water once a design elevation is reached in an SCM. In general, drop inlets also incorporate a lower elevation outlet or designed exfiltration. Drop inlets often consist of a riser structure in the storage area connected to a pipe or box culvert that extends through the containment structure (embankment or dam). The riser acts like a broad-crested weir. To ensure that the assumed weir function of the riser, the head over a weir should not exceed 1/3 of the inlet riser diameter. Above this elevation, the inlet begins to act as an orifice with unpredictable behavior.

Figure 5.11: A drop inlet structure with a perforated riser as the outlet to a bioretention cell in Nashville, TN.

Orifice

An orifice is a hole sized to provide a targeted flow rate given the stage above the orifice elevation. An orifice is used to draw down storage volume over a period of time at a designed rate. A drawdown orifice should always have a turned-down elbow to prevent trash or other materials from clogging the pipe. The SCM-side of an orifice must be protected from debris that may clog as well.

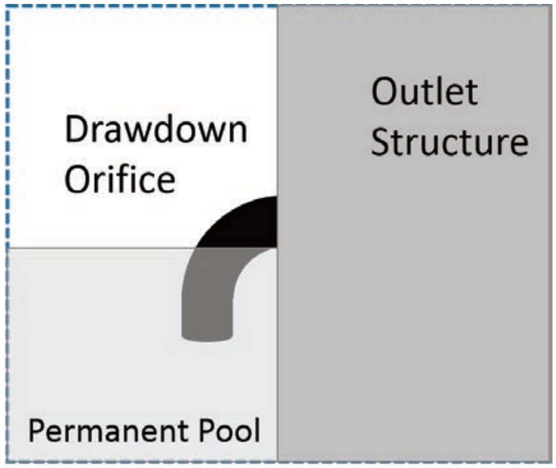

Figure 5.12: A drawdown orifice comprised of a downward turned elbow as part of an outlet structure to prevent clogging.

Underdrains

Underdrains are used to route water from the bottom or and internal elevation of an SCM. Underdrains are 1) made of pipe, 2) should have a minimum slope of 0.5%, 3) are constructed of schedule 40 (or equivalent) smooth wall PVC pipe, and 4) sized to carry 2-10 times the maximum flow expected from the SCM with a minimum diameter of 4 inches. Perforations should extend the length of the pipe with a minimum of 6 inches on center. The underdrain should have a minimum of 3 inches of washed #57 stone above and on all sides of the pipe. It is recommended to have at least 2 inches of choke stone (#89 stone) above the #57 stone and to avoid the use of filter fabric due to its high potential for clogging. Use commonly accepted engineering methods to determine the adequate amount and size of underdrain systems.

Spillways

A spillway is a section of an embankment that is designed to route water from a storage SCM. Spillways can be lined with grass, rip-rap, concrete, or other such materials. Uniform flow may be assumed in the exit channel and there is relatively flat slope (< 10%). Riprap emergency spillways should be considered when design velocities exceed those that are acceptable for vegetated emergency spillways.

Applications

Infiltration zones – The flow source to an infiltration zone may be anything from a single rooftop downspout, to a large channel or curb cut. The inlet to this SCM must be designed to protect against erosion, dissipate energy, and spread the flow over the entire design area. This may be accomplished with an inlet control device as simple as a splash pad or rock apron for small contributing areas or, for larger contributing areas, a level spreader. The designer is responsible for ensuring an adequate level of design for inlet control devices as well as for overflow spillway structure when the contributing area is large enough to warrant these measures.

Bioretention – Forebays or other particulate settling devices are strongly encouraged to preserve the function and extend the longevity of bioretention/infiltration practices. If allowed to flow into a bioretention practice, sediment and other particulate pollutants accumulate on the surface, creating a caking effect that seals the surface, clogging pore space within media, or sealing beneath course media layers.

Figure 5.13: Paver inlet area of a bioretention cell that protects the media, dissipates inflow energy, and helps settle large solids for ease of maintenance.

Wetlands – Forebays are required for the implementation of stormwater treatment wetlands for pollutant removal. Forebays are necessary in wetland systems because they provide the following: 1) dissipates the inflow energy, 2) creates a wide area to encourage flow spreading and maximum mixing, and 3) settles out solids that may cake or otherwise disrupt sensitive wetland soils downstream in the cell.

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Chapter 6

Using the Tennessee Runoff Reduction Assessment Tool (TNRRAT)

6.1 Overview – Terminology and Inputs

6.2 Design Examples

What's in this Chapter?

Section 6.1 provides general instruction on the use of the TNRRAT, mainly focusing on terminology used within the tool as well as preparing a user to execute the tool. This section does not provide substantial detail, relying for that instead on available video tutorials, which provide not only background but also step-by-step instructions.

Section 6.2 steps through two basic design examples from data input to running the tool.

The Tennessee Stormwater Management website is the clearinghouse for all state-stormwater management resources in Tennessee. Here, you will find a digital copy of this manual, a zip file that contains the TNRRAT files, and the tutorial videos described above. These videos walk users through the process of using the TNRRAT from loading the program to interpreting tool outputs.

www.tnpermanentstormwater.org

6.1 Overview – Terminology and Inputs

The Tennessee Runoff Reduction Assessment Tool, or TNRRAT, was created to help engineers, landscape architects, and other planners create development designs that meet Tennessee's runoff reduction requirements for permanent stormwater control performance. The tool was developed specifically to help designers and plan reviewers determine if projects meet requirements and to facilitate transparency throughout the process.

The TNRRAT models hydrologic processes on a time-mass basis using fundamental relationships to describe infiltration and storage phenomena under unique user-input conditions. Table 6.1 shows the equations used to characterize each pertinent hydrologic cycle component.

Table 6.1: Equations used to characterize each pertinent hydrologic cycle component.

Component	Equation	Justification
Storage	$= S_1 + P + RO_{on} - RO_{off} - 1 - ET$	A time-mass approach that accounts for runoff volume using a mass balance calculation of every 15 minutes of the representative storm event.
Precipitation	Representative Storm Event	95th-percentile rainfall depth over the median duration of storm event in a Type II storm intensity distribution.
Infiltration	Kostiakov-Lewis method (Walker and Skogerboe, 1987) $I = k * t^a + f_0 * t$	USDA-NRCS method developed from a range of large-scale supporting data in flooded systems across a wide range of soils and geographic locations. Where I = cumulative infiltration capacity, and *k*, *a*, and f_0 are empirical fit coefficients.
Management Adjustment	SCS Curve Number Approach (Hann et al., 1994) $MIR = \frac{S_{management}}{S_{bare}}$	Using a Management Infiltration Ratio (MIR) to adjust infiltration to account for the effects of vegetation and cover management. Curve Numbers were consistent with common values.

The fundamental approach of the TNRRAT design process is to divide the entire site into a number of design elements, which are units of land area or devices that affect the flow of water through the site. A design is created by defining and linking these elements in such a way to account for the entire site surface area that intercepts rain and then follow the path of any runoff until it goes offsite. The tool allows for treatment train routing configurations and multiple outfalls from the site. Each design element is a unique combination of factors including management or cover (including impervious), soil type, and routing information describing the flow patterns through contributing and receiving elements. Ultimately, performing a design analysis in the TNRRAT involves defining the elements and flow paths and then sizing and placing those elements such that permit requirements are met. User inputs and tool outputs are described in detail below.

User Inputs:

Location – the geographic location that best represents the project, which determines the representative rainfall information. Select the most proximate location to the proposed project site.

Target requirements – optional credits for special site land uses, as determined by the local jurisdiction. Credits may be applied towards meeting target requirements for the following types of projects: high density, vertical, brownfield/redevelopment, mixed use, and transit oriented projects.

Design elements – units of surface area or stormwater control measures (SCMs) that affect stormwater runoff and are spatially linked together to describe the entire project site. Design elements are delineated as having common characteristics of management (cover), soil type, and drainage point. There is no limit to the number of design elements within a project. Design elements are described, linked together, and routed to an outfall through the following element characteristics:

a. **Design element #** – a number given to the design element and used in describing flow routing. Design elements are automatically numbered sequentially starting with 1. Design element “0” is defined as being off-site.

b. **Discharges to design element #** – the design element to which discharge is routed, where “0” indicates routing off-site.

c. **Area, ft^2** – design element area. The only types of design elements not requiring specified areas are rainwater harvesting systems and manufactured treatment devices.

d. **Special condition** – indication that the element is a special management area that may place limits on allowable flow paths during the design process. Special conditions currently include hotspots, karst features, contaminated soil allowing infiltration, and contaminated soil without infiltration.

e. **Soil** – soil texture of the surface or otherwise “receiving” surface (i.e., the infiltration surface). If the design results in no or very little infiltration in this area (as for imperious surfaces or designs with and impermeable liner), this information is still shown, but has little impact on the result. Soils information may be gathered from the NRCS web soil survey for undisturbed areas. For highly disturbed area or areas without a true soil designation (such soils are often classified as “urban soils”, a soil texture analysis or infiltration test is needed to classify soils (See Appendix A).

f. **Depth surf to restrictive, in** – depth from the final grade down to a restrictive layer. Restrictive layers include any material that impedes the infiltration of water into soil beneath and include bedrock, tight clay lenses, water table, etc. Most soils, whether undisturbed or disturbed, have a restrictive layer that will reduce infiltration. If the soil survey or expert opinion indicates that this location has no such restriction, entering a very large depth (e.g., 10 ft) will remove this impact.

g. **Base SCM/management** – the type of stormwater control measure and/or management of a design element. The menu includes impervious surface, unmanaged vegetated areas, and SCMs. Impervious surface characterizes all hard surfaces that contribute runoff, which is considered “dirty” and associated with target treatment volumes. Unmanaged vegetated areas are areas that do not meet management requirements of managed vegetated areas (see Chapter 5) and do not contribute pollutants. Variants of the SCMs are differentiated within the directory folders.

h. **Element SCM values** – information table of all pertinent design parameters associated with selected SCM/management. Some of these will be for informational purposes, and some will be eligible to be modified by the user as part of their design.

i. **Design element description** – optional description and notes.

TNRRAT Outputs:

Total surface area (ft^2) – the total project surface area, which includes all of the land area considered as part of the project. This is a summation of all the surface areas of the design elements and automatically calculated by the tool.

Impervious: Treatment ratio – calculated ratio of total impervious area to total treatment measure area used to evaluate spatial efficiency and optimization. TNRRAT result indicators – a set of three indicators that express the results of calculations for contaminant removal and runoff volume reduction requirements. These indicators are updated every time the user changes an input, and are as follows:

a. **"Pollutant removal OK?"** – indicates design status in meeting the minimum treatment requirement, defined in the permit as 80% pollutant removal from the first inch of rainfall through runoff reduction SCMs (infiltration or reuse). Green indicates a successful project design, yellow indicates that the pollutant removal requirement was nominally met, but not through volume reduction. Red indicates failure to meet requirements.

b. **"Volume reduction OK?"** – indicates whether the design meets the runoff volume reduction requirement, defined as one inch of the reduction sometime during the representative storm event. Green indicates a successful project design, yellow indicates that the designer indicated special management areas or other circumstances which lowered runoff reduction requirements and that these lower targets are met (but should be verified by a plans reviewer), and red indicates failure to meet requirements.

c. **"Flow paths OK?"** – indicates that routing between elements and saturation duration is acceptable.

Runoff requirements – tool outputs that show volume calculation results. "Net volume reduction depth (in)" is the total runoff depth that is reduced on the project elements. This number must be equal to or greater than the "Required volume reduction depth (1 inch)". "Net runoff volume (ft^3)" is the overall runoff leaving the site during the representative rainfall event. "Net runoff depth (in)" is the depth of runoff coming from the project site.

Treatment requirements – tool outputs that show pollutant calculation results. "Portion pollutant removed (%)" is the percent of the calculated contributed contaminated water that has been removed by the design. This number must be equal to or greater than the "Required pollutant portion removed (%)". "Portion pollutant removed by reduction (%)" is the percent of total flow volume treated through the preferred runoff reduction methods. "Net pollutant volume released (ft^3)" is the volume of runoff from pollutant potential areas released offsite. "Net hotspot volume released (ft^3)" is the volume of runoff from hotspot areas released offsite.

Using the Tool

The TNRRAT should be used early in the design process to help identify realistic design options and to optimize a project plan for meeting use targets (i.e., lot size, road size, impervious footprints) as well as runoff reduction targets. To complete a TNRRAT analysis, a designer must provide the following user inputs: 1) geographic location, 2) target requirements, 3) total project size, 4) exact locations of special conditions, 5) pertinent landscape capacity conditions, 6) locations of soil types, and 7) depth to any restrictive layers on the site.

A project concept plan should be developed to the extent that impervious surfaces and preferred SCMs are identified for the site given the intended landuse, keeping in mind long-term maintenance and operation. The areas of roadways, rooftops and all other impervious surfaces, as well as the pervious areas, should be determined with a known level of flexibility. For example, a target roadway and rooftop area per unit may be identified. Given the available pervious areas (i.e., lawns, landscaping, and common greenspace), the number of units and driveway dimensions may be optimized depending on runoff reduction capacity of that pervious area. Similarly, in a tight footprint commercial project, the area for parking may be limited by the selection and design of SCMs. Note too that flow patterns through the site are as important as the relative areas. This is the case since the net runoff from impervious areas must meet the pollutant removal requirements before leaving the site.

Suburban residential projects are often composed of repetitive units of roofs, driveways, roads, and lawn that may have consistent relative areas, as in Figure 6.1. Such repeated units comprise sub-basins that are delineated by a change in discharge element, soil, or other special site condition (i.e., hotspot, karst, depth to restrictive layer, etc.). If applicable, a representative unit may be created to determine the necessary size of lot-scale or sub-basin scale SCMs. The results can then be scaled up by multiplying the representative unit by the number of units in a particular plan. This will be successful for sub-basins that have relatively consistent management configurations. If the discharge element changes, then a new sub-basin is needed. Complex topography and natural drainages necessitate the use of routing and should be considered when creating representative units.

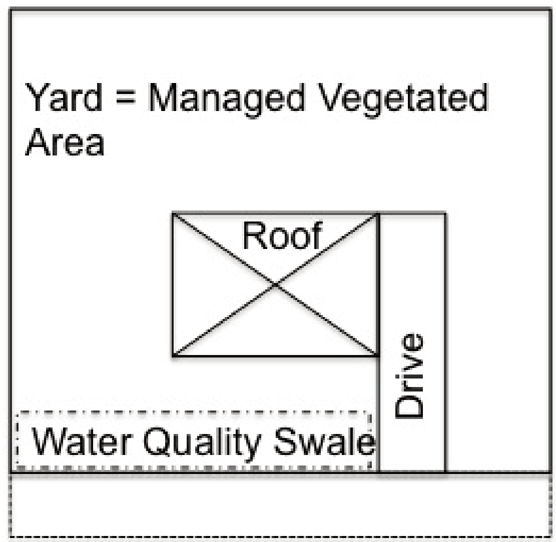


Figure 6.1: A representative single-family residential unit used to determine lot-scale SCM dimensions and scaled up by a factor equal to the number of units in a sub-basin.

The flowchart (Figure 6.2) provides a list of steps for general TNRRAT operation to help a designer integrate the tool into their design process. Information from the initial site inventory (see Chapter 3) will guide the concept plan stage. It is then advantageous to use the TNRRAT as a high-level check to ensure the envisioned land use needs can be accomplished within the available space, while taking into account any unique site conditions. Iterative use of the design worksheet and selecting appropriate SCMs is then required until routing flow paths from impervious surfaces and between sub-basins all connect to offsite discharge locations. From here, this plan may be tested using the TNRRAT to optimize placement and sizing of SCMs and other flexible elements.

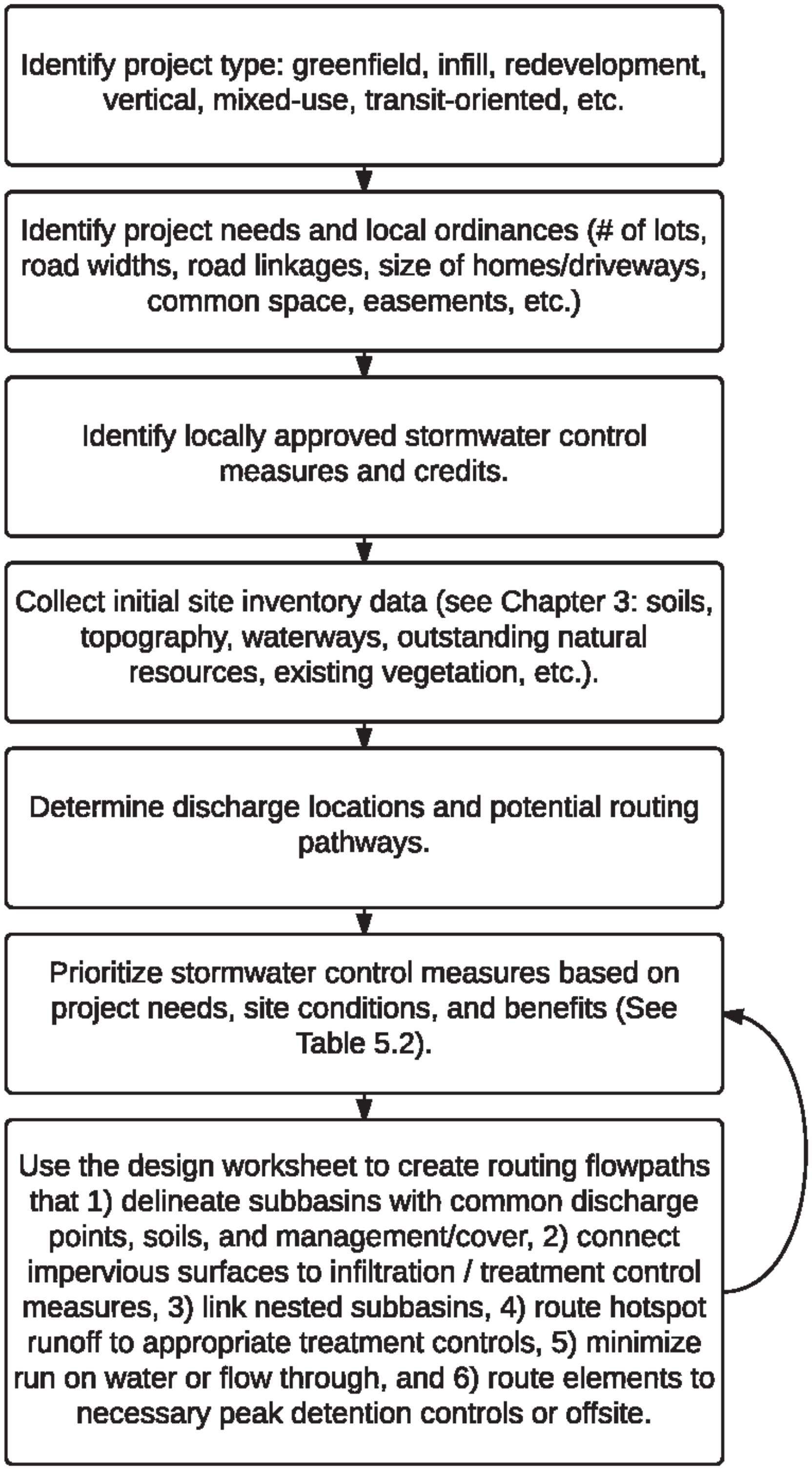
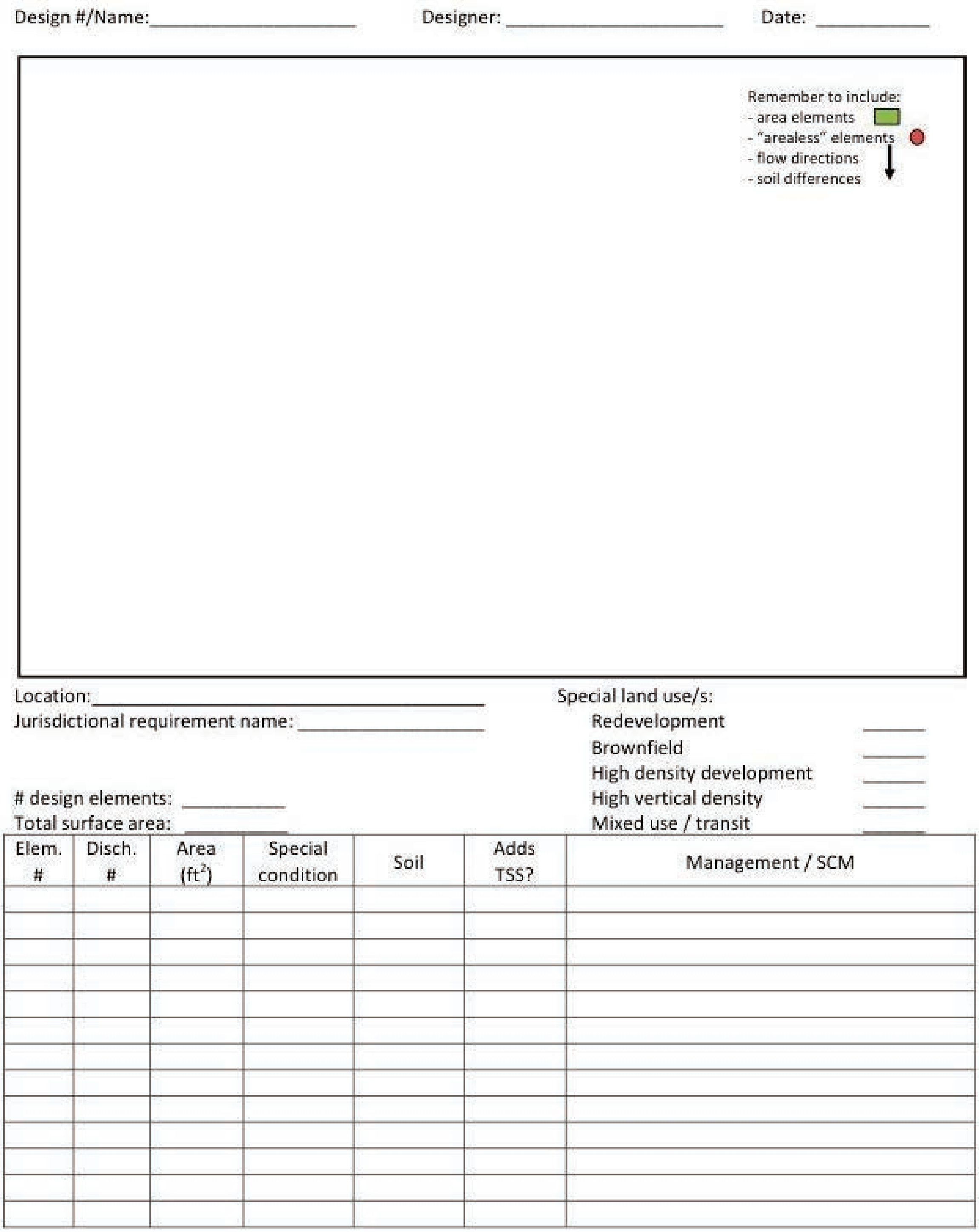


Figure 6.2: General design steps from project conceptualization and site inventory, transitioning to TNRRAT use.

Finally, a designer must understand the site and project conditions that affect routing between design elements. To assist in conceptualizing a project in terms of routing, the following design worksheet was developed to accompany the TNRRAT. Use this worksheet to lay out design elements, create flow paths, and delineate sub-basin units that discharge off-site. Once the worksheet is complete, a TNRRAT run can be easily performed.



Design #/Name:__________________ Designer: ___________________ Date: __________

Location:__________________________________

Jurisdictional requirement name: ________________

\# design elements: _________

Total surface area: _________

Special land use/s:

- Redevelopment _____
- Brownfield _____
- High density development _____
- High vertical density _____
- Mixed use / transit _____

Elem. #	Disch. #	Area (ft^2)	Special condition	Soil	Adds TSS?	Management / SCM

Figure 6.3: Tennessee Runoff Reduction Assessment Tool design worksheet to assist with efficient model use.

Now that the project has been conceptualized and routing flow paths have been identified, use the TNRRAT to determine the precise size of all elements. Revisit the project goals to help prioritize which elements may be adjusted to reach a successful design and set reasonable bounds for SCMs and other flexible elements.

1. Use unit blocks to represent areas of a project plan that: 1) have consistent soil types; 2) are comprised of consistently sized lots with consistent ratios of impervious to pervious surfaces; 3) have a common discharge point; and 4) incorporate the same lot-scale runoff reduction measures. Some additional considerations include:
   a. Once targets have been met for a unit, these elements may be routed offsite if there is no treatment to be accounted for in downstream practices. For example, if swales in the associated right-of-way of each lot create a successful design and there are no other areas of impervious runoff to treat, then the unit elements may be routed offsite even if there is a peak flow detention measure in place at the end of the flow path (assuming this measure is not needed to meet treatment requirements).
   b. Elements of each unit must be entered individually if treatment is needed in additional elements off the lot.
   c. Volume results may be scaled up by multiplying by the number of units; however, area may not be linearly scaled up due to the manner in which deep infiltration is modeled. Lateral infiltration is accounted for when the potential for infiltration into an adjacent soil is greater than the soil at the base of the cell. Due to this, many small infiltration cells will have a different overall impact on retention than one large cell.
2. SCMs will typically occupy areas that would otherwise be a managed vegetated or impervious area. It would be advantageous to highlight on the design worksheet the elements that are flexible in size (eg. the ones that can shrink as SCM space is needed). Remember to subtract the SCM area from the design element area it has replaced. Frequently check the Total Surface Area box to ensure the target project size is correct.
3. To gain runoff reduction volume, increase the ratio of pervious to impervious area or incorporate infiltration SCMs. These measures are most effective when applied as diffusely as possible throughout the project plan (keeping in mind operation and maintenance activities).
4. To gain pollutant removal percentages, look for opportunities to first increase infiltration. Keep in mind that the smaller the contributing drainage area, the smaller the necessary SCM footprint. Once these options are exhausted, look for opportunities to incorporate treatment measures or add storage to infiltration practices as appropriate.
5. The “Impervious:Treatment ratio” can be used as a general scaling tool to evaluate the efficiency of the space used for treatment measures relative to the contributing area, assuming an underlying goal is to minimize their footprint within the plan. Some SCMs such as infiltration areas and swales that rely purely on surface infiltration with no storage will have a relatively low ratio (< 4) while other SCMs with large storage volumes, such as bioretention or underground infiltration systems, may have ratios above 15. However, this number is also sensitive to soil characteristics including texture and depth to restrictive layer, and to the quality of the management vegetation.
6. If flow from an element runs onto an impervious surface that does not route to a SCM, then those elements may all be routed to offsite (aka “0”), assuming none of these elements are hotspots. There is no need to route impervious surfaces together if they both ultimately flow offsite without flowing through another SCM. The maximum percentage of offsite routing of impervious surface runoff without treatment is 20%, which would require 100% treatment of the remaining 80% volume.
7. Run on flow should be included as “upslope areas.” These management selections are located in the “miscellaneous management” folder and are classified as either “dirty” or “clean.” Calculate the volume of run on coming from the off-site contributing area. Input an element size equal to the volume divided by the representative rainfall depth for your location.

Additional useful tips and design examples may be found at the Tennessee Stormwater Management website. This site will be constantly updated with answers to frequently asked questions.

6.2 Design Examples

Design Example 1 – Mixed Single-Family (SF) and Multi-Family (MF) Residential, 40-acre Greenfield project in Knox County, TN

Site Location: Knox County, TN

Watershed: Beaver Creek, Clinch River

Size: 40 acres

Target Requirement Credits: None

Special Management Areas: None

Soils: Silt Loam, Clay Loam, restrictive layer at least 40”

Project Use: 70 single-family residential units, 35 condominium units

Typical Units:

- Single-family (SF) unit: 1/3-acre lot, 3200 ft^2 rooftop, 1000 ft^2 driveway, 105 ft frontages
- Condominium unit: 0.15-acre lot, 2100 ft^2 rooftop, 350 ft^2 driveway, 80 ft frontages

Roadways: 27 ft-wide roadways, 5,115 total length

Local Municipal Program Ordinance on SCM Use: All acceptable

Site considerations: The general lay of the parcel is along an existing roadway, where the highest elevations lie at the north end and elevations fall at a relatively consistent slope to the lower end. A natural drainage exists at the lower end of the project site between the SF units and condominiums. Another drainage runs along the eastern perimeter of the condominiums. These two drainages converge at the bottom of the site and are routed through a culvert under an existing road. A soil type change from silt loam to clay loam at the upper most elevations delineates a line between two single-family unit sub-basins.

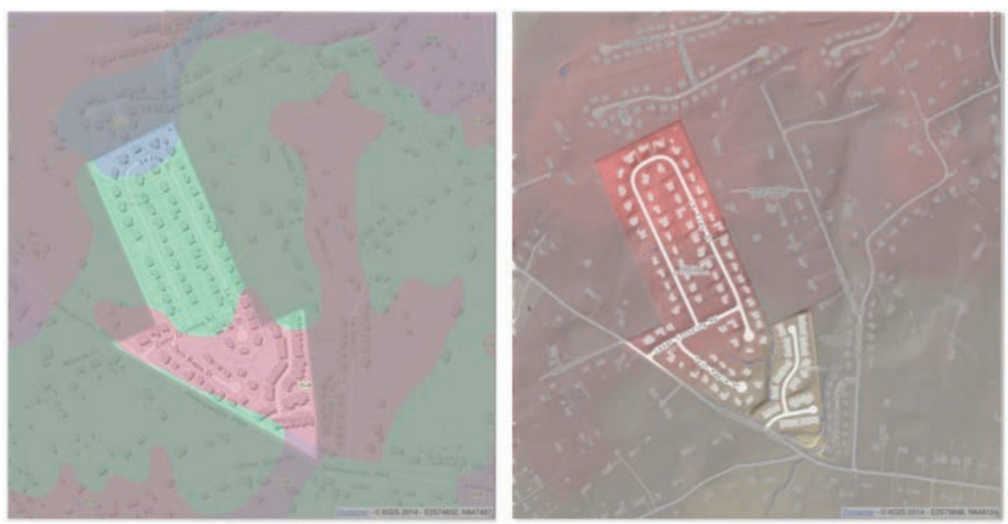


Figure 6.4: Project site maps with proposed plat overlay
***Left:* Soil classifications (blue show silt loam, green and pink show clay loams)**
***Right:* Topographic map showing higher elevations on the north of the property (red) and lower elevations in the south end (tan).**

Two approaches were used to model potential stormwater management systems. First, an approach using lot-scale SCMs was used to show how targets may be met through maximizing the use of small, diffuse pockets of storage on each individual lot. While this approach will require a larger inspection effort given the increased number of practices and their locations on private property, it most effectively uses a site’s vegetated areas as SCMs to capture stormwater runoff as close to its source as possible. The second approach recognizes that many communities will not have the capabilities to allow lot-scale practices. Here, subbasins of 2-3 acres are delineated throughout the project site and bioretention and swales capture flow from these subbasins. These SCMs are all located in either drainage easements along the rear property line or in common open spaces, which were already part of the neighborhood plan layout.

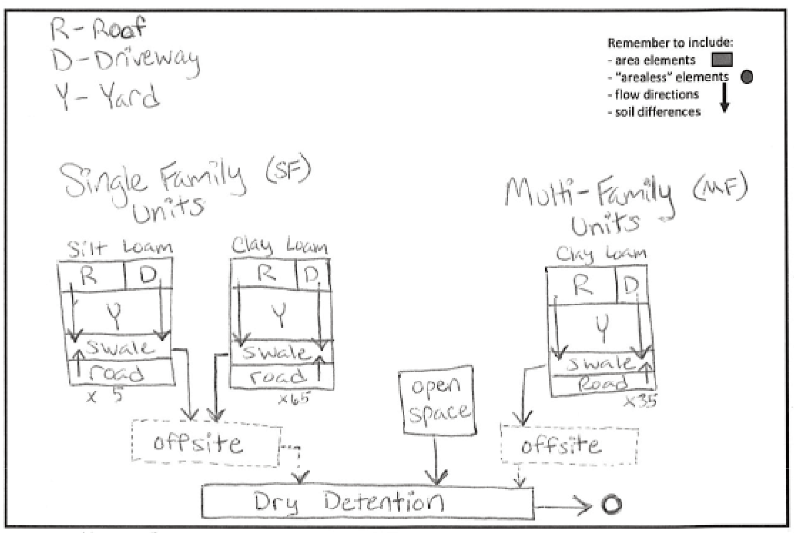
Approach 1: Lot-scale treatment of all "dirty" impervious areas (roads, roofs, driveways) with right-of-way, 8ft-wide vegetated swales with 3" storage.

The design worksheet below shows the compilation of design elements needed to test the overall plan in the tool. In this approach, there are two types of unit designs: single-family and multi-family units. Two single-family units are identified due to a change in soil type from silt loam to clay loam going down slope. Since there is a consistent density of impervious surface to lawn ratios among the units, lot-scale measures can be sized using a single individual unit comprised of a group of elements (roof, driveway, yard, road, and swale).

The only remaining management not treated in on-lot swales is open space, or managed vegetated area (turf, fair). Since there is no runoff volume coming from this open space that must be treated for pollutant removal requirements, the dry detention basin will be sized outside of the RRAT based on local detention requirements. The units are routed to "offsite" even though on the plan they will discharge to storm drains that carry flow to the detention basin. This type of routing to a false "offsite" location can only take place here because we have met runoff reduction and pollutant removal requirements at the lot scale for all the "dirty" areas in the entire plan.

TN Runoff Reduction Assessment Tool (RRAT) Design Worksheet

Design #/Name: Greenfield 1 Designer: A. Ludwig Date: 10/1/2014



Location: Knox County, TN
Jurisdictional requirement name: Knox County

Special land use/s: NA
Redevelopment
Brownfield
High density development
High vertical density
Mixed use / transit

design elements: 17
Total surface area: 1742,400 ft² → 40 acres

Elem. #	Disch. #	Area (ft²)	Special condition	Soil	Adds TSS?	Management / SCM
1	5	3200	NA	silt loam	Y	SF roof - unit
2	5	1000	NA	"	Y	SF drive - unit
3	5	9580	NA	"	N	SF yard - unit
4	5	1418	NA	"	Y	SF road - unit
5	0	740	NA	"	N	SF swale - 3" store - unit
6	10	3200	NA	clay loam	Y	SF roof - unit
7	10	1000	NA	"	Y	SF drive - unit
8	10	9580	NA	"	N	SF yard - unit
9	10	1418	NA	"	Y	SF road - unit
10	0	740	NA	"	N	SF swale - 3" store - unit
11	15	2600	NA	"	Y	MF roof - unit
12	15	350	NA	"	Y	MF drive - unit
13	15	3084	NA	"	N	MF yard - unit
14	15	1080		"	Y	MF road - unit
15	0	525		"	N	MF swale - unit 3" store
16	17	359,170		"	N	open space - MVA
17	0	ND		"	N	Dry Detention

Figure 6.5: Design Worksheet from the lot-scale management approach of a greenfield development in Knox County, TN.

On-lot swales were sized to treat runoff from the roof, driveway, and road. From this result, the yard area was determined as the difference in element 1-3 area and the sum of the hard surfaces and the swale area. The final project plan uses vegetated swales on SF lots with an area of 740 ft2 and 3” storage capacity and on MF lots with an area of 525 ft2 and the same storage. The overall Impervious:Treatment ratio is approximately 6. A detention facility will be required at base of the project to meet local flood protection standards. This facility does not need to be in included in the model because the system does not rely on the treatment by this facility in order to meet targets (e.g. treatment from the detention facility will be above and beyond the minimum requirement).

Approach 2: Roof and driveways all connected to roads (no on-lot treatment), sub-basin SCMs in common areas and linked with vegetated swales.

Bioretention and swales were selected for use on this project due to the aesthetic benefits for the neighborhood and potential for flexible storage capacity. The design worksheet shows the compilation of design elements in this second approach. Fourteen sub-basins of 2-3 acres of SF and MF lots are delineated to drain to bioretention cells that are located either in drainage easements (running along the rear property line of SF lots) or in common green space areas. Larger bioretention cells are used in the common areas and smaller cells used in the easements. A network of swales connects bioretention cells and routes flow down through the site and ultimately to the inlet of a detention facility.

On the worksheet, a SF unit and an MF unit are described in the box to the left and represented in the flow network with an abbreviation. Because this approach necessitates careful tracking of routing flow paths, elements and units should be placed on the worksheet in a spatially-representative pattern to reflect the general overall topography of the site. A dashed dotted line delineates the soil transition from silt loam soils to clay loam soils and the associated design elements for each.

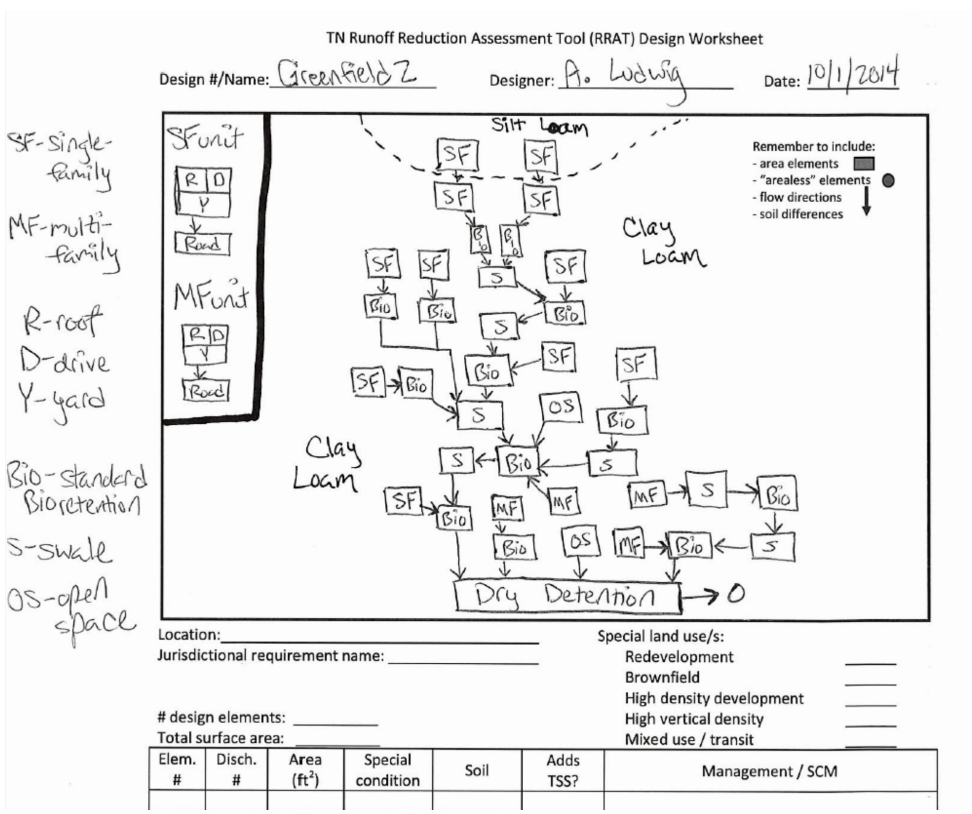


Figure 6.6: Design Worksheet from the common space management approach of a greenfield development in Knox County, TN.

The system of SCMs is completely located in common space and easement areas, with no on-lot practices.

The managed vegetated area in the design layout is large enough relative to the amount of impervious surface that the plan meets volume reduction requirements. However, structural SCMs need to be implemented to meet pollutant removal requirements. Water quality swales and bioretention were selected for the site due to the following characteristics: 1) provides adequate surface storage, 2) easily incorporated into landscaping aesthetics of the neighborhood, and 3) provides infiltration-based treatment since there is no restrictive layer influence. Water quality swales with 6 inches of surface storage with a width of 10-12 ft lie along major routing flowpaths. Standard bioretention cells receive water from 6-8 single family (SF) units, or approximately 2.5 acres. There are 14 bioretention cells that vary in size from 600-2000 ft^2, for a total cumulative area of 17,225 ft^2. There are approximately 3,360 linear feet of water quality swale, for a total cumulative area of 37,000 ft^2. Finally, MVA (open space, OS) size was determined by subtracting the needed bioretention area from the available managed vegetation area space. The Impervious:Treatment ratio is approximately 10. Again, the detention facility is outside of this system, as it is only needed to meet flood and channel protection requirements.

REFERENCES

Hann, C.T., B.J. Barfield, J.C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, New York.

Walker, W.R., G.V. Skogerboe. 1987. Surface irrigation: Theory and practice. Prentice-Hall, Englewood Cliffs.

Chapter 7

Long-term Operation and Maintenance of Stormwater Control Measures

7.1 Importance of Maintaining Stormwater Control Measures (SCMs)

7.2 Legal and Financial Issues

7.3 Summary of SCM Maintenance Tasks

7.4 Inspection and Maintenance Checklists

What's in this Chapter?

Section 7.1 provides an overview of why it is important to inspect and maintain the SCMs that have been designed and installed as part of an overall stormwater management control plan.

Section 7.2 reviews the legal and financial issues associated with implementing an inspection and maintenance program at the community level and site level.

Section 7.3 provides an overview of basic maintenance tasks to be performed by an SCM owner or operator

Section 7.4 discusses examples of inspection and maintenance check lists for many of the SCMs found in this manual.

7.1 Importance of Maintaining Stormwater Control Measures (SCMs)

Most of this manual is devoted to proper design and construction of stormwater control measures, tasks that require significant investment and expense. Once they are constructed, SCMs are crucial in protecting water quality from impacts of development projects. However, no matter how well they are designed and constructed, SCMs will not function correctly nor look attractive unless they are properly maintained. Failure to provide effective maintenance can reduce the hydraulic capacity and pollutant removal efficiency of SCMs and conveyance systems. ***SCM maintenance is the purposeful management of an SCM to maintain a desired level of performance and efficiency.***

We need of think of SCMs as key element of a community's stormwater infrastructure. As with any infrastructure, deferred maintenance can increase costs and negatively affect receiving waters. Unmaintained SCMs will ultimately fail to perform their design functions and might become a nuisance or pose safety problems. Local governments inherit problems arising from deferred maintenance. Most maintenance problems with SCMs are less costly to correct when they are caught early – as the old adage goes, "an ounce of prevention is worth a pound of cure." Therefore, developing and implementing an effective maintenance program is essential. As well, designers should give considerable thought to future long-term maintenance during the design of site plans and stormwater control measures.

Regular inspection and maintenance is an ongoing legal requirement after the SCM is constructed – in order to ensure that all SCMs are operating correctly and are properly maintained". Documentation of these inspections must be maintained and made available upon request. An appropriate professional should conduct the SCM inspections. The Tennessee Stormwater Training and Certification Program will begin offering a Tennessee SCM Inspection and Maintenance Certification course in spring of 2015; more information is available at their website:

www.tnstormwatertraining.org

This chapter will discuss the logistical issues associated with SCM inspection and maintenance as well as provide an overview of the tasks associated with maintaining SCMs. This chapter also discusses SCM design and construction considerations that affect maintenances and provides tips and sample checklists for conducting inspections. Each SCM section in this manual includes a table explaining the specific inspection and maintenance activities required to ensure proper functioning of the SCM.

7.2 Legal and Financial Issues

7.2.1 SCM Maintenance Agreements

All stormwater SCMs must be maintained in perpetuity, as required by local ordinance or other enforceable policy. Owners or operators of any SCM must develop and implement a maintenance agreement (or an equivalent document) addressing maintenance requirements. The agreement should allow the local authority, or its designee, to conduct inspections of the SCMs and also account for transfer of responsibility in leases and/or deeds. When inadequacies are discovered, the owner must initiate corrective action within 30 days of notification.

The agreement should also allow the local stormwater management authority, or its designee, to perform necessary maintenance or corrective actions neglected by the property owner/operator, and bill or recoup costs from the property owner/operator when the owner/operator has not performed the necessary maintenance within 30 days of notification. The local stormwater authority must conduct subsequent inspection (or obtain sufficient written and photographic evidence) to ensure completion of all required repairs.

7.2.2 Verification of Maintenance Responsibilities

Owners or operators of any SCM must provide verification of maintenance to the local authority. Verification of maintenance by SCM owners is typically required either by ordinance regulation or contractual agreement, or should include one or more of the following as applicable:

1. The owner/operator's signed statement accepting responsibility for maintenance with a provision for transferring maintenance responsibility if the property is legally transferred to another party; and/or
2. Written conditions in the sales or lease agreement that require the recipient to assume responsibility for maintenance; and/or
3. Written project conditions, covenants and restrictions for residential properties assigning maintenance responsibilities to a home owner’s association, or other appropriate group, for maintenance of runoff reduction and pollutant reduction stormwater SCMs; and/or
4. Any other legally enforceable agreement that assigns permanent responsibility for maintenance of runoff reduction and pollutant reduction stormwater SCMs, including, but not limited to a SCM permit tracking system developed by the local authority.

The signed and notarized Inspection and Maintenance Agreement should be filed with the appropriate Register of Deeds. The responsible party should keep a copy of the Inspection and Maintenance Agreement along with a current set of SCM plans at a known set location.

7.2.3 Owner or Operator Inspections

In order to ensure that all SCMs are operating correctly and are properly maintained, owners or operators of SCMS are required, at a minimum, to:

1. Perform routine inspections to ensure that the SCMs are properly functioning. These inspections shall be conducted on an annual basis, at a minimum. These inspections shall be conducted by a person familiar with control measures implemented at a site. Owners or operators shall maintain documentation of these inspections.
2. Perform comprehensive inspections of all stormwater management facilities and practices. These inspections shall be conducted once every five years, at a minimum. Such inspections must be conducted by either a professional engineer or landscape architect. Complete inspection reports for these five year inspections shall include:

a. Facility type,
b. Inspection date,
c. Latitude and longitude and nearest street address,
d. SCM owner information (e.g. name, address, phone number, fax, and email),
e. A description of SCM condition including: vegetation and soils; inlet and outlet channels and structures; embankments, slopes, and safety benches; spillways, weirs, and other control structures; and any sediment and debris accumulation,
f. Photographic documentation of SCMs, and
g. Specific maintenance items or violations that need to be corrected by the BMP owner along with deadlines and re-inspection dates.

Sample inspection and maintenance provisions are included at the end of each SCM section. The most effective maintenance agreements are site-specific for the particular SCM components that are used on the site as well as any conditions that are unique to the site. Owners or operators must maintain documentation of these inspections, and make them available upon request.

Table 7.1: Recommended Inspection Frequency for SCMs.

Inspection Frequency	SCMs
Monthly and within 24 hours after every storm event greater than 1.0 inch.	Stormwater wetlands Wet detention basins Bioretention cells
Quarterly and within 24 hours after every storm event greater than 1.0 inch.	Level spreaders Infiltration devices Sand filters Extended dry detention basins Permeable pavement Rooftop runoff management Filter strips* Grassed swales* Restored riparian buffers*

* *Although it is recommended that these devices be inspected quarterly, mowing will usually be done at more frequent intervals during the growing season.*

To summarize Table 7.1, practices that include vegetation in a highly engineered system are recommended to be inspected monthly and after large storm events to catch any problems with flow conveyance or vegetative health before they become serious. It is recommended that all other SCMs be inspected quarterly and after large storm events.

7.2.4 Maintenance Responsibilities

As stated in the previous section, maintenance is usually the responsibility of the owner, which in most cases is a private individual, corporation, or homeowners association. Simple maintenance items such as minor landscaping tasks, litter removal, and mowing can be done by the owner, or can be incorporated in conventional grounds maintenance contracts for the overall property.

Although a nonprofessional can undertake many maintenance tasks effectively, a professional (professional engineer or registered landscape architect) must be consulted once every five years, at a minimum, to ensure that all needs of the SCM facility are met. Some elements that can need professional review and consultation include structure, outlets, and embankments/dams, as well as plant health. Some developing problems may not be obvious to the untrained eye.

In addition, it is advisable to have professionals do the more difficult or specialized work. Filling eroded areas and soil-disturbing activities, such as re-sodding or replanting vegetation, are tasks that are best assigned to a professional landscaping firm. If the work is not done properly the first time, not only will the effort have been wasted, but also the facility may have been damaged by excessive erosion. Grading and sediment removal are best left to professional contractors.

7.2.5 Providing for Maintenance Expenses

The expenses associated with maintaining a SCM are highly dependent on the SCM type and design. However, the most important factor that determines the cost of SCM maintenance is the condition of the drainage area upstream of the SCM. If a drainage area conveys a high load of sediment and other pollutants to a SCM, the costs of maintaining the SCM will increase dramatically. Preventing pollution in the drainage area as much as possible will reduce the costs of SCM maintenance.

A funding mechanism should be created and regularly funded with an amount that provides enough money to pay for the maintenance expenses over the lifetime of the SCM. One option is to establish an escrow account, which can be spent solely for sediment removal, structural, biological or vegetative replacement, major repair, or reconstruction of the SCMs. In the case of a residential subdivision, the escrow account could be funded by a combination of an initial payment by the developer and regular contributions by the homeowners' association.

Routine Maintenance costs are relatively easy to estimate, and include the expenses associated with the following activities and tasks:

- Conducting SCM inspections at the one and five year required minimums as detailed in Section 4.2.5.7 of the MS4 Permit and as recommended in Table 7.1.
- Maintaining site safety, including any perimeter fences and other access inhibitors (trash racks or pipe grates).
- Removing trash.
- Removing sediment that has accumulated in any components of the SCM.
- For infiltration-type systems, maintaining the filtering media and cleaning or replacing it when necessary.
- Restoring soils to assure performance.
- Pruning woody vegetation.
- Replacing dead vegetation.
- Stabilizing any eroding side slopes.
- Repairing damaged or eroded outlet devices and conveyance systems.
- Repairing embankments, dams, and channels due to erosion or rodents.

Emergency maintenance costs are more difficult to estimate. They depend on the frequency of occurrence and the nature of the problem, which could vary from erosion problems to complete failure of a structure.

7.3 Summary of SCM Maintenance Tasks

7.3.1 Emergency Maintenance

Maintenance after floods and other emergencies requires immediate mobilization. It can include replanting and repairs to structures. Living systems are likely to need at least minor repairs after emergencies. Following an emergency such as a flood, standing water may pose health risks because of mosquitoes. Mosquito control should be considered if it becomes a problem.

For all installations obstructions and debris deposited during storm events should be removed immediately. Exceptions include debris removal that provides habitat and does not damage vegetation or divert currents to, from, or in the SCM. In fact, because of the high quality of habitat that can be found in woody debris, careful re-positioning rather that complete removal may be desirable. Educating adjacent property owners about the habitat benefits of debris and vegetation can decrease requests for removal.

Formations of sinkholes or other evidence of subsidence within an SCM footprint or its drainage pathways indicates failure of the SCM. The practice should be repaired as soon as feasible after the first observation, using appropriate engineering techniques. (e.g., VDOT IIM228 – *Sinkholes: Guidelines for the Discharge of Stormwater at Sinkholes; WVDEP, 2004; MDE, 2000; etc.).*

Figure: 7.1 Sinkhole Collapse in SCM.

7.3.2 Routine Debris and Litter Removal

Trash removal is an integral part of SCM maintenance. Generally, a "spring cleanup" is needed to remove trash from all surface SCMs. Subsequently, trash removal is to be performed as required, based on observations during regular inspections. Special attention should be given to removing floating debris, which can clog the outlet device or riser. Regularly removing debris and litter is well worth the effort and can be expected to help in the following ways:

- Reduces the chance of clogging outlet structures, trash racks, and other facility components.
- Prevents damage to vegetated areas.
- Reduces mosquito breeding areas.
- Maintains facility aesthetics.
- Reduces conditions for excessive surface algae.
- Reduces the likelihood of stagnant pool formations.

7.3.3 Stability and Erosion Control

The best way to promote soil stability and erosion control is to maintain a healthy ground cover in and around the SCMs. Areas of bare soil quickly erode, potentially clogging the facility with sediment and threatening its integrity. Therefore, bare areas must be stabilized as quickly as possible. Newly seeded areas should be protected with mulch and/or an erosion control blanket is securely staked. For SCMs that rely on filtration, such as bioretention facilities, it is critical that adjacent soils do not contaminate the selected filter media during or after construction. If the site is not permanently stabilized with vegetation when the filter media is installed, the best design practice is to specify sod or other robust erosion control practices for all slopes in and immediately around the SCM.

Erosion is quite common in or around the inlets and outlets of SCM facilities and should be repaired as soon as possible. Erosion control efforts should also extend to areas immediately downstream of the SCM.

The roots of woody vegetation (e.g. young trees and shrubs) can cause embankments to be unstable. Consistent mowing of the embankment controls stray seedlings that take root. Growth of trees and shrubs further away from the embankment should not pose a threat to the stability of the embankment and can provide important runoff filtering benefits. Trees and shrubs should not be planted within maintenance and access areas.

Animal burrows also diminish the structural integrity of an embankment. Muskrats, in particular, burrow tunnels up to 6 inches in diameter. Efforts should be made to control animal burrowing. Burrows should be filled as soon as possible.

Finally, subsidence can result in sinkholes on embankments or basin and channel bottoms. Subsidence is not solely related to karst areas. The presence of subsidence or sinkholes anywhere within the SCM perimeter or along the treatment train can short-circuit the stormwater management system, and it should always be considered a criterion for SCM failure that must be addressed and corrected as soon as possible.

7.3.4 Sediment Removal and Disposal

Sediment gradually accumulates in SCMs and must eventually be removed. However, removal intervals vary so dramatically among facilities that no “rules of thumb” are applicable. The required frequency of sediment removal is dependent on many factors, including the following:

- The type of SCM;
- The design storage volume (e.g. if the active and permanent pool storage is oversized for sediment storage);
- The characteristics of the upstream catchment area (e.g. land use; level of imperviousness; upstream construction activities and effectiveness of sediment and erosion control activities);
- Municipal practices (e.g. winter weather roadway sanding and salting etc.) in the contributing drainage area.

Before installing a SCM, the designers should estimate the lifetime sediment accumulation that the SCM will have to accommodate. Several time periods may be considered, representing expected changes in land use in the watershed. To estimate sediment accumulation, an estimate of the long term sediment load from upstream must be calculated. Then an estimate of the SCM’s sediment removal efficiency must be determined. The analysis of watershed sediment loss and SCM efficiency can be expedited by using a sediment delivery computer model.

The frequency of sediment removal is then based on the sediment accumulation rate versus the amount of sediment storage volume that is inherently provided in the SCM without affecting treatment efficiency or stormwater storage volume. Again, the frequency of sediment removal is SCM site-specific. It could be as often as every 2 years, or as long as 15-25 years. The volume of sediment that must be removed and disposed of each dredging cycle is the volume calculated above multiplied by any density or dewatering factors, as appropriate.

Sediment removal is usually the largest single cost of maintaining a SCM facility, so the necessary funds should be allocated in advance. Since sediment removal costs are so site specific and dependent on disposal plans, it is difficult to provide good estimates. Actual estimates should be obtained during the design phase of the SCM. The estimates should include: mobilization expenses, sediment removal expenses, material transport expenses (if applicable), and disposal expenses (if applicable).

Wet sediment is more difficult and expensive to remove than dry sediment. Ideally, the entire facility can be drained and allowed to dry sufficiently so that appropriate equipment can operate on the bottom. Provisions for draining permanent pools should be incorporated in the design of water impoundments, where feasible. Also, low-flow channels and outlets should be included in all SCMs in order to bypass stormwater flow during maintenance. However, in many impoundments periodic rainfall keeps the sediment soft, preventing access by equipment. In these cases, sediment may have to be removed from the perimeter by using backhoes, grade-alls or similar equipment.

Underground or proprietary SCMs – such as vaults, chambers, and other structures that require accumulated material to be pumped out – require special consideration. For such facilities, inspection and maintenance staff may be required to have confined-space training to satisfy OSHA safety requirements. Also, some types of proprietary devices require more frequent maintenance in order to perform as designed. Maintenance contracts are essential when such SCMs are specified on plans.

At sites where sediment loads are expected to be high, designers should designate a dewatering and storage area on the site. This area must be located outside of the floodplain. If such a disposal area is not set aside, transportation and landfill tipping fees can greatly increase cost of the SCM maintenance, espically if disposal of wet sediment is not allowed in the local landfill. If on-site storage is not feasible, sediment can be used elsewhere after dewatering, unless the material was generated from a stormwater hot spot (e.g. a gasoline station). In this case, a Toxicity Characteristic Leachate Procedure (TCLP) or other analysis should be performed on the removed sediment to determine if it meets the criteria of a hazardous waste, which requires special handling and disposal. If the waste is not hazardous waste and is going to be managed as a solid waste, other testing may be required by a receiving facility.

Sediment removed from an SCM requires proper disposal, which must be carefully planned. Some pump-outs result in waste material that is composed of both liquids and solids. Wastewater plants usually will do not accept wastewater with solids, and landfills usually do not accept any liquids or saturated sediments. Therefore, sediment removal activities must result in a waste material that meets the various disposal requirements. State and local waste disposal requirements should be consulted for information pertaining to the exact parameters and acceptable levels for different disposal options. Generally, sediment removal from SCMs will not be contaminated to the point that it should be classified as a hazardous waste. However, all sediment removed from SCMs should be tested to determine the proper disposal option. Most private laboratories are familiar with waste disposal regulations and can test sediment samples with these in mind. Generally, there are three sediment disposal options:

- **On-Site Disposal.** On-site disposal allows the sediment to be disposed of on any land area that is not regulated (i.e., land other than floodplain, buffer zone, etc.) During the site planning process, when determining land requirements for stormwater control measures, land can be set aside for on-site disposal of sediment removed from the various SCMs during maintenance. The areas that are used for sediment disposal should be landscaped after each sediment removal operation, in order to stabilize the soil and provide a natural appearance.
- **Off-Site Disposal.** Off-site disposal is often preferred by developers and local governments. Off-site disposal does not reduce the developable area, landscaping/grading does not have to be performed, and there are no perceived liability/health concerns with respect to the surrounding landowners. Off-site disposal can mean disposal at a landfill or disposal at another area undergoing filling. The decision of where the material is deposited depends on the quality of the sediments and the availability of and distance to the alternative fill areas.
- **Hazardous Waste Disposal.** Although sediment removed from SCMs is expected to contain some contaminant's (metals, bacteria, nutrients), the levels of pollutants involved are typically not sufficient for it to be classified as hazardous waste. Hazardous waste must be deposited at a hazardous waste facility. Transportation costs and disposal fees are expensive for hazardous waste, since licensed hauler must be used to transport the material and the number of accessible hazardous waste receiving facilities may be limited in number and distance.

7.3.5 Maintenance of Mechanical Components

Each type of SCM may have mechanical components that need periodic attention. For example, valves, sluice gates, fence gates, locks, and access hatches should be functional at all times. The routine inspection, exercising, and preventive maintenance for each mechanical component should be included on a routine inspection/maintenance checklist.

7.3.6 Vegetation Maintenance

Vegetation maintenance is an important component of any stormwater maintenance program. The grasses and plants in all SCMs, but particularly in vegetative SCMs such as filter strips, grass swales, restored riparian buffers, bioretention facilities, and constructed stormwater wetlands, require regular attention. The development of distressed vegetation, bare spots and rills, indicate that a SCM is not functioning properly. Problems can have many sources, such as:

- Excessive sediment accumulation, which clogs the soil pores and produces anaerobic conditions.
- Nutrient deficiencies or imbalances, including pH and potassium.

- Water-logged conditions caused by reduced soil drainage or high seasonal water table.
- Invasive species.

The soil in vegetated areas should be tested every other year and adjustments made to sustain vigorous plant growth with deep, well-developed root systems. Aeration of soils is recommended for filter strips and grassed swales where sediment accumulation rates are high. Ideally, vegetative covers should be mown infrequently, allowing them to develop thick stands of tall grass and other plant vegetation. Also trampling from pedestrian traffic should be prevented.

Areas immediately up and downstream of some SCM plantings often experience increased erosion. Although properly designed, located, and transitioned installations experience this effect to only a minor degree, all erosion should be repaired immediately to prevent spreading. Live stakes, live fascines and other soil bioengineering techniques, possibly in combination with geotextiles, can be applied to eroded areas in natural drainage ways with minor grading.

Table 7.2 describes some specific vegetation maintenance activities at various types of SCMs. It is important to note that there are specific requirements related to certain management practices that must be followed, such as those preformed in buffers. In addition, any vegetation that poses threats to human safety, buildings, fences, and other important structures should be removed. Finally, vegetation maintenance activities naturally change as the vegetation matures after construction.

Table 7.2: Vegetation Maintenance for SCMs.

Maintenance Activity	Instructions
Replacement of Dead Plants	All dead plants should be removed and disposed of in an environmentally friendly manner. Before vegetation that has failed on a large scale is replaced, the cause of such failure should be investigated. If the cause can be determined, it should be eliminated before any replanting.
Fertilization	The objective of fertilizing at a SCM is to secure optimum vegetative growth rather than yield (often the objective with other activities such as farming). Infertile soils should be amended before installation and then fertilized periodically thereafter. Fertilizer can be composed of minerals, organic matter (manure), compost, green crops, or other materials.
Irrigation/ Watering	Watering of the vegetation can often be required during the germination and establishment of the vegetation, as well as occasionally to preserve the vegetation through drought conditions. This can typically be accomplished by pumping water retained in the SCM or from the stream, installing a permanent irrigation system or frost-proof hose bib, or using portable water trucks.
Mulching	Mulching should be used to maintain soil temperature and moisture, as well as site aesthetics. A half-inch layer is typically adequate. Ideally, mulch should be removed before winter to prevent an infestation of rodents.
Weeding	Weeding is often necessary in the first growing season, particularly if herbaceous grasses are out-competing the young woody vegetation growth. The need for weeding may be largely eliminated by minimizing the amount of seed used for temporary erosion control. Weeding may also be required if, over time, invasive or undesirable species are entering the site and outcompeting plants that are specifically involved in the treatment of the stormwater.
Cultivating/ Hoeing	Hoeing is often required to loosen overly compacted soil and eliminate weeds that compete with the desirable vegetation.
Pruning	Pruning is used to trim to shape and remove dead wood. It can force single shoot shrubs and trees to assume a bushier configuration.

Maintenance Activity	Instructions
Thinning	Thinning dense brush may be necessary for particular species to thrive, increase the vigor of individual specimens, to reduce flow obstructions, and to increase the ability of maintenance staff to access the entire SCM. Tall maturing trees, for the most part, have no place in a SCM (except for buffers) and should be removed as soon as possible.
Staking	Saplings of tall trees planted in or near the SCM may require staking. Care should be taken not to damage the tree's roots with stakes. Stakes should be kept in place for 6 to 18 months, and the condition of stakes and ties should be checked periodically.
Wound Dressing	The wounds on any trees found broken off or damaged should be dressed following recommendations from a trained arborist.
Disease Control	Based on monitoring observations, either insecticides or (preferably) organic means of pest and fungal control should be used.
Protection from Animals and Human Foot Traffic	Fencing and signage should be installed to warn pedestrians and to prevent damage due to trampling. These measures are often most necessary during the early phases of installation but may be required at any time. Measures for controlling human foot traffic include signs, fencing, floating log barriers, impenetrable bushes, ditches, paths, and piled brush. Wildlife damage is caused by the animals browsing, grazing, and rubbing the plants. The use of chemical wildlife repellents should be avoided. Fences and meshes can be used to deter entry to the SCM. Tree tubes can be used to prevent damage to individual specimens.
Mowing	Mowing of perennial herbaceous grasses and wildflowers, especially once seed heads have set, promotes redistribution of seed for this self-sustaining system. Mowing should be carefully controlled, however, especially when performed for aesthetics. As adjacent property owners and customers in general learn more about SCMs, their vision of what is aesthetically pleasing can change. Grasses, in healthy herbaceous stands, should never be mown more than once per year.

7.3.6.1 Grass Cutting

Generally, grass-cutting should be limited or eliminated around SCM facilities. Allowing grass to grow tends to enhance water quality and provides other benefits for wet facilities. Short grass around a wet stormwater facility provides ideal habitat for nuisance species such as geese. Allowing grass to grow is an effective means of discouraging geese. Grass cutting is one maintenance activity that is undertaken solely to enhance the perceived aesthetics of the facility. The frequency of grass cutting depends on surrounding land uses, local municipal or HOA by-laws, and public or peer pressure. In view of the various influences, grass cutting should be done as infrequently as possible but with sensitivity to the aesthetic concerns of nearby residents.

Grass around wet facilities should not be cut to the edge of the permanent pool. As a safety precaution, cutting should be done parallel to the shoreline with grass clippings being ejected upland, in order to avoid adding organic matter to the pond.

7.3.6.2 Weed Control

Weeds are generally defined as any kind of vegetation which is unwanted in a particular area. In terms of SCMs, weeds are generally invasive species which cannot provide the intended function of the planting strategy, or other non-invasive species such as purple loosestrife, the spread of which is undesirable. Local weed control rules should be consulted for local requirements. Weed control may be required annually or more frequent as determined by inspection of the SCMs.

Ideally, weeding should be done by hand to prevent the destruction of surrounding vegetation. The use of herbicides and insecticides, which cause water quality problems, should be prohibited near SCMs. The use of fertilizer should also be limited to minimize nutrient loading to the downstream receiving waters.

7.3.7 Plantings

Upland and flood fringe plantings are generally stable and should not need much maintenance or re-establishment. Shoreline fringe areas are subject to harsher conditions as a result of the frequent wetting and drying associated with this zone. Aquatic plantings are the hardest to establish initially. Typically, vegetation in the aquatic and shoreline fringe zones will require some replanting or enhancement during the first two years of SCM facility operation. Preliminary results of studies of stormwater plantings indicate that a healthy vegetative community will establish if proper conditions are created (although the final set of species may not be those that were originally planted).

Planting methods can be separated into the following three main categories (from terrestrial to aquatic), based on the wetness level and types of vegetation that will grow in these conditions:

- **Upland/Flood Fringe.** The two types of plantings used are herbaceous (ground covers and grasses) and woody vegetation (shrubs and trees). Planting should occur in the spring after groundwater levels have normalized. Ground cover can be installed either by hydroseeding or using a custom seed mix in a nutrient rich medium impregnated in a biodegradable mesh-like blanket. Individual shrubs and trees can be planted manually, with openings made in the mesh blanket for each individual plant, if necessary.
- **Shoreline Fringe (Wet Riparian).** Shoreline fringe vegetation should be planted in mid-May to early June but after water levels have subsided to a stable level. Some form of protection of the seed mixture and soil nutrient medium (if required) should be provided in this dynamic zone of water level fluctuation. In order to establish ground cover in this zone, the biodegradable mesh-like blanket suggested for the upland zone is also highly recommended for this zone. Shrubs and trees can be planted through openings created in the mesh blanket.
- **Aquatic Fringe/Shallow Water.** The establishment of plantings in this zone will require greater material handling and growth monitoring, both in the short-term and over the long-term. Emergent vegetation is easily planted by hand if the substrate is suitable (e.g., ideally, a firm substrate with at least 10% organics by volume). Young shoots (rather than rhizomes or corms) are preferable for planting, since these plants are already growing with an established root structure (for early stability). The plants should be at least 10 cm tall, and planting should occur from late May to early June. Sprigs or plugs are preferable for planting emergent plants, since the root material is already contained in a suitable growth medium.

Mature growth should be planted to establish submerged rooted plants (including pondweeds), if planted in late spring to early summer when the mature plants can take advantage of warmer water and sunlight penetration. Plantings in early spring or fall should use vegetative propagules such as turions or rhizome plugs, which can germinate in the spring or over the winter and begin growing in the following growing season.

7.3.8 Maintenance of the Aquatic Environment

An important yet often overlooked aspect of non-routine maintenance of SCMs that maintain a permanent pool of water is the need to regularly monitor and manage conditions to promote a healthy aquatic environment. An indicator of excess nutrients (a common problem) is excessive algae growth in the permanent pool of water. In most cases, such problems can be addressed by encouraging the growth of more desirable aquatic and semi-aquatic vegetation in and around the permanent pool. The plants selected should be tolerant of varying water levels and have a high capacity to incorporate the specific nutrients associated with the problem. If algae proliferation is not addressed, algae-laden water will be washed downstream during rain events and may contribute to nuisance odors and pollution stresses in downstream aquatic habitat.

7.3.9 Insect Control

Ponded water can function as breeding grounds for mosquitoes and other insects. Mosquito problems can be minimized through proper design and maintenance. The most effective control technique for prevention of mosquito breeding is to ensure that permanent impoundments do not develop stagnant areas. SCMs with permanent pools should include a source of steady dry-weather flow. Promptly removing floatable debris helps eliminate areas where water can collect and then stagnate. Fish that feed on mosquito larvae can be stocked in larger basins. Additionally, splash aerators can be employed to prevent stagnant water, however, this requires electricity at the site, increases maintenance costs, and must be properly designed so as to not decrease the settling efficiency of the SCM.

7.3.10 Winter Operation

Infiltration facilities are subject to reduction in capacity due to freezing or saturation of the soil. Surface filters and bioretention areas are generally subject to similar problems. Subsurface filters, while less susceptible that surface filters, may demonstrate poorer performance in the winter due to freezing in underdrain pipes or the filter medium. Filters which use organic media are particularly prone to freezing because they retain water.

There is also an increased likelihood of infiltration facilities and filters clogging during winter operation due to the high sediment loads resulting from road maintenance activities (e.g. sanding and salting). Furthermore, there is an increased risk of groundwater contamination from road salt associated with winter operation of infiltration facilities that receive road runoff.

7.3.11 Maintenance of Other Project Features

All other devices and features associated with the SCM should be monitored and maintained appropriately. These additional items could affect the safety or aesthetics of the facility, which can be as important if not more important than the operational efficiency of the facility. Such items include:

- Fences
- Access roads
- Trails
- Lighting
- Signage (e.g. no trespassing, emergency notification contact information, etc.)
- Nest boxes
- Platforms
- Watering systems

7.4 Inspection and Maintenance Checklist

Appendix F provides examples that may be part of a comprehensive SCM operation and maintenance program. Appendix F includes examples of operation and maintenance agreements; example operation and maintenance plans for select SCMs; an example of a Declaration of Restrictions and Covenants; and templates of SCM Inspection checklists. Examples of these documents were provided by Metro Nashville-Davidson County, City of Franklin, and the City of Murfreesboro.

Glossary and Acronyms

Glossary

303(d) List – A list maintained by the State as required by Section 303(d) of the Federal Clean Water Act of waterbodies that do not support their designated uses. It is common to refer to this list as the 303(d) list. The Tennessee Department of Environment and Conservation publishes this list: http://www.tn.gov/environment/water/water-quality_publications.shtml

Absorption – A process by which one substance is taken up by another substance, in other words, a substance is assimilated by another substance

Adsorption – A process by which dissolved compounds separate from liquid to form a physical or chemical bond to solid materials.

Anthropogenic – Originating from or caused by human activities; often describes land use disturbance in watersheds.

Antidegradation – Legal policies mandated by the Federal Clean Water Act and implemented in Tennessee through the Water Pollution Control Act that protects water quality by limiting deterioration from the current condition (or to not make matters any worse than they were before). In the context of an NPDES permit, usually means conditions and associated progress of previously issued permits must remain.

Baseflow – The portion of flow in a stream that is relatively constant.

Basin – A structural facility that holds stormwater.

Berm – A raised, earthened structure that directs runoff.

Best Management Practice (BMP) – A method that is recognized as an efficient, effective, and practical means of preventing or reducing the movement of pollutants into the waters of the state. A BMP may be a physical facility or a management practice achieved through action.

Biological Integrity – The capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region.

Bioretention – An SCM of various physical forms where runoff is captured in a designed structure and pollutants are filtered through physical, chemical, and biological processes. Bioretention facilities are sized to retain a target storage volume, designed with specific vegetation and engineered media, and may incorporate an underdrain to route treated water to a receiving drainage system.

Bioswale – A landscape feature that is designed to convey, retain, and treat stormwater.

Bog Garden – A small-scale constructed or enhanced wetland used as a landscaping feature to retain and filter stormwater.

Buffer – A vegetated strip of land along a sensitive area (like a stream) that helps protect that area from the land disturbance on the adjacent land. SEE RIPARIAN BUFFER.

Catch Basin – A structure used to collect stormwater (especially from paved surfaces) and direct the flow to a stormwater drainage system.

Channelization – 1) Hydrologic modification and straightening of stream plan form (sinuosity) that may cause destabilization of streambanks and stream bed; 2) the formation of steep channel walls that separate the stream from its primary floodplain.

Cistern – A tank that stores captured rainwater runoff from impervious surfaces (most often rooftops) for later use.

Clean Water Act (CWA) – A 1972 federal act that provides the basic regulatory framework for the protection of water quality through control of discharge of pollutants into surface waters, including the management of stormwater runoff. Public Law 92-500.

Coir Fiber – A natural fiber that is often used in erosion control products (like matting, logs, and socks) as an environmentally friendly alternative to plastic netting.

Combined Sewer System (CSS) – A collection system that accepts both municipal wastewater and stormwater. The system directs the combined water to a treatment facility.

Combined Sewer Overflow (CSO)/ Sewer Overflow – Overflow from a sewer system that occurs when the system is overwhelmed with excessive water – typically occurring during a storm event. The overflow results in a discharge of a mixture of partially treated wastewater and runoff to surface **water.**

Concentrated Flow – A flow regime where water flows in a channel – the moving water is concentrated, as opposed to being spread out across the landscape, as in sheet flow.

Confluence – The point where one waterbody flows into another.

Constructed Wetland – A wetland that is designed specifically to capture and remove pollutants and created on a site that previously was not a wetland.

Contour – A path on the land where the elevation remains constant; describes topography or relief.

Contributing Drainage Area (CDA) – The land area from which surface water drains to a specific point of reference.

Culvert – Pipe or box structure that drains surface water or runoff under a roadway or embankment.

Design Element – A term used in reference to a land area input in the Tennessee Runoff Reduction Assessment Tool that has an identified land area and management.

Design Storm – The precipitation depth with a specific return period or frequency which may be used to size and select materials for stormwater treatment.

Designated Use – The use of a water resource as identified by the state. In Tennessee, these include fish and aquatic life, recreation, drinking water supply, irrigation, industrial water supply, livestock and wildlife watering, and navigation.

Detention – Temporary storage of stormwater to decrease peak flow rate into receiving waters. Typically relates to a basin.

Discharge – 1) The release of a water containing pollutants into surface waters, 2) or the volume of water that passes a certain point in time.

Downspout Disconnection – Disconnecting the rooftop impervious surface from the stormwater conveyance system as to reduce total runoff volume by allowing downspouts to drain onto pervious surface or into another retention practice.

Drainage Area – The area that contributes runoff to a point of reference and is enclosed by a ridgeline or divide. See Basin.

Dry Detention – An SCM that provides stormwater flow control designed to temporarily store and release stormwater at an acceptable rate (for permanent stormwater management).

Ecoregion – A recurring pattern of ecosystems associated with characteristic combinations of soil and landform that characterise that region-Brunckhorst, D. (2000). Bioregional planning: resource management beyond the new millennium. Harwood Academic Publishers: Sydney, Australia.

Ecosystem Services – Collectively, the processes that occur in the environment that benefit humans and society. For example, water purification in wetlands, nutrient cycling in streams, and carbon storage in soil.

Effluent – Water that has passed through a treatment process and discharged into the environment.

Energy Dissipater – A structure used to absorb the energy carried by concentrated flow and reduce velocity.

Engineered Media – Engineered mixture of materials (such as sand, soil, clay, granular activated carbon, perilite, zoelite, compost, organic matter, water treatment residuals, etc.) that is designed to infiltrate and filter pollutants from stormwater runoff.

Environmental Site Design – Method of using small-scale stormwater management practices, nonstructural techniques, and better site planning to mimic natural hydrologic runoff characteristics and minimize the impact of land development on water resources. Similar terms include low impact development, green infrastructure, and better site design.

Erosion – The detachment and transport of soil or rock due to physical movement of water or air or other chemical or biological means.

Erosion Control Matting – A sheet-like material that is placed on the soil surface to reduce erosion. These materials are typically used to protect the soil during the germination and growth of the permanent vegetation and are made of various materials.

Eutrophication – The process of being well nourished; an enrichment of nutrients (mostly nitrogen and phosphorus) in surface waterbodies that may result in excessive aquatic plant growth – frequently associated with algal blooms. Eventually may lead to the filling in and loss of the water body.

Evapotranspiration – The sum of evaporation of water from the soil and transpiration of water from plants.

Exceptional Tennessee Waters – 1) Surface waters of the state that satisfy a set of characteristics, including being within state or national parks, wildlife refuges, wilderness or national areas; 2) State or Federal Scenic Rivers; Federally-designated critical habitat; 3) waters within an area designated as Lands Unsuitable for Mining; 4) waters with naturally reproducing trout; 5) waters with exceptional biological diversity or; 6) waters with outstanding ecological or recreational value as determined by TDEC.

Exfiltration – The process in which water moves out of a media, or permeable pavement.

Extended Detention – Design for the temporary storage of stormwater in a detention facility that gradually discharges volume, allowing for increased settling of pollutants and protection of receiving channels. See wet pond.

Filter Strip – An SCM that uses dense vegetation with uniform grade to slow runoff and facilitate deposition of sediment in runoff before runoff reaches surface water.

First Flush – The stormwater that is first to run off a surface and usually carries the largest load of pollutants. Generally considered to be the first inch of rainfall.

Floatables – Litter and debris that will float and travel with water.

Floodplain – The flat area along a stream between the streambank and the valley wall that is periodically inundated by floodwaters.

Flow Path – The path water takes as it moves across land surfaces.

Forebay – A separate segment within a stormwater basin used to trap sediment, chosen to facilitate maintenance and removal of the sediment. Use of a forebay is intended to facilitate sedimentation and thus protect other unit treatment processes.

Green Infrastructure (GI) – Using natural hydrologic features and open space to manage water and provide environmental and community benefits. Similar terms include low impact development and environmental site design.

Green Roof – A rooftop that is covered with beds or a single bed of soil and vegetation and designed to infiltrate precipitation. An extensive application uses media depths between 4-6 inches deep, while an intensive application is deeper than 6 inches. Also known as a vegetated roof.

Groundwater – Water below the ground surface.

Heavy Metals – Elements, such as zinc, mercury, lead, and copper. These elements can become dissolved in stormwater and are prone to accumulate in urban areas due to anthropogenic activities (mainly automobile use).

Hotspots – A term used to describe land use or activities that pose a relatively higher potential threat to surface or groundwater pollution due to the nature of contaminants that are associated with the operations and land use. Some examples are, but not limited to, gasoline stations, trash collection areas, mulching operations, chemical storage facilities, car washes, nurseries, golf courses, etc.

Hydraulic Residence Time (HRT) – The time that a volume of water is held within a defined area. Generally, the longer the HRT, the more effective the treatment of stormwater pollution.

Hydric Soils – A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of water-loving vegetation.

Hydrocarbons – Organic chemical compounds that are made up of solely carbon and hydrogen. Predominantly used as combustible fuel and, as solid state, asphalt. A pollutant of concern in urban areas due to their contribution to ground level ozone and smog.

Hydrograph – A graph that depicts the flowrate past a specific point of reference as a function of time.

Hydrologic Cycle – The continuous movement of water on, above, or below the earth surface through processes including precipitation, interception, condensation, evapotranspiration, infiltration/percolation, storage, runoff, surface water, groundwater, and interflow.

Hydrologic Unit Code (HUC) – A standardized watershed classification system created by the USGS. See Section II B for more on Tennessee HUCs.

Illicit Discharge – Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges authorized under an NPDES permit and discharges resulting from fire fighting activities.

Impaired Water – A segment of surface waters that has been identified as failing to support its designated uses.

Impervious Surface – 1) A hard surface that either prevents or limits the movement of water into the soil as would naturally occur in a pre-development condition. 2) A hard surface that causes water to runoff in greater quantities than that occurring under natural or pre-development conditions, usually associated with building structures or pavement.

Infiltration – The movement of water into the ground surface.

Infiltration Area – An SCM used with downspout/impervious surface disconnection where an area's vegetation and soil are sized and designed to receive and infiltrate runoff from impervious surfaces.

Infiltration Trench – A runoff reduction facility that captures stormwater in a long and narrow pit that is filled with porous material (usually a sand mixture) and holds water until it has time to soak into surrounding native soils; usually used in areas with poor draining soils.

Inlet – The location where water flows into a structure or facility.

Interflow – The rapid lateral flow of water below the ground surface and above the water table.

Karst – Geological formations shaped by the dissolution of soluble rock, usually carbonate rock like limestone or dolomite.

Load – 1) A measurement of total mass of a constituent in water. 2) The product of the concentration and the water volume

Low Impact Development (LID) – A style of development that incorporates techniques to minimize impacts to natural resources, preserves ecosystem services, and implements best management practices to mimic natural hydrology.

Management – A clearly defined state of soil and vegetation that provides the desired degree of infiltration and contaminant removal under the design conditions. This design condition is considered to be 15 years following stabilization, when the site has reached a reasonable level of maturity and is undergoing only gradual changes. The management is the defined desired endpoint, and depends on a series of techniques to get from the current disturbed condition to that endpoint. A management has clearly defined specifications including vegetation type and density, soil hydrologic characteristics, etc. The term Cover is sometimes used to describe a management that has minimal inputs.

Managed Vegetated Area (MVA) – An SCM that describes and area that sustains a determinant density and type of vegetated cover such that it intercepts rainfall, covers the soil surface and has an established root matrix.

Maximum Extent Practicable (MEP) – Technology-based discharge standard for MS4s to reduce pollutants in stormwater discharges as established by the CWA. MS4 operators shall develop and implement their programs to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions appropriate for the control of pollutants.

Minimum Control Measure – Stated requirements from the USEPA for permitted groups to be in compliance and include the implementation of selected BMPs to minimize stormwater and related pollutants into surface waters.

Municipal Separate Storm Sewer System (MS4) – A stormwater drainage network (including road drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, SCMs, or storm drains) that are owned or operated by a local government or designated entity (such as a State, city, town, borough, county, parish, district, association, or other public body). See Section II C for the MS4s in Tennessee.

National Pollutant Discharge Elimination System (NPDES) – A provision of the CWA that prohibits the discharge of pollutants into waters of the United States unless a permit is issued by the USEPA, state, or tribal government.

Native Vegetation – Vegetation that is naturally found in an area and adapted to the climate, which makes them good candidates for many bioengineered BMPs.

Nonpoint Source (NPS) – Diffuse pollution source without a single point of origin. Commonly references NPS are agriculture, forestry, mining operations, dams, channels, and urbanized areas.

Nutrients – Compounds that are needed for growth of any biological organism and often carried in harmful quantities by runoff from over-fertilized areas; high nutrient concentrations lead to eutrophication in surface waters. Major nutrients include nitrogen, phosphorus, and potassium.

Outlet – The point of release of water usually through a control, such as a concrete structure.

Overflow Spillway – A control structure that safely delivers storm flows that exceeds the capacity of a structural practice to receiving stormwater conveyance system or waters of the state.

Pathogen – An organism that causes disease.

Percolation (Perc) Test – A test that quantifies the rate of infiltration through soils, which is associated with soil hydraulic conductivity.

Perennial Vegetation – Plants live for longer than 2 years and re-establish from the same rootstock.

Permeability – The ease at which water flows through soil or rock.

Permeable Pavement – Alternative pavement surfaces that allow rainwater or stormwater runoff to filter through voids in pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated.

Permeable Pavers – Interlocking block system typically used in driveways, parking lots, and sidewalks, designed to infiltrate precipitation into a porous subgrade and into native soils or underdrain.

Pervious Concrete – Permeable concrete that is mixed of course aggregates (minimal sand) and installed in a special way as to leave pathways for water to infiltrate into a porous subgrade.

Physiographic Region – A geographic region with similar geomorphology, rock, and soil structure, also known as provinces. Tennessee has a very diverse physiography with 10 distinct regions: the Unaka Mountains, which is part of the Blue Ridge); the Great Valley of East Tennessee, which is part of the Appalachian Ridge and Valley; the Cumberland Plateau; the Sequatchie Valley; the Western and Eastern Highland Rim; which circles the Central Basin; the Western Valley; the Plateau Slope of W. Tennessee; and the Mississippi Flood Plain. The latter two are part of the Gulf Coastal Plain.

Point Source – A confined, discernible conveyance that discharges into surface waters. This term refers to but is not limited to a pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural runoff.

Pollutant – A contaminant in a concentration or amount that adversely alters the physical, chemical, or biological properties of the natural environment.

Pollutant Removal – A requirement of permanent stormwater management systems; the desired outcome of treatment stormwater control measures. Generally, total suspended solids is used as a surrogate for overall pollutant removal.

Porosity – The ratio of void space to total volume of a soil or other media.

Pre-development Conditions – The condition that existed just prior to the disturbance at hand; often a target for design of stormwater control facilities.

Rain Barrel – A small storage container used to capture rooftop runoff from downspouts and store for later use.

Rain Garden – A shallow depression (usually 6" deep when complete) in the landscape created to capture rooftop and/or driveway runoff and infiltrate it into the ground. Rain gardens usually contain perennial vegetation, amended soils, and mulch.

Rainwater Harvesting – A system of collecting rainwater in tanks and releasing it for later use as a water supply. If managed appropriately, runoff can be reduced.

Receiving Waters – A river, stream, lake, or other waterway into which wastewater, treated water, or other material is discharged.

Redevelopment – Alteration of developed land that disturbs one acre or more, or less than one acre if part of a larger common development plan, and increases the site or building impervious footprint.

Restoration – The management of physical, chemical, or biological characteristics of a site with the goal of returning natural or pre-development functions to sites that formerly supported a healthy aquatic ecosystem.

Retention – The process of collecting and holding a designed volume of stormwater runoff that does not leave the SCM as surface flow.

Return Frequency – An estimate of the probability of the occurrence of a storm event or stream flow of a certain intensity or magnitude. By definition, the inverse of frequency is the return period, or expected time between similarly sized events.

Rip Rap – A layer of protective rock placed in erosion-prone areas or sloughing slopes only to be used when vegetative controls are not adequate.

Riparian Buffer/Zone – Area of land that runs between a waterway and land disturbance and provides ecological services for water quality and wildlife habitat. Critical functions of a riparian buffer include providing shade a source of organic matter, stabilizing banks, attenuating stormwater runoff, filtering eroded sediments, and facilitating the uptake and treatment of nutrients.

Runoff – The rainfall that is shed by the landscape to a receiving waterbody; when rainfall exceeds the infiltration capacity of the land.

Runoff Reduction – A requirement of permanent stormwater management systems; An approach to permanent stormwater management that uses avoidance and minimizing design approaches as well as infiltration-based control measures to reduce the amount of impervious surface runoff.

Saturated – A moisture condition when the soil void space is fully occupied with water

Sediment – Eroded rock and soil material that has been moved and subsequently deposited. Material generated by weathering or erosion that has been transported by wind, water, or gravity. In watersheds, sediment is transported in streams.

Sheet Flow – The thin layer of water that accumulates on the soil surface and moves down gradient as a sheet of water.

Siltation – 1) The accumulation or deposition of sediment. 2) Pollution of surface water by fine particulate matter with particle sizes in the silt and clay range; usually associated with loss of biological integrity.

Soil Amelioration – A technique of physical manipulation and/or adding soil amendments to restore the lost capacity of a soil to grow plants or hold water. Also called soil restoration.

Soil Amendment – A soil additive, usually organic matter, used to increase quality and structure of degraded soils.

Soil Texture – The ratio of sand, silt, and clay that creates the mineral soil matrix.

Sorption – The combination of the adsorption and absorption processes

Storage Volume – Volume of stormwater that a structural control facility is designed to hold. Related to storage capacity.

Stormwater Control Measure (SCM) – Measures meant to directly affect the flow of stormwater and/or contaminants, and that have defined specifications and standards. These measures have one or both of two parts: 1) a defined surface management to encourage infiltration and contaminant removal; and/or 2) a clear Protocol defining engineering design, installation, and maintenance. A measure such as a "good forest" has just a Management, a Measure such as a manufactured stormwater treatment device has just an engineering Protocol, and a "bioretention cell" has both.

Stormwater Drainage/Conveyance System – Constructed and/or natural features that function together as a system to collect, convey, channel, hold, inhibit, retain, detain, infiltrate, or divert, stormwater.

Stormwater Facility – A constructed component of a stormwater drainage system, designed or constructed to perform a particular function. Some examples are pipes, swales, ditches, culverts, street gutters, detention basins, retention basins, constructed wetlands, infiltration devices, catch basins, oil/water separators, sediment basins, and permeable pavements.

Stormwater Management – Any action taken to minimize and mitigate the negative impacts of hydrologic modification and pollutant additions (associated with stormwater infrastructure. This includes physical devices and techniques, but also more general strategies like minimizing fertilizer and pesticide use, reducing illicit discharges to drains, etc. Note that Management will often take place between storm events through preventative approaches, though the purpose is to minimize contaminant availability and hydrologic impact during those events.

Stormwater Management Plan (SWMP) – A written plan that describes a comprehensive program to manage the quality of stormwater discharged from the MS4.

Stormwater Pollution Prevention Plan (SWPPP) – A written plan that includes site maps, identification of construction/contractor activities that could cause pollutants in stormwater, a monitoring and documentation system to evaluate performance and maintenance, and a description of measures or BMPs to control these pollutants as required by state regulations.

Stormwater Retrofit – Updated design of a storm drainage system from a conventional system to a new system that incorporates innovative approaches to minimize impacts to water quality. Because of intensive impervious cover and utility constraints, a compromise of LID goals is usually made.

Stormwater Treatment Facility – A type of structure that is designed to reduce pollutants and impacts of stormwater.

Stormwater Treatment Wetland – A constructed wetland comprised of multiple cells that receive and treat stormwater runoff.

Stormwater Utility – A municipal governing body that operates a stormwater system which provides for the collection, treatment, storage and disposal of stormwater provides benefits and services to all property within the incorporated city limits and, in doing so, shall administer and enforce all policy and ordinance pertaining to stormwater runoff and have the authority to assess user fees.

Surface Water – Water collected on the landscape in a stream, river, lake, or ocean (Note: there are no estuaries in Tennessee).

Suspended Solids – Sediment that is entrained in the water column and transported downstream in suspension and forms deposits.

Swale – A shallow drainage conveyance with relatively gentle side slopes and longitudinal grade and generally conveys flows of less than one foot of water depth.

Technique – Method or operation that progresses or sustains progress from one state of management to another higher-functioning management. These can fall in either of two general categories:

1) Methods of getting from "here" to "there"; from the presumed worst-case condition immediately following development to the desired management endpoint. The Techniques used in a specific site design will vary greatly depending on these starting conditions. For example, if an area of "good forest" is left undisturbed, no Technique at all is necessary to achieve a "good forest" management. On the other hand, if the post-construction condition is a bare highly-disturbed mixture of surface and subsoil and is heavily compacted by traffic, the required techniques to achieve a "good forest" management in 15 years may well include the following: soil ripping; soil amendments; temporary vegetative cover; slope erosion control to allow establishment of the temporary vegetation;

planting of trees of a specified type, size, and density; and perhaps fertilization and irrigation schemes and other maintenance requirements.

2) The operations necessary to maintain the required trajectory towards the desired design condition, and to maintain that condition once it is achieved. In other words, the protocol for maintenance of a "good forest" management may refer to Techniques for tree thinning, tree fertilization, and invasive removal. Note that the protocol for a "fair forest" management might refer to the same techniques, but with less intensive requirements.

Tennessee Runoff Reduction Assessment Tool (TNRRAT) – A computer program that allows designers and plan reviewers to assess whether a project plan meets runoff reduction and pollutant removal requirements based on modeled performance-based outcomes.

Treatment Train – A series of structural BMPs that maximizes stormwater treatment by maximizing the number of unit treatment processes achieved in facilities.

Turbidity – A measurement of the clarity of water, which is indicative of the light transmissivity and relates to suspended solids in the water column.

Ultra Urban – Urban land use that has a high percent impervious.

Underdrain – A perforated pipe in the bottom or at a design elevation of a treatment facility that conveys treated water downstream.

Vegetated Swale – A swale lined with vegetation (see swale) that may or may not have storage capacity.

Water Quality Buffer – A setback from the top of a waterbody bank of undisturbed vegetation, including trees, shrubs, and herbaceous vegetation; enhanced or restored vegetation; or the re-establishment of native vegetation bordering streams, ponds, wetlands, springs, reservoirs or lakes, which exists or is established to protect those waterbodies.

Water Quality Swale – A swale lined with vegetation with storage capacity in engineered media.

Water Quality Volume – Volume of runoff to be captured and treated for pollutants in order to meet water quality regulations/limits in receiving waters. Check local municipal program for specific requirements. Also called Treatment Volume (TV).

Water Table – The depth at which soil is saturated with water.

Waters of the State – As defined by the Tennessee Water Quality Control Act as any and all water, public or private, on or beneath the surface of the ground, which are contained within, flow through, or border upon Tennessee or any portion thereof except those bodies of water confined to and retained within the limits of private property in single ownership which do not combine to effect a junction with natural surface or underground waters.

Watershed – Land area that drains surface water and groundwater to a point of reference. See Section II B for information on Tennessee Watersheds.

Wet Weather Conveyance – Man-made or natural watercourses: 1) that flow only in direct response to precipitation runoff in their immediate locality; 2) whose channels are at all times above the groundwater table (excluding piped systems), that are not suitable for drinking water supplies, and 3) in which hydrological and biological analyses indicate that, under normal weather conditions, due to naturally occurring ephemeral or low flow, there is not sufficient water to support fish, or multiple populations of obligate lotic aquatic organisms whose life cycle includes an aquatic phase of at least two months.

Wet Pond – An SCM that treats stormwater in a permanent pool of water to remove common pollutants from urban stormwater runoff through sedimentation, biological uptake, and microbial conversion.

Wetland – Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, pocosins, fens, and similar areas.

Acronyms

BMP – Best Management Practice
CDA – Contributing Drainage Area
CSO – Combine Sewer Overflow
CWA – Clean Water Act
GI – Green Infrastructure
IDD – Illicit Discharge Detection
I/I – Inflow and Infiltration
LID – Low Impact Development
MS4 – Municipal Separate Storm Sewer System
MVA – Managed Vegetated Area
NPDES – National Pollutant Discharge Elimination System
NPS – Nonpoint Source
SCM – Stormwater Control Measure
SWPPP – Stormwater Pollution Prevention Plan
TDEC – Tennessee Department of Environment and Conservation
TNRRAT – Tennessee Runoff Reduction Assessment Tool
TV – Treatment Volume
USEPA – United States Environmental Protection Agency
WQV – Water Quality Volume

Appendix A

Infiltration and Soil Texture Testing Methods

A.1 General Description

A.2 Infiltration Testing: A Four-Step Process

A.3 Other Soil Tests

A.3.1 Soil Compaction – Bulk Density Tests

A.3.2 Soil Contamination

A.3.3 Soil Texture, Organic Matter Content, Nutrient Levels, and pH

A.4 Sample Soil Log

Infiltration and Soil Texture Testing Methods

A.1 General Description

Sites can be defined as unsuitable for infiltration SCMs and soil-based SCMs due to natural or built site limitations (see Chapter 3). However, if suitable areas exist, these areas must be identified early in the Stormwater Management Concept Plan phase (see Chapter 2) and utilized to the greatest extent practicable.

This soil testing protocol describes the necessary field testing procedures to:

- Understand and evaluate site soil conditions: soil compaction (soil porosity) and missing soil components (including microorganisms and organic matter) needed to reestablish the soil's long-term capacity for infiltration, storage, and pollutant removal;
- Obtain the required data for infiltration SCM design; and
- Help determine which SCMs are suitable at a site and at what locations.

Qualified professionals who can substantiate by qualifications/experience their ability to carry out the evaluation (such as soil scientists, agronomists, civil engineers with appropriate experience, geotechnical engineers, and trained technicians) should evaluate the soil test pits and soil samples. A professional experienced in observing and evaluating soil conditions is necessary to ascertain conditions that might affect SCM performance (e.g., clay layers, groundwater movement, etc.).

As with all field work and testing, attention should be given to all applicable Occupational Safety and Health Administration (OSHA) regulations and local guidelines related to earthwork and excavation. Digging and excavation should never be conducted without adequate notification through the Tennessee One Call system (phone 811). Excavations should never be left unsecured or unmarked, and all applicable authorities should be notified prior to any work.

Detailed soil testing for compaction and soil fertility is described in Section III, after infiltration testing.

A.2 Infiltration Testing: A Four-Step Process

Infiltration testing is a four-step process to obtain the necessary data for the design of the Stormwater Management Plan. The four steps include:

1. Desktop analysis – conducted prior to Stormwater Management Concept Plan Submittal
    - Based on available published site-specific data
    - Includes consideration of proposed development plan
    - Used to identify potential SCM locations and testing locations
    - Prior to field work, onsite screening test may be conducted (visual observation of site conditions)
2. Test pit observation or soil boring
    - Includes multiple testing locations
    - Provides an understanding of subsurface conditions
    - Identifies limiting conditions
3. Infiltration testing
    - Must be conducted onsite
    - Different testing methods available
    - Alternate methods for additional screening and verification testing
4. Consideration of infiltration rate in design and modeling application
    - Determination of a suitable infiltration rate for design calculations
    - Consideration of SCM drawdown
    - Consideration of peak rate attenuation

Step 1. Desktop Analysis

Step 1, Desktop Analysis, should be conducted early in the Stormwater Management Concept Plan phase of the project (and prior to concept stormwater management plan submission to the local stormwater program). Information developed in the desktop analysis will focus on information gathering during site visits and inform the Concept Stormwater Management Plan. Following the Desktop Analysis, the design team should have a preliminary understanding of potential SCM locations prior to detailed soil testing. The design team should conduct detailed testing as early as possible during the Preliminary Stormwater Management Plan phase. If indicated by the testing results, adjustments to the design should be made. The designer may need to adjust the site layout and grading to incorporate the results of detailed soil testing and to achieve necessary infiltration results.

Prior to performing testing and developing a detailed site plan, existing conditions at the site should be inventoried and mapped including, but not limited to:

- Existing mapped individual soils and USDA hydrologic soil group classifications, which can be found on USDA Web Soil Survey website (websoilsurvey.sc.egov.usda.gov);
- Existing geology, including the locations of any dikes, faults, fracture traces, solution cavities, landslide prone strata, or other features of note;
- Existing streams (perennial and intermittent, including intermittent swales), water bodies, wetlands, hydric soils, floodplains, alluvial soils, stream classifications, headwaters, and first-order streams;
- Existing topography, slope, and drainage patterns;
- Existing and previous land uses; and
- Other natural or manmade features or conditions that may impact design, such as past uses of site, existing nearby structures (buildings, walls), etc.

A Concept Site Layout Plan for development should be evaluated, including:

- The concept grading plan and areas of cut and fill;
- The locations of other features of note such as utility rights-of-way, water and sewer lines, etc.;
- Existing data such as structural borings, drillings, and geophysical testing; and
- The proposed locations of development features (buildings, roads, utilities, walls, etc.).

In step 1, the designer should determine the potential locations of infiltration SCMs. The approximate locations of these SCMs should be indicated on the proposed development plan and should serve as the basis for the location and number of tests to be performed onsite following Concept Stormwater Management Plan approval, where applicable.

Note: If the proposed development plan is located in areas that may otherwise be suitable for SCM location, or if the proposed grading plan is such that potential SCM locations are eliminated, the designer is strongly encouraged to revisit the proposed layout and grading plan and adjust the development plan as necessary. Full build-out of areas suitable for infiltration SCMs should not preclude the use of SCMs for runoff reduction.

Step 2. Test Pits

A test pit allows visual observation of the soil horizons and overall soil conditions both horizontally and vertically in that portion of the site. A large number of test pit observations can be made across a site at a relatively low cost and in a short time period. The use of soil borings as a substitute for test pits may be necessary in areas where existing pavement or structure precludes a test pit excavation. Visual observation is narrowly limited in a soil boring and the soil horizons cannot be observed in-situ, but must be observed from the extracted borings. Borings and other procedures, however, may be substituted for test pits if necessary because of site constraints.

A test pit typically consists of a backhoe-excavated trench, 2½ to 3 feet wide, to a depth of between 72 inches and 90 inches, or until bedrock or fully saturated conditions are encountered. The trench should be benched at a depth of 2 to 3 feet for access and/or infiltration testing.

The recommended number of test pits or standard soil borings for a site is based on existing soil data availability and proposed infiltration SCM location, and has been listed below.

1. Sites where NRCS soil data is available:
   a. utilize NRCS soil data testing for site-wide design purposes;
   b. and soil testing on a twenty-five feet master-grid for locations of proposed infiltration SCM installations.
2. Sites where NRCS soil data is unavailable, or soils have either been classified as urban or have been disturbed since the NRCS survey:
   a. soil testing on a one hundred (100) feet master-grid system for site-wide design purposes;
   b. and soil testing on a twenty-five feet master-grid for site locations of proposed infiltration SCM installations.

At each test pit or boring, the following conditions shall be noted and described. Depth measurements should be described as depth below the ground surface:

- Identification and depth of soil horizons (upper and lower boundary)
- Soil texture and color for each horizon
- Color patterns (mottling) and observed depth
- Depth to water table
- Depth to bedrock
- Observance of pores or roots (size, depth)
- Estimated type and percentage of coarse fragments
- Hardpan or limiting layers
- Strike and dip of horizons (especially lateral direction of flow at limiting layers)
- Additional comments or observations

The sample soil log form at the end of this protocol may be used for documentation of each test pit.

At the designer's discretion, soil samples may be collected at various horizons for additional laboratory analysis. Following testing, the test pits should be refilled with the original soil and the surface replaced with the original topsoil. A test pit should never be accessed if soil conditions are unsuitable for safe entry, or if site constraints preclude entry. OSHA regulations must always be observed.

It is important that the test pit or boring provide information related to conditions at or near the bottom of the proposed infiltration SCM. If the SCM depth will be greater than 90 inches below existing grade, deeper excavation will be required. However, such depths are discouraged, as infiltration rates tend to decrease with depth until weathered bedrock is encountered. Except for surface discharge SCMs (filter strips, etc.), the designer is cautioned regarding the proposal of systems that are significantly lower than the existing topography. The suitability for infiltration may decrease, and risk factors are likely to increase. The designer should reduce grading and earthwork as needed to reduce site disturbance and compaction.

The recommendations above are guidelines. Additional tests should be conducted if local conditions indicate significant variability in soil types, geology, water table levels, bedrock, topography, etc. Similarly, uniform site conditions may indicate that fewer test pits are required. Excessive testing and disturbance of the site prior to construction are not recommended. Designers must also check with the local stormwater program for any additional requirements they may have related to the type, number and location of soil testing.

Step 3. Infiltration (Soil Absorption) Tests

A variety of field tests exist for determining the infiltration capacity of soil. Laboratory tests for infiltration are strongly discouraged, as a homogeneous laboratory sample does not represent field conditions. Tests should not be conducted in the rain or within 24 hours following significant rainfall events (greater than 0.5 inches), or when the temperature is below freezing. It is recommended that at least one infiltration test be conducted at the proposed bottom elevation of an infiltration SCM, and a minimum of two tests conducted per test pit. The designer may elect to test two different elevations to allow flexibility in SCM design. Based on observed field conditions, the designer may elect to modify the proposed bottom elevation of a SCM. Personnel conducting infiltration tests should be prepared to adjust test locations and depths depending on observed conditions.

Methodologies discussed in this protocol include:

- Double-ring infiltrometer tests
- Percolation tests

A double-ring infiltrometer test estimates the vertical movement of water through the bottom of the test area. The outer ring helps to reduce the lateral movement of water in the soil. A percolation test allows water movement through both the bottom and sides of the test area.

For infiltration basins, it is recommended that an infiltration test be carried out with a double-ring infiltrometer (not a percolation test) to determine the saturated hydraulic conductivity rate. This precaution is taken to account for the fact that only the surface of the basin functions to infiltrate, as measured by the test. In addition, tests should "not be conducted in the rain, within 24 hours of significant rainfall events (> 0.5 inches), or when the temperature is below freezing" (SEMCOG 2008).

a. Methodology for Double-Ring Infiltrometer Field Test

A double-ring infiltrometer consists of two concentric metal rings. The rings are driven into the ground and filled with water. The outer ring helps to prevent divergent flow. The drop in water level or volume in the inner ring is used to calculate an infiltration rate. The infiltration rate is determined as the amount of water per surface area and time unit that penetrates the soils. The diameter of the inner ring should be approximately 50 percent to 70 percent of the diameter of the outer ring, with a minimum inner ring size of 4 inches, preferably much larger. Double-ring infiltrometer testing equipment designed specifically for that purpose may be purchased. However, field testing for SCM design may also be conducted with readily available materials.

Equipment for double-ring infiltrometer test:

- Two concentric cylinder rings 6 inches or greater in height. Inner-ring diameter equal to 50 percent to 70 percent of outer-ring diameter (i.e., an 8-inch ring and a 12-inch ring). Material typically available at a hardware store may be acceptable.
- Water supply
- Stopwatch or timer
- Ruler or metal measuring tape
- Flat wooden board for driving cylinders uniformly into soil
- Rubber mallet
- Log sheets for recording data

Procedure for double-ring infiltrometer test:

- Prepare level testing area. This should be at or close to the proposed SCM location bed bottom.
- Place outer ring in place; place flat board on ring and drive ring into soil to a minimum depth of 2 inches.
- Place inner ring in center of outer ring; place flat board on ring and drive ring into soil a minimum of 2 inches. The bottom rim of both rings should be at the same level.
- The test area should be presoaked immediately prior to testing. Fill both rings with water to water level indicator mark or rim at 30-minute intervals for 1 hour. The minimum water depth should be 4 inches. The drop in the water level during the last 30 minutes of the presoaking period should be applied to the following standard to determine the time interval between readings:
  - If water level drop is 2 inches or more, use 10-minute measurement intervals.
  - If water level drop is less than 2 inches, use 30-minute measurement intervals.
- Obtain a reading of the drop in water level in the center ring at appropriate time intervals. After each reading, refill both rings to water level indicator mark or rim. Measurement to the water level in the center ring shall be made from a fixed reference point and shall continue at the interval determined until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.
- The drop that occurs in the center ring during the final period or the average stabilized rate, expressed as inches per hour, shall represent the infiltration rate for that test location.

b. Methodology for Percolation Test

Equipment for percolation test:

- Post hole digger or auger
- Water supply
- Stopwatch or timer
- Ruler or metal measuring tape
- Log sheets for recording data
- Knife blade or sharp-pointed instrument (for soil scarification)
- Course sand or fine gravel
- Object for fixed-reference point during measurement (nail, toothpick, etc.)

Procedure for percolation test:

This percolation test methodology is based largely on traditional onsite sewage investigation of soils:

- Prepare level testing area.
- Prepare hole having a uniform diameter of 6 to 10 inches and a depth of 8 to 12 inches. The bottom and sides of the hole should be scarified with a knife blade or sharp-pointed instrument to completely remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Loose material should be removed from the hole.
- (Optional) Two inches of coarse sand or fine gravel may be placed in the bottom of the hole to protect the soil from scouring and clogging of the pores.
- Test holes should be presoaked immediately prior to testing. Water should be placed in the hole to a minimum depth of 6 inches over the bottom and readjusted every 30 minutes for 1 hour. Between June 1 and December 31, the presoak should be conducted for 2 hours to simulate saturated spring conditions.
- The drop in the water level during the last 30 minutes of the final presoaking period should be applied to the following standard to determine the time interval between readings for each percolation hole:
  - If water remains in the hole, the interval for readings during the percolation test should be 30 minutes.
  - If no water remains in the hole, the interval for readings during the percolation test may be reduced to 10 minutes.
  - After the final presoaking period, water in the hole should again be adjusted to a minimum depth of 6 inches and be readjusted when necessary after each reading. A nail or marker should be placed at a fixed reference point to indicate the water refill level. The water level depth and hole diameter should be recorded.
- Measurement to the water level in the individual percolation holes should be made from a fixed reference point and should continue at the interval determined from the previous step for each individual percolation hole until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.
- The drop that occurs in the percolation hole during the final period, expressed as inches per hour, shall represent the percolation rate for that test location.

Step 4. Consideration of Infiltration Rate in Design and Modeling Application

Infiltration systems can be modeled similarly to traditional detention basins. The marked difference with modeling infiltration systems is the inclusion of the infiltration rate, which can be considered as another outlet. For modeling purposes, it is convenient to develop infiltration rates that vary (based on the infiltration area provided as the system fills with runoff) for inclusion in the Stage-Storage-Discharge table.

Alternate tests or investigations can be used for verification. For instance, if the final SCMs are not located precisely over the test locations, alternate testing or investigations can be used to verify that the soils are the same as the soils that yielded the earlier results. However, the design team should document these verification test results or investigations. Other testing methods are acceptable to assess a soil's suitability for infiltration for early screening and occasionally for verification. Only professionals with substantiated qualifications may carry out verification procedures.

A.3 General Description

Other soil tests are extremely useful when the design team needs to identify the better soils on a site – both for SCMS (structural, preventive, and restorative) and for landscape plantings. Tests for bulk density, contamination, texture class, organic matter content, and pH should be conducted before designing SCMs with vegetation or before specifying plants in restorative SCMs such as cover change, and before designing and planting ornamental landscapes.

A.3.1 Soil Compaction – Bulk Density Tests

A.3.1.1 Purpose of Bulk Density Tests

Bulk density tests can help determine the relative compaction of soils before and after site disturbance and/or restoration. These tests measure the level of compaction of a soil as an indicator of a soil's ability to absorb water. Disturbed and urbanized sites often have very high bulk densities. These soils have limited ability to absorb rainfall and therefore have high rates of stormwater runoff. Both the use of deep-rooted vegetation and the restoration of soil structure, missing chemical components, and living soil organisms can lower soil bulk density and improve the site's ability to absorb rainfall and reduce runoff.

Macropores occur primarily in the upper soil horizons and are formed by plant roots (both living and decaying), soil animals, bacteria and fungi, weathering processes caused by the movement of water, the freeze-thaw cycle, soil shrinkage due to desiccation of clays, chemical processes, and other mechanisms. These macropores are a critical method to infiltrate water and exchange atmospheric gases, both oxygen and carbon dioxide, under natural conditions. Good engineering and design should maintain or restore these macropores during construction of site SCMs.

A.3.1.2 Relationship of Soil Type to Bulk Density

A major indicator for compacted soil is bulk density, which is calculated as the dry weight of soil divided by its volume. Bulk density is important because it reflects the soil's ability to function for structural support, water and solute movement, and soil aeration. In general, higher bulk density of a soil correlates to a lower infiltration rate and a higher stormwater runoff volume.

Different soil types have different bulk densities:

- Maximum allowable bulk densities for sustainable soil management are based on 95 percent of the bulk density value at which growth limitations are expected for an average range of plant material, as described by Daddow and Warrington (1983).
- While these requirements are expressed as maximum allowable bulk densities, it is important to note that densities that are too low can also cause problems, especially for lawn areas or steep slopes.

To calculate the maximum allowable bulk density for a soil:

- Obtain a laboratory analysis of the sand, silt, and clay percentages as well as existing bulk density.
- Refer to Table A.1 to determine the ideal bulk density for a determined soil texture.

Table A.1: Soil Textures and Bulk Densities.

Soil Texture	Ideal Bulk Densities (g/cm^3)	Bulk Densities that may affect root growth (g/cm^3)	Bulk Densities that restrict root growth (g/cm^3)
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.10	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

A.3.1.3 Procedures for Bulk Density Tests

Various procedures are available to conduct bulk density tests, including a procedure developed by USDA. website:

http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050957.pdf

The density measurements should be carried out in conjunction with a soil texture analysis. Sandy soils infiltrate well, but tend to have a somewhat higher bulk density than finer soils. Experienced personnel can perform the texture analysis manually onsite.

A.3.2. Soil Contamination

Contaminated sites have a wide range of complexity, primarily dependent on previous, existing, and proposed land use. Land development at brownfield sites normally occurs in three stages:

1. Site assessment
2. Site remediation
3. Redevelopment

Step 1. Site Assessment

a. Develop a preliminary survey to determine the presence of contaminants.
b. Develop a plan to sample, measure, and monitor the site.
c. Conduct special tests to determine the type and degree of contamination.
d. Specialists such as soil scientists, geologists, chemists, hydrologists, and engineers should be consulted. The design team with expert help can then develop a Site Remediation Plan.

Step 2. Site Remediation

Typical site remediation uses earth-moving solutions to address soil and groundwater contamination. How stormwater is managed depends largely on how the site was remediated. Contaminated soil can be completely removed from the site, isolated and capped, or blended with clean soil so that it meets state standards for public health and safety. Assessment and cleanup of properties must conform to the requirements of both U.S. Environmental Protection Agency (USEPA) and Tennessee state requirements.

For more information on site remediation, go to the TDEC Division of Remediation website:

http://www.tn.gov/environment/dor/

Step 3. Redevelopment

After the environmental concerns are addressed through cleanup or institutional controls, assessment is complete, and the appropriate actions taken, plans must be developed for resolving unacceptable environmental risks and integrating solutions into the development plans. Contact economic development staff of local, state, and federal agencies to determine possible financial and technical resources available to help with planning and financing brownfield redevelopment.

A.3.3. Soil Texture, Organic Matter Content, Nutrient Levels, and pH

It is recommended that soils be amended based on information provided by the results of soil tests for the following parameters - texture class, organic matter content, nutrient deficiencies, and pH:

- Take soil samples from representative areas on the site.
- Do not mix these soils together.
- Test each individual sample for texture class, organic matter content, nutrient levels, and pH.
- Send samples to your local University of Tennessee Extension Office for analysis. Website:

  https://extension.tennessee.edu/Pages/Office-Locations.aspx

  Also see the Soil, Plant and Pest Center for soil testing information:

  https://ag.tennessee.edu/spp/Pages/soiltesting.aspx

- Results should be interpreted by a professional soil scientist or USDA Extension Service expert. (Laboratory tests often include professional interpretation of results and recommendations.)

Please note: Sands and soils based off of limestone parent material are calcareous and therefore basic. You cannot permanently amend limestone-based soils with sulfur to reduce pH. Some soils are amendable, but calcareous soils are not. Elemental sulfur, with the help of bacteria, will work to decrease the pH for a little while (+/-5 years), but the pH will increase again and plants will turn yellow and die unless more sulfur is added in perpetuity. Helpful hint: know if local soils are limestone based and make sure plant material can handle the high pH. This is easier than playing soil alchemy.

A.4 Sample Soil Log

Tested by: ____________________

Test Pit: ____________ Date: ____________ Elevation: ____________ Equipment Used: ____________

Geology: ____________ Soil Type: ____________ Land Use: ____________ Weather: ____________

Additional comments: ____________________

____

____

Horizon	Upper Boundary	Lower Boundary	Soil Textural Class	Type, Size, Coarse Fragments, etc.	Soil Color	Color Patterns	Pores, Roots, Rock Structure	Depth to Bedrock	Depth to Water	Comments

REFERENCES

Daddow and Warrington. 1983. Growth-limiting Soil Bulk Densities as influenced by Soil Texture, USDA Forest Service, Fort Collins, Colorado.

Resource Rain: Rainwater Management Guide. City of Chattanooga Rainwater Management Guide. November 2012. 652 pages. Website: http://www.chattanooga.gov/public-works/city-engineering-a-water-quality-program/water-quality-program/44-public-works/989-resource-rain

University of Tennessee Institute of Agriculture: Soil, Plant and Pest Center. https://ag.tennessee.edu/spp/Pages/soiltesting.aspx

Appendix B

Stormwater Design Guidelines for Karst Terrain

B.1 Why Karst Terrain is Different

B.2 A Unified Approach for Stormwater Design in Karst Terrain

B.3 Preliminary and Detailed Site Karst Investigations
- B.3.1 Preliminary Site Investigations
- B.3.2 Detailed Site Investigations
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B.4 Assess Future Groundwater Contamination Risk
- B.4.1 Designation of Stormwater Hotspots
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B.6 Design Adaptations for Specific Stormwater Treatment Practices
- B.6.1 Preferred Practices
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B.7 Sinkhole Remediation in Stormwater Practices
- B.7.1 Sinkhole Notification
- B.7.2 Sinkhole Investigation
- B.7.3 Sinkhole Stabilization
- B.7.4 Final Grading

The effect of land development on karst terrain is complex, hard to predict, and requires professional analysis to reduce the risk of geological hazards, damage to infrastructure, and groundwater contamination. There is always some inherent risk when development occurs on this sensitive terrain. Consequently, the best local approach is to craft stronger comprehensive land use plans that direct new growth away from karst areas to more appropriate locations (although it is recognized that this may be problematic for communities that are completely underlain by karst).

B.1 Why Karst Terrain is Different

Karst in Tennessee watersheds is a dynamic landscape characterized by sinkholes, springs, caves, and a pinnacled, highly irregular soil rock interface that is a consequence of the presence of underlying carbonate rocks such as limestone, dolomite, and marble. The karst terrain in Tennessee is distinct from some other regions (e.g., Florida) in that the bedrock is very ancient and, in some areas, is deeply buried by residual soils and other areas on or near the surface. Consequently, many sinkholes form due to collapse of surface sediments caused by the intrusion of stormwater from the surface into deep, underlying voids. The presence of karst terrain within the Ridge and Valley and Interior Plateau regions of Tennessee complicates the land development process and requires a unique approach to stormwater design. Some of the important considerations include:

Post Development Runoff Rates are Greatly Increased: In an undeveloped state, karst terrain produces about two-thirds less stormwater runoff than in non-karst regions like the Mississippi Alluvial Plain region. Even less runoff is produced if the site discharges into an existing sinkhole. As land is developed, however, the paved surfaces and compacted soils produce a much greater rate and volume of runoff. Three important consequences arise due to the increased runoff:

- More runoff is conveyed into a poorly defined surface drainage system that often lacks the capacity to handle it.
- More runoff greatly increases the risk of new sinkhole formation (e.g., collapse or subsidence), particularly if runoff is allowed to pond in the landscape. The increased risk for sinkholes may apply to the development site or down-gradient off-site areas.
- More runoff could deprive the karst system of recharge, thereby causing a lowering of the water table and diminished spring flows. These changes can profoundly alter the hydrology of surface streams.

Highly Variable Subsurface Conditions: Karst terrain is notorious for its spatial variability, meaning that subsurface conditions and the consequent risk of sinkhole formation can change in a matter of yards across a development site. As a result, a sequence of karst feature analyses, geotechnical investigations, and borings must be performed prior to site layout and the design of any stormwater practice to minimize the risk of unintended consequences or failure.

Surface/Subsurface Drainage Patterns are Poorly Understood: Drainage patterns are highly dynamic in karst terrain and involve a great deal of interaction between surface water and groundwater. Often, there is not a well-defined stream network that moves water to a downstream point. Furthermore, subsurface conduits commonly convey their flow in different directions than the overlying surface streams, in some cases crossing beneath topographical divides. Designers face a confusing surface drainage pattern, full of **losing streams, estavelles, turloughs, swallets,** and **insurgences,** which makes it hard to predict exact discharges points for runoff and groundwater. Designers in karst terrain need to think in three dimensions rather than just two.

Lower Stream Density and More Karst Swales: Another characteristic of karst landscapes is they have less perennial stream mileage per unit area than other physiographic regions. Consequently, many development sites cannot discharge to the stream network within their property boundaries.

Instead, much of the length of the headwater stream network in karst terrain is composed of karst swales which appear as wide, shallow, parabolic swales (Fennessey, 2003). Karst swales lack defined channels, beds, or banks and may only briefly hold water during extreme storm events. Nevertheless, karst swales are an integral element of the natural drainage system and often exhibit significant infiltration capacity (SEA, 2000). The protection of natural karst swales is an important element of effective stormwater design in karst regions.

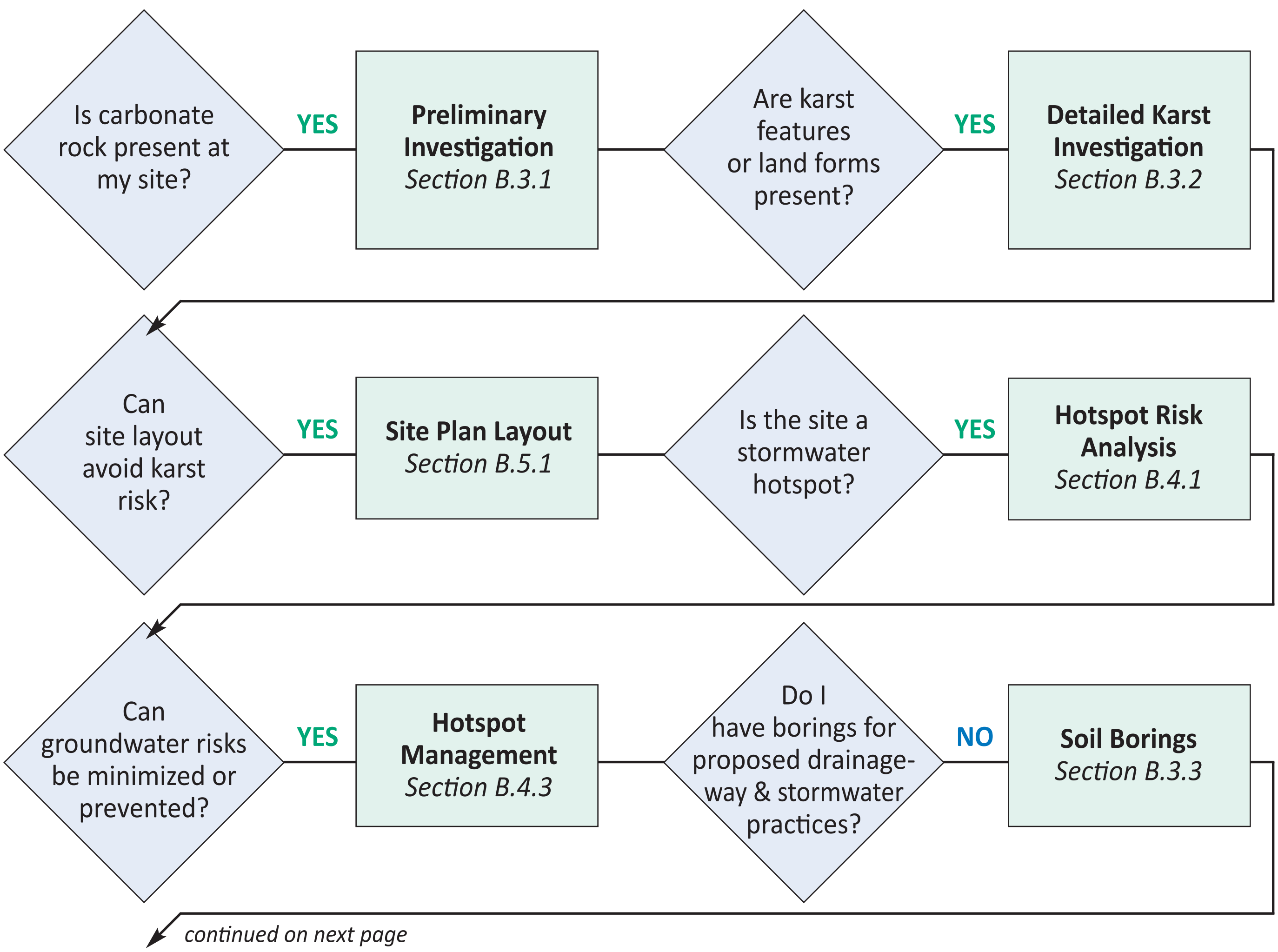
Groundwater Contamination Risks: In many cases, contaminants in polluted runoff and spills can pass rapidly from the surface into groundwater in karst terrain, with little or no filtration or modification. In other cases, contaminants are "hung up" above the water table in the **epikarst**, releasing toxins more gradually. The strong interaction between surface runoff and groundwater poses risks to the drinking water quality upon which residents in karst terrain rely. As a result, designers need to consider groundwater protection as a first priority when they are considering how to dispose of stormwater since there is always a risk that it will end up in the groundwater system.

Increased Sinkhole Formation: The increased rate of sinkhole formation caused by increased runoff from land development can cause damage to public infrastructure, roads, and buildings. In addition, the existing drainage system can be further modified by land development, and larger centralized stormwater practices may fail. Consequently, designers need to carefully assess the entire stormwater conveyance and treatment system at the site to minimize the risk of sinkhole formation. In most cases, this means installing a series of small, shallow runoff reduction practices across the site, rather than using the traditional pipe-to-pond approach.

Endangered Species: In some cases, development sites may have a subsurface discharge to caves, springs, and surface streams that are home to legally protected rare, threatened, or endangered species such as cave-obligate aquatic and terrestrial invertebrates, bats, and aquatic fauna in surface streams. Designers are encouraged to screen for the presence of rare, threatened, or endangered species to minimize project impact to habitat and ensure the project complies with the legal protections afforded under the Endangered Species Act. The specific agency that designers should consult will vary depending on the state: see Appendix A and B for some contact information.

B.2 A Unified Approach for Stormwater Design in Karst Terrain

This Appendix outlines a sequence of investigations to provide an adequate basis for stormwater design for any site underlain by limestone and/or dolomite. These special studies are organized in the flow chart on the next page. The flow chart outlines a series of questions about the nature of the development. Based on the answers, designers can determine whether a special analysis is needed, and in which section of this Appendix they can find more information about it.



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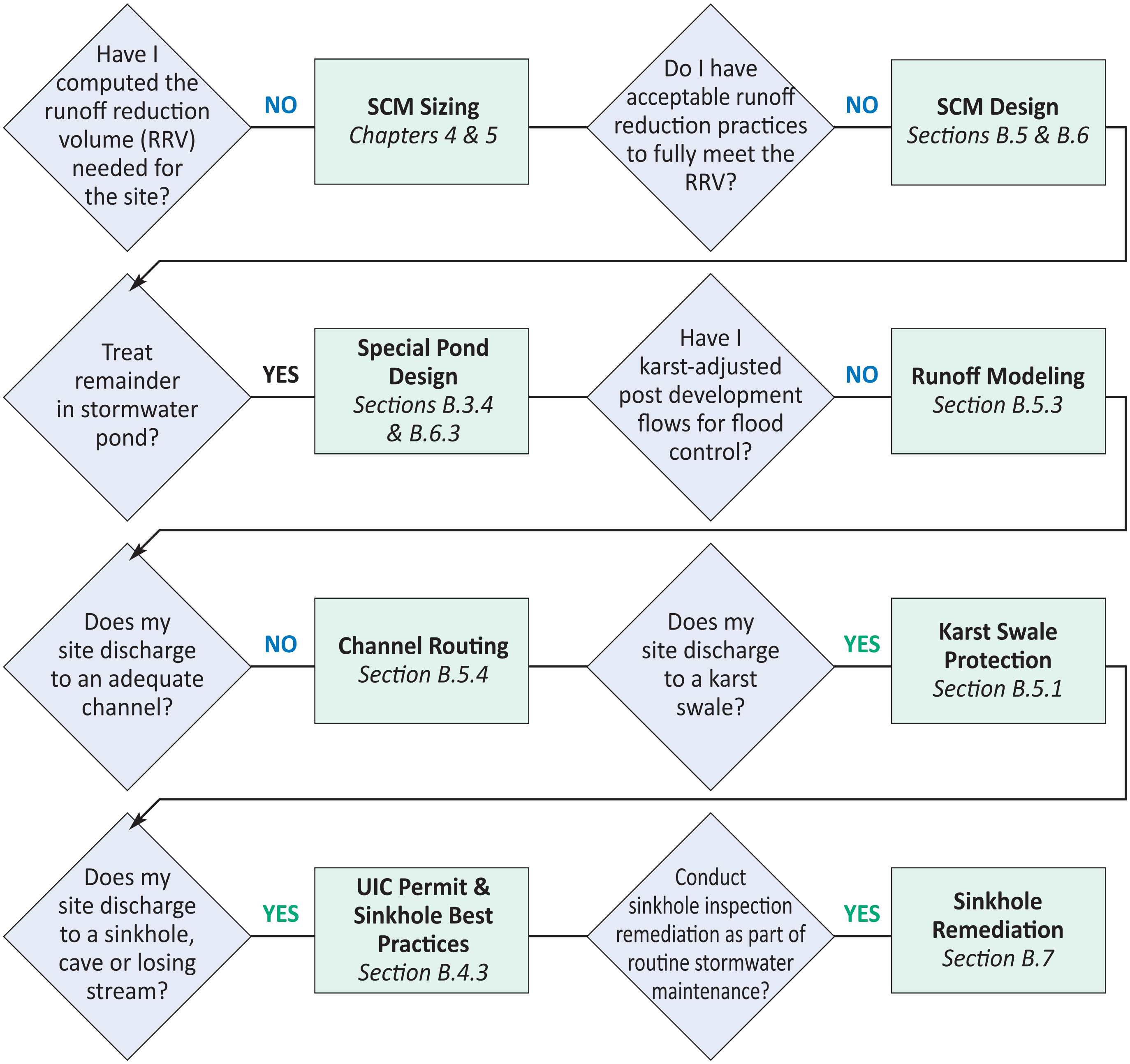

Figure B.1: Flow Chart for Stormwater Design in Karst Terrain.

The flow chart was synthesized from several sources, including the Minnesota Stormwater Manual (2005), VA DCR (1999), CCDP (2007), MDE (2000), and PADEP (2006). It is important to note that the flow chart is solely intended as a guide for stormwater design and is not meant to be used as a prescriptive process for local stormwater plan review.

B.3 Preliminary and Detailed Site Karst Investigations

B.3.1 Preliminary Site Investigations

Developers need to undertake a preliminary site investigation prior to any design work for projects or building in areas known to be prone to karst. The level of investigation depends on the probability of karst being present and the local regulatory requirements. The scope of the preliminary site investigation involves analysis of geological and topographic maps, aerial photography, and a site visit by an experienced professional knowledgeable in karst terrain. The preliminary site investigation should also include screening for proximity to known caves through the state natural resource agency or directly from the relevant state cave survey.

Various methods are available to collect information about the bedrock and soil conditions at a proposed development site. These can range from inspecting topographic and geologic maps and aerial photographs of the site, to drilling test borings at the location of planned facilities. Professionals involved with projects in karst areas should make a special effort to observe signs of ground subsidence during development.

Site evaluation for karst features is usually carried out in two phases: (1) preliminary site investigation done prior to site design and development and (2) site-specific investigation conducted once the decision is made to design a site plan and proceed with development.

Preliminary site investigation includes a review of topographic and geologic maps, soil surveys, aerial photography, and any previous technical reports prepared for the site. This phase of investigation should include a site visit, where the experienced professional studies the site terrain in an effort to locate any obvious features, such as rock outcrops, sinkholes, springs, caves, etc. The purpose of the preliminary investigation is to identify areas of concern that may require additional investigation and to review the preliminary site design in relationship to potential problem areas. The preliminary site investigation will often result in immediate changes to the site layout to avoid future problems.

Site-specific investigation includes collecting subsurface information at sites identified as potential problem areas during the preliminary investigation. During the site-specific investigation process the professional may examine subsurface soil and geologic conditions using test pits, test borings, and geophysical instruments to evaluate the stability of soil and rock at locations of proposed site facilities. If unstable subsurface conditions are encountered, a decision can be made to proceed to remediate prior to construction or to modify the site layout to avoid problem areas. The record of findings during this phase of the investigation includes logs of test pits, probes, and borings; noting evidence of cavities in soil and rock; loss of air pressure or drilling fluid during drilling; and the condition of soil and bedrock from samples collected.

A discussion of the various site investigation methods follows:

Geologic maps: Geologic maps contain information on the physical characteristics and distribution of the bedrock and/or unconsolidated surficial deposits in an area. Geologic features such as the strike and dip of strata, joints, fractures, folds, and faults are usually depicted. The orientation of strata and geologic structures generally controls the location and orientation of solution features in carbonate rock. Geologic contacts, faults, and certain fracture sets may be more prone to solution than others. The relationship between topography and the distribution of geologic units may reveal clues about the solubility of the specific rock units. Geologic maps are often available at various scales, the most common being 1:24,000. Digital geologic data may be available as well.

Aerial photography: Aerial photos are a simple, quick method of site reconnaissance. Inspection of vegetation can quickly reveal vegetation and moisture patterns that provide indirect evidence of the presence of cavernous bedrock. Piles of rock or small groups of brush or trees in otherwise open fields can indicate active sinkholes or rock pinnacles protruding above the ground surface. Circular and linear depressions associated with sinkholes and linear solution features and bedrock exposures are often visible when viewed in stereo image. Inspecting photos taken on more than one date can be especially valuable in revealing changes that take place over time. Images defined at wavelengths other than visible light can be useful in detecting vegetative or moisture contrasts.

Site visit: An onsite reconnaissance is an inexpensive, important step in finding potential site constraints. Although many karst features are obvious to the eye, it is advantageous to conduct the site visit with an individual knowledgeable in karst geology. Prior to the site visit, field personnel should review geologic maps, topographic maps, and aerial photos to help anticipate where problems might be found. It is important to review drainage patterns, vegetation changes, depressions, and bedrock outcrops to look for evidence of ground subsidence. Sinkholes in subdued topography can often only be seen at close range. Disappearing streams are common in karst areas, and bedrock pinnacles that can be a problem in the subsurface will often protrude above the ground surface. A particularly simple and often overlooked part of the site visit is to interview the property owner. Often property owners can recount a history of problems with ground failure that may not be evident at the time of the site evaluation. The location of karst features should be noted on the site map for later reference. These can be compared to other information collected to assess the risk potential for karst-related problems.

Test pits: Test pit excavations are a simple, direct way to view the condition of soils that may reveal the potential for ground subsidence and to inspect the condition and variability of the limestone bedrock surface where bedrock is sufficiently shallow. Soil texture is an important indicator of soil strength and, therefore, the ability of soils to bridge voids. An inspector should look for evidence of slumping soils, former topsoil horizons, and fill (including surface boulders, organic debris, and other foreign objects) in the test pit. Voids in the soil or underlying bedrock can be revealed. The presence of organic soils at depth is an indicator of potentially active sinkhole sites. Leached or loose soils may also indicate areas of existing or potential ground subsidence. Observations of this type should be recorded in the soil log.

Test probes: Test probes are performed by advancing a steel drill bit into the ground using an air-percussion-drilling rig. Probes can be installed rapidly and are an effective way to quickly test subsurface conditions. Penetration depths are usually less than 50 feet. During the installation of a test probe, the inspector should be aware of the rate of advance of the drill bit, sudden loss of air pressure, soft zones, free-fall of the bit, and resistant zones. These observations can provide clues to the competency of the bedrock and the presence of cavities in soil or bedrock. The volume of fluid cement grout needed to backfill the probe hole can yield a measure of the size of subsurface voids encountered during drilling.

Test borings: Test borings often yield virtually complete and relatively undisturbed soil and rock samples. Borings may provide direct evidence of the presence and orientation of fractures, weathering, fracture fillings, and the vertical dimensions of cavities and provide undisturbed samples that can be subjected to laboratory testing. Use of a split inner core barrel in rock coring provides the most meaningful results because this method collects a relatively undisturbed sample in the core barrel. Losses of drilling fluid can indicate the presence of soil or rock cavities. When drill holes are sealed, the volume of fluid cement grout placed in the drill hole can also yield a measure of the size of openings in the subsurface.

Geophysical methods: Geophysical methods can serve as a rapid reconnaissance tool to detect physical anomalies in the subsurface that may be caused by karst features. These methods are especially suited to surveying linear corridors and are non-disruptive to the land. Geophysical data are often useful for extrapolating between locations where other sampling methods are used. Generally it is advisable to apply more than one geophysical technique, owing to the variability in physical properties of karst terrain. Geophysical methods require an experienced professional to interpret the data collected. The properties of weathered limestone, including a highly variable bedrock surface and soils with high clay content, often hinder the depth of penetration and resolution of geophysical signals and can compromise the effectiveness of geophysical surveys. Despite these limitations, geophysics can sometimes provide a cost-effective, relatively rapid means of determining the potential for problems with karst features, including the location of shallow bedrock and significant cavities in the soil or bedrock. Geophysical anomalies should be targeted for additional direct testing procedures.

Recommended Procedures When Karst Features Are Identified

The site investigations described above may reveal the location of suspected areas of ground subsidence. These findings should be compared to the proposed layout of site facilities. Wherever possible, facilities should be sited to avoid suspected areas of potential ground subsidence. Where relocation of facilities is not practical, remedial measures and design standards can be employed to minimize future ground failure. Remedial sealing of voids in the soil or bedrock and/or compaction of soil and rock voids maybe a viable in some areas.

The product of the preliminary site investigation is a determination of whether the development site has karst features and therefore warrants a more detailed site investigation. The product is usually a site map, which shows the location of any known or suspected karst features. It should be noted that while the presence of sinkholes or caves is diagnostic of karst, their absence does not necessarily mean that karst will not be a problem at the site (Hubbard 2004).

B.3.2 Detailed Site Investigations

Detailed site investigations are required in the design of all building, roads, stormwater conveyance, and centralized stormwater facilities proposed within karst areas. The purpose of the investigation is to develop a karst feature plan that identifies the location and elevation of subsurface voids, cavities, fractures, and discontinuities. Presence of any of these features could pose a danger to groundwater quality, a construction hazard, or an increased risk of sinkhole creation at a proposed centralized stormwater facility.

The design of the geotechnical investigation should reflect the size and complexity of the development project, and no single investigative approach works in every location. The sequence begins with a visual assessment of diagnostic karst features and analysis of subsurface heterogeneity through geophysical investigation and/or excavation. Based on this information and the preliminary site plan, the number and pattern of soil borings or observations needed to adequately characterize subsurface conditions can be determined by the geotechnical consultant and the requirements of the local reviewing authority.

The investigation should determine the nature and thickness of subsurface materials including the depth to bedrock and the water table in the area(s) of the site where construction is planned. The investigation is an iterative process that may need to be expanded until the desired detailed knowledge of the site is obtained and fully understood. Pertinent site data to collect includes:

- Bedrock characteristics (e.g., type, geologic contacts, faults, geologic structure).
- Soil characteristics (type, thickness, spatial variability, mapped unit, geologic parent/history, infiltration rate, depth to seasonally high water table)
- Identification/verification of geological contacts if present, especially between karst and non-karst formations
- Photo-geologic fracture trace map
- Bedrock outcrop areas
- Sinkholes, closed depressions, and solution-enlarged voids
- Cave openings
- Springs
- Perennial, intermittent, and ephemeral streams and their flow behavior and surface or subsurface discharge points (e.g., losing or gaining streams), channels, and surface drainage network
- Site-scale watershed boundaries based on large scale site topography (i.e., one foot or less contour intervals)
- Layout of proposed buildings, roads, and stormwater structures (and estimated site impervious and turf cover)
- Existing stormwater flow pattern

Stormwater designers should retain the services of a qualified consultant experienced in working in karst landscapes. There are many different techniques to reveal the nature of subsurface conditions in karst terrain, including:

- Electric resistivity tomography
- Seismic refraction
- Gravity surveys
- Electromagnetic (EM) inductance/conductivity surveys

Electric resistivity tomography has proven to be a particularly useful technique to identify subsurface anomalies at a scale that impacts stormwater design. These surveys provide a qualitative evaluation of the site area and may identify "suspect areas" to be further evaluated by borings. The use of these surveys may reduce the total number of soil borings by narrowing down the locations of suspect areas at the site.

If karst features are expected to receive additional runoff after land development, it is advisable to conduct dye tracing to determine the flow direction of water entering the subsurface. Stormwater designers should retain the services of a qualified karst hydrologist or hydrogeologist to perform the trace. Also, designers are advised to coordinate with the Underground Injection Control (UIC) Program prior to initiating a trace to acquire pre-existing information on karst hydrology in the area and avoid potential cross-contamination with dyes from other investigations. Lastly, designers should notify local emergency response staff prior to introducing dye into the aquifer.

B.3.3 Soil Borings

Once the general character of the surface cover is understood, borings are used to reveal its characteristics at specific locations at the site where construction is planned. The extreme spatial variability in subsurface conditions cannot be over-emphasized, with major differences seen a few feet away. Therefore, the consultant should obtain borings:

- Within each individual geologic unit present based on local, state, or federal geological mapping sources
- Adjacent to sinkholes or related karst features at the site
- Along photo-geologic fracture traces, including alignment of sinkholes
- Adjacent to bedrock outcrop areas
- Within the planned boundaries of any centralized stormwater facility
- Near any areas identified as anomalies from prior geophysical or subsurface studies

The number and depth of borings at the site will depend entirely on the results of the subsurface investigations, the experience of the geotechnical consultant, and the requirements of the local review authority. All borings or excavations should include:

- Description, logging, and sampling over the entire depth of the boring
- Any stains, odors, or other indications of environmental degradation
- A minimum laboratory analysis of two soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to field descriptions
- Minimum identified characteristics should include color, mineral composition, grain size, shape, sorting, and degree of saturation.
- Any indications of water saturation should be carefully logged to include both perched and ground water table levels and descriptions of soils that are mottled and gleyed. Note that groundwater levels in karst terrain can change dramatically in a short period of time and will not always leave evidence of mottling or gleying.
- Water levels in all borings should be fully open to a total depth that reflects seasonal variations in water level fluctuations.
- When conducting a standard penetration test, record the estimates of soil engineering characteristics including “N” or estimated unconfined compressive strength.

B.3.4 Boring Requirements for Centralized Stormwater Facilities

The density of borings shall result in a representative sampling of the proposed facility. In general, a minimum of five borings shall be taken for each centralized stormwater facility (or five per acre, whichever is greater) with at least one on the centerline of the proposed embankment and the remainder within the proposed impoundment.

For carbonate rocks, borings should extend at least 20 feet below the bottom elevation of the proposed centralized stormwater facility. Where refusal is encountered, the boring may either be extended by rock coring or moving to an adjacent location within 10 linear feet of the site in order to attain the 20 foot minimum depth. Upon completion, the boring should be backfilled with an impermeable plugging material such as grout mixed with bentonite, particularly when the boring intercepts subsurface voids.

B.3.5 Plan Submittals

At least one subsurface cross section should be submitted with the stormwater plan, showing confining layers, depth to bedrock, and water table, if encountered. It should extend through the centerline of the proposed centralized stormwater facility, using actual geophysical and boring data. A sketch map or construction drawing indicating the location and dimension of the proposed practice should be included for reference to present subsurface data.

Consultants should identify and locate karst features and submit these with both the development and stormwater management plan for the proposed site. Any existing sinkholes should be surveyed and permanently recorded on the property deed. In these cases, an easement, buffer, or reserve area should be identified on the development plats for the project so that all future landowners are aware of the presence of sinkholes on their property.

B.4 Assess Future Groundwater Contamination Risk

B.4.1 Designation of Stormwater Hotspots

The other key task in karst terrain is to assess whether the proposed operation or activity being built has a significant risk of becoming a future stormwater hotspot. **Stormwater hotspots** are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks, or illicit discharges.

Table 1 presents a list of potential land uses or operations that may be designated as a stormwater hotspot. It should be noted that the actual hotspot generating area may only occupy a portion of the entire proposed use and that some “clean” areas (such as rooftops or buffer areas) can be diverted away to another infiltration or runoff reduction practice. Communities should carefully review development proposals to determine if future operations, in all or part of the site, should be designated as a stormwater hotspot.

Table B.1: Potential Stormwater Hotspot and Site Design Responses.

Potential Stormwater Hotspot Operation	SWPP Required?	Restricted Infiltration	No Infiltration
Facilities w/NPDES Industrial permits	Yes	■	■
Public works yard	Yes		●
Auto and metal recyclers/scrap yards	Yes		●
Petroleum storage facilities	Yes		●
Highway maintenance facilities	Yes		●
Wastewater, solid waste, composting facilities	Yes		●
Industrial machinery and equipment	Yes	●	
Trucks and trailers	Yes	●	
Aircraft maintenance areas	Yes		●
Fleet storage areas	Yes		●
Parking lots (40 or more parking spaces)	No	●	
Gas stations	No		●
Highways (2500 ADT)	No	●	
Construction business (paving, heavy equipment storage and maintenance)	No	●	
Retail/wholesale vehicle/equipment dealers	No	●	
Convenience stores/fast food restaurants	No	●	
Vehicle maintenance facilities	No		●
Car washes (unless discharged to sanitary sewer)	No		●
Nurseries and garden centers	No	●	
Golf courses	No	●	

Note: *For a full list of potential stormwater hotspots, please consult Schueler et al (2007)*

Key: ■ depends on facility ● Yes

Shaded Area Facilities or operations not technically required to have NPDES permits, but can be designated as potential stormwater hotspots by the local review authority, as part of their local water ordinance.

If a site is designated as a hotspot, a range of stormwater treatment and pollution prevention practices can be applied to prevent contamination of surface or groundwater, particularly when the hotspot discharges to a community drinking water supply or **wellhead protection area**. Depending on the severity of the hotspot, one or more of the following management strategies outlined in Section B.4.2 may be required by the local review authority.

B.4.2 Management Strategies for Stormwater Hotspots

If the future operations at a proposed development project are designated as a stormwater hotspot, then one or more of the following management actions are required (Table B.1).

1. **Stormwater Pollution Prevention Plan (SWPPP).** This plan is required as part of an industrial or municipal stormwater permit and outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the site. Other facilities or operations are not technically required to have NPDES permits but can be designated as potential stormwater hotspots by the local review authority as part of their local stormwater ordinance (these are shown in the shaded areas of Table B.1).

It is recommended that these facilities include an addendum to their stormwater plan that details the pollution prevention practices and employee training measures that will be used to reduce contact of pollutants with rainfall or snowmelt.

2. **Restricted Infiltration**. A minimum of 50% of the total runoff reduction volume must be treated by a filtering or bioretention practice prior to any infiltration. Portions of the site that are not associated with the hotspot generating area should be diverted away and treated by an acceptable stormwater practice.

3. **Infiltration Prohibition.** If a site is classified as a potentially severe hotspot, the risk of groundwater contamination is so great that infiltration of stormwater is prohibited. In these cases, an alternative stormwater practice, such as closed bioretention, sand filters, or constructed wetlands must be used to filter the entire runoff reduction volume before it reaches surface or groundwater.

B.4.3 Underground Injection Control Permits

The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations under the Underground Injection Control (UIC) Program, which is administered by either the EPA or a delegated state groundwater protection agency, Tennessee Department of Environment and Conservation. The UIC regulations are intended to protect underground sources of drinking water from potential contamination. Depending on their design, some stormwater infiltration practices and all improved sinkholes can be potentially regulated as “Class V” wells.

Typically, Class V wells are shallow wells used to place a variety of fluids directly below the land surface. By definition, a well is “any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system.” In karst terrain, improved sinkholes are the most common type of Class V well that will be encountered, although some infiltration practices may also qualify.

Federal and State regulations require all owners and operators of Class V wells to submit information to the appropriate state or federal authority. This includes the facility name and location, name and address of legal contact, ownership of property, nature and type of injection well(s), and operating status of injection wells. Additional information on Class V well requirements can be accessed at:

http://www.tn.gov/environment/permits/injetwel.shtml

The regulatory authority then reviews this inventory data, and may determine the injection is authorized, require more information, issue a UIC permit with best management practice requirements, or order the well closed.

Class V well requirements are primarily triggered by two conditions in karst terrain. The first and most serious condition is when increased post-development runoff is directed to an “improved sinkhole.” EPA defines an “improved sinkhole” as a naturally occurring karst depression or other natural crevice, which has been modified by a man-made structure to direct fluids into the subsurface. EPA defines man-made structures as including pipes, swales, ditches, excavations, drains, graded slopes, or any other device that is intended to channel fluids toward or into a sinkhole. In Tennessee, this definition would also include directing increased stormwater runoff volumes into an existing sinkhole from new upland development.

The act of directing increased stormwater runoff from developed land into a sinkhole or other karst feature constitutes a “modification” and as such, becomes a de facto improved sinkhole requiring a Class V UIC permit. This is even true if the improved sinkhole is downstream of stormwater treatment practices, either on site of off-site. Discharges to improved sinkholes on adjacent downstream properties are only allowed when appropriate legal agreements are made with the property owners of the improved sinkhole.

The second situation where a UIC permit or authorization may be required is for certain “dug-out” stormwater practices that infiltrate runoff into the subsurface, or have a subsurface fluid distribution system. The specifications for the stormwater practices in this Technical Bulletin have been created to avoid classification as Class V injection wells. These design modifications include minimum geometric dimensions, surface pretreatment, soil filtering, and design of “closed practices” that have filter fabric or under drains which daylight to the surface.

B.4.4 Stormwater Discharge to Improved Sinkholes

Under some circumstances, post development stormwater must be discharged into an existing sinkhole or other karst feature. This may occur where significant portions of a site are internally drained and/or the majority of a site is underlain by karst. In other cases, it may be desirable to maintain predevelopment flows to the existing sinkhole to maintain subsurface hydrology. In either case, the following rules pertain:

- The sinkhole or karst feature receiving post development stormwater runoff shall be considered a Class V Injection Well.
- The designer should conduct a survey for public or private drinking water wells with a ¼ mile of their improved sinkhole, and submit data on any wells found to the UIC permit authority.
- As such, the designer must notify the appropriate agency that regulates groundwater and administers the UIC permit. An underground injection permit will be extremely difficult to obtain if the proposed land use or operation at the site is designated as a severe stormwater hotspot.
- It is strongly advised that a dye trace be performed to understand how additional stormwater flows will move through groundwater, particularly if wells are located nearby.
- The design goals are to prevent increased runoff volumes from discharging to the sinkhole, but to maintain the discharge of the predevelopment runoff volumes so as to maintain groundwater recharge.
- Designers should maintain both the quality and quantity of runoff to predevelopment levels prior to discharge into an existing sinkhole. Operationally, this means that designers must treat the full water quality volume in an acceptable runoff reduction practice before discharging to a sinkhole (i.e., full runoff reduction volume for runoff produced by one inch of rainfall over contributing impervious surfaces.
- The operation and maintenance of stormwater practices shall be included as a condition of the required underground injection permit issued by the appropriate state or federal reviewing agency.

B.5 General Stormwater Design Principles in Karst

B.5.1 Site Design

- Designers should perform the preliminary and detailed site investigations prior to beginning site and stormwater design to fully understand subsurface conditions, assess karst vulnerability, and define the actual drainage pattern present at the site.
- Any existing sinkholes and karst swales should be surveyed and permanently recorded on the property deed or plat. In addition, an easement, buffer, or reserve area should be identified on the development plat for the project so that all future landowners are aware of their presence.
- Minimize site disturbance and changes to soil profile, including cuts, fills, excavation, and drainage alteration near karst features.
- Sediment traps and basins should only be used as a last resort after all other erosion and sediment control options have been considered and rejected. In the rare instance they are employed, they should serve small drainage areas (2 acres or less) and be located away from known karst features.
- Require notification procedures on the design plans for both erosion and sediment control and stormwater management.
- Minimize the amount of impervious cover created at the site so as to reduce the volume and velocity of stormwater runoff generated.
- Take advantage of subsurface conditions when locating building pads, and place foundations on sound bedrock.
- The location of new or replacement septic systems near improved sinkholes may be regulated by the local public health authority. Many recommend that septic systems should be located at least 100 feet away of the base of an existing or remediated sinkhole.
- Designers should place a high priority on preserving as much of the length of natural karst swales present on the site as possible to increase infiltration and accommodate flows from extreme storms.

B.5.2 Stormwater Design

- Treat runoff as sheet flow in a series of small runoff reduction practices before it becomes concentrated. Practices should be designed to disperse flows over the broadest area possible to avoid ponding, concentration, or soil saturation.
- Small-scale low impact design (LID) practices work well in karst areas, although they should be shallow and sometimes use perforated under drains to prevent groundwater interaction. For example, micro-bioretention and infiltration practices are a key part of the treatment train.
- Distributed treatment is recommended over centralized stormwater facilities, which are defined as any

practice that treats runoff from a contributing drainage area greater than 20,000 square feet IC, and/or has a surface ponding depth greater than three feet. Examples include wet ponds, dry extended detention (ED) ponds, and infiltration basins.

- The use of centralized stormwater practices with large drainage areas is strongly discouraged even when liners are used. Centralized treatment practices require more costly geotechnical investigations and design features than smaller, shallower distributed LID practices. In addition, distributed LID practices generally eliminate the need to obtain an underground injection permit.
- Designers should refer to the list of preferred and acceptable stormwater practices as outlined in Table B.2.
- Designers must address both the flooding and water quality aspects of post development stormwater runoff. In most localities, the sequence of stormwater practices should have the capacity to safely handle or bypass the 2- and 10- year design storm, following the methods outlined in Section B.5.4.
- Designers should maintain both the quality and quantity of runoff to predevelopment levels and minimize rerouting of stormwater from existing drainage.

Table B.2: Stormwater Practice Selection in Karst Regions.

Stormwater Practice	Stability in Karst Regions	UIC Permit?	Design and Implementation Notes
Bioretention	Preferred	No	
Urban Bioretention[1]	Preferred	No	
Rain Tank/Cistern	Preferred	No	
Rooftop Disconnection	Preferred	No	15 feet foundation setback
Green Roofs	Preferred	No	
Dry Swale	Preferred	No	Lined with underdrains
Filtering Practices	Preferred	No	Water-tight
Filter Strips	Preferred	No	Flow to karst swales
Grass Channel	Adequate	No	Compost amendments
Soil Compost Amendment	Adequate	No	
Small Scale Infiltration[2]	Adequate	No	Not at stormwater hotspots
Micro-bioretention	Adequate	No	Closed systems
Permeable Pavers	Adequate	No	
Constructed Wetlands	Adequate	Maybe	Use Liner and Linear Cells
Wet Ponds	Discouraged	Maybe	Liner Required
Dry ED Ponds	Discouraged	Maybe	Liner Required
Wet Swale	Prohibited	No	Infeasible
Large Scale Infiltration[3]	Prohibited	Maybe	Use Small-Scale Instead

1 Closed, above-ground facilities with no groundwater interaction
2 See definitions and design requirements for micro- and small- scale infiltration in Table B.4
3 Contributing drainage area of 20,000 sf of IC or more

- As a general rule, the stormwater system should avoid large contributing areas, deep excavation, or pools of standing water.
- The potential hotspot status of the proposed use of the development should be evaluated prior to design. If the site is defined as a stormwater hotspot, full water quality treatment must be provided prior to any discharge to groundwater.
- When existing or new sinkholes are determined to require remediation, the repair will use appropriate techniques as outlined in WVDEP (2006), MDE (2000), or CCDP (2007). These techniques are related to the size of the sinkhole and are further described in Section B.7.

B.5.3 Stormwater Modeling

Many of the traditional NRCS hydrologic models over predict predevelopment runoff from karst terrain, as a result of the high initial abstraction of karst, as well as the fact that concentrated storm flows are often rapidly converted to subsurface flows (Laughland, 2007). In general, model over-predictions are greatest for the smaller storms and lower for larger storm events, such as the 100-year storm.

Consequently, designers must carefully modify their NRCS hydrologic and hydraulic computations to reflect the lower predevelopment peak discharge rates. Several options are provided by VA DCR (1999) and Laughland (2007), the most common of which are the multiplier factors used to adjust TR-55 and TR-20 pre-development rates, shown in Table B.3.

It should be noted, however, that the authors indicate more hydrologic monitoring and modeling research is needed to get predictions that are more reliable. Karst designers are advised to consult Fennessey and Miller (2001) who recommend that post development runoff rates should be computed based on site impervious cover alone. In any event, the adjustment factors shown in Table B.3 apply only to predevelopment runoff and should never be used for post-development runoff computations.

Table B.3: Multipliers for Adjusting Predevelopment Runoff Quantities for Karst Impact Adapted from Laughland (2007) and VADCR (1999).

% of Drainage Area in Karst	Design Storm Return Frequency		
	2-year Storm	10-year Storm	100-year Storm
100	0.33	0.43	0.50
80	0.38	0.51	0.62
60	0.55	0.66	0.74
40	0.73	0.80	0.85
20	0.91	0.92	0.93
0	1.00	1.00	1.00

Local stormwater review authorities and state regulations may require management of different design storms for quantity control, including:

- Runoff reduction or detention of the one-year storm event for downstream channel protection
- Detention of the 10-year storm for safe conveyance
- Detention or floodplain control to manage the 100-year storm event

B.5.4 Recommended Procedures for Conveying Runoff from Larger Storms

Karst areas often have no defined channels in or near small or moderate sized development sites. Instead, predevelopment runoff is conveyed in parabolic type swales across adjoining properties. When developing a karst site, the peak storm runoff rate to these swales shall be restricted to the existing karst-adjusted peak runoff rate or the pre-development forest rate, whichever is less.

This is calculated by reducing the allowable peak flow rate resulting from the 1.5-, 2-, and 10-year, 24-hour storms to a level that is less than or equal to the peak flow rate from the site assuming the site was in a good forested condition. This is typically computed by multiplying the forested peak flow rate by a reduction factor (i.e., the runoff volume from the site when the site was in a good forested condition divided by the runoff volume from the site in its proposed condition).

The total post development runoff volume may not exceed the pre development volume for the 2-year storm or more frequent storms. Storms in excess of the 2-year storm may discharge a larger volume.

B.6 Design Adaptations for Specific Stormwater Treatment Practices

B.6.1 Preferred Practices

Impervious Area Disconnection: Impervious area disconnection is strongly recommended for most residential lots less than 6,000 square feet, particularly if it can be combined with a secondary micro-practice to increase runoff reduction and prevent seepage problems. The discharge point from the disconnection should extend at least 15 feet from any building foundations.

Rainwater Harvesting Tanks: Rainwater harvesting tanks are a preferred practice in karst terrain of the Tennessee, as long as the rooftop surface is not designated as a stormwater hotspot.

- Above ground tank designs are preferred to below ground tanks
- Tanks should be combined with automated irrigation, front-yard bioretention or other secondary practices to maximize their runoff reduction rates.
- The overflow from the rain tank should extend at least 15 feet away from the building foundation.

Bioretention: Since bioretention areas require shallow ponding and treat runoff through a prepared soil media, they are generally appropriate for karst regions with the following design modifications to reduce the risk of sinkhole formation or groundwater contamination:

- If bedrock is within three feet of the bottom invert of a proposed bioretention area, the bioretention should be equipped with an under drain to convey treated runoff to an appropriate discharge point. If groundwater contamination is a strong concern, the bottom of the facility should be lined by an impermeable filter fabric.
- The scale of bioretention application is extremely important in karst terrain. Larger bioretention designs that rely on exfiltration of treated runoff into underlying soils are not recommended.
- It is recommended that the contributing area to individual bioretention areas be kept to less than 20,000 square feet of IC. Micro-bioretention and small-scale bioretention practices are preferred over larger bioretention basins.
- The minimum depth of the filter bed can be relaxed to 18 inches if the geotechnical investigation indicates that further excavation may increase karst vulnerability.
- Other tips to reduce the vertical footprint are to limit surface ponding to 6 to 9 inches, and save additional depth by shifting to a turf cover rather than mulch.
- It is important to maintain at least a 0.5% slope in the underdrain to ensure drainage and tie it into the ditch or conveyance system.
- The mix of plant species selected should reflect native plant communities present within the same physiographic region or eco-region in order to be more tolerant of drought conditions.
- The standard down-gradient setbacks from buildings, structures, and roadways should be as described in Table B.4.

Table B.4: The Three Design Scales for Bioretention Practices.

Design Factor	Micro Bioretention (Rain Garden)	Small-Scale Bioretention	Bioretention Basins
Impervious Area Treated	250 to 2500 sf	2500 to 20,000 sf	20,000 to 200,000 sf
Type of Inflow	Sheetflow or roof leader	Shallow concentrated flow	Concentrated flow
Runoff Reduction Sizing	Minimum 0.1 inches over CDA	Minimum 0.3 inches over CDA	Runoff Reduction Volume
Observation Well/Cleanout Pipes	No	No	No
Type of Pretreatment	External (leaf screens, etc.)	Filter strip or grass channel	Pretreatment Cell
Recommended Max Filter Depth	Max 3 Foot Depth	Max 5 Foot Depth	Max 6 Foot Depth
Media Source	Mixed on site	Obtained from Approved Vendor	
Head Required	Nominal 1 to 3 foot	Moderate 1 to 5 feet	Moderate 2 to 6 feet
Building Setbacks	15 ft down-gradient 25 ft up-gradient	15 ft down-gradient 50 ft up-gradient	25 ft down-gradient 100 ft up-gradient

Dry Swale (closed): Shallow dry swales work well in karst terrain when they utilize impermeable filter fabric liners and under drains.

- The invert of the dry swale shall be located at least two feet above bedrock layers or pinnacles.
- If a dry swale facility is located in an area of sinkhole formation, standard setbacks to buildings should be increased.
- The minimum depth of the filter bed can be relaxed to 18 inches, if head or water table conditions are problematic.
- A minimum underdrain slope of 0.5% slope must be maintained to ensure positive drainage and be tied into an adequate discharge point.

Urban Bioretention: Three forms of bioretention for highly urban areas can work acceptably within karst terrain since they are enclosed in a concrete shell and do not interact with groundwater - stormwater curb extensions, expanded tree planters and foundation planters. Designers should consider the above-ground design variants since they reduce excavation, and also incorporate the general karst design modifications for regular bioretention described above.

Filtering Practices: Stormwater filters are a good option in karst terrain since they are not connected to groundwater and therefore minimize the risk of sinkhole formation and groundwater contamination.

- They are highly recommended for the treatment of hotspot runoff.
- Construction inspection should certify that the filters are indeed water tight
- The bottom invert of the sand filter should be at least two feet above bedrock
- The minimum depth of the sand filter bed can be reduced to 24 inches.

Green Roofs: Green roofs are a preferred treatment option in karst terrain for commercial institutional and industrial sites, but they may somewhat limited application given the forms and intensity of development in the Ridge and Valley Province. The overflow from the green roof should extend at least 15 feet away from the building foundation.

Filter Strips: The use of conservation filter strips is highly recommended, particularly when storm flow discharges to the outer boundary of a karst swale protection area. Grass filter strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 20,000 square feet). Some communities use wide grass filter strips to treat runoff in the roadway shoulder.

B.6.2 Adequate Practices

Grass Channel: Grass channels are an acceptable practice in karst terrain, as long as they do not treat hotspot runoff. The following design adaptations apply to grass channels in karst terrain.

- Soil compost amendments can be incorporated into the bottom of grass channels to improve their runoff reduction capability.
- Check dams are generally discouraged for grass swales in karst terrain since they pond too much water (although flow spreaders that are flush with ground surface may be useful in spreading flows more evenly across the channel width).
- The minimum depth to the bedrock layer can be 18 inches.
- A minimum slope of 0.5% must be maintained to ensure positive drainage.
- The grass channel may have off-line cells and should be tied into an adequate discharge point.

Soil Restoration: No special adaptations are needed in karst terrain, but the designer should take soil tests to ensure that soil pH is adjusted to conform to pre-existing soil conditions.

- **Micro and Small Scale Infiltration:** The karst region is an acceptable environment for micro-infiltration and small-scale infiltration practices (for definitions and design requirements, See Table B.4). Designers may choose to infiltrate less than full water quality volume in a single practice (and use another runoff reduction practice to pre-treat or filter runoff prior to the infiltration facility.

Some other design modifications for small scale infiltration in karst terrain include:

- Designers should maximize the surface area of the infiltration practice, and keep the depth of infiltration to less than 24 inches.
- Soil borings must indicate at least three feet of vertical separation exist between their bottom invert and the bedrock layer.
- Where soils are marginal, under drains may be used.
- In many cases, bioretention is a preferred stormwater alternative to infiltration in karst areas.

Infiltration is prohibited if the contributing drainage area is classified as a severe stormwater hotspot.

Permeable Pavers: Permeable pavers are an acceptable option in karst terrain if geotechnical investigations have eliminated concerns about sinkhole formation and groundwater contamination.

- Full infiltration from permeable pavement is not recommended for large scale pavement applications and is prohibited if the site is designated as a severe stormwater hotspot, or discharges to areas known to recharge to aquifers used as a water supply.
- Permeable pavement is acceptable when they are designed to with an impermeable bottom liner and underdrain. A minimum 0.5% underdrain slope must be maintained to ensure proper drainage.
- The rock used in the reservoir layer should be carbonate in nature to provide extra buffering capacity.

Constructed Wetlands (lined): Even shallow pools in karst terrain can increase the risk of sinkhole formation and groundwater contamination. Designers should always conduct geotechnical investigations in karst terrain to assess this risk in the planning stage. If they are employed, designers should:

- Use an impermeable liner and maintain at least three feet of vertical separation from underlying bedrock.
- Shallow, linear and multiple cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system and the ED wetland have limited application in karst terrain.

B.6.3 Discouraged Practices

Dry Extended Detention (ED) Ponds and Wet Ponds: The use of either dry ED or wet ponds in karst terrain is highly discouraged, because of frequent recurring failures due to sinkhole formation. At a minimum, designers must demonstrate that:

- A minimum of six feet of unconsolidated soil material exists between the bottom of the basin and the top of the bedrock layer.
- Maximum temporary or permanent water elevations with basins do not exceed six feet. Annual maintenance inspections are conducted to detect sinkhole formation. Sinkholes that develop should be reported

immediately to local and state officials (see Section B.7.1) and should be repaired, abandoned, adapted or observed over time following the guidance prescribed by the appropriate local or state groundwater protection authority (see Section B.7).

- A liner is installed that meets the requirements outlined in Table B.5.

Table B.5: Required Groundwater Protection Liners for Ponds in Karst Terrain (WVDEP, 2006 and VADCR, 1999).

Pond Excavated at least 3 Feet Above Bedrock	24 inches of soil with maximum hydraulic conductivity of 1 x 10^{-5} cm/sec
Pond Excavated within 3 Feet of Bedrock	24 inches of clay[1] with maximum hydraulic conductivity of 1 x 10^{-6} cm/sec
Pond Excavated Near Bedrock within wellhead protection area, in recharge area for domnestic well or spring, or in area with high fracture density or significant geophysical anomalies	Synthetic liner with a minimnum thickness of 60 ml.
1 Clay properties as follows: *Plasticity Index of Clay: Not less than 15% (ASTM D-423/424)* *Liquid Limit of Clay: Not less than 30% (ASTM D-2216)* *Clay Particles Passing: Not less than 30% (ASTM D-422)* *Clay Compaction: 95% of standard proctor density (ASTM D-2216)*	

B.6.4 Prohibited Practices

Wet Swale: These practices are not generally feasible in karst terrain since the water table rarely reaches the land surface.

Large Scale Infiltration: Large scale infiltration is defined as individual practices that infiltrate runoff from a contributing drainage area between 20,000 to 100,000 square feet of impervious cover. These practices should not be used in karst terrain due to concerns about sinkhole formation and groundwater contamination. Micro- and small scale infiltration or bioretention are preferred stormwater alternatives in karst terrain.

B.7 Sinkhole Remediation in Stormwater Practices

Since karst terrain is so dynamic, there is always some risk that sinkholes will be created in the conveyance system or with stormwater practices. This section outlines a four-step process of sinkhole remediation, involving notification, investigation, stabilization and final grading, which has been loosely adapted from CCDP (2007). The choice of sinkhole remediation techniques is contingent on the scope of the perceived problem, nature of contributing land uses, and the cost and availability of equipment and materials.

B.7.1 Sinkhole Notification

The existence of a new sinkhole within a temporary erosion control practice, road right of way or stormwater management practice shall be reported to the local stormwater review authority within 24 hours or the next business day. A plan for investigation and stabilization shall be coordinated with the local review authority, and repairs shall commence immediately after receiving design approval. Until repairs are completed, a temporary berm shall be constructed to divert surface flow away from the sinkhole. Documentation of sinkhole repairs shall be submitted to the UIC program.

B.7.2 Sinkhole Investigation

The investigation phase should determine the areal extent and depth of the new sinkhole, as well as the depth of bedrock pinnacles upon which sinkhole stabilization may be founded. The investigation may involve visual inspection, excavation, borings and/or geophysical studies, as described below.

Visual Inspection is generally used for smaller sinkholes (less than ten feet in diameter) where the bedrock throat of a sinkhole is entirely visible from the ground surface.

Excavation by backhoe is commonly used for small to moderate-sized sinkholes (up to 20 feet in diameter) when the throat of the sinkhole is not visible from the ground surface. Track hoes, clam shells or other excavating equipment are typically used when soil depths exceed about 20 feet. The equipment is used to remove soil and fill from the sinkhole until the bedrock pinnacles and/or throat of the sinkhole are clearly visible.

Soil Borings may be taken using augers, core, air track or other boring equipment at larger sinkholes, particularly when more extensive sinkhole development is anticipated and/or critical foundation structures are at risk (bridge abutments, major roads, load bearing structures). This investigation involves a closely spaced boring program to determine the location and depth of bedrock pinnacles, cavities and sinkhole throats.

Geophysical Studies may be needed in conjunction with more intrusive methods to further delineate the scope of sinkhole dimensions, using techniques such as electromagnetic terrain conductivity, seismic refraction or resistivity.

B.7.3 Sinkhole Stabilization

Stabilization of reverse-grade backfilling, grouting or subsurface engineering structures, as follows:

a) **Reverse-graded backfilling** is generally applied to small and moderately sized sinkholes. Once the throat of the sinkhole is fully excavated, it is filled with clean, interlocking rock material. The stone diameter of the initial fill layer shall generally be one-half the diameter of the throat or cutter width. Once the initial fill layer is placed, progressively smaller diameter clean rock fill is installed above, up to or near the ground surface. Compaction of each layer of rock fill is essential. In general, at least three gradation sizes of fill are needed for adequate stabilization.

b) **Grouting** is generally discouraged, unless it is combined with the graded filter (a) within moderate to large sinkholes. Borings are placed in the ground adjacent to the sinkhole and a concrete (grout) mix is injected by pressure or gravity into the subsurface until the throat is sealed. Grouting may be used to remediate small diameter voids, such as test borings or abandoned well.

c) **Engineered subsurface structures** are used on larger sinkholes or where concentrated load bearing structures are present. The technique involves creating a bridge between bedrock pinnacles to form a stable base, above which appropriate fill and construction may be completed.

B.7.4 Final Grading

In order to provide permanent stabilization and prevent groundwater contamination, final grading at the repaired sinkhole must be completed to avoid excess infiltration from the ground surface. The final grading should include placement of low permeability topsoil or clay and a vegetative cover. A positive grade should also be maintained away from the sinkhole to avoid local ponding or infiltration, although this is not always possible if the sinkhole forms within the stormwater conveyance system or centralized pond.

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Appendix C

Soil Amendments

C.1 General Description

C.2 Physical Feasibility & Design Applications

C.3 Design Criteria

C.3.1 Soil Testing

C.3.2 Determining Depth of Compost Incorporation

C.3.3 Compost Specifications

C.4 Construction and Maintenance

C.4.1 Construction Sequence

C.4.2 Construction Inspection

C.4.3 Maintenance Criteria

C.1 General Description

Soil amendment (also called soil restoration) is a technique applied after construction, to deeply till compacted soils and restore their porosity by amending them with compost. This can reduce the generation of runoff from compacted urban lawns and may also be used to enhance the runoff reduction performance of impervious surface disconnections, grass channels, and filter strips.

C.2 Physical Feasibility & Design Applications

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 the pervious area will be used to filter runoff. The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system. Soil restoration is recommended for sites that will experience mass grading of more than a foot of cut and fill across the site.

Soil amendments are not recommended where:

- Existing soils have high infiltration rates (e.g., HSG A and B), although compost amendments may be needed at mass-graded B soils in order to maintain runoff reduction rates;
- The water table or bedrock is located within 1.5 feet of the soil surface;
- Slopes exceed 10%;
- Existing soils are saturated or seasonally wet;
- 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; and
- The contributing impervious surface area exceeds the surface area of the amended soils.

Soil amendments can be applied to the entire 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:

- Reducing runoff from compacted lawns,
- Enhancing rooftop disconnections on poor soils,
- Increasing runoff reduction within a grass channel,
- Increasing runoff reduction within a vegetated filter strip, and
- Increasing the runoff reduction function of a tree cluster or reforested area of the site.

C.3 Design Criteria

C.3.1 Soil Testing

Soil tests are required during two stages of the compost amendment process. The first testing is done to ascertain pre-construction soil properties at proposed amendment areas. The initial testing is used to determine soil properties to a depth 1 foot below the proposed amendment area, with respect to bulk density, pH, salts, potential drainage problems and determine what, if any, further soil amendments are needed.

The second soil test is taken at least one week after the compost has been incorporated into the soils. This soil analysis should be conducted by a reputable laboratory to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth. This soil analysis should be done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths.

C.3.2 Determining Depth of Compost Incorporation

The depth of compost amendment is based on the relationship of the surface area of the soil amendment to the contributing area of impervious cover that it receives. Table C.1 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.

Table C.1: Short-cut Method to Determine Compost and Incorporation Depths.

	Contributing Impervious Cover to Soil Amendment Area Ratio[1]			
	IC/SA = 0[2]	IC/SA = 0.5	IC/SA = 0.75	IC/SA = 1.0[3]
Compost (in)[4]	2 to 4[5]	3 to 6[5]	4 to 8[5]	6 to 10[5]
Incorporation Depth (in)	6 to 10[5]	8 to 12[5]	15 to 18[5]	18 to 24[5]
Incorporation Method	Rototiller	Tiller	Subsoiler	Subsoiler

1 IC = contrib. impervious cover (sq. ft.) and SA = surface area of compost amendment (sq. ft.)
2 For amendment of compacted lawns that do not receive off-site runoff
3 In general, IC/SA ratios greater than 1 should be avoided
4 Average depth of compost added
5 Lower end for B soils, higher end for C/D soils

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed using the following estimator equation:

Equation C.1 Compost Quantity Estimation:

$$C = A * D * 0.0031$$

Where:

C = compost needed (cu. yds.)

A = area of soil amended (sq. ft.)

D = depth of compost added (in.)

C.3.3 Compost Specifications

The basic material specifications for compost amendments are outlined below:

- Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program. See www.compostingcouncil.org for a list of local providers.
- The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and 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 Compost Technical Data Sheet provided by the vendor:

a. 100% of the material must pass through a half inch screen
b. The pH of the material shall be between 6 and 8
c. Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0% by weight
d. The organic matter content shall be between 35% and 65%
e. Soluble salt content shall be less than 6.0 mmhos/cm
f. Maturity should be greater than 80%
g. Stability shall be 7 or less
h. Carbon/nitrogen ratio shall be less than 25:1
i. Trace metal test result = "pass"
j. The compost must have a dry bulk density ranging from 40 to 50 lbs./cu.ft.

C.4 Construction and Maintenance

C.4.1 Construction Sequence

The construction sequence for compost amendments differs depending on whether the practice will be applied to a large area or a narrow filter strip, such as in a rooftop disconnection or grass channel. For larger areas, a typical construction sequence is as follows:

Step 1. Prior to building, the proposed area should 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 step is usually omitted when compost is used for narrower filter strips.)

Step 2. A second deep tilling to a depth of 12 to 18 inches is needed after final building lots have been graded.

Step 3. It is important to have dry conditions at the site prior to incorporating compost.

Step 4. An acceptable compost mix is then incorporated into the soil using a roto-tiller or similar equipment at the volumetric rate of 1 part compost to 2 parts soil.

Step 5. The site should be leveled and seeds or sod used to establish a vigorous grass cover. Lime or irrigation may initially be needed to help the grass grow quickly.

Step 6. Areas of compost amendments exceeding 2,500 square feet should employ simple erosion control measures, such as silt fence, to reduce the potential for erosion and trap sediment.

C.4.2 Construction Inspection

Construction inspection involves digging a test pit to verify the depth of mulch, amended soil and scarification. A rod penetrometer should be used to establish the depth of uncompacted soil at one location per 10,000 square feet.

C.4.3 Maintenance Criteria

Maintenance Agreements. When soil amendments are applied on private residential lots, homeowners will need to be educated on their routine maintenance needs, understand the long-term maintenance plan, and be subject to a deed restriction or other mechanism enforceable by the local stormwater program to ensure that infiltrating areas are not converted or disturbed. The mechanism should, ideally, grant authority for local agencies to access the property for inspection or corrective action. In addition, the GPS coordinates for all amended areas should be provided upon facility acceptance to ensure long term tracking.

A simple maintenance agreement should be provided if soil restoration is associated with more than 10,000 square feet of reforestation. A conservation easement or deed restriction, which also identifies a responsible party, may be required to make sure the newly developing forest cannot be cleared or developed management is accomplished (i.e., thinning, invasive plant removal, etc.). Soil amendments within a filter strip or grass channel should be located in a public right-of-way, or within a dedicated stormwater or drainage easement.

First Year Maintenance Operations. In order to ensure the success of soil amendments, the following tasks must 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.

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Appendix D

Stormwater Control Measures (SCMs) Landscaping and Plant Lists

D.1 Plant List Categorized by Plant Type

- Canopy
- Understory
- Shrubs
- Vines
- Herbaceous Perennials
- Grasses and Sedges
- Ground Cover
- Ferns

D.1 Plant List Categorized by Plant Type

Canopy: Largest trees 50-100' or more

Understory: Small trees or large shrubs 15-50'

Shrub: Woody stems from a few inches to 15 feet

Herbaceous: A plant that has leaves and stems that die down at the end of the growing season to the soil level. Herbaceous can be grasses, ferns, and wildflower. It can also be annual, perennial, and biennial.

Regional Distribution (RD)

E = East Tennessee	UM = Unaka Mountain	V = Valley
W = West Tennessee	WR = Western Highland Rim	R = Ridge
CP = Cumberland Plateau	CB = Central Basin	

Width

Plant or crown spread

Light

F = full sunlight	P = partial shade	S = shade

Moisture

H = hydric, wet, plants periodically or often inundated by water	S = sub-xeric, moist to dry, seasonally moist, periodically dry
M = mesic, moist, adequate soil moisture retention year-round	X = xeric, dry & drought resistant, little moisture retention, excessively drained

Soil pH

A = acidic (slightly acidic to strongly acidic)	B = basic (tolerate alkaline)

Common Name	Scientific Name	RD	Height	Width	Light			Moisture				Soil pH		SOURCE
					F	P	S	H	M	S	X	B	A	
CANOPY														
Red maple	*Acer rubrum*	All	50'-75'	50'-75'	<	<		<	<	<			<	1
Sugar Maple	*Acer saccharum*	All	70'-100'	70'-100'		<	<		<	<			<	1
Sweet Birch	*Betula lenta*	E	up to 60'		<	<			<	<			<	1
River Birch	*Betula nigra*	E	40'-70'		<	<		<	<				<	1
Pecan	*Carya illinoinensis*	W	up to 120'		<	<			<	<				1
Pignut, Shagbark, Mockernut Hickory	*Carya glabra, C. ovata, C. tomentosa*	All	50'-80'	25'-40'	<	<			<	<	<		<	1
Bitternut Hickory	*Carya cordiformis*	All	50'-80'	25'-40	<				<				<	1
American Chestnut	*Castanea dentata*	All	up to 100'			<	<		<	<				4
Northern catalpa	*Catalpa speciosa*	W	up to 60'		<	<		<	<	<				4
Hackberry	*Celtis occidentalis*	All	60'-80'	60'-80'	<	<			<					1
Sugarberry	*Celtis laevigata*	All	up to 80'		<	<			<					2
Yellowood	*Cladrastis kentuckea*	All	40'-60'	40'-60'	<				<					4
Persimmon	*Diospyros virginiana*	All	35'-60'	25'-40'	<	<			<	<			<	4
American Beech	*Fagus grandifolia*	All	>85'	2/3H		<	<		<	<			<	1
White Ash	*Fraxinus americana*	All	up to 85'	up to 60'	<	<			<				<	1
Green Ash	*Fraxinus pennsylvanica*	All	up to 60'	up to 30'	<	<		<	<					4
Blue ash	*Fraxinus quadrangulata*	E,M	up to 70'		<	<	<		<	<				4
Kentucky Coffeetree	*Gymnocladus dioicus*	M	60'-85'	60'-85'	<	<	<		<	<		<	<	1
American Holly	*Ilex opaca*	E, W	20'-40'			<	<		<	<	<		<	1
Black Walnut	*Juglans nigra*	E, M	up to 85'	up to 85'	<	<			<	<		<		1
Red Cedar	*Juniperus virginiana*	All	40'-50'		<	<				<	<	<		1
Sweetgum	*Liquidambar styraciflua*	All	60'-85'		<	<		<	<	<	<		<	1
Tulip Poplar	*Liriodendron tulipifera*	All	70'-90'		<	<			<	<			<	1
Cucumbertree	*Magnolia acuminata*	E,M	50'-80'	50'-80'	<	<			<	<			<	1
Southern Magnolia	*Magnolia grandiflora*	E,M	60'-80'	30'-40'	<	<			<					1
Blackgum	*Nyssa sylvatica*	All	30'-60'	20'-40'	<	<	<		<	<	<		<	4
Water Tupelo	*Nyssa aquatica*	W	up to 100'		<			<						4
Shortleaf/ Yellow Pine	*Pinus echinata*	E,M	50'-75'		<	<		<	<	<				1
Pitch Pine	*Pinnus rigida*	NE	45'-65'						<	<			<	4
White Pine	*Pinus strobus*	E	50'-85'	40'-55'	<				<	<			<	4
Sycamore	*Platanus occidentalis*	All	75'-100'		<	<		<	<			<		1
Eastern Cottonwood	*Populus deltoides*	All	80'-100'	40'-60'	<	<		<	<					1
Black Cherry	*Prunus serotina*	All	50'-75'		<	<			<	<			<	1
White, Scarlet oak	*Quercus alba, Q. coccinea*	All	60'-85'		<	<			<	<	<			1,4
Southern Red / Spanish Oak	*Quercus falcata*	W	70'-80'		<					<	<		<	4
Shingle / Laurel Oak	*Quercus imbricaria*	M	35'-55'	35'-55'	<	<			<	<			<	1
Overcup Oak	*Quercus lyrata*	M,W	35'-60'		<			<	<	<				1
Bur Oak	*Quercus macrocarpa*	M,W	70'-85'		<					<	<	<		1
Chestnut Oak	*Quercus montana*	E,W	55'-70'	55'-70'	<	<			<	<	<			1
Chinkapin Oak	*Quercus muhlenbergii*	All	40'-50'		<	<			<	<	<	<		1
Pin / Swamp Oak	*Quercus palustris*	W,M	50'-75'		<			<	<				<	4
Cherrybark oak	*Quercus pagoda*	W	up to 120'		<	<		<	<					1
Willow Oak	*Quercus phellos*	All	50'-70'	50'-70'	<	<			<	<				1
Northern Red Oak	*Quercus rubra*	All	60'-85'	60'-85'	<	<			<	<				4
Shumard Oak	*Quercus shumardii*	All	50'-80'		<	<			<	<	<		<	4
Black Oak	*Quercus velutina*	All	50'-75'	35'-50'	<	<			<	<	<		<	4
Black Locust	*Robinia pseudoacacia*	All	40'-70'		<				<	<	<	<	<	4
Black willow	*Salix nigra*	All	up to 100'		<	<		<				<		1
Sassafras	*Sassafras albidum*	All	30'-60'	20'-40'	<	<			<	<	<		<	1,4
Bald Cypress	*Taxodium distichum*	W	40'-100'		<	<		<	<				<	1
American Basswood	*Tilia americana*	All	up to 100'		<	<			<	<		<		1
White Basswood	*Tilia heterophylla*	E,M	60'-80'	40'-50'	<	<			<					1
Canadian Hemlock	*Tsuga canadensis*	E	40'-70'	20'-35'	<	<			<	<				4
Winged Elm	*Ulmus alata*	All	up to 65'			<			<	<			<	2
American/ White Elm	*Ulmus americana*	All	up to 80'		<	<			<	<		<		4
Slippery Elm	*Ulmus rubra*	All	up to 65'		<	<				<			<	

Common Name	Scientific Name	RD	Height	Width	Light			Moisture				Soil pH		SOURCE
					F	P	S	H	M	S	X	B	A	
UNDERSTORY														
Striped Maple	*Acer pensylvanicum*		20'-30'			<			<					4
Yellow, Ohio buckeye	*Aesculus flava, A. glabra*	E,M	30'-50'			<	<		<	<			<	1
Serviceberry	*Amelanchier arborea, A. laevis*	E	15'-25'		<	<	<			<	<		<	1
Hercules Club	*Aralia spinosa*	All	10'-20'		<	<				<	<		<	1,4
Pawpaw	*Asimina triloba*	All	15'-20'			<	<		<				<	1,4
Ironwood	*Carpinus caroliniana*	All	25'-40'	25'-40'		<	<	<	<				<	1,4
Redbud	*Cercis canadensis*	All	20'-30'		<	<			<	<	<	<	<	1
Fringe tree	*Chionanthus virginicus*	E,M	12'-20'			<	<		<	<			<	1
Alternate leaf / Pagoda Dogwood	*Cornus alternifolia*	E,M	15'-25'			<	<		<	<			<	1
Roughleaf Dogwood	*Cornus drummondii*	M,W	up to 25'		<	<				<	<	<		1
Flowering Dogwood	*Cornus florida*	All	20'-30'	20'-30'	<	<			<	<			<	1
Washington Hawthorn	*Crataegus phaenopyrum*	M	20'-30'	13'-20'	<	<			<	<	<			4
Cockspur Hawthorn	*Crataegus crus-galli*	All	20'-30'	13'-20'	<	<			<	<	<			4
Parsley Hawthorn	*Crataegus marshalii*	W	20'-30'	13'-20'	<	<			<	<	<			4
Green Hawthorn	*Crataegus viridis*	W	20'-30'	13'-20'	<	<			<	<	<			4
Common Persimmon	*Diospyros virginiana*	All	35'-60'	25'-40'	<	<			<	<				
Wahoo	*Euonymus atropurpureus*	All	20'		<	<			<	<		<		1
Carolina Silverbell	*Halesia tetraptera*	E	30'			<	<		<	<			<	1
Witch-hazel	*Hamamelis virginiana*	E,M	20'-30'			<	<		<	<			<	1
Possumhaw	*Ilex decidua*	All	12'-20'		<	<				<	<			2,3
Bigleaf Magnolia	*Magnolia macrophylla*	E,M	30'40'		<	<			<					4
Umbrella Magnolia	*Magnolia tripetala*	E,M	30'		<	<			<					4
Sweetbay magnolia	*Magnolia virginiana*	E,W	10'-35'	10'-35'		<	<	<	<	<			<	1
Southern Crabapple	*Malus angustifolia*	All	20'-35'		<	<			<	<			<	4
Red Mulberry	*Morus rubra*	All	40'-50'		<	<			<	<	<	<		1,4
Hophornbeam	*Ostrya virginiana*	All	25'-40'			<	<		<	<		<		1
Sourwood	*Oxydendrum arboreum*	E,M	25'-45'		<	<				<	<		<	1
Virginia/ Scrub Pine	*Pinus virginiana*	E,M	15'40'	10'-30'	<					<				4
American/ Wild Plum	*Prunus americana*	All	15'-25'		<	<			<	<	<		<	1,4
Chicksaw Plum	*Prunus angustifolia*	All	5'-15'		<	<			<	<	<			1,4
Hoptree	*Ptelea trifoliata*	E,M	15'-25'		<	<	<		<	<	<			1
Post Oak	*Quercus stellata*	All	40'-50'		<					<	<		<	4
Carolina buckthorn	*Rhamnus caroliniana*	E,M	20'			<	<			<	<	<		1
Rosebay/Great Laurel Rhododendron	*Rhododendron maximum*	E	20'	10'		<			<					4
Shining/ Flameleaf/ Winged Sumac	*Rhus copallinum*	All	20'-30'	20'-30'	<	<				<	<			1
Smooth Sumac	*Rhus glabra*	All	9'-15'		<	<				<	<			1
Staghorn Sumac	*Rhus typhina*	All	up to 25'		<	<				<	<			1
Carolina Willow	*Salix caroliniana*	All	up to 33'		<	<		<				<		4
Rusty Blackhaw Viburnum	*Viburnum rufidulum*	All	20'-25'		<	<	<		<	<	<	<		4
Blackhaw Viburnum	*Viburnum prunifolium*	NE	20'-25'		<	<	<		<	<	<	<		4
SHRUBS														
Tag Alder	*Alnus serrulata*	All	10'-20'	10'-20'	<			<	<					4
Indigobush	*Amorpha fruticosa*	All	6'-12'		<	<			<	<	<			1
Red Chokeberry	*Aronia arbutifolia*	E,M	6'-11'	3'-5'	<	<		<	<	<				1
Red Chokeberry	*Aronia melanocarpa*	E,M	3'-6'		<	<		<	<	<				1
American Beautyberry	*Callicarpa americana*	All	3'-6'		<	<		<	<	<	<			1
Sweetshrub	*Calycanthus floridus*	E,M	6'-9'	6'-9'		<	<		<	<				4
New Jersey tea	*Ceanothus americanus*	All	3'	3'		<	<		<	<	<		<	1
Buttonbush	*Cephalanthus occidentalis*	All	5'-12'	5'-12'	<	<		<	<					1
Cinnamon Clethra	*Clethra acuminata*	All	8'-12'						<					1
Sweet pepperbush	*Clethra alnifolia*	M	5'-10'	4'-6'	<	<			<	<	<		<	1
Cumberland rosemary	*Conradina verticillata*	E	1'		<				<	<	<			1
Silky dogwood	*Cornus amomum*	All	6'-12'		<	<		<	<					1,4
Hazelnut	*Corylus americana*	All	6'-12'	6'-12'	<	<			<	<				1,4

Common Name	Scientific Name	RD	Height	Width	Light			Moisture				Soil pH		SOURCE
					F	P	S	H	M	S	X	B	A	
SHRUBS *cont'd*														
Southern bush honeysuckle	*Diervilla sessilifolia*	E,M	3'-5'	3'-5'	<	<			<	<	<		<	1,4
Water willow/ Swamp loosestrife	*Decodon verticillatus*	All	3'	3'-5'	<			<					<	
Leatherwood	*Dirca palustris*	E,M	3'-6'			<	<		<					1
Hearts-a-bustin	*Euonymus americanus*	All	4'-6'	3'-4'	<	<	<		<	<				1
Wild hydrangea	*Hydrangea arborescens*	E,M	3'-6'	3'-6'		<	<		<	<		<		1
Oakleaf hydrangea	*Hydrangea quercifolia*	All	3'-6'	3'-6'	<	<	<		<	<				1
Cedarglade/ St. John's Wort	*Hypericum frondosum*	M	3'-4'	3'-4'	<	<			<	<	<			1,4
Shrubby St. John's Wort	*Hypericum prolificum*	E,M	1'-4'		<	<			<	<	<			1,4
Dense St. John's Wort	*Hypericum densiflorum*	E,M	4'-6'		<	<			<	<	<			1,4
Common winterberry	*Ilex verticillata*	E,W	6'-12'		<	<	<	<	<				<	1
Virginia sweetspire	*Itea virginica*	All	4'-10'	4'-10'	<	<	<	<	<	<				1
Mountain laurel	*Kalmia latifolia*	E,M	7'-15'		<	<			<	<	<		<	1
Doghobble/ Dog-laurel, Fetterbush	*Leucothoe fontanesiana*	U,E	2'-6'											4
Spicebush	*Lindera benzoin*	All	6'-12'	6'-12'		<	<		<					1
Hairy Mock Orange	*Philadelphus hirsutus*	E	4'-6'		<	<			<	<		<		1,4
Common Mock Orange	*Philadelphus inodorus*	All	6'-9'		<	<			<	<		<		1,4
Downy Mock Orange	*Philadelphus pubescens*	M	4'-10'		<	<			<	<		<		1,4
Ninebark	*Physocarpus opulifolius*	E,M	5'-10'		<	<		<	<	<	<			1
Alabama Azalea	*Rhododendron alabamense*	M	4'-6'			<	<			<	<		<	4
Sweet Azalea	*Rhododendron arborescens*	E	10'-20'			<	<	<	<				<	1
Flame Azalea	*Rhododendron calendulaceum*	U	8'-10'	8'-10'		<	<	<	<	<			<	4
Mountain rosebay (Cawtawba R.)	*Rhododendron catawbiense*	E	6'-10'			<	<		<	<			<	1
Cumberland Azalea	*Rhododendron cumberlandense*	E	3'-8'			<	<	<	<	<			<	4
Pietmon Azalea	*Rhododendron canescens*	All	6'-15'			<	<		<	<			<	1,4
Carolina Rhododendron	*Rhododendron minus*	E	3'-6'			<	<		<					
Pixterbloom Azalea	*Rhododendron periclymenoides (R. nudiflorum)*	M	4'-6'			<	<	<	<				<	1
Roseshell Azalea	*Rhododendron prinophyllum (R. roseum)*	M	3'-8'			<	<	<	<			<		1
Swamp Azalea	*Rhododendron viscosum*	E	4'-8'		<	<		<	<					4
Fragrant Sumac	*Rhus aromatica*	E,M	2'-6'		<	<				<	<			1
Carolina/ Pasture Rose	*Rosa carolina*	All	3'-4'		<			<	<	<		<		1
Swamp Rose	*Rosa palustris*	All	6'-7'		<	<	<	<	<					4
Prairie Rose	*Rosa setigera*	All	12'	3'-6'	<	<			<	<	<	<		4
Blackcap Raspberry (Tall Blackberry)	*Rubus occidentalis, R. argutus*	All	3'-6'		<				<	<		<		4
Northern Dewberry	*Rubus flagellaris*	All	3'		<	<			<	<				4
Elderberry	*Sambucus canadensis*	All	6'-8'		<	<		<	<	<	<			4
Bladdernut	*Staphylea trifolia*	All	8'-14'			<	<		<	<				1
American Snowbell, Bigleaf S.	*Styrax americana, S. grandifolius*	W	6'-10'			<	<	<	<				<	1
Coralberry	*Symphoricarpos orbiculatus*	E,M	2'-5'		<	<	<		<	<	<			1
Farkleberry (Sparkleberry)	*Vaccinium arboreum*	All	20'			<	<		<	<				4
Late Lowbush Blueberry	*Vaccinium pallidum(V. vacillans)*	E,M	1'-3'		<	<				<	<		<	4
Deerberry	*Vaccinium stamineum*	E,W	6'-12'		<	<				<	<		<	4
Mapleleaf Viburnum	*Viburnum acerifolium*	E,M	3'-6'			<	<		<	<			<	4
Northern Witerod	*Viburnum cassinoides*	E	15'		<	<	<	<	<	<			<	4
Arrowood Viburnum	*Viburnum dentatum*	E,M	6'-12'	6'-12'	<	<		<	<				<	4
Possumhaw Viburnum	*Viburnum nudum*	E,M	6'-15'	4'-10'	<	<	<	<	<	<			<	4
Yellowroot	*Xanthorhiza simplicissima*	E,M	3'			<	<	<	<	<			<	4

Common Name	Scientific Name	RD	Height	Width	Light			Moisture				Soil pH		SOURCE
					F	P	S	H	M	S	X	B	A	
VINES														
Dutchman's Pipe	*Aristolochia macrophylla*	E,M				<	<		<	<		<	<	1,4,5
Wolly Pipevine	*Aristolochia tomentosa*	All				<	<		<	<		<	<	1,4,5
Ratan Vine	*Berchemia scandens*	All			<	<	<	<	<	<			<	1,4,5
Crossvine	*Bignonia capreolata*	All			<	<		<	<	<		<	<	1,4,5
Trumpet Creeper	*Campsis radicans*	All			<	<			<	<	<	<	<	1,4,5
American Bittersweet	*Celastrus scandens*	E,W							<					1,4,5
Leather-Flower	*Clematis versicolor*	M				<	<		<	<				4
Virgin's bower (Traveller's Joy)	*Clematis virginiana*	All			<	<			<	<				4
Leather-Flower	*Clematis viorna*	M				<	<		<	<				4
Marsh Leather-Flower (Blue Jasmine)	*Clematis crispa*	W			<	<		<	<			<		4,5
Carolina Snailseed	*Cocculus carolinus*	All			<	<	<		<	<	<		<	4
Climbing Hydrangea	*Decumaria barbara*	All			<	<	<	<	<			<	<	5
Yellow Jasmine	*Gelsemium sempervirens*	E			<	<			<	<		<	<	1,5
Yellow Honeysuckle	*Lonicera flava*	S				<	<		<	<				4
Coral Honeysuckle	*Lonicera sempervirens*	All			<	<	<		<	<	<	<	<	4,5
Common (Canada) Moonseed	*Menispernum canadense*	All				<	<	<	<	<				4
Virginia Creeper	*Parthenocissus quinquefolia*	E,M			<	<	<		<	<	<	<	<	4,5
Purple Passion Flower (Maypop)	*Passiflora incarnata*	All			<	<				<	<	<	<	4,5
Yellow Passion Flower	*Passiflora lutea*	All				<	<		<	<				4
Riverbank Grape	*Vitis riparia*				<	<	<	<	<	<				4
American Wisteria	*Wisteria frutescens*	W			<	<		<	<			<		4,5
HERBACEOUS PERENNIALS														
Doll's Eyes	*Actaea pachypoda*	All	1-2.5′			<			<					
White Snakeroot	*Ageratina altissima*	All	2-5′			<			<					
Nodding Onion	*Allium cernum*	E, M	12″		<	<						<		
Blue Star	*Amsonia tabernaemontana*	All	3′		<	<			<					3
Thimbleweed	*Anemone virginiana*	All	2-3′							<			<	
Wild Columbine	*Aquilegia canadensis*	E, M	1-2.5′			<							<	3
Spikenard	*Aralia racemosa*	E, M	2-3′			<			<				<	
Jack-in-the-pulpit	*Arisaema triphyllum*	All	12″			<			<					3
Goat's-beard	*Aruncus dioicus*	E	3-6′			<			<				<	
Wild Ginger	*Asarum canadense*	All	4-6″			<			<					3
Swamp Milkweed	*Asclepias incarnata*	E, M	3-4′		<			<					<	
Butterfly-weed	*Asclepias tuberosa*	All	1-2′		<					<	<			
Blue Wood Aster	*Aster cordifolius*	All	1.5-4′											
White Wood Aster	*Aster divaricatus*	E	1-3′			<			<	<			<	
Short's Aster	*Aster shortii*	M	2-4′		<				<	<				
New England, Aromatic aster	*Aster novae-angliae, A. oblongifolius*	All	3-5′		<			<	<				<	
False Indigo	*Baptisia alba*	W	3′											
Tickseed Sunflower	*Bidens polylepis*	M, E	2-4′		<			<	<					
Tickseed Sunflower	*Bidens aristosa*	M, W	2-4′		<			<	<					
Downy Wood-mint	*Blephilia ciliata*	M	1-2′			<			<	<			<	
False Aster	*Boltonia asteroides*	M, W	3-4′		<					<			<	
Blue Cohosh	*Caulophyllum thalictroides*	M, E	1-3′			<			<					
Black Cohosh	*Cimicifuga racemosa*	M, E	3-6′			<			<	<				
Spring Beauty	*Claytonia virginica*	All	7″-2′											
Blue-eyed Mary	*Collinsia verna*	Nashville	1-2′			<			<				<	
Mist Flower	*Conoclinium coelestinum*	All	2′			<				<				
Dwarf Larkspur	*Delphinium tricorne*	M, E	6-12″						<					
Cutleaf Toothwort	*Dentaria laciniata, Cardamine concatenata*													
Squirrel Corn	*Dicentra canadensis*	M, E	6-8″						<					
Wild Bleeding Heart	*Dicentra eximia*	All	12-18″		<	<			<	<			<	

Common Name	Scientific Name	RD	Height	Width	Light			Moisture				Soil pH		SOURCE
					F	P	S	H	M	S	X	B	A	
HERBACEOUS PERENNIALS *cont'd*														
Dutchman's Breeches	*Dicentra cucullaria*	M, E	8-12"						<					
Spotted Mandarin	*Disporum maculatum*	E	2'			<			<				<	
Shooting Star	*Dodecatheon meadia*	M, E	10-20"						<				<	
Flat-topped Aster	*Doellingeria umbellata*	ER, CP	3-5'		<				<				<	
Purple Coneflower	*Echinacea purpurea*	All	3-5'		<				<	<				3
Carolina Elephantsfoot	*Elephantopus carolinianus*	All	1-3'		<	<				<			<	
Robin's Plantain	*Erigeron pulchellus*	M, E	8-20"			<			<				<	
Rattlesnake-master, Button Snakeroot	*Eryngium yuccifolium*	All	2-4'		<	<			<	<			<	
Trout Lily	*Erythronium americanum*	M, E	3-5"						<				<	
Joe Pye-weed	*Eutrachium spp.*	All	5-9'		<				<				<	
Soapwort Gentian, Harvestbells	*Gentiana saponaria*	ER, CP	8-20"			<			<				<	
Wild Geranium	*Geranium maculatum*	All	1-2'			<			<				<	3
Sneezeweed	*Helenium autumnale*	M, E	2-4'		<				<	<			<	
Purplehead sneezeweed	*Helenium flexuosum*	All	1-4'		<				<	<			<	3
Swamped Sunflowers	*Helianthus angustifolius*	All	5-7'		<			<	<	<	<		<	
Sharp-lobed Liverleaf	*Hepatica acutiloba*	M, E				<			<	<			<	
Alumroot	*Heuchera americana*	All	2'											
Swamp Rose-mallow	*Hibiscus moscheutos*	All	4-8'											
Goldenseal	*Hydrastis canadensis*	All	6-15"			<			<				<	
Great Waterleaf	*Hydrophyllum appendiculatum*	M	1-3'			<			<				<	
Blazing Star	*Liatris spp.*	All	2-5'											
Turk's Cap Lily	*Lilium superbum*	UM	3-9'			<			<				<	
Cardinal Flower, Great Blue Lobelia	*Lobelia cardinalis, L. siphilitica*	All	2-4'			<							<	
Virginia Bluebells	*Mertensia virginica*	M, E	1-1.5'		<				<					
Bee Balm	*Monarda didyma*	UM	3-4'		<	<			<					
Wild Bergamot	*Monarda fistulosa*	All	3-4'		<	<			<	<			<	
Sundrops	*Oenothera fruticosa*	M, E	1.5-2'							<	<		<	
Smooth/ Eastern Beard-tongue	*Penstemon laevigatus*	M, E	2-3'		<	<			<	<			<	
Wild Blue Phlox	*Phlox divaricata*	All	1-1.5'			<			<					3
Jacob's Ladder	*Polemonium reptans*	All						<				<		
Solomon's Seal, False Solomon's seal	*Polygonatum biflorum; Smilacina racemosa*	All	up to 6'			<			<				<	3
Prairie Coneflower, Blackeyed Susan	*Ratibida pinnata, Rudbeckia spp.*	All	3-5'		<				<	<			<	
Perennial Black-eyed Susan	*Rudbeckia fulgida*	All	2-3'		<				<				<	
Wreath, Zigzag, Wrinkleleaf goldenrod	*Solidago caesia, S. flexicaulis, S. rugosa*	All	3-6'			<			<	<				
Indian Pink	*Spigelia marilandica*	All	1-2'		<	<			<				<	
Wood / Celandine Poppy	*Stylophorum diplyllum*	M, V, R	1-1.5'			<			<				<	
Rue Anemone	*Thalictrum thalictroides*	M, E	3-8"		<	<			<	<			<	
Spiderwort	*Tradescantia virginiana*	WR, V, R	1-2'			<			<	<			<	
Trillium	*Trillium spp.*	All	3-16"						<					
Violet	*Viola spp.*	All				<				<			<	
GRASSES AND SEDGES														
Big bluestem	*Andropogon gerardii*	All	4-8'		<				<					4
Broomsedge	*Andropogon virginicus*	All	2-4'		<					<				4
Splitbeard Bluestem	*Andropogon ternarius*	CP, WR			<					<				4
Giant River Cane	*Arundinaria gigantea spp. gigantea*	All	30'		<	<		<	<					4
Side Oats Grama	*Bouteloua curtipendula*	CB, V, R	1-2'		<					<				4
Sedges	*Carex spp.*	All	3-5'		<			<						4
River oats	*Chasmanthium latifolium*	All	2.5-4'			<			<					4

Common Name	Scientific Name	RD	Height	Width	Light			Moisture				Soil pH		SOURCE
					F	P	S	H	M	S	X	B	A	
GRASSES AND SEDGES *cont'd*														
Bottlebrush grass, Virginia Wild Rye	*Elymus hystrix, E. virginicus*	E, M	2-3'		<				<					4
Purple Love Grass	*Eragrostis spectabilis*	All	1-2'		<					<				4
Common Rush	*Juncus effusus*	All	2-4'			<		<						4
Pink Muhly Grass	*Muhlenbergia capillaris*		1.5-4'		<				<	<			<	4
Switchgrass	*Panicum virgatum*	All	3-4'		<				<					4
Silver, Sugarcane Plume Grass	*Saccharum alopecuroidum, S. giganteum*													4
Little Bluestem	*Schizachyrium scoparium*	All	2-4'		<					<		<		4
Black Bullrush	*Scirpus atrovirens*	All	2-5'		<			<						4
Indian Grass	*Sorghastrum nutans*	All	7'		<				<	<				4
Eastern Gama Grass	*Tripsacum dactyloides*	All	4-8'		<			<						4
GROUND COVER														
Pussytoes	*Antennaria plantaginifolia*	All	4-8"				<			<			<	
Galax, Beetleweed, Coltsfoot	*Galax urceolata*	UM, V, R	3-6"			<	<		<	<			<	
Rose Verbena	*Glandularia canadensis*													
Sharp-lobed Hepatica, Liverleaf	*Hepatica americana*	M, E	3-5"			<	<		<	<		<		
Dwarf crested iris	*Iris cristata*	All	3-6"		<					<			<	
Running Cedar, Ground pine	*Diphasiastrum digitatum*		5-10"		<	<				<			<	
Partridge Berry	*Mitchella repens*	All	1-2"		<	<	<		<				<	
Allegheny Spurge	*Pachysandra procumbens*	M, E	4-9"			<	<		<			<	<	
Fernleaf Phacelia	*Phacelia bipinnatifida*	All	8-24"		<	<			<	<				
Mayapple	*Podophyllum peltatum*	All	12-18"			<			<				<	
Bloodroot	*Sanguinaria canadensis*	M, E	6-8"			<			<					
Golden ragwort	*Senecio aureus*	M, E	1-3'			<			<					
Blue-eyed grass	*Sisyrinchium albidum, S. angustifolium*	All	6-10"		<					<				
Foam flower	*Tiarella cordifolia*	M, E	6"		<	<	<		<			<		
FERN														
Maidenhair fern	*Adiantum pedatum*	All	1-2'				<		<			<	<	
Ebony spleenwort	*Asplenium platyneuron*	All	1-1.5'			<	<		<	<		<	<	
Ladyfern	*Athyrium filix-femina spp. asplenioides*	All	1.5-3'			<			<				<	
Lowland bladderfern	*Cystopteris protrusa*	M, E	8-15"				<		<					
Hayscented fern	*Dennstaedtia punctilobula*	E	1.5-2.5'				<		<					
Silvery spleenwort	*Deparia acrostichoides*	All	2-3.5'				<		<					
Glade fern, Narrow-leaved Spleenwort	*Diplazium pycnocarpon*	All	1.5-3.5'				<		<					
Marginal fern	*Dryopteris marginalis*	E	1-2'			<	<		<			<	<	
Goldie's woodfern	*Dryopteris goldiana*	E	2-4'				<		<					
Scouring Rush	*Equisetum hyemale*	All	2-4'			<	<	<	<					
Sensitive fern	*Onoclea sensibilis*	All	1-2'			<	<	<	<				<	
Cinnamon, Royal fern	*Osmunda cinnamomea, O. regalis*	All	2-3'		<	<	<	<	<				<	
Interrupted Fern	*Osmunda claytoniana*	E	2-4'				<		<					
Royal fern	*Osmunda regalis*	All	3-5'		<	<	<	<	<				<	
Broad beech fern	*Phegopteris hexagonoptera*	All	2'				<		<	<				
Christmas fern	*Polystichum acrostichoides*	All	1.5-2'			<	<		<			<	<	
Bracken fern	*Pteridium aquilinum*		1-4'			<	<		<	<			<	
New York fern	*Thelypteris noveboracensis*	All	1-1.5'			<	<		<				<	
Blunt-Lobed Cliff-fern	*Woodsia obtusa*	All				<	<		<	<		<		
Chain fern	*Woodwardia areolata*	All	2'		<	<	<	<	<	<				

REFERENCES

1 *Landscaping with Plants, Tennessee: Promoting Biodiversity Endorsing a Land Ethic that Celebrates Our Natural Heritage. <http://s3.amazonaws.com/tneppc2/uploads/583/original/natives2010- web.pdf>*

2 *University of Florida Plant Information Database. <http://hort.ifas.ufl.edu/database/>*

3 *Native Plant List – Kentucky and Tennessee. <http://www.plantnative.org/rpl-kytn.htm>*

4 *Hunter, Margie. 2002. Gardening with the Native Plants of Tennessee: The Spirit of Place. University of Tennessee Press.*

5 *Wasowski, Sally. 2010. Gardening with Native Plants Of the South. Taylor Trade Publishing.*

ADDITIONAL WEBSITES

USDA Natural Resources Conservation Service Plants Database:
http://plants.usda.gov/

UT Forest Resources AgResearch and Education Center Arboretum:
http://forestry.tennessee.edu/arboretum.htm

Tennessee Smart Yards Native Plant Database and Blog:
http://tynnativeplants.wordpress.com/

Tennessee Valley Authority Native Plants of the Tennessee Valley:
http://www.tva.gov/river/landandshore/stabilization/pdf/plantguide.pdf

Appendix E

Plan Review and Construction Check Lists

- **Site Assessment and Inventory Check List**

Tennessee Stormwater Management Program

Project Name: ____

Location: ____

File Number: ________________ Date of Submittal: _______________

Reviewer: ______________________ Review Date: _______________

Project Meeting Chronology: __________________________________

Type of Meeting: ______________________ Date: _______________

Quick Check

- ❑ Vicinity Map within Watershed Context
- ❑ Soil Map
- ❑ Pre-existing and proposed Topographic and Management Map
- ❑ Special Management Area Map
- ❑ Site Assessment and Inventory Checklist
- ❑ Construction Plans
- ❑ Permanent Stormwater Management Plans
- ❑ Runoff Reduction Assessment (TNRRAT output)
- ❑ Operation and Maintenance Agreements

Stormwater Management Site Assessment and Inventory Checklist

for Project Concept Plan Review

Applicant: ____

Contact Name: ____

Phone Number: ____

E-mail: ____

S = Satisfactory • U = Unsatisfactory • NA = Not Applicable				
Item	**S**	**U**	**NA**	**Comments**
A. General Project Information				
1 Site address and legal description				
2 Vicinity map				
3 Project narrative				
a Purpose/Intended Use				
b Impact of development on site hydrology and stormwater quality				
c Description of stormwater management targets				
d Rational for selection of permanent stormwater control measures				
4 Evidence of special management areas				
a Brownfield redevelopment				
b Karst				
c Pollution hotspots				
d Other:				
5 Incentives				
a Redevelopment				
b Brownfield redevelopment				
c High density (>7 units per acre)				
d Vertical density				
e Mixed use and transit-oriented				
6 Runoff Reduction Requirement Obtained				
7 Stormwater Control Measures Implemented				
a Smart Site Design Elements Implemented				
Preserving native topography and drainages				
Preserving trees and other native vegetation				
Minimizing soil disturbance				
Avoiding steep slope development				
Avoiding floodplain development				
Preserving riparian buffers				
Minimizing soil disturbance				
Reducing roadway lengths and widths				
Reducing limits of clearing				
Utilizing open space development				
Reducing total impervious cover				
Preserving sheet flow and vegetative filters				
Other:				

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Item	**S**	**U**	**NA**	**Comments**
b Structural Stormwater Control Measures				
Bioretention				
Dry Detention				
Extended Detention				
Filter Strips				
Vegetated Swales				
Green Roofs				
Managed Vegetated Areas				
Infiltration Practices				
Stormwater Treatment Wetlands				
Manufactured Treatment Devices				
Permeable Pavement				
Rainwater Harvesting and Reuse				
Other:				
B. Project Plans				
1 Existing and proposed topography (minimum 2-ft contours or local standards)				
2 Existing and proposed stormwater management systems				
a Catchments/Subbasins				
b Drainage areas and flowpaths				
c Stormwater management practices; specified type and surface area indicated on plan				
d Proposed drainage and maintenance access routes and easement locations				
e Streams and wet weather conveyances				
f Proposed channel modification locations				
3 Soil classifications and hydrologic information				
4 Existing land management/cover				
5 Limits of disturbance				
6 Resource protection areas (e.g. headwater streams, wetlands and lakes)				
7 Flooplain limits				
8 Development setbacks				
a Ripairan buffers				
b Stormwater Control Measure buffers				
c Building setbacks d Property line setbacks				
e Well/septic system setbacks				
9 Existing and proposed roads, buildings and other structures (impervious surfaces)				
10 Existing and proposed utilities and utility easements				

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Item	**S**	**U**	**NA**	**Comments**
C. Design Computations				
1 Preliminary assessment for runoff reduction				
requirements				
a Special Management Areas				
b Resource Protection Additional Requirements				
c Incentive Programs				
2 Implementation of Smart Design Approach				
3 Selection of Appropriate SCMs				
4 Appropriate SCM sizing and deisgn implementation				
5 Adequate use of pre-treatment				
6 Adequate inlet/outlet control design				
7 Adequate flow routing and SCM trains				
D. Permit Approval and Documentation				
1 Status of other applicable local, state and federal permits				
a Construction stormwater discharge permit				
b State/federal aquatic resource alteration permits				
c Dam safety permit				
d Floodplain construction permit				
e Other:				
E. Additional Smart Site Design Approaches Implemented				
1 Site Layout Techniques				
a Pre-development topography, soils, and vegetative cover identified				
b Minimized amount of grading				
c Steep slopes left undisturbed				
d Open space preservation				
e Additional riparian buffer width				
f Preservation of headwater streams and their floodplains				
g Minimized street length				
h Minimized street right-of-way				
i Stream channel crossings minimized				
j Cul-de-sac alternatives used				
k Grass swales and roadside verges used instead of curb and gutter				
l Minimized drive way lengths and/or shared drive ways				
m Grading to encourage sheet flow				
n Impervious surface disconnections				
o Other:				

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Item	**S**	**U**	**NA**	**Comments**
2 Site Layout Techniques for Redevelopment				
a Urban forestry/ tree preservation				
b Green roofs				
c Setbacks and/or height restrictions reduced for efficient use of space				
d Multimodal transit considerations (pedestrian and bicycle assess and facilities)				
e Connection with existing pedestrian/bicycle infrastructure (e.g. bike lanes, greenways, etc.)				
f Wildlife cooridor connections				
g Other:				

Appendix F

Example SCM Inspection & Maintenance Checklists

Once construction is completed, the SCM takes on the role for which it was intended. Periodic site inspections are essential in order to monitor the effectiveness and to anticipate the maintenance needs of the SCM. When conducting inspections, attention should be given not only to the SCM installed for stormwater control, but also to the conveyance system carrying runoff to the SCM and the receiving channel immediately downstream of the SCM. The conveyance channel, curbing and/or storm sewer that convey flow to the SCM or, by design, intentionally divert flows around it are all considered SCM components and must function as intended.

The necessary frequency of inspections will vary with each SCM based on the type of facility, the size of the contributing drainage area, and the land use conditions within the contributing drainage area. The MS4 Permit (Sections 4.2.5.5 BMP Maintenance; 4.2.5.6 Inventory and Tracking of Management Practices; and 4.2.5.7 Owner/Operator Inspections) provides general criteria local stormwater programs on BMP maintenance and inspection programs. While, there is some flexibility provided for inspection frequency for SCMs, an a minimum all SCMs must be inspected on an annual basis by a person familiar with the control measures implemented on the site and a more comprehensive inspections of all SCMs shall be conducted once every five years. The comprehensive inspection shall be conducted by either a professional engineer or landscape architect. The owner or operator of the control measures shall maintain documentation of all inspections and the local stormwater program may require submittal of this documentation on an annual basis. Ideally, periodic inspections for trash and debris accumulation and general aesthetics should be performed more frequently, especially after significant storm events.

This Appendix provides a series of individual SCM example checklists for local stormwater programs and others to use to guide inspection and maintenance of specific stormwater control measures. Users should feel free to customize these templates, as appropriate, to more effectively address the situations typically encountered during inspection and maintenance activities and to make them easier for inspectors to use. The checklists are detailed enough for a qualified inspector or the owner/operator that may not be familiar with the specific components of the facility. The Appendix also provides examples for communities in Tennessee of long term maintenance plans for select SCMs, long term maintenance agreements and other legal documents that are necessary for a local stormwater program to verify and document that inspection and maintenance of the SCMs will be reformed as required by the MS4 permit. The example forms and document should be modified and customized to meet the needs of the local stormwater program.

The documents listed below are available on the Tennessee Permanent Stormwater website at:

http://tnpermanentstormwater.org/Appendix.asp

- Metro Nashville-Davidson County Stormwater Structural BMP Inspection Checklist Templates:
  1. Stormwater Ponds
  2. Water Quality Swale
  3. Grass Channel
  4. Filter Strip
  5. Bioretention
  6. Urban Bioretention
  7. Cistern
  8. Permeable Pavement
  9. Green Roof
  10. Constructed Wetlands
  11. Proprietary BMP

- Examples of Operation and Maintenance Documents:
  1. Metro Nashville –Davidson County Inspection and Maintenance Agreement, Declaration of Restrictions and Covenants and Long Term Maintenance Plan Instructions
  2. City of Franklin Inspection and Maintenance Agreement of Private Stormwater Management Facilities
  3. City of Murfreesboro Stormwater Facilities Operation and Maintenance Plan