# NORTH CAROLINA
# DEPARTMENT OF TRANSPORTATION

# STORMWATER BEST MANAGEMENT PRACTICES TOOLBOX

North Carolina
Department of Transportation

NCDOT Highway Stormwater PROGRAM

Version 2, April 2014

## DISCLAIMER

This Toolbox is not intended to be a comprehensive design reference on structural Best Management Practices (BMPs). Its intended uses are as follows:

- This Toolbox was developed by North Carolina Department of Transportation (NCDOT) Hydraulics Unit for use on linear drainage systems designed and constructed by or in association with NCDOT-funded projects.

- This Toolbox is not intended for use on non-NCDOT roads or projects.

- Any use of this Toolbox by non-NCDOT entities is the responsibilities of the user, and is done so at the user's risk.

- The user assumes the full responsibility in determining the applicability of this Toolbox for the purposes below:

  - Design and construction of drainage system and/or stormwater BMPs
  - Compliance with other Federal and State regulatory requirements
  - Meeting the NCDOT design standards for non-NCDOT roads and projects

- The design criteria in this Toolbox are guidelines. However, unique circumstances may require the designer to deviate from them. Should a specific situation require deviation from specified methods, procedures, and criteria presented in this Toolbox, approval for a variance is required from the State Hydraulics Engineer, or his designees.

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# North Carolina Department of Transportation

# Stormwater Best Management Practices Toolbox

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# Acronyms

| | |
|---|---|
| BDDD | Bridge Deck Drainage Design |
| BIMS | Basinwide Assessment Information Management Systems Reports |
| BMP | Best Management Practice |
| DCIA | Directly Connected Impervious Area |
| ESD | Environmental Site Design |
| ET | Evapotranspiration |
| FHWA | Federal Highway Administration |
| HEC | Hydraulic Engineering Circular |
| IWS | Internal Water Storage |
| NBUA | New Built-Upon Area |
| NCDENR | North Carolina Department of Environment and Natural Resources |
| NCDOT | North Carolina Department of Transportation |
| NCDWR | North Carolina Division of Water Resources (NCDENR) |
| NCEM | North Carolina Division of Emergency Management |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| NRCS | National Resources Conservation Service |
| PCSP | Post-Construction Stormwater Program |
| PDE | Permanent Drainage Easement |
| PSRM | Permanent Soil Reinforcement Matting |
| SHWT | Seasonal High Water Table |
| SMP | Stormwater Management Plan |
| TIP | Transportation Improvement Plan |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |
| URL | Uniform Resource Locator |
| UIC | Underground Injection Control |
| WQv | Water Quality Volume |

# CHAPTER 1 Introduction

This document, entitled *North Carolina Department of Transportation Stormwater Best Management Practices Toolbox*, presents guidance, criteria, and considerations for the design and application of post-construction structural best management practices (BMP). The BMPs covered in this document have been evaluated for both linear and transportation facility applications.

## 1.1 Purpose

North Carolina Department of Transportation (NCDOT) has been issued a statewide National Pollutant Discharge Elimination System (NPDES) stormwater permit. This permit authorizes NCDOT to discharge roadway stormwater runoff and borrow pit wastewater into surface waters of the state using appropriate stormwater management. As part of the program requirements of the permit, NCDOT must develop a BMP toolbox of stormwater treatment structures. By documenting current BMP design methods and criteria, these guidelines will improve the consistency of BMP design and performance.

The objectives of this toolbox are as follows:

- Meet NPDES stormwater permit compliance.
- Standardize existing design and application of NCDOT structural BMPs.
- Clearly communicate NCDOT design requirements.

## 1.2 How to Use this Toolbox

This toolbox supports other NCDOT documents that discuss stormwater management policy, NCDOT standard requirements, and drainage studies. Some BMP design criteria are required by stormwater management regulations, whereas others are based on NCDOT Hydraulics Unit practices. This toolbox does not discuss policy or detailed hydrologic and hydraulic design procedures. In addition to North Carolina regulations, the designer is directed to the following NCDOT references, including any updates:

- *Best Management Practices for the Protection of Surface Waters*, 1997
- *Guidelines for Drainage Studies and Hydraulic Design*, 1999
- *Best Management Practices for Construction and Maintenance Activities*, 2003
- *Roadway Standard Drawings*, 2012
- *Standard Specifications for Roads and Structures*, 2012

This toolbox presents an overview of BMPs in Chapter 2, followed by chapters on each BMP type. In each chapter, conceptual figures are provided for educational purposes and have been simplified technically for clarity. These figures are not appropriate for construction purposes. BMP checklists are provided in the appendices.

A summary of chapter content follows.

### Chapter 2 - NCDOT Stormwater Best Management Practices

This chapter presents introductory information about BMPs, basic hydrologic and hydraulic design principles, and design considerations that impact BMP construction and maintenance.

### Chapters 3 Through 14 – Stormwater Best Management Practice Chapters

Each chapter contains an Overview, photos of the BMP in transportation applications, and sections entitled Description, Applications, Design, and Inspection and Maintenance. Some chapters also include a section entitled Safety Considerations. The design criteria for BMP components are also presented in summary boxes for quick reference.

### Appendix A - Checklists

A checklist for each BMP is provided to facilitate the BMP design and preparation of the construction package. The checklists contain items relating to site feasibility, BMP configuration, and optional components.

### Appendix B – NCDOT Sponsored Research Projects Investigating Stormwater Best Management Practice Effectiveness

Appendix B provides a table listing the various studies that have been or are being performed to investigate the effectiveness of the BMPs used for stormwater management control. The table provides the name of the study and the performing institution, a description of the study, and the implications or conclusions drawn from the study.

## 1.3 Users of this Toolbox

The primary intended users of this toolbox are highway design engineers and regional planners throughout NCDOT, as well as NCDOT-contracted agencies and companies. The user is assumed to have a foundation in hydrologic and hydraulic principles and highway drainage design.

## 1.4 Toolbox Vision

The BMPs and design guidance provided in this toolbox reflect current NCDOT design practices. The considerations and criteria are based on the experience gained to date by NCDOT in designing structural BMPs for highway and transportation facility applications. As NCDOT design practices evolve based on lessons learned, so will this toolbox.

## 1.5 Contact Information

To provide comments or ask questions related to this toolbox, please contact the NCDOT Hydraulics Unit at (919) 707-6700.

# CHAPTER 2 NCDOT Stormwater Best Management Practices

## 2.1 What Are Best Management Practices?

The field of stormwater management currently has an evolving terminology that reflects the relatively recent inclusion of stormwater control and treatment in drainage system designs. Several terms are used to describe the structures and practices that are used to control, treat, and prevent stormwater pollution. Throughout this toolbox, the term *best management practice or BMP* is used to refer to both structural and nonstructural practices that protect the quality of surface water.

Nonstructural BMPs are designed to achieve source control. Some examples of nonstructural BMPs applicable to the highway environment include street sweeping, public outreach and education, litter control, and management of fertilizer application within the right-of-way. Structural BMPs, such as dry detention basins and swales, are designed to reduce pollutant loadings to the environment by managing flow rates and treating highway runoff, generally during storm events. Although the focus of this toolbox is on structural BMPs, the implementation of nonstructural BMPs is important to the success of any stormwater management program.

Structural BMPs are classified as temporary (construction) and permanent (post-construction) controls. Temporary BMPs are used during the construction phase of a project to mitigate the impact of short-term land disturbance on the site’s ground cover and hydrology. Most construction BMPs either reduce the likelihood of erosion from exposed soil or capture solids after erosion has already occurred to minimize sedimentation in receiving streams. Typical erosion and sedimentation control practices include soil and slope stabilization, diversion of off-site runoff, and sediment trapping. The *Erosion and Sediment Control Planning and Design Manual* (NCDENR.01) and *Best Management Practices for Construction and Maintenance Activities* (NCDOT.01) are comprehensive guidance manuals for the design and implementation of temporary BMPs. More information about erosion and sedimentation control is available at the NCDOT Roadside Environment Unit website.

Post-construction structural BMPs are permanent controls that treat stormwater runoff from stabilized drainage areas. Post-construction BMPs are either incorporated as part of the overall site drainage design or retrofitted in areas where additional surface water protection is necessary. Because post-construction BMPs are permanent, they require a long-term maintenance commitment to function as designed. Additional information and guidance for inspection and maintenance of these BMPs is provided in the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05). Figure 2-1 provides an outline of the various types of BMPs.

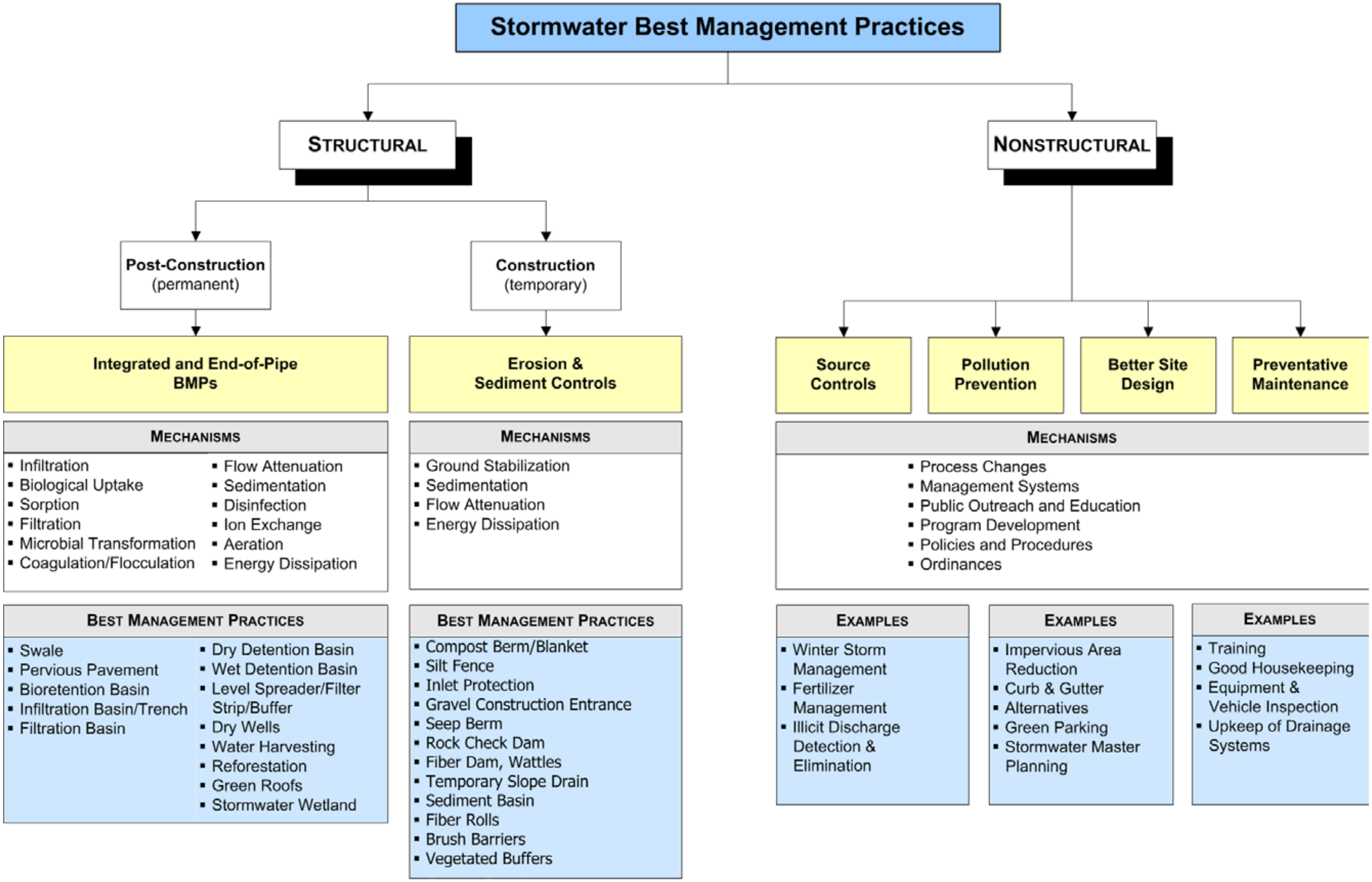



**Figure 2-1.** Types of BMPs

## POLLUTANT REMOVAL MECHANISMS

To improve BMP design and support innovative applications, the designer should understand pollutant removal mechanisms and how they impact the design components. Some of the more common pollutant removal mechanisms are discussed briefly in this section; designers should consult other references for a thorough explanation of treatment mechanisms.

### *Sedimentation*

Sedimentation is the removal of suspended solids from stormwater runoff via settling and is one of the most important and widely used treatment mechanisms. Suspended solids can act as absorptive and adsorptive binding sites for some pollutants, such as petroleum hydrocarbons and metals. Absorption is a physical process whereby one substance is incorporated and held by another substance in a different state (e.g., water held within a sponge). Adsorption is a physiochemical process whereby one substance adheres or bonds to the surface of another substance (in this case, pollutants adhering to suspended solids) (NCHRP.01). By removing suspended solids, particulate-bound pollutants can be removed from runoff without chemical treatment.

Sedimentation can occur under both quiescent and dynamic scenarios. Discrete particle settling occurs in relatively dilute solutions where particles settle as individual units. When there is adequate particle-to-particle interaction, such as under dynamic conditions, stormwater solids can naturally flocculate, or agglomerate, to produce composite particles of greater mass. Sedimentation efficiency in a basin is dependent on several factors, including particle size distribution (PSD), total suspended solids concentration, detention time, and basin size and layout (USEPA.01; USEPA.02).

One key component of successful treatment via sedimentation is the consistent removal of settled solids from the BMP once a critical sediment depth has been reached. If sediment is not excavated and removed, particulate-bound pollutants may partition to the dissolved phase during subsequent storm events.

### *Filtration and Infiltration*

Filtration is the physical straining of particulates as stormwater runoff passes through a filter media, such as sand, soil, or an engineered media. Unless the filter media has sorptive characteristics, filtration targets particles and particulate-bound pollutants only.

Infiltration occurs when stormwater migrates below the ground surface through subsoils to aquifers and receiving streams. Infiltration is a complex mechanism influenced by the type and extent of surface cover, physical properties of the soil, and groundwater conditions (NCHRP.01).

Despite its complexity, infiltration is a desirable means of stormwater pollutant removal. Infiltration provides filtration of stormwater particulates, adsorption of soluble pollutants onto soil particles, reduction of runoff quantity, and aquifer recharge. Infiltration should not be implemented when the existing in-situ soil conditions are not conducive to adequate infiltration or when the pollutant profile of stormwater could negatively impact groundwater.

### *Microbially Mediated Transformations*

Microbial activity in stormwater control systems is a critical mechanism for removing soluble pollutants. Microbial activity can promote or catalyze reduction-oxidation (redox) reactions to decompose organic and transform inorganic constituents. Many BMPs inherently have the key elements to support a diverse microbial population, including a substrate for colonization, carbon sources and other nutrients, and moisture. For this reason, the use of microbes to treat the soluble fraction of pollutants in stormwater can be more feasible and economical than other chemical treatments.

One of the important transformation processes facilitated by microbes in stormwater treatment is the conversion of nitrogen species as part of the nitrogen cycle. Ammonification, nitrification, denitrification, and fixation are all microbially mediated processes that are more significant to nitrogen removal than physical treatment (i.e., filtration, sedimentation) (NCHRP.01).

### *Bioligical Uptake*

The process of plants and other organisms taking in nutrients, metals, and other stormwater pollutants and storing them or incorporating into their cellular structure is referred to as biological uptake. Biological uptake is constrained in BMPs with limited retention times (NCHRP.01). Biological uptake is most effective in BMPs such as stormwater wetlands with extended detention times and significant biological activity.

## TYPES OF BEST MANAGEMENT PRACTICES

Table 2-1 is a list of potential post-construction BMPs applicable in the linear environment and their treatment mechanisms.

**Table 2-1.** Potential BMPs approved for linear applications

| Name | Description | Pollutant Removal Mechanism |
|---|---|---|
| Filtration Basin | A type of media filter with a shallow basin, engineered media, and an underdrain system. | Filtration, sorption, microbially mediated transformation, biological uptake |
| Bioretention Basin | A type of media filter with a shallow basin, engineered media, an underdrain system, and landscaped vegetation. | Microbially mediated transformation, biological uptake, sorption, filtration |
| Dry Detention Basin | A shallow, dry basin with an outlet pipe or orifice near the invert of the basin. | Detention, sedimentation, sorption |
| Filter Strip | A linear section of land, either grassed or forested, that physically filters and infiltrates stormwater. | Filtration, infiltration, sorption, microbially mediated transformation, |
| Swale | A broad and shallow channel with dense vegetation. | Filtration, infiltration, sedimentation, microbially mediated transformation, |
| Hazardous Spill Basin | A shallow basin with an outlet control structure that can trap all flow that enters the basin. | Pollution prevention |
| Infiltration Basin | A shallow basin in permeable soils that detains and infiltrates stormwater runoff. | Infiltration, sorption |
| Level Spreader | A trough and level lip used to redistribute concentrated stormwater as diffuse flow. Typically combined in a system with a filter strip. | Energy dissipation, infiltration |

| Name | Description | Pollutant Removal Mechanism |
|---|---|---|
| Wet Detention Basin | A shallow basin that maintains a permanent pool of water by using an elevated outlet control structure. | Detention, sedimentation, biological uptake, microbially mediated transformation |
| Preformed Scour Hole | A riprap-lined basin formed at the outlet of a pipe with a diameter less than or equal to 18 inches. | Energy dissipation, infiltration |
| Forebay | A small basin located upstream of another BMP. | Detention, sedimentation |
| Stormwater Wetland | An engineered marsh or swamp with dense wetland vegetation. | Microbially mediated transformation, biological uptake, detention, sedimentation, sorption |

## 2.2 Feasibility and Selection of Best Management Practices

NCDOT is required to implement a Post-Construction Stormwater Program (PCSP) to control runoff from new NCDOT development for new built-upon area (NBUA). The PCSP defines the process by which NCDOT evaluates a project for the appropriate level of stormwater management for protecting water quality standards. Implementation of the BMPs in this Toolbox are determined by the processes set forth in the PCSP and in consultation with regulatory agencies as required.

NBUA includes such impervious or partially impervious surfaces as paved and unpaved roads, parking lots, paths, and buildings. It is the designer's responsibility to be guided by the PCSP and to evaluate each potential BMP against unique project constraints for applicability to the site and general drainage design goals.  In addition to the structural post-construction BMPs discussed previously, designers should also consider applicable planning and design-related minimum measures as outlined in the PCSP and subsequently in this section during the feasibility assessment process.

The following is a list of planning and design-related minimum measures often considered on NCDOT projects:

- Maximize vegetative conveyance of stormwater.
- Grade to encourage diffuse flow and lengthen flow paths.
- Minimize directly connected impervious area (DCIA).
- Minimize diversion of stormwater.
- Preserve naturally vegetated areas and soil types that slow runoff, filter pollutants, and facilitate infiltration.
- Provide small scale BMPs and devices that meet regulatory and resource objectives that promote infiltration, evapotranspiration, and water harvest or reuse.
- Treat pollutants where they are generated or prevent their generation.

Incorporation of these concepts can provide flexibility and opportunities in the feasibility and selection of BMP options.

## EVALUATING FEASIBILITY OF BEST MANAGEMENT PRACTICES

The site-specific constraints that should be evaluated for each project can be grouped into three general categories:

- Roadway Project Layout
- Environmental Context
- BMP Design

These categories are interdependent, as illustrated in Figure 2-2, and determining the feasibility of a BMP for a particular location may require an iterative approach that balances BMP design, environmental concerns, and the hydraulic requirements of other roadway project site components. Transportation projects generally pose constraints and limiting conditions in developing the stormwater management plan and designing the appropriate BMP. Sound engineering judgment should be applied when incorporating these considerations into BMP selection. The following sections provide more details about the site-specific constraints that should be considered during the BMP selection and feasibility assessment process.


**Figure 2-2.** Common considerations for determining BMP feasibility and selection

## ROADWAY PROJECT LAYOUT

### *Slope and Topographic Constraints*

The majority of BMPs included in this toolbox are applicable only under certain geographic and topographic conditions. These constraints can apply to both the project right-of-way and downgrade areas. Typically, orienting the BMP to conform to the contours of the site is recommended, if practical. Gentle slopes are preferred because they naturally induce and maintain diffuse flow conditions, provide adequate contact time between the vegetation and runoff, and control outflow velocities. Therefore, steep slopes and other topographic constraints may limit BMP applicability in the piedmont and mountain regions of North Carolina.

Several areas in coastal North Carolina have karst topography. Karst topography is underlain by soluble rock, typically limestone, which can gradually dissolve when it comes into contact with stormwater and carbon dioxide. Infiltration or concentrated runoff in an area with karst topography may result in sinkhole formation, jeopardizing the structural stability of the BMP and adjacent structures. The placement of BMPs in areas of known karst topography may necessitate additional geotechnical testing or consultation with a professional geologist or engineer. In karst areas, site drainage should be designed to minimize the pooling of runoff, and infiltration practices are not recommended.

### *Adjacent Land Use*

As development occurs adjacent to NCDOT projects, the land use cover changes as well, affecting both the quantity and quality of stormwater runoff. An increase in impervious area may increase the rate at which off-site runoff reaches the project area. In addition, the activities occurring in and around the project drainage area may impact the amount and types of pollutants in the stormwater runoff. For instance, sites that receive runoff from adjacent construction may contribute suspended solids to a drainage area. Various land uses, such as industrial and agricultural, may contribute nutrients from both wet and dry atmospheric deposition.

Historic land uses can also impact BMP design and implementation. Activities such as farming and industrial processes that were conducted on the project site or on a site from which fill material has been imported may contain particulate-bound metals, nutrients, or hydrocarbons. When determining whether implementation of a BMP is feasible at the project site, the designer should consider how past land use could impact soil quality. Although not required, it may be prudent to collect preliminary soil samples at the site to determine whether the soil conditions are appropriate for the selected BMP.

### *Contributing Drainage Area*

Most controls function efficiently within a range of stormwater runoff volumes and velocities. During the BMP feasibility assessment, the contributing drainage area for the project and the peak discharge should be determined. These factors will determine whether the proposed control will be capable of treating stormwater runoff from the project. If the contributing impervious area is large, the subsequent discharge volume or rate may be too great for the proposed BMP. In this case, a BMP system (two or more BMPs implemented together) may be required to meet treatment objectives as determined through feasibility assessment.

In delineating the contributory drainage area, the designer should exercise care to identify and address drainage along the roadway corridor versus off-site drainage. In many cases, off-site flows will need to be routed away from the BMP. In general, it is not NCDOT policy to treat off-site drainage.

### *Available Right-of-Way*

Some BMPs are more land-intensive than others. In general, detention basins require larger footprints and may not be feasible in linear settings. The available right-of-way for the BMP application should be confirmed prior to design. Clear recovery zone and operation and maintenance requirements should be considered when determining whether adequate easement is available for the BMP. If the available right-of-way is not sufficient for the required BMP even after diverting off-site flows, then the designer should seek other options. These options include seeking approval for alternative controls, purchasing additional easement, and obtaining property from other land owners that are contributing drainage.

### *Critical Elevations*

No component of a BMP should increase the risk of flooding on the roadway or adjacent properties. Pipe networks, open channels, and basins included in a BMP system should be capable of maintaining a hydraulic grade line lower than any critical elevations. Critical elevations of the BMP should avoid hydraulic encroachments or hydraulic trespass. For more information about critical elevations, refer to NCDOT's *Guidelines for Drainage Studies and Hydraulic Design* (NCDOT.03).

### *Soils*

Soil type can play a critical role in determining whether a BMP will function as designed or act as a pollutant source. When the soil at a site will be used to support vegetation as part of a BMP, such as a swale, general soil quality should be considered. Soil quality characteristics that can impact the ability of the soil to support vegetation include pH, nutrients, organic content, and minerals (NCDENR.01). If it is determined that site soils are too poor to support vegetation, engineered soils or seed mixes should be considered. The designer should also stabilize the soil before the vegetation has become established by incorporating a temporary erosion-resistant lining in the BMP design. Procedures for designing temporary erosion-resistant liners are provided in the *Erosion and Sediment Control Planning and Design Manual*, Appendix 8.05 (NCDENR.01).

For infiltration BMPs, the permeability of the site soil should be determined by a geotechnical investigation. Areas that have been recently subjected to heavy equipment or areas within the right-of-way that are designed for road stability may not support infiltration.

### *Other Limiting Factors*

Additional project layout factors that should be considered for BMP feasibility follow:

- A high water table can impact the proper functioning of BMPs. A permanent pool may develop in BMPs intended to be generally dry, such as dry detention basins and swales. Standing water will encourage the growth of wetland vegetation and may improve nutrient removal, but may conflict with other stormwater management goals.
- The clear recovery zone requirements will vary, depending on the roadway type and speed limit.
- The cost of excavating areas with bedrock close to the surface will increase significantly, especially if blasting is required.
- BMPs that interact with the water table can influence groundwater conditions in localized areas, which can lead to transient periods of saturated conditions. Impacts to nearby foundations, footings, wells, subgrades, etc., should be considered.
- The location and required setbacks for existing and proposed utilities should be accounted for when determining the placement of a BMP.
- Drainage requirements of other hydraulic structures should be considered.

## ENVIRONMENTAL CONTEXT

Environmental concerns and requirements for a given NCDOT project will likely vary based on the location of the project. Meeting specific stormwater objectives depend on the local or physiographic context. For example, conveying pathogens via stormwater to shellfish waters is a unique concern in some coastal areas of the state. In various areas of the Piedmont, project sites may need to control the levels of nitrogen and phosphorus in stormwater as well as provide additional erosion prevention for the runoff flow path. Likewise, in some areas of the Mountain region, suspended solids may need to be managed in a manner that does not increase temperature in order to protect high quality streams that provide sensitive species habitat. Thus, the designer must clearly define the project specific environmental context objectives that are important to provide water quality protection.

BMP selection and design will also be influenced by parameters of concern. Parameters of concern are pollutants that can reasonably be expected to be present in stormwater runoff based on the origin of the runoff. Parameters of concern can also be identified by water body impairments or other regulatory requirements. Similarly, it is also important to consider receiving stream characteristics (e.g., stream hydrology and assimilative capacity) during the selection and design of BMPs.

As noted, BMPs are often designed to capture and treat runoff with the goal of discharging it in a manner that protects water quality standards. One strategy used to achieve this objective is to reduce runoff volume and peak rates of discharge. This is accomplished through practices that facilitate infiltration, evapotranspiration (ET), and water harvest or reuse. It is also important to consider receiving stream characteristics when analyzing hydrologic design parameters as runoff volume and peak flow rates may not be as critical as other parameters of concern for some receiving water bodies.

The overall effectiveness of a BMP in removing pollutants and its flow reduction capabilities depend on the flow rate into and out of the system. Flow rate and rainfall intensity have a marked influence on the particle size distribution of sediment transported during rainfall. A larger fraction of both small and large particles and total mass of solids are transported during high flow events. Because other parameters of concern adsorb to solid material conveyed in runoff, many BMPs attempt to prevent solid material from reaching surface waters either through infiltration of runoff or sedimentation to target a wide range of parameters of concern. One of the most cost-effective and low maintenance approaches to removing solid material from stormwater is through manipulation of stormwater flow rates and volume.

Volume reduction can be addressed through minimization of upstream runoff by hydrologic source control and through the installation of BMPs that emphasize infiltration and ET. In the linear environment, most BMPs perform as hydrologic source controls by incorporating the planning and design-related concepts previously discussed and managing runoff next to the pavement edge. Hydrologic source controls reduce the overall volume of the runoff and delay the peak flow rate of storm events through distributed storage. Infiltration basins, filtration basins, bioretention basins, stormwater wetlands, and wet and dry detentions basins can be incorporated for volume reduction upgradient of the receiving stream. Many of the same BMPs reduce runoff volume through the combined mechanisms of infiltration and ET.

### *Vegetation*

The vegetation incorporated in a BMP can remove soluble pollutants and provide resistance to the flow of stormwater, thereby reducing velocity. As a secondary benefit, vegetation in and around a BMP can be used to restrict public access to unsafe areas and improve the aesthetics of the treatment area (Figure 2-3).

In general, vegetation native to North Carolina should be used in BMP design. Native vegetation generally requires less maintenance and replanting, and does not adversely affect the local ecology. However, to provide rapid stabilization and erosion control, non-native vegetation may be used in the seed mix. When the primary purpose of the vegetation is to remove soluble pollutants, the selected plants should be planted densely. Also, the height of water in the BMP should be close to the maintained height of the vegetation to optimize contact time.

**Figure 2-3.** Bermuda grass filter strip and level spreader

When selecting vegetation, the designer should consider the conditions to which the vegetation will be subjected. For instance, if the vegetation will be subjected to flowing runoff, such as in a swale or an emergency spillway, the vegetation should be resistant to bending and capable of withstanding design flow rates. Vegetation selection will be influenced by the frequency of mowing and the height of the water table. Plants that require significant maintenance and chemical applications should be avoided.

Additional suggestions for BMPs with vegetation include the following:

- Avoid the use of trees and woody vegetation near embankments or berms because their roots may compromise structural integrity.
- Divert flows and provide temporary erosion control to areas where vegetation is being established.
- Consider root type when incorporating vegetation near underdrain systems to avoid impacting perforated pipes.

The designer should consult the North Carolina Department of Environment and Natural Resources’ (NCDENR) *Erosion and Sediment Control Planning and Design Manual* (NCDENR.01) and NCDOT Roadside Environmental Unit's *Vegetation Management Manual* (NCDOT.02) for information on the selection and characteristics of North Carolina's native plant species.

## 2.3 Hydrologic and Hydraulic Concepts

This section contains general information on basic hydrologic and hydraulic concepts as they apply to post-construction BMP design. The concepts presented pertain to more than one BMP and are deemed appropriate for design-level guidance for a transportation system. Concepts covered include design storms, water quality volume, peak flow rate, and basic hydrologic and hydraulic equations. This section should be used in tandem with NCDOT's *Guidelines for Drainage Studies and Hydraulic Design* (NCDOT.03). References to other texts are provided in this section.

## DESIGN STORMS

As used in this toolbox, the design storm refers to a synthetic storm event for which a control is sized to treat or safely pass. Design storms can be expressed in terms of a return period, which is the average amount of time between storm events of the same intensity and duration. The traditional design storms, historically used in flood control design, include the 10-, 25-, 50-, and 100-year return-frequency storms. However, these traditional design storms do not account for the majority of the precipitation and subsequent runoff that is produced on an annual basis. Frequent, smaller storm events (less than 1 inch of rainfall) account for the majority of annual stormwater runoff, associated pollutant load, and groundwater recharge in an area. Control of these storm events is critical for successful stormwater management and surface water quality protection.

To address stormwater management from a water quality treatment perspective, structural BMPs may be sized using a water quality design storm. A common benchmark is to capture and treat all runoff from NBUA for the $80^{th}$ to $90^{th}$ percentile precipitation events. A North Carolina State University study that provides validation to this benchmark is summarized in Table 2-2 (Bean.01). Based on thirty years (1974 to 2003) of meteorological data, the rainfall depths associated with the $80^{th}$, $85^{th}$, and $90^{th}$ percentile runoff-generating rainfall events is noted for numerous cities. For example, in Raleigh, storm events equal to or less than 1.16 inches account for 85% of rainfall events.

**Table 2-2.** Rainfall depths (inches) for various percentile storms and cities in NC (adapted from Bean.01)

| City | $80^{th}$ percentile event | $85^{th}$ percentile event | $90^{th}$ percentile event |
|---|---|---|---|
| Asheville | 0.83 | 1.01 | 1.28 |
| Brevard | 1.08 | 1.28 | 1.55 |
| Charlotte | 1.06 | 1.28 | 1.60 |
| Elizabeth City | 1.00 | 1.23 | 1.59 |
| Fayetteville | 1.03 | 1.24 | 1.55 |
| Greensboro | 1.02 | 1.23 | 1.56 |
| Greenville | 1.15 | 1.41 | 1.85 |
| Raleigh | 0.97 | 1.16 | 1.44 |
| Wilmington | 1.40 | 1.72 | 2.24 |

Treating the rainfall depth associated with 80 to 90% of precipitation events is a target benchmark; however, the actual volume treated for linear transportation facilities will depend on the existing site conditions and should be based on best professional judgment. In some cases, treatment may exceed the target benchmark; others may not due to site constraints.

## WATER QUALITY VOLUME

The water quality volume (WQv) is the volume of runoff that can be captured and temporarily stored within a BMP. The WQv within a BMP may be restricted by site constraints such as available footprint, topography, or water table elevation. In general, the WQv for a BMP should be maximized, within the given site constraints, to the extent practicable. For comparison and reporting purposes, the rainfall depth across the NBUA that generates the WQv is calculated. The following equation can be used to determine the equivalent rainfall depth treated over the NBUA.

$$P = \frac{V_{WQ}}{3{,}450\ A_{NBU}}$$

where

| | | |
|---|---|---|
| $P$ | = | rainfall depth (inches) |
| $V_{WQ}$ | = | (WQv) water quality volume ($ft^3$) |
| $A_{NBU}$ | = | (NBUA) new built upon area (acres) |

The calculated rainfall depth can be compared against values in Table 2-2 to approximate the percentage of annual rainfall treated. Generally, a target rainfall depth between the 80th and 90th percentile storm is desirable. However, research has shown that smaller devices still produce significant water quality benefits (Luell.01).

Some BMPs, such as swales (Chapter 6), are designed based on runoff flow rate ($Q_n$) rather than runoff volume.

## PEAK FLOW RATE

Estimating the peak flow rate expected to occur from a specific watershed in response to a specific rainfall event is a challenge. Hydrologists have conducted detailed research to define the many critical relationships that define the processes and the interrelationships between these processes. The designer should be aware of the capabilities and limitations of each method presented and make the appropriate selection on a project by project basis.

### *Rational Method*

The rational formula estimates the peak discharge of runoff (cubic feet per second, $ft^3/s$) as a function of drainage area (acres), runoff coefficient (dimensionless), and mean rainfall intensity (inches per hour, in./hr) for a duration equal to the time of concentration for the drainage area. The rational formula is as follows:

$$Q = CIA$$

where

| | | |
|---|---|---|
| $Q$ | = | peak runoff rate ($ft^3/s$) |
| $C$ | = | runoff coefficient (dimensionless) |
| $I$ | = | average rainfall intensity (in/hr) for a storm event with a duration equal to the time of concentration |

A = size of the drainage area (acres)

Values of the runoff coefficient are dependent on land use and land cover. As most urban drainage areas are not homogenous, it is advisable to use a composite, weighted-average C value. C values have been determined for different materials and are available in various texts. Table 2-3 presents commonly used C values (NCDOT.03).

**Table 2-3.** Typical C Values

| Type of Surface | Rational C Value |
|---|---|
| Pavement | 0.7–0.9 |
| Gravel surfaces | 0.4–0.6 |
| Grassed, steep slopes | 0.3–0.4 |
| Grassed, flat slopes | 0.2–0.3 |
| Woods | 0.1–0.2 |

To determine the time of concentration ($t_c$), use the Kinematic Wave Equation for overland flow time (NCDOT.03). To determine intensity, refer to National Oceanic and Atmospheric Administration (NOAA) Atlas 14, *Precipitation-Frequency Atlas of the United States* (NOAA.01). The data for which can be found by navigating to the Precipitation Frequency Data Server on NOAA's website. For additional information on $t_c$ and intensity, refer to *Guidelines for Drainage Studies and Hydraulics Design* (NCDOT.03). For more information about the rational method, refer to the Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 22, *Urban Drainage Design Manual* (FHWA.02).

Peak discharge is commonly used as a design criterion for sizing BMP components. The peak discharge generally should be evaluated for a variety of storm events. The notation used in this toolbox for peak discharge for various storm events is $Q_{n,}$ where n is the return storm event used to select the average rainfall intensity, I. For example, the $Q_2$ denotes the peak discharge calculated using the 2-year storm event intensity for a duration equal to the time of concentration.

### *SCS-TR55 Method*

The Natural Resources Conservation Service (NRCS) TR-55 method and its computer version WinTR-55 provide peak discharge and runoff volume for small watersheds using hydrologic and hydraulic parameters (USDA.01). They include soil-cover runoff numbers, 24-hour rainfall, time of concentration, impervious area, drain pattern, and drainage area. In general, the NRCS method tends to overestimate the peak discharge (Genereux.01).

## ALLOWABLE RELEASE RATE

The allowable release rate for a particular BMP depends on the proposed function of the control (water quality or water quantity control), the downstream conditions, and regulatory requirements. The allowable release rates from a BMP require that the drawdown times meet the required criteria, typically 2–5 days. The designer should also be aware of other detention BMPs adjacent to the project site and their proposed release rates. If the combined release of stormwater runoff from several detention facilities in the same watershed is not coordinated, downstream flooding and erosion can occur. The designer should be familiar with the requirements for the project watershed before beginning the design.

### HYDROGRAPH ROUTING

Hydrograph routing is a technique used to confirm that a detention facility provides adequate storage and will satisfy any drawdown requirements (typically 2–5 days). For most water quality applications, the sizing of the detention volume is based on the water quality volume. However, to optimize the design and address outlet velocities, hydrograph routing may be necessary.

Hydrograph routing defines the outflow hydrograph that is the result of runoff flow attenuation from storage in a detention BMP and the influence of the outlet control device. The greater the storage volume of the BMP, the greater the moderation of the flow at the outlet. Routing storm events through a BMP may be used to accomplish the following:

- Determine the potentially erosive effects to the receiving stream based on various design storms for a given basin configuration.
- Reduce the size of downstream controls in a BMP system. The routed hydrograph of the upstream BMP can be used to size the downstream BMP.
- Evaluate the performance of a detention BMP design.
- Estimate the release rate of the detention BMP.

Hydrograph routing is sufficiently addressed in multiple hydrologic and hydraulic texts. The Highway Design Engineer is directed to FHWA's Hydraulic Design Series No. 2, *Highway Hydrology* (FHWA.03) and HEC No. 22, *Urban Drainage Design Manual* (FHWA.02) for further information on stage-discharge relationships.

### BYPASS SYSTEMS

Bypass systems are incorporated into structural BMP designs to convey discharges greater than the design storm away from the BMP. Bypass systems protect structural integrity while reducing maintenance costs and extending the life of the BMP by reducing runoff to required amounts. Bypass systems must be designed to safely convey the 10-year storm event at a minimum. The designer should address runoff velocity and capacity within the bypass system and at the confluence of receiving waters. The designer should also confirm that the bypass system is properly designed to avoid short-circuiting and subsequent failure of the BMP.

The appropriate bypass structure configuration should be selected on a site-by-site basis. The weir and pipes associated with the bypass structure should be sized to convey all runoff generated by the water quality design storm into the basin. Hydrograph generation and BMP routing calculations are recommended to size the weir and pipes; however, peak discharge and pipe flow capacity calculations are also acceptable sizing methods. In addition, consideration should be given to the potential impacts of backwater conditions in the basin. An outlet control structure and emergency spillway may still be needed with some flow bypass configurations.

Typically, the designer will be required to determine an appropriate peak flow rate that can be used to configure the flow bypass structure to direct the WQv into the BMP. The Pitt Method is commonly used for this purpose.

### *Pitt Method*

The Pitt method, or small storm hydrology method, was developed to predict runoff from small storms and areas with short concentration times. This method for calculating the peak rate of discharge is beneficial for the sizing of off-line diversion structures using the water quality design storm. Conventional SCS methods underestimate the volume and rate of runoff for rainfall events less than 2 inches. This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the BMP due to an inadequately sized diversion structure. Use the Pitt method to determine a curve number associated with the WQv precipitation depth. The Pitt Method equation is:

$$CN = \frac{1000}{10 + 5\,P + 10\,Q - 10\sqrt{Q^2 + 1.25\,Q\,P}}$$

where

| | | |
|---|---|---|
| CN | = | SCS curve number (unitless) |
| Q | = | runoff volume (inches) – equal to WQv (watershed inches) |
| P | = | water quality storm rainfall (inches) |

The following equation was adapted from the 1987 document by Schueler entitled *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs* (Schueler.01) and can be used to calculate rainfall (P).

$$P = \frac{12\,V_{WQ}}{Rv\,A}$$

where

| | | |
|---|---|---|
| P | = | water quality storm rainfall (inches) |
| $V_{WQ}$ | = | (WQv) water quality volume (ac-ft) |
| Rv | = | volumetric runoff coefficient, 0.05 + 0.009(I) where I is percent impervious cover (dimensionless) |
| A | = | total drainage area (acres) |

The runoff volume (Q) in the Pitt Method equation is simply the water quality storm rainfall times the volumetric runoff coefficient (P Rv). Based on the CN, calculate the peak flow for the water quality design storm using the SCS-TR55 method previously described. The designer may refer to technical guidance for this method contained in the *Georgia Stormwater Management Manual*, Appendix D3 (GA.01).

## DRAWDOWN ORIFICES

Orifices are used in water quality treatment to control the drawdown of detained runoff. By controlling the drawdown, orifices provide time for particle settling. Detention time for most BMPs should be 2–5 days. For drawdown purposes, the orifice can be sized using a routing spreadsheet or the orifice equation, as follows:

$$Q = C_D A \sqrt{2gh}$$

where

| | | |
|---|---|---|
| Q | = | discharge ($ft^3/s$) |
| $C_D$ | = | orifice coefficient (dimensionless), typically 0.6 |
| A | = | area of the orifice opening ($ft^2$) |
| g | = | acceleration of gravity (32.2 $ft/s^2$) |
| h | = | driving head (ft), measured from the centroid of the orifice to the upstream water surface (free outfall conditions) |

One advantage to using a routing method to size the orifice is that it incorporates the effect of changing head with drawdown. To achieve a longer detention, several small orifices are used instead of one large orifice. This practice reduces the velocity of currents near the outlet. In general, it is preferable that all orifices be between 2 and 3 inches in diameter.

## OUTLET CONTROL STRUCTURES, EMBANKMENTS, AND EMERGENCY SPILLWAYS

A stormwater detention pond generally has an outlet control structure (principal spillway) and an emergency spillway. Figure 2-4 shows a simple outlet control structure with two discharge methods. The WQv is contained beneath the top of the outlet control structure and is slowly released from the basin via the drawdown orifices. All storm events greater than the WQv exit in whole or in part via the top of the riser. Figure 2-5 shows a detention basin embankment, outlet control structure, and emergency spillway.

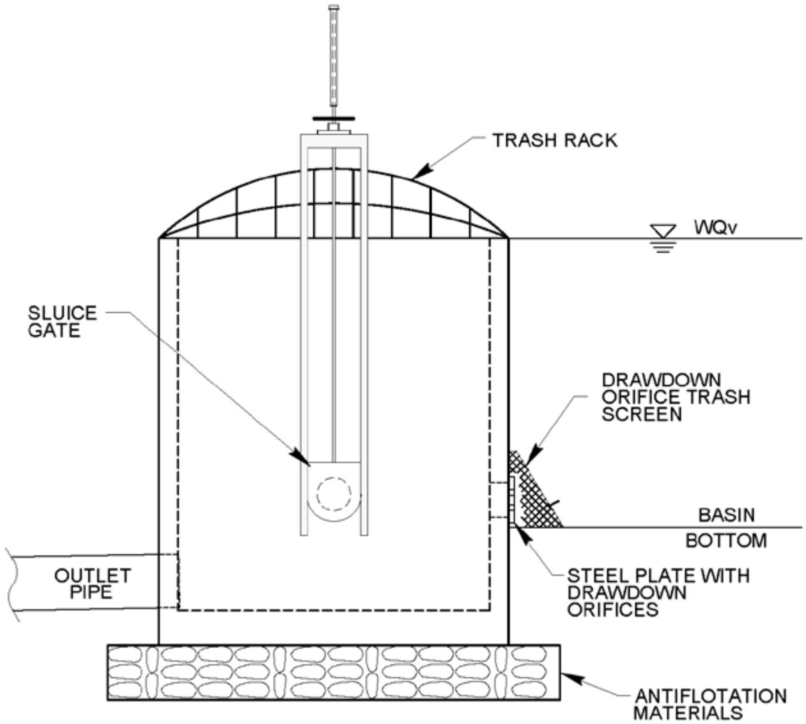



**Figure 2-4.** Outlet control structure

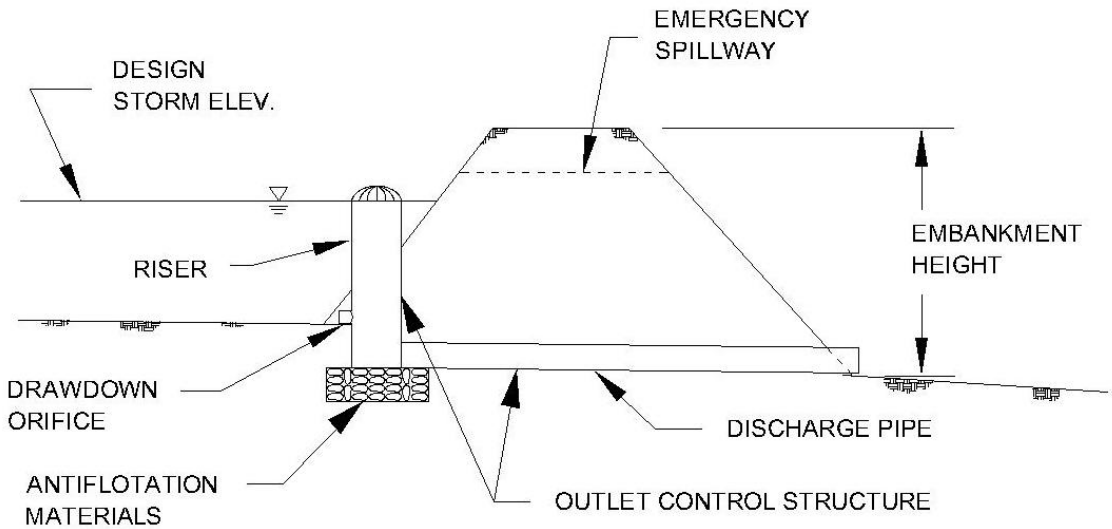



**Figure 2-5.** Detention basin components

Stage-discharge curves for the outlet control structure are a function of the riser, the drawdown orifice, and discharge pipe hydraulics. Initially, as runoff from a storm event enters the basin, the riser acts as a weir, as defined by the weir equation:

$$Q = C_w L h^{3/2}$$

where

| | | |
|---|---|---|
| $Q$ | = | discharge ($ft^3/s$) |
| $C_w$ | = | weir coefficient (dimensionless), typically 3.0 for control structures |
| $L$ | = | length of the weir along the crest (ft) |
| $h$ | = | driving head (ft) measured vertically from the weir crest to the surface water elevation |

When the outlet control structure acts as a weir, its weir length is equal to its circumference, and the driving head is equal to the height of the surface water elevation above the crest elevation of the control structure. As the stage rises, the weir flow transitions to orifice flow as the riser structure is inundated. When the water surface elevation or stage exceeds the design storm elevation as depicted in Figure 2-5, the outlet control structure conveys the flow up to the emergency spillway. If the flow from the riser is greater than the capacity of the discharge pipe, then the discharge pipe may control and operate as an inlet or outlet control culvert.

The designer should confirm that the discharge pipe is large enough to convey the flows from the drawdown orifice and the riser section combined. It is recommended that the elevation between the top of the riser and the emergency spillway be no more than one (1) foot. Once the stage reaches the elevation of the emergency spillway, the outflow hydrograph becomes a summation of the stage-discharge relationships for the drawdown orifice, the riser structure, and the emergency spillway.

The emergency spillway is typically constructed in natural ground to safely discharge storm runoff during large storm events. The channel must safely convey the discharge for the 50-year storm event without overtopping the embankment or creating excessive erosive velocities in the downstream channel. If there is not enough available right-of-way to construct the emergency spillway, an alternative design can be used provided it is designed to convey the 50-year storm event. The emergency spillway can be designed using the weir equation, and the channel can be designed using Manning's equation. Manning's equation is as follows:

$$v = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where

| | | |
|---|---|---|
| $v$ | = | average velocity in the channel (ft/s) |
| $n$ | = | Manning's roughness coefficient (dimensionless) |
| $R$ | = | hydraulic radius (ft) |
| $S$ | = | slope of the channel (ft/ft) |

Emergency spillways can be designed with vegetation or riprap, depending on the design velocity in the channel. Manning's n is a roughness coefficient based on the lining of the channel. The maximum water surface elevation for the emergency spillway should be 1 foot less than the top of the embankment. For a complete discussion of stable channel design using Manning's equation as well as roughness coefficients for various channel lining materials, refer to the *Erosion and Sediment Control Planning and Design Manual,* Appendix 8.05 (NCDENR.01).

The height of embankments should not exceed 12 feet and should not exceed an impoundment capacity of 10 acre-feet or the dam will be regulated by the State. The North Carolina Administrative Code states that “the height of a dam shall be measured from the highest point on the crest of the dam to the lowest point on the downstream toe” (NCAC.01). Figure 2-5 provides guidance on how to measure embankment height.

Generally, a homogeneous earthen material is sufficient for NCDOT BMPs requiring embankments. However, consideration for the size of the embankment and the type of soil should be evaluated to determine if anti-seep collars, a clay core, impervious liners, diaphragms, or internal drains are needed. Anti-seep collars and clay cores are generally the NCDOT-preferred options. Other seepage prevention measures typically require additional engineering. The Natural Resource Conservation Service’s Agriculture Handbook 590 provides guidance on embankment design (USDA.03). Consult with the NCDOT Geotechnical Unit for embankment designs.

## 2.4 Design Implications of Best Management Practice Construction, Inspection, and Maintenance

Although designing a BMP for functionality is critical, proper construction and maintenance are equally important for surface water protection. BMPs designed without constructability and location-specific constraints in mind often result in costly change orders or reduced pollutant removal efficiency. The designer should anticipate construction and maintenance needs when siting the BMP, selecting and specifying materials, and developing the construction plans.

This section introduces general construction, inspection, and maintenance guidance to be considered in the BMP design phase; subsequent chapters present specific guidance for each BMP. Each location and BMP will present unique construction and maintenance issues. It is important to educate construction and maintenance personnel about the purpose and function of the BMP to avoid alterations that could impact treatment capability.

### CONSTRUCTION

During the design phase, the designer should be mindful of BMP constructability in addition to volume and flow requirements. Choosing a layout that facilitates equipment access and ease of construction while still meeting quantity and quality objectives will result in an easier, more economical BMP to build and maintain.

Because post-construction controls can resemble more common structures, construction staff may not realize that some installation methods can reduce the efficiency of the BMP. Until BMP installation becomes more standardized, careful quality control and oversight during construction is recommended. Potential problems can be prevented through adequate planning and by addressing constraints clearly in the construction plans. Figure 2-6 shows a bioretention basin during construction. Additional recommendations to streamline the construction process follow:

- Coordinate with other phases of project construction to reduce equipment mobilization, landscaping, and drainage system installation costs.
- Consider developing construction sequencing recommendations when appropriate.
- Consider availability and lead time for specified materials.
- Use site visits to gather information for estimating material quantities in addition to evaluating site feasibility for BMP application.
- Consider the time of year the construction project will take place when specifying vegetative components.
- Clearly document critical design criteria in the construction plans. Also, discuss the influence of critical dimensions on BMP functionality at any preconstruction meetings.
- Delineate, in the construction plans, those areas that should not be disturbed by construction when designing BMPs for NCDOT facilities.
- Verify that the BMP has been built according to plan and performance standards before acceptance.

**Figure 2-6.** Bioretention basin during construction

## INSPECTION AND MAINTENANCE

The primary design requirement for inspection and maintenance activities is providing adequate and safe access to the BMP. BMP maintenance in the linear highway environment introduces the safety risk of working near traffic, with limited space and potentially steep slopes. The inspection and maintenance needs for each BMP type, and potentially every site, will necessitate different equipment and frequency of site visits. It is recommended that the designer consult with the appropriate maintenance engineer to determine what maintenance activities are feasible. Almost all BMPs must be safely inspected on foot, whereas some BMPs must be accessible to heavy equipment and require stabilized access roads. Additional recommendations follow:

- Allow for adequate permanent drainage easement or right-of-way around the BMP for inspection and maintenance activities.
- Balance the needs of public safety against those of accessibility for inspection and maintenance. If fences are specified to mitigate public safety hazards, consider how to

make the area accessible for maintenance equipment by installing gates, adjusting the fence height, and choosing the fence location wisely.

- When designing access roads, determine what vehicles and equipment will be needed for emergency, as well as routine maintenance.
- Determine whether the deepest grade point can be accessed by a backhoe or vacuum truck.
- Account for vehicle turnaround space, swing radius, and accessibility to different areas of the BMP. For a dry detention basin, this may mean access to the emergency spillway, the inflow pipe, the outlet control device, and the sides of the basin. The size and characteristics of a maintenance access road will vary according to the equipment used.

Consult the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for comprehensive inspection and maintenance guidance.

## 2.5 Stormwater Management Plan

A Stormwater Management Plan (SMP) is an effective tool for evaluating potential stormwater impacts to surface waters and to document stormwater management efforts. An SMP should be completed for all projects following the NCDOT *Guidelines for Drainage Studies and Hydraulic Design*. A SMP spreadsheet tool is available for download from the NCDOT Hydraulic's Unit website at the following Uniform Resource Locator (URL) address:

https://connect.ncdot.gov/resources/hydro/Documents/Stormwater Management Plan.zip

# CHAPTER 3 Level Spreader

## OVERVIEW

A LEVEL SPREADER is a structural best management practice that redistributes concentrated stormwater flow into diffuse flow.

### PURPOSE AND DESCRIPTION

- A level spreader provides a nonerosive outlet for concentrated runoff by diffusing the water uniformly across a stable slope.
- A level spreader consists of a trough with a level nonerosive lip.

### APPLICATIONS

- Level spreaders are typically implemented as part of an off-line system that includes a flow bypass system, forebay, and level spreader trough and lip.
- Level spreaders should be implemented only where uniform, diffuse flow can be achieved downgrade of the level spreader.
- Level spreaders are appropriate when concentrated runoff from a project area is conveyed by ditch or storm pipe toward the buffer zone of a receiving water body.
- Level spreaders are suitable for many highway applications, including interchanges, intersections, linear roadways, bridges, and facility areas.

### WATER QUALITY BENEFITS

- Diffuse flow exiting a level spreader increases stormwater infiltration.
- Level spreaders mitigate downgrade erosion and ponding.
- Level spreaders reduce the water velocity, which allows larger particles to settle.

## 3.1 Description

A level spreader is a BMP used to convert concentrated flow into diffuse flow. Level spreaders consist of a trough to collect stormwater runoff and a nonerosive lip that evenly distributes stormwater runoff to downgrade areas. By eliminating concentrated flow, level spreaders promote infiltration, sorption of pollutants onto surficial soils, biological uptake of pollutants, and reduction of downgrade erosion. Level spreaders are implemented in an off-line configuration to protect the level spreader from failure and to prevent flow reconcentration.

The main components of a level spreader system follow:

- Flow bypass structure
- Forebay (optional)
- Level spreader trough
- Level spreader lip
- Drawdown system

Runoff enters the level spreader via a flow bypass structure. Any runoff entering the flow bypass structure with flow rates up to the design flow rate is diverted to the trough of the level spreader. Runoff rises in the level spreader trough until the runoff elevation exceeds the height of the level spreader lip. The level spreader lip, acting as a weir, distributes flow evenly over a wide area. A typical level spreader system layout with buffer is shown in Figure 3-1.

The level spreader lip must be level to promote uniform, diffuse flow along its entire length. The flow bypass structure allows flow rates greater than the design flow rate to bypass the level spreader and discharge directly to the receiving stream via a bypass swale or pipe. If a pipe is used, it should discharge to an energy dissipator or culvert. The level spreader trough should be constructed of concrete for durability and to facilitate maintenance. Figure 3-2 (on the following page) depicts a profile view of the level spreader and typical components.

Incorporating drawdown within a level spreader trough provides additional volume reduction of runoff and minimizes the potential for a water-filled trough. A drawdown system consisting of weep holes draining through the lower wall of the level spreader lip into a dry cell is detailed in Figure 3-3 (on the following page).

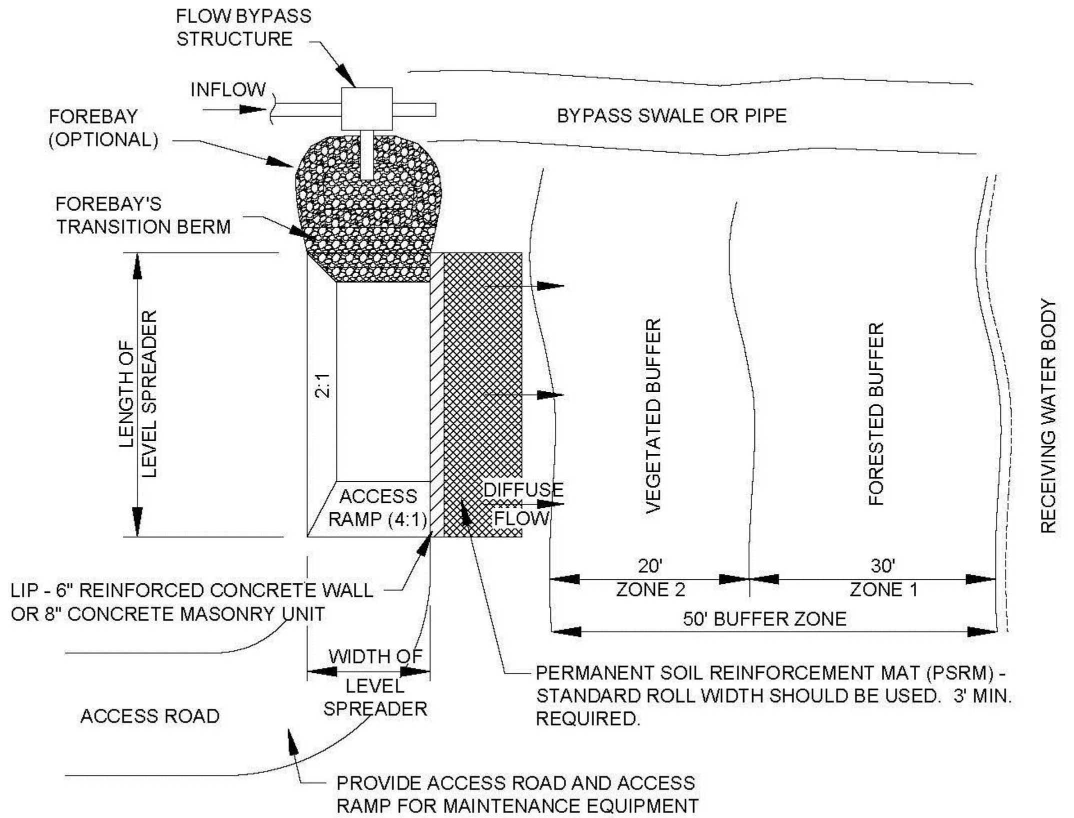



**Figure 3-1.** Plan view: typical level spreader layout with buffer

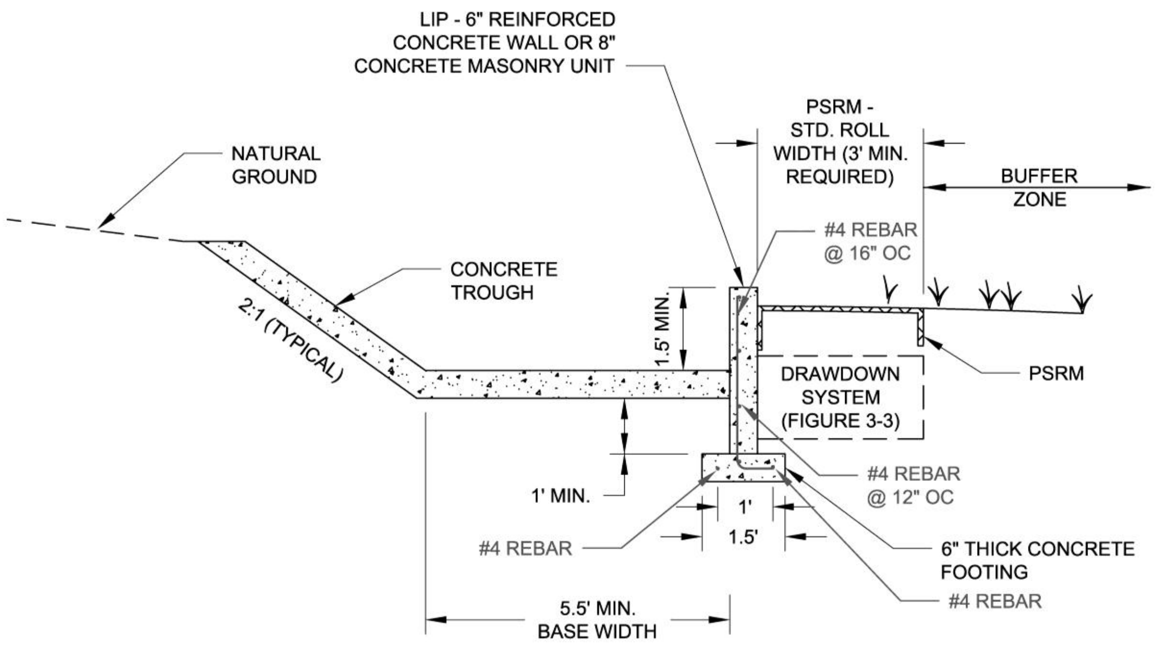



**Figure 3-2**. Profile View: typical level spreader details and components

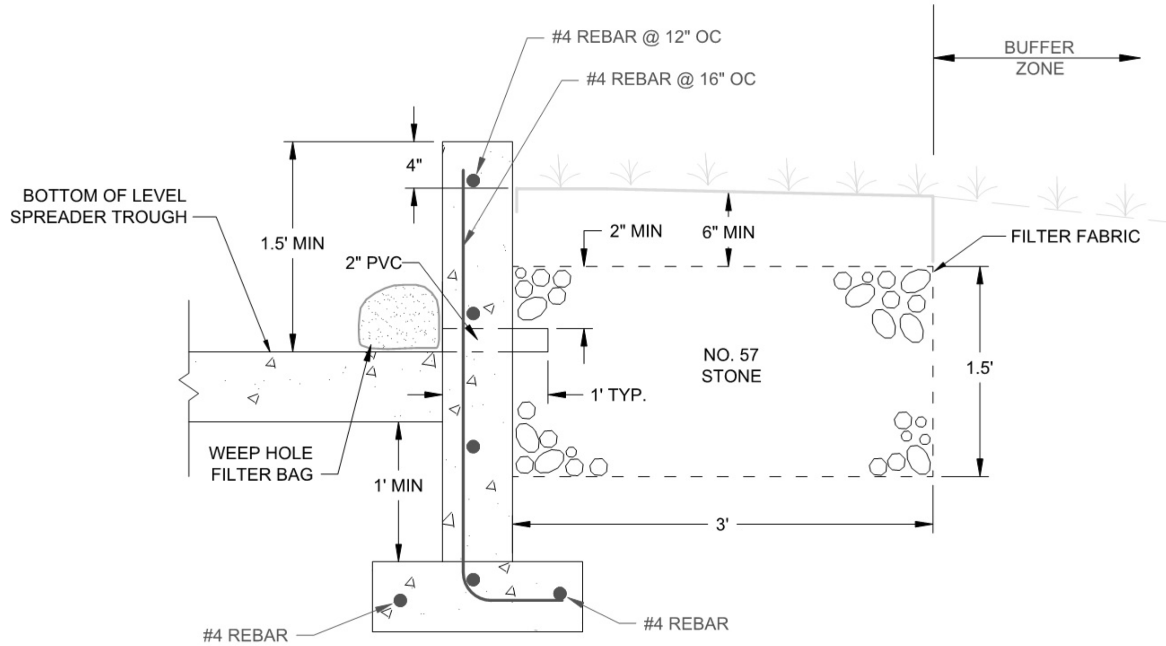



**Figure 3-3**. Profile view: weep hole dry cell detail for level spreader

## 3.2 Applications

The level spreader is applicable primarily when a concentrated flow is discharged upgrade of a protected buffer. The release of concentrated flow in regulated buffer zones is restricted unless runoff is treated by acceptable practices. Level spreaders alone do not provide stormwater treatment; they are combined with existing buffers or other BMPs, such as filter strips, to achieve pollutant removal. Figure 3-4 shows an example of a level spreader and buffer system.

**Figure 3-4.** Example of a level spreader and buffer system

Level spreaders are commonly used on many highway facilities, including linear roadways, interchanges, intersections, bridges, and facility areas. The use of a level spreader may not be feasible in every linear highway application and will depend on site-specific constraints, such as limited right-of-way or steep slopes. The level spreader should be located so that ground contours are parallel to the lip and the downgrade slope to the stream is smooth. The smooth transition from the level spreader to the stream will prevent diffuse flow from rechannelizing as stormwater makes its way through the buffer. Level spreaders should not be used in areas where slopes exceed 5% for forested areas or 8% for dense ground cover and grass.

The level spreader is applicable when objectives are to provide diffuse flow, promote infiltration, and filter pollutants through a vegetative buffer. Figure 3-5 illustrates the pollutant removal processes of a level spreader.

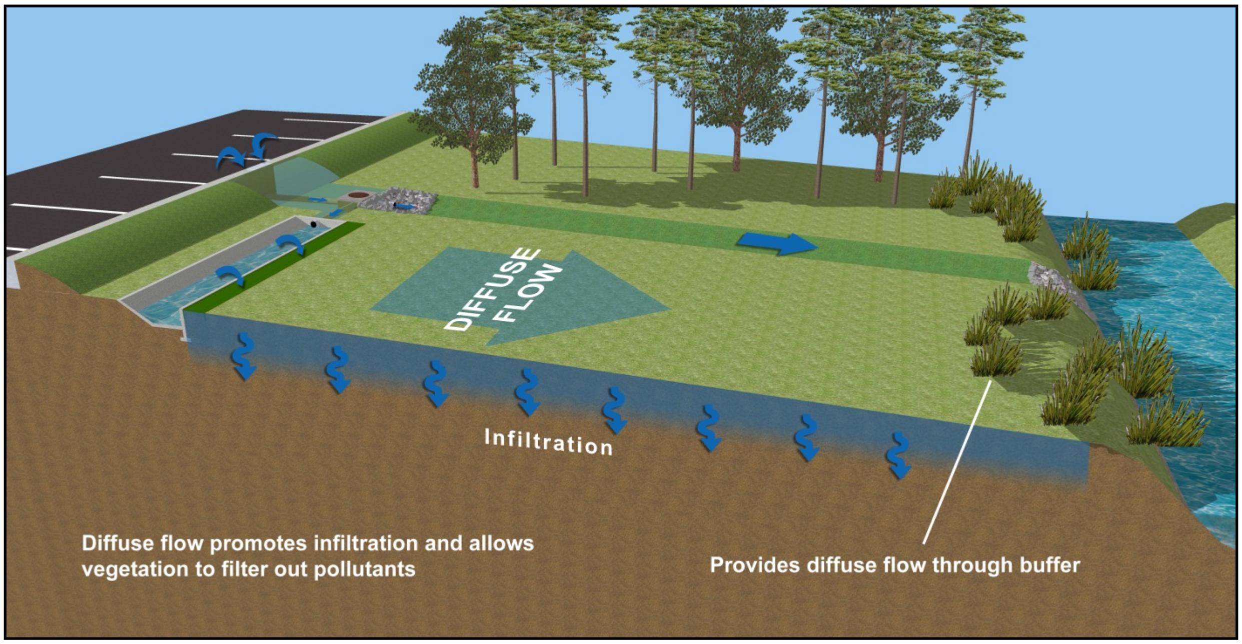



**Figure 3-5.** Typical level spreader configuration and pollutant removal processes

## 3.3 Design

This section provides guidance on designing level spreaders and the associated components that comprise the level spreader system. The following design information has been compiled from current NCDOT practice and NCDENR guidance (NCDENR.02).

### LEVEL SPREADER DESIGN CRITERIA

The entire level spreader system must pass the peak discharge from the 10-year storm event ($Q_{10}$) without degrading the buffer or receiving stream. The designer must determine the $Q_{10}$ discharge using the rational method, which is described in more detail in Chapter 2.

### Flow Bypass System

The flow bypass system consists of a flow bypass structure and a bypass swale or pipe. The flow bypass structure should be designed to route runoff from the 1-inch-per-hour storm to the level spreader. Flow in excess of the design storm intensity should bypass the level spreader and be transported directly to the receiving stream via the bypass swale or pipe. The bypass swale or pipe should be designed to convey the $Q_{10}$. The bypass swale or pipe should discharge into the stream in a manner that does not degrade the stream channel or banks.

Bypass swales or pipes are typically allowed within the buffer. As rules vary by watershed, activities allowed in the buffer zone should be confirmed before the design is selected.

### Level Spreader Lip and Trough

Inflow to the trough should be oriented so that the direction of flow is parallel to the lip. The lip of the level spreader must be made of concrete to prevent the lip from eroding. The level spreader trough should be constructed of concrete. The trough also includes a concrete end wall to help contain water and direct it over the lip. The end wall is constructed at terminal end of the lip, perpendicular to the lip. The wall can be vertical or have 3:1 side slopes, depending on site-specific conditions.

The length of the level spreader will vary, depending on the vegetation present in the buffer system. The dimensions of the level spreader are determined by the allowable velocity of the downgrade cover. Grassed or densely vegetated buffer systems are capable of handling flow rates higher than those in forested buffers without eroding.

### Drawdown System

The level spreader should include a drawdown system to prevent runoff from impounding and standing in the trough over extended periods. A series of weep holes that drain through the lower wall of the level spreader lip into a dry cell composed of an envelope of washed aggregate minimize the potential for a water filled trough.  The designer may include filter bags containing washed aggregate (#5/57), gravel, or coarse sand to minimize the potential for clogging of weep holes. An illustration of a typical drawdown system configuration is provided in Figure 3-3.

### Forebay

The inclusion of a forebay upstream of a level spreader should be considered. A forebay increases the life span of the level spreader and reduces the required frequency of maintenance to remove settled solids. The forebay should be sized for 0.1 inches of runoff from the impervious area within the contributing drainage area. Additional information on forebay design is presented in Chapter 7.

Additional design information is provided in the Level Spreader Design Criteria Summary.

## Level Spreader Design Criteria Summary

***General Design Criteria***

- ❒ Contributing area should be delineated to determine runoff amounts.
- ❒ The level spreader should be designed to treat runoff from the 1-inch-per-hour storm.
- ❒ The entire system must pass a 10-year storm event without erosion or failure.
- ❒ The length of the level spreader should be a minimum of 10 feet and a maximum of 100 feet.
- ❒ The lip of the level spreader must be on a zero percent grade.
- ❒ The trough should have a minimum depth of 1.5 feet with a minimum base width of 5.5 feet.
- ❒ The trough should have side slopes no steeper than 2:1. Provide a maintenance equipment access point with a side slope no steeper than 4:1.
- ❒ The lip should extend 4 inches above the ground surface.
- ❒ The first 3 feet immediately downgrade of the level spreader lip should be covered by permanent soil reinforcement mat (PSRM).

***Level Spreader with Grassed or Densely Vegetated Buffer***

- ❒ Level spreaders can be installed upgrade of grassed or densely vegetated buffers where buffer slopes are 8% or less.
- ❒ 10 feet of level spreader is required for every 1 $ft^3/s$ of flow.

***Level Spreader with Forested Buffer***

- ❒ Level spreaders can be installed upgrade of forested buffers where buffer slopes are 5% or less.
- ❒ 50-foot forested buffer: 50 feet of level spreader per 1 $ft^3/s$ of flow

## Alternative Design Options

A level spreader may not be capable of conveying the 1-inch-per-hour storm discharge because of topography, size, and imperviousness of the drainage area; limited right-of-way; or other site constraints. Under these circumstances, it may be necessary to implement another BMP such as a dry detention basin in series with the level spreader. Alternatively, where the drainage area is small and slopes are gradual, a preformed scour hole may be a more economical option. Additional information on preformed scour hole design is presented in Chapter 4. The level spreader design flowchart provided in Figure 3-6 is intended to guide the designer to the most appropriate BMP option for a particular site. This section outlines design criteria and considerations for implementing another BMP upstream of a level spreader.

### *Level Spreader with other BMPs*

When the required size of a level spreader exceeds the maximum size of 100 feet, it may be necessary to implement another BMP such as a dry or wet detention basin upgrade of the level spreader. The other BMP is used to regulate the flow rate of runoff entering the level spreader, minimizing the required level spreader length while allowing solids to settle.

When another BMP is combined with a level spreader, it should generally be sized to detain and release the water quality volume to the level spreader over a period of 2 to 5 days. Even when level spreaders are incorporated into such a system, all flow greater than the 1-inch-per-hour storm should be routed directly to the receiving stream via a bypass swale or pipe. The entire system should be capable of conveying the 10-year storm without erosion or failure. More information is presented in the Upgradient BMP Design Criteria Summary.

**UPGRADIENT BMP DESIGN CRITERIA SUMMARY**

- ❐ The level spreader length is calculated using the maximum discharge release rate from the upgradient BMP instead of the runoff from a 1-inch-per-hour storm.
- ❐ The upgradient BMP is typically sized to detain the water quality volume. Runoff is then released to the level spreader over 2 to 5 days.
- ❐ All flow greater than the 1-inch-per-hour storm is routed to the receiving stream via a bypass swale or pipe.

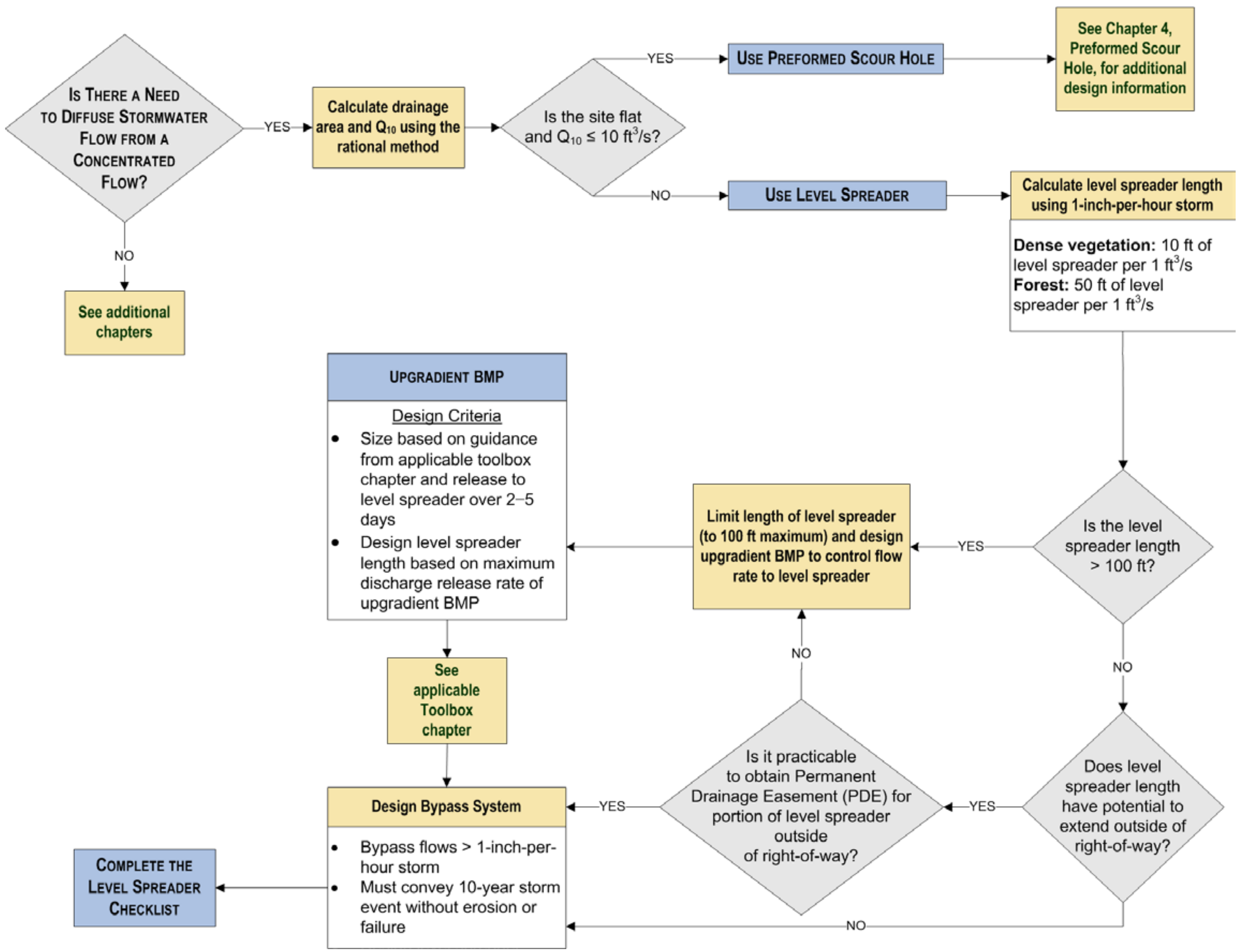



**Figure 3-6.** Level spreader design flowchart

### DESIGN AND CONSTRUCTION CONSIDERATIONS

Additional design and construction recommendations follow:

- Design the system to prevent off-site flows from entering the level spreader or the buffer directly downgrade from the level spreader.
- Design the transition between the level spreader and other BMPs or buffers to avoid erosion once installation is complete.
- Confirm that the location of the BMP is outside of roadway clear recovery zones.
- Provide safe ingress and egress of the level spreader for inspection and maintenance. An access area into the trough that is no steeper than 4:1 with adequate room to maneuver equipment should be provided.
- Check the available right-of-way when determining the BMP footprint.
- Construct the level spreader on undisturbed soil where practical.
- Install the level spreader and lip at a zero percent grade.
- Install appropriate erosion control to prevent sediment entry into the weep holes and dry cell during construction.
- Position the inflow device parallel to the lip of the level spreader (perpendicular to the direction of diffuse flow) if possible.
- Install permanent soil reinforcement matting (PSRM) at the transition between the trough lip and buffer to prevent erosion at the interface.

## 3.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance.

## 3.5 Safety Considerations

Any BMP that has the potential for standing water presents a drowning hazard. Consider fencing and signage around the BMP to ensure safety. See NCDOT Specification 866 (NCDOT.08) for fencing options.

# CHAPTER 4 Preformed Scour Hole

## OVERVIEW

A PREFORMED SCOUR HOLE is a structural best management practice designed to dissipate energy and promote diffuse flow.

### PURPOSE AND DESCRIPTION

- Preformed scour holes are riprap depressions constructed at the outlet of a point discharge.
- By providing a stable impact point for peak flows, a preformed scour hole dissipates energy and diffuses flow for specific applications.

### APPLICATIONS

- Preformed scour holes can provide energy dissipation for a variety of drainage applications.
- When used to diffuse flow, preformed scour holes are applicable only for small drainage areas and flat outlet areas outside the clear recovery zone. If these site conditions cannot be met, a preformed scour hole should not be used.

### WATER QUALITY BENEFITS

- Preformed scour holes reduce the amount of end-of-pipe erosion by eliminating unabated scour.
- When inducing diffuse flow conditions, preformed scour holes promote runoff infiltration and reduce downgrade erosion.

## 4.1 Description

Preformed scour holes are preshaped, riprap-lined basins located directly downgrade of a discharge point (Figure 4-1). The man-made structure mimics the natural scour hole that would otherwise form at the conveyance outlet if no energy dissipation were provided. The basin is stabilized with filter fabric and riprap to absorb the impact of the discharge and to prevent additional erosion. Once runoff has filled the shallow basin, it overtops the preformed scour hole and is redistributed as diffuse flow to the surrounding area.

To prevent erosion immediately downgrade of the preformed scour hole, an apron of permanent soil reinforcement matting (PSRM) is required downgrade of the BMP.

**Figure 4-1**. Preformed scour holes in a linear highway application

Preformed scour holes absorb the impact of high velocities and reduce the potential for downgrade erosion from point discharges by reducing flow velocities. When preformed scour holes are implemented under small peak flow conditions and installed on level ground, they redistribute concentrated inflow to diffuse outflow to adjacent land. Preformed scour holes provide a water quality benefit by dispersing flow, which achieves the following:

- Prevents scour at the pipe discharge
- Promotes runoff infiltration
- Reduces soil erosion

A typical example of a preformed scour hole layout and its components is shown in Figure 4-2. Figure 4-3 is a cross section of a typical preformed scour hole.

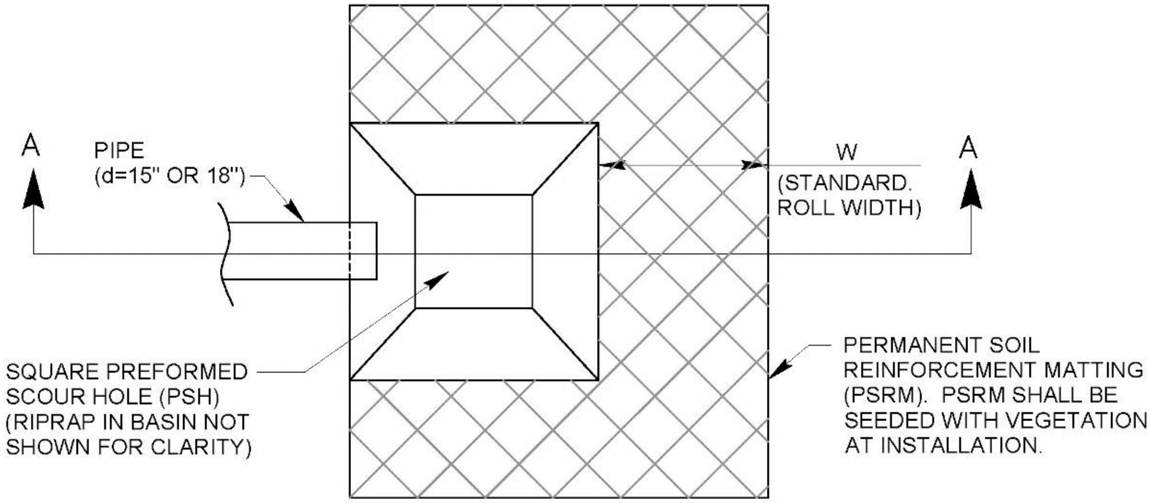



**Figure 4-2.** Plan view: typical preformed scour hole layout and components

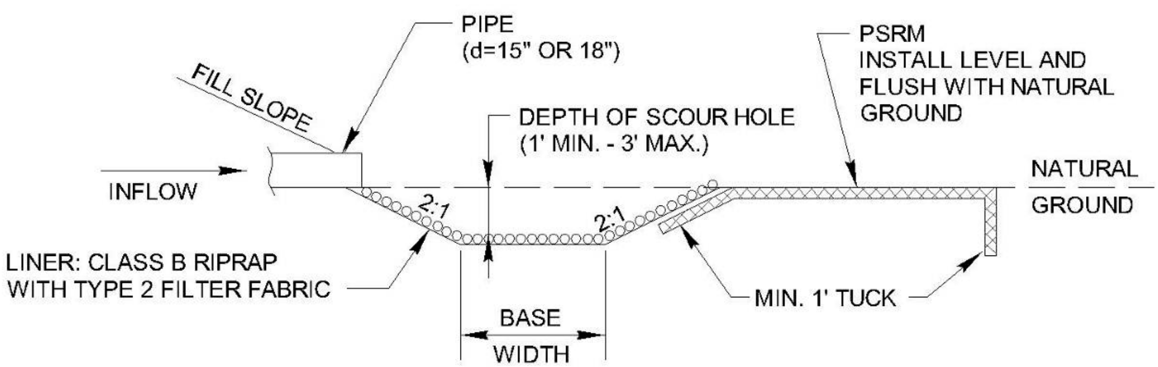



**Figure 4-3.** Profile view: preformed scour hole cross section

## 4.2 Applications

Preformed scour holes, sometimes referred to as riprap basins, can be used for energy dissipation in a variety of man-made conveyance systems. When the preformed scour hole is used for energy dissipation only, the runoff can exit the BMP either to a downgrade pipe or channel, or from fewer than three sides of the scour hole. Considerable guidance exists on the use of preformed scour holes for energy dissipation purposes. However, this toolbox will focus on the specific application of the preformed scour hole to provide energy dissipation and diffuse flow from small drainage areas. For a preformed scour hole to perform both functions, specific conditions must exist.

Most importantly, the ground downgrade must be flat to prevent reconcentration of runoff. To redistribute runoff from channelized flow to diffuse flow, preformed scour holes should be implemented only for (Q10) peak flows of 10 ft3/s or less. If these site and flow conditions exist and the BMP is designed and implemented in accordance with this toolbox, preformed scour holes can be used upgrade of protected buffer areas outside of Zone 2.

If diffuse flow is required and either (1) the Q10 peak flow is greater than 10 ft3/s or (2) the site slope is not relatively flat, other BMPs should be considered instead of a preformed scour hole.

## 4.3 Design

For the purpose of diffusing flow, preformed scour holes can be used downgrade of 15-in. and 18-in. pipes[1]. For a preformed scour hole to be installed upgrade of riparian areas, the following requirements must be met:

- The downstream area must be flat.
- The BMP should preferably be located outside of Zone 2 in buffer areas.
- The maximum allowable discharge for a 15-in. pipe is 6 $ft^3/s$, based on the $Q_{10}$ discharge.
- The maximum allowable discharge for an 18-in. pipe is 10 $ft^3/s$, based on the $Q_{10}$ discharge.

For 15-in. and 18-in. pipes, only Class B riprap ($d_{50}$ = 8 in.) can be used to line the preformed scour hole. This specification is based on empirical relationships between the area of the discharge pipe and the riprap $d_{50}$ and unsuccessful applications of smaller riprap sizes. A $d_{50}$ of 8 inches allows for a minimum scour hole depth of approximately 1 foot and a maximum scour hole depth of 3 feet. The minimum and maximum stone sizes for Class B riprap are 5 inches and 12 inches, respectively.

### DESIGN CRITERIA

A summary of additional design information follows.

**DESIGN CRITERIA SUMMARY**

- ❒ The base of the scour hole is square (See Figure 4-3). The width is calculated as follows:

  Base width = 3 × Discharge pipe size
- ❒ Riprap must be Class B ($d_{50}$ = 8 inches).
- ❒ Minimum width of the PSRM apron is the standard PSRM roll width.
- ❒ PSRM must be tucked a minimum of 1 foot underneath the filter fabric and natural ground around the perimeter of the scour hole.
- ❒ Scour hole must be installed in a flat area.

[1] If the discharge pipe diameter is greater than 18 in. and/or diffuse flow is not a goal, the designer is directed to the Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 14 entitled *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA.05) for complete design procedures.

**DESIGN CRITERIA SUMMARY (CONTINUED)**

- ❒ Side slope for all four sides of the scour hole is 2:1.
- ❒ Minimum depth of the scour hole is 1 foot.
- ❒ Maximum depth of the scour hole is 3 feet.

**DESIGN AND CONSTRUCTION CONSIDERATIONS**

Where diffuse flow is a primary goal, preformed scour holes must be installed level in relatively flat areas. To avoid shifting of the scour hole after installation, the scour hole should be installed in undisturbed soil instead of in fill material.

Additional design recommendations follow:

- Confirm that the location of the BMP is outside of clear recovery zones and environmentally sensitive areas.
- Check the available right-of-way when determining the BMP footprint and orientation.
- Confirm that the apron is flush with the natural ground. The elevation of the top of the preformed scour hole should be the same as the elevation of the PSRM.
- Confirm that riprap consists of a well-graded mixture of stone. Smaller-size riprap stones should be used to fill voids between larger stones.
- Where practical, route off-site runoff away from the preformed scour hole.
- Immediately after construction, stabilize the exit areas with vegetation.
- Clear the area of all construction debris and check the exit areas for any potential obstructions that could promote channelized flow.

## 4.4 Inspection and Maintenance

Preformed scour holes are inspected by the Central Roadside Environmental Unit for downstream erosion, improper construction, and structural damage one year after project acceptance by NCDOT. If the scour hole is considered functional during this inspection, no further inspection and maintenance activities are performed. If the preformed scour hole is considered non-functional at this inspection, repairs are made, and the scour hole is re-inspected one year after the repair. If the preformed scour hole is considered functional at this second inspection, no further inspection and maintenance activities are performed.

# CHAPTER 5 Dry Detention Basin

## OVERVIEW

A DRY DETENTION BASIN is a BMP that attenuates peak stormwater flows, promotes settlement of suspended pollutants, and reduces erosive velocities downstream of the outlet structure.

### PURPOSE AND DESCRIPTION

- Dry detention basins are designed to temporarily capture stormwater runoff and attenuate peak flows.
- Inflow to the basin is detained and released from a primary outlet control structure over a period of time.
- Dry detention basins are designed with a drawdown component that keeps the basin dry between storm events.

### APPLICATIONS

- Dry detention basins are suitable for a variety of highway applications, provided there is adequate area for the basin.

### WATER QUALITY BENEFITS

- Dry detention basins promote sedimentation of suspended solids.
- By reducing peak discharges, dry detention basins prevent downgrade erosion and hydrologic impacts to receiving water bodies.
- Incorporation of an underdrain system can maximize stormwater particle and particulate-bound pollutant removal.
- To maximize water quality benefits, dry detention basins can be integrated into a system with other structural BMPs that target removal of solids and dissolved pollutants.

## 5.1 Description

**Figure 5-1**. Typical dry detention basin

A dry detention basin is a permanent structural BMP with an outlet structure that captures, detains, and releases stormwater runoff over a period of time. Dry detention basins provide water quality benefits through quantity control and the settling of suspended solids. By controlling the release of stormwater flows, dry detention basins mitigate the erosive impacts of frequent and/or intense storm events. When stormwater is temporarily detained in a dry detention basin, suspended solids are separated through sedimentation. Dry detention basins are designed to completely drain within 2 to 5 days after a storm event. Figure 5.1 shows a dry detention basin during construction.

The main components of a dry detention basin follow:

- Forebay
- Basin
- Outlet control structure
- Drawdown device
- Embankment
- Emergency spillway
- Access road
- Underdrain system (optional)

Runoff enters a dry detention basin as diffuse flow, a point discharge from an open channel and/or conveyance pipe, or a discharge from a pretreatment BMP. Inflowing stormwater runoff fills the basin until it reaches the design storm elevation, defined by the outlet control structure. Typically, the design storm elevation is equivalent to the water quality volume (WQv) elevation. For more information about the WQv, refer to Chapter 2. For storm events less than or equal to the WQv storm, stormwater runoff is detained and the discharge is controlled through a combination of the drawdown device and soil infiltration.

The embankment is an earthen dam over the barrel outlet pipe leading from the riser. The embankment allows the basin to temporarily detain volumes from storm events greater than the WQv. For larger storm events, an emergency spillway is necessary to minimize the potential for overtopping the basin and causing downgrade flooding. The emergency spillway serves as an overflow structure that is typically constructed as a channel in natural ground.

Typical examples of a dry detention basin layout and its components are shown in Figures 5-2 and 5-3.

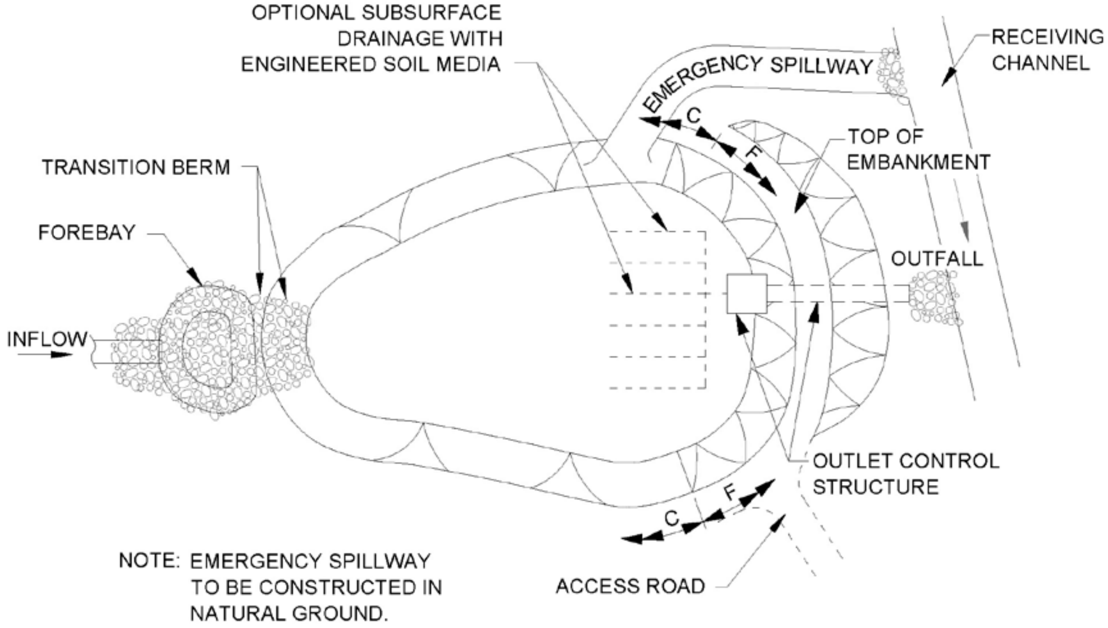



**Figure 5-2.** Plan view: typical dry detention basin layout and components

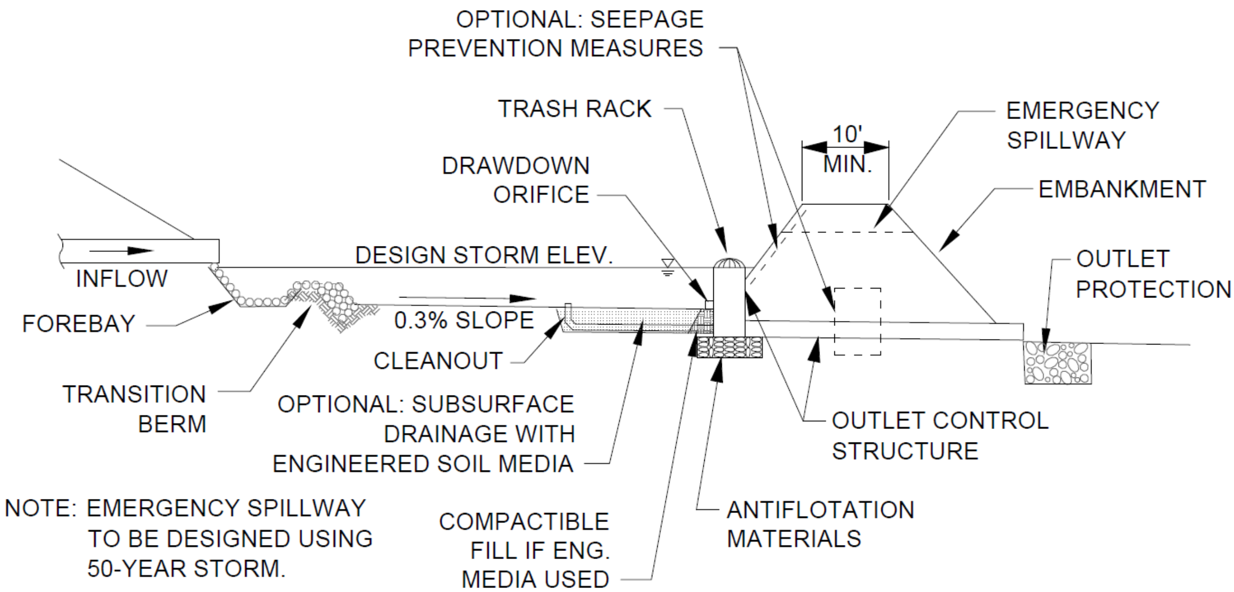



**Figure 5-3.** Profile view: dry detention basin cross section

## 5.2 Applications

Dry detention basins are suitable for collecting and detaining runoff from a variety of highway applications, such as linear rights-of-way, facility areas, and interchanges. Compared to other structural BMPs, the basin footprint can be relatively large, making some linear right-of-way applications impractical.

The dry detention basin is applicable when the primary objective is controlling and reducing peak flow rates into receiving water bodies. Because stormwater is detained in the basin, the settling of particles and particulate-bound pollutants is the primary pollutant removal mechanism, as illustrated in Figure 5-4. Pollutant removal efficiencies are increased, especially for soluble pollutants, when significant infiltration occurs. Underdrain systems with engineered soil media can be used to improve infiltration rates. Dry detention basins can also be implemented in series with other structural BMPs, such as forebays, filter strips, or swales, to meet pollutant removal efficiency requirements.

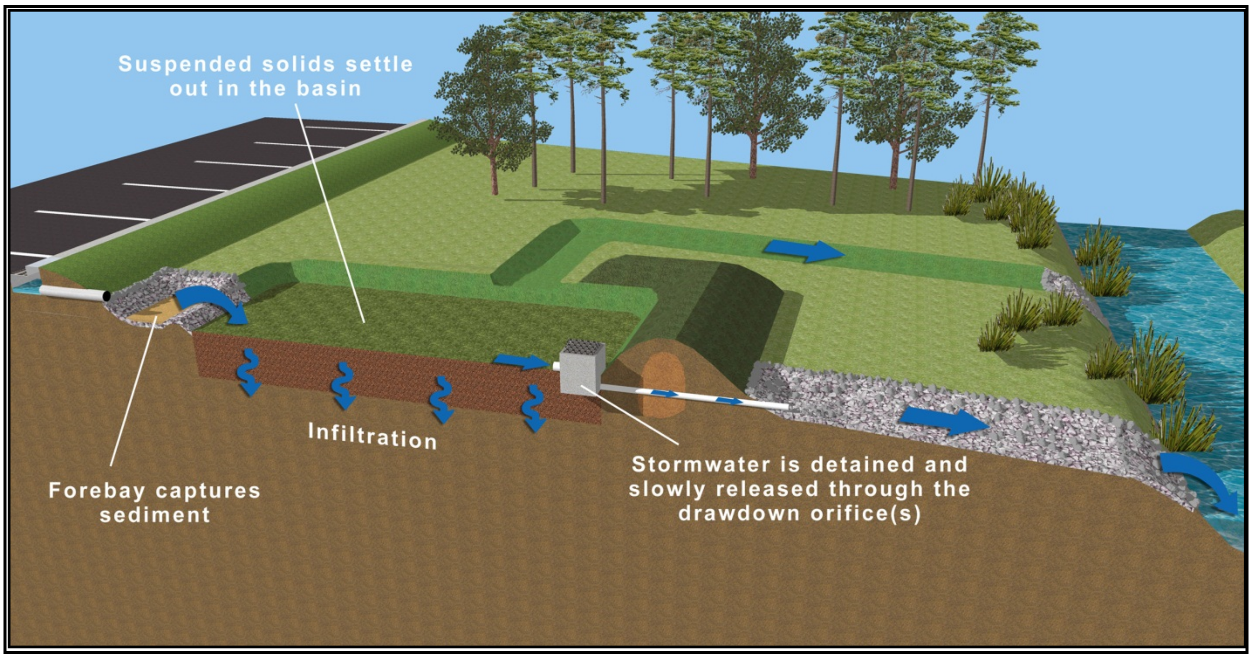



**Figure 5-4.** Typical dry detention basin configuration and pollutant removal processes

## 5.3 Design

The design of the dry detention basin must account for the drainage area hydrology and the BMP component hydraulics. The inflow and outflow hydrographs for all design storms (e.g., WQv and 50-year storm events) must be determined and considered during design. Outlet structure hydraulics must also be evaluated. The routing procedure and hydrograph computation can be performed by a variety of methods and procedures contained in spreadsheets or modeling programs. The routing must be completed for each design storm under consideration to determine the water surface elevation of that storm as well as overall functionality of the system. More information on hydrologic analysis and design methods is presented in Chapter 2.

This section provides guidance on designing dry detention basins for both water quantity and quality control. These design criteria may not apply if the sole purpose of the dry detention basin is to attenuate peak flow rates. In this case, the designer should consider both the appropriate design storms for detainment as well as downstream conditions when determining final design criteria.

## BASIN SIZING CRITERIA

Dry detention basins are sized to temporarily store the volume of runoff from the first inch of rain, at a minimum. However, this common benchmark may vary as the actual volume treated will depend upon existing site conditions and other constraints. The height of the riser structure above the basin invert is determined by the required WQv.

To improve the removal efficiency of solids using gravitational settling, the distance between the basin inlet and the outlet control structure should be maximized. Criteria to guide basin sizing and orientation are provided in the box entitled Basin Sizing Criteria Summary. The final orientation of the basin will be determined by site-specific constraints.

### BASIN SIZING CRITERIA SUMMARY

- ❒ Basin should capture the runoff from the WQv storm and allow it to draw down over a period of 2 to 5 days.
- ❒ Minimum flow length-to-width ratio is 3:1 to prevent short-circuiting.
- ❒ Basin volume should not exceed 10 acre-feet.
- ❒ Basin side slopes should be 3:1 or flatter. For steeper slopes, slope stabilization should be considered.
- ❒ Basin should be located at a minimum of 2 feet above the seasonal high groundwater table.

## BASIN COMPONENT DESIGN CRITERIA

Basin components include the outlet control structure, drawdown device, embankment, and emergency spillway.

### *Outlet Control Structure*

The outlet control structure is composed of a riser and a discharge pipe (refer to Figures 5-2 and 5-3). The top of the riser should be set at a higher elevation than the basin floor to provide detention time for attenuation and delayed release of stormwater runoff peaks. The riser structure is typically made of concrete for durability. The material for the barrel or the pipe outlet structure is selected based on the outlet velocity and slope.

### *Drawdown Device*

The drawdown device or orifice has small-diameter holes to allow for flow release and runoff infiltration. For drawdown purposes, it is preferable to use an orifice diameter between 2 and 3 inches. If a larger opening is required, then two or more orifices are recommended. The orifice should be designed to draw down the water quality volume within 2 to 5 days. Drawdown orifice size can be calculated using a routing spreadsheet or the orifice equation. The routing spreadsheet will include the changing head elevation; the orifice equation alone should use an average height equal to one-half of the WQv depth.

### *Embankment*

The height of the embankment is determined by providing a minimum of 1 foot of freeboard above the water surface elevation of the 50-year storm event. The embankment should be less than 12 feet in height and have an impoundment capacity of less than 10 acre-feet. The top width of the embankment should be 10 feet to provide maintenance access. For most applications, a simple homogeneous earthen embankment is sufficient. However, the size of the embankment and the type of soil should be evaluated to determine if anti-seep collars, a clay core, impervious liners, diaphragms, or internal drains are needed. Anti-seep collars and clay cores are generally the NCDOT-preferred options. Other seepage prevention measures typically require additional engineering. The NRCS Agriculture Handbook 590 provides guidance on embankment design (USDA.02). Consult the NCDOT Geotechnical Unit for embankment designs. Refer to Chapter 2 for further guidance.

### *Emergency Spillway*

The emergency spillway is typically constructed in natural ground to serve as an overflow structure to safely discharge storm runoff during large storm events. The channel is typically designed to convey the discharge for the 50-year storm event. If there is not enough available right-of-way to construct the emergency spillway, an alternative design can be used.

Often the top of the riser is converted into an emergency overflow device, such as an open-throat riser. If the riser serves as the emergency spillway, it must be designed to pass the discharge from the 50-year storm. Any deviation from the listed criteria requires review and approval from the State Hydraulics Engineer or delegated representative. Additional design criteria for basin components are provided in the Basin Component Design Criteria Summary.

#### BASIN COMPONENT DESIGN CRITERIA SUMMARY

***Outlet Control Structure***

- ❒ Outlet control structure should be designed to handle the 10-year storm if an emergency spillway channel is provided.
- ❒ Outlet control structure should be designed to handle the 50-year storm if an emergency spillway channel is not provided.
- ❒ An emergency sluice gate should be provided. The sluice gate invert should be set to the basin invert with a minimum opening of 8 inches.

***Drawdown Device***

- ❒ Preferred orifice size is between 2 and 3 inches.
- ❒ Drawdown device should be sized to provide a 2- to 5-day drawdown time of the WQv.

## BASIN COMPONENT DESIGN CRITERIA SUMMARY (CONTINUED)

***Embankment***

- ❒ Height should be less than 12 feet and impoundment capacity less than 10 acre-feet. Refer to Chapter 2 for guidance on measuring embankment height.
- ❒ Embankment structure should have a minimum top width of 10 feet with side slopes of 3:1 or flatter.
- ❒ A minimum of 1 foot of freeboard must be provided between the surface water elevation of the 50-year storm event and the top of the embankment.

***Emergency Spillway***

- ❒ Emergency spillway invert elevation should be set to safely convey the 50-year storm event and prevent flooding of the roadway.
- ❒ Emergency spillway liner material should be designed to handle the peak velocity from the 50-year storm event.

## DESIGN OPTIONS CRITERIA

Two design options that can improve the performance of the dry detention basin are a pretreatment forebay and an underdrain system with engineered soil media.

### *Forebay*

A pretreatment forebay removes some sediment and trash through energy dissipation before the runoff enters the detention basin. Incorporation of a forebay upstream of the basin decreases the incidence of the drawdown orifice clogging, improves overall pollutant removal efficiencies, reduces the required frequency of maintenance, and extends the lifetime of the detention basin. The forebay should be sized for 0.1 inches of runoff from the impervious area within the contributing drainage area. The transition berm between the pretreatment BMP and the dry detention basin should be designed to prevent erosion. More information on forebays is provided in Chapter 7.

### *Underdrain System*

An underdrain system with engineered soil media can reduce pollutant loads by infiltrating a larger volume of runoff within the basin. Promoting runoff infiltration is recommended only at sites where contamination of groundwater is not a concern. The underdrain is a secondary drawdown device and is not intended to be the primary drawdown device. The branches of the underdrain should connect to a single stub-out from the outlet control structure to minimize penetrations into the outlet structure, where possible. The configuration of the underdrain system will vary based on site constraints.

## DESIGN OPTIONS CRITERIA SUMMARY

### *Forebay*

- ❒ Forebay should be sized for 0.1 inches of runoff from the impervious area. Refer to Chapter 7 for more guidance.
- ❒ Forebay should have a minimum length-to-width ratio of 2:1 where practical to promote sedimentation.
- ❒ Depth of the forebay should be between 3 and 5 feet.
- ❒ Forebay side slopes should be flatter than or equal to 2:1.

### *Underdrain System*

- ❒ The basin bottom should have a 0.3% slope.
- ❒ The underdrain pipes should have a minimum slope of 0.5%.
- ❒ Six-inch perforated pipes are recommended.
- ❒ Underdrain system should connect to the outlet control structure.

## DESIGN AND CONSTRUCTION CONSIDERATIONS

When determining the location of a detention basin, the designer must take into account the topography and soils. The detention basin's shape will be subject to the contours of the site in some locations. The orientation should maximize the length-to-width ratio at 3:1 or more.

Additional design and construction recommendations follow:

- Confirm the depth to the seasonally high groundwater table. Dry detention basins should not be placed where the water table is less than 2 feet below the bottom of the basin.
- Grade the basin bottom to drain. A minimum slope of 0.3% is recommended.
- Consider the consequences of groundwater interaction with runoff. If the site soils are highly permeable and pollutant concentrations are elevated, an impermeable liner can be used to prevent groundwater impacts.
- Verify soil types using soil survey maps or existing geotechnical reports.
- Use impermeable liners in regions with karst topography (southeastern Coastal Plain) to prevent collapse of underlying soils.
- Locate the basin outside of the clear recovery zone.
- Check the available right-of-way when determining the basin footprint and orientation.
- Place detention basins in undisturbed soil, not in fill material.
- Consider anticipated construction methods and equipment and provide adequate space for construction of basin components.
- Avoid using heavy equipment in the basin bottom to maintain the hydraulic conductivity of in-situ soils and media, and to avoid damaging the underdrain, if applicable.

- Provide a watertight connection at all pipe connections to concrete structures. Connections for nonconcrete pipes should be made using flexible boot, gasket, or similar device.
- Backfill around outlet control structure with compactable material.
- Determine proper ballast for  the outlet control structure to prevent flotation as needed.
- Plant native grasses in the basin or cover with sod. Alternative vegetation, such as low weed species or riparian shrubs, can be planted as well, provided it can withstand both dry and ponding conditions.
- Consider whether bypass or diversion of off-site drainage is necessary based on site constraints. These options are useful in retrofit applications.
- Stabilize all basin system outlets to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042 (NCDOT.08).
- Provide a debris screen or trash rack over the drawdown inlet and riser structure to prevent clogging and human entry.
- Consider using baffles to increase the effective flow length in the basin.
- Include a minimum 10-foot wide maintenance access road to the dry detention basin for cleanup and repair.

## 5.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance.

Where possible, provide an area on site where sediment removed from the BMP can be disposed. The area should be relatively flat to promote stabilization after sediment is deposited. The sediment disposal area should also be gently sloped away from the BMP to prevent deposited sediment from reentering the BMP. The sediment disposal area should be configured in a manner that prevents adverse effects to receiving waters or adjacent properties.

## 5.5 Safety Considerations

Dry detention basins are typically large, so any standing water can present a drowning hazard, especially in residential or public areas. Trash racks and other structures should be designed to prevent entry by children. Consider fencing and signage around the BMP if children are expected to be in the area (i.e., nearby schools or playgrounds). Refer to NCDOT Standard Specifications, Section 866 (NCDOT.08) for fencing options.

# CHAPTER 6 Swale

## OVERVIEW

A SWALE is a vegetated channel designed to convey and treat runoff from small drainage areas.

### PURPOSE AND DESCRIPTION

- Swales have trapezoidal or V-shaped cross sections with side slopes 3:1 or flatter.
- The channel is sized to treat the two-year discharge ($Q_2$) at low velocities and to convey the 10-year discharge ($Q_{10}$) at nonerosive velocities.

### APPLICATION

- Swales are appropriate for linear highway, interchange, and facility applications.
- To maximize water quality benefits, swales are best suited for small drainage areas.
- Swales are often integrated into other best management practices (BMPs) as part of a treatment train that may include level spreaders, filter strips, etc.

### WATER QUALITY BENEFITS

- By reducing flow velocity, swales promote sedimentation, infiltration and runoff attenuation.
- Swales remove suspended solids, metals, and nutrients through sedimentation, interception by grass blades, infiltration, and biological uptake.

## 6.1 Description

Swales are broad, shallow vegetated channels designed to convey and treat runoff and attenuate peak flows from small drainage areas. The purpose of a swale is to decrease the velocity of runoff to promote sedimentation of suspended solids, infiltration and interception of particulates by vegetation. To perform this function, swales typically have denser vegetation and flatter slopes than most drainage channels. When incorporated into roadway or facility design as part of the conveyance system, swales can provide water quality benefits and be aesthetically pleasing.

**Figure 6-1.** Swale with water quality rock check

Swales treat runoff through sedimentation, physical filtration, infiltration, and biofiltration. As runoff moves through the vegetated channel, reduction in velocities (and the resultant increase in residence time) allows for greater settling of suspended solids. This process is aided by interception by the vegetation, improving water clarity and removing particulate-bound pollutants such as metals. In sufficiently permeable soils and on shallow slopes without excessive compaction, infiltration plays a significant role in reducing runoff volume. Depending on the residence time and other conditions, removal of metals, nitrogen, and phosphorus may be enhanced through biological uptake.

The main component of a swale is the vegetated channel. In some applications, water quality rock checks are incorporated to terrace the swale to maintain a flat effective slope and provide erosion control (Figure 6-1). An example of a swale and its components is shown in Figure 6-2. Figure 6-3 shows a cross section of a swale.

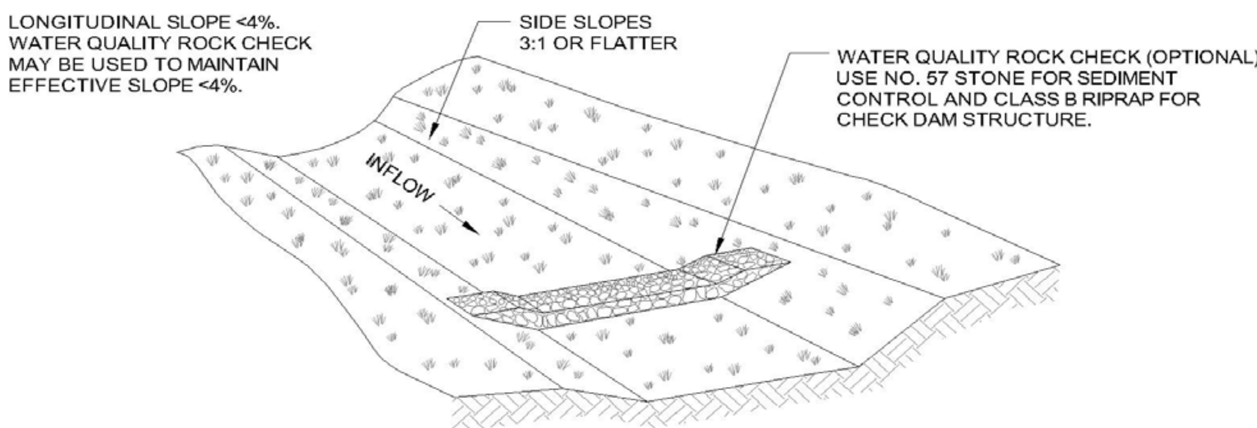



**Figure 6-2.** Isometric view: swale with optional water quality rock check

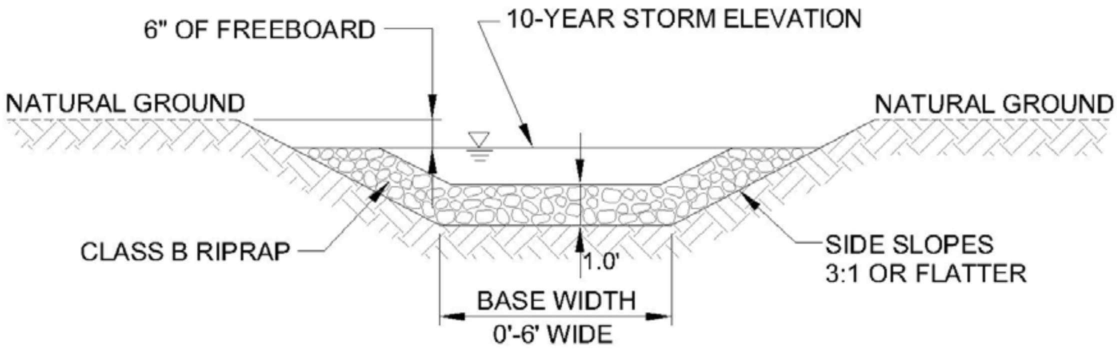



**Figure 6-3.** Profile view: swale cross section with optional water quality rock check

## 6.2 Applications

Swales are appropriate for a variety of transportation applications, including linear rights-of-way, highway interchanges, and NCDOT facilities. Swales are also well-suited for secondary roadway applications because of the available pervious area along the roadside. Figure 6-4 shows swales in typical highway applications.

Swales improve runoff quality for small drainage areas. Designers should be mindful of water depth and velocity when implementing swales in larger drainage areas. As flows deepen and velocities increase, the swale's effectiveness is reduced and erosion within the swale may become an issue. Other BMPs may be implemented with swales to offset these effects.

**Figure 6-4.** Linear highway applications of swales

## 6.3 Design

To maximize water quality benefits, swales are designed to reduce the flow velocity, which increases the time that the runoff is in contact with the swale vegetation and promotes sedimentation, filtration, and infiltration, as depicted in Figure 6-5. Therefore, broad swales on relatively flat slopes with dense vegetation and permeable soil will be most effective at removing pollutants from stormwater.

The longitudinal slopes of the swale should be 4% or less. In addition, swale side slopes should be 3:1 or flatter.

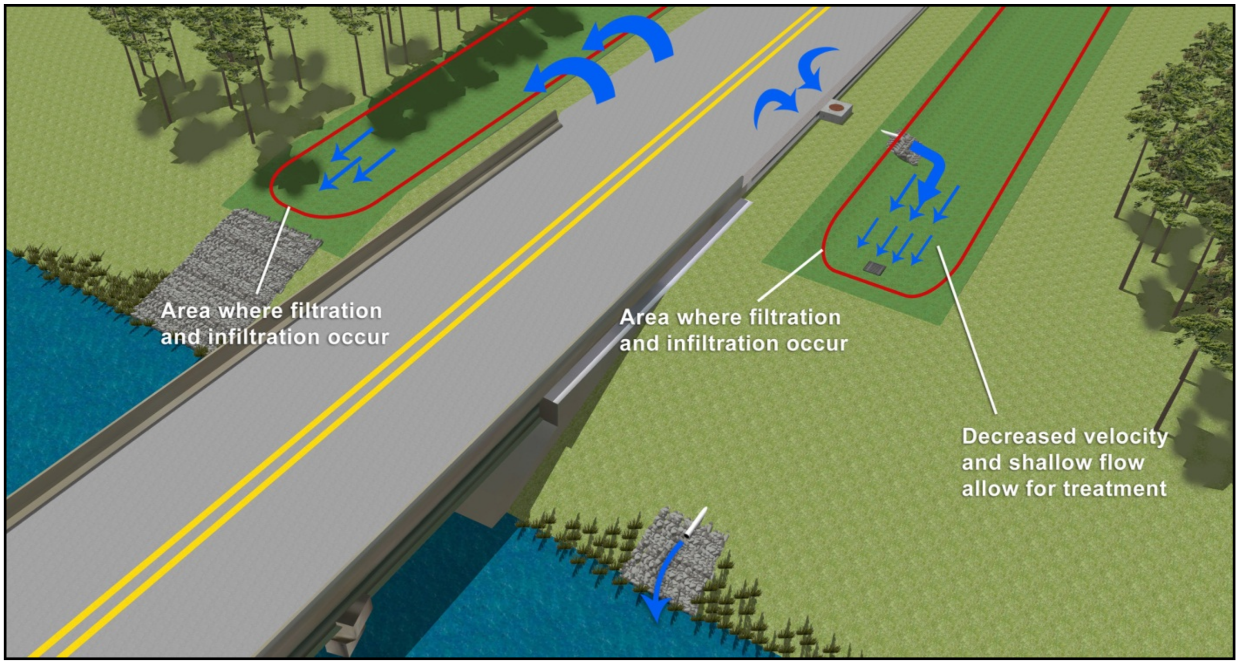



**Figure 6-5.** Typical swale with associated pollutant removal processes

## CONFIGURATION CRITERIA

Trapezoidal or V-shaped cross sections should be used in swale design.

## SIZING CRITERIA

Swales are typically sized to (1) treat the runoff from the 2-year storm discharge ($Q_2$) and (2) safely convey the 10-year storm discharge ($Q_{10}$) without overtopping the swale or eroding the swale lining. Discharges should be calculated using the rational method or other approved method. General design criteria are provided in the Design Criteria Summary.

To maximize the treatment capacity of the swale, the velocity for the $Q_2$ should be no greater than 2.0 ft/s. The swale should also be capable of conveying the $Q_{10}$ at a velocity less than the permissible velocity and with 6 inches of freeboard. Permissible velocity is a function of the lining material. Most established grass linings have permissible velocities between 3.5 and 6.0 ft/s. For simplicity, 4.0 ft/s and less is considered a nonerosive velocity for grass-lined channels. The designer should consider the flow depth to grass height relationship as submerged flows obviously provide better treatment capacity than overflows.

The dimensions of the swale are determined using Manning's equation and the continuity equation. Complete guidance on stable channel design methods is provided in the NCDENR *Erosion and Sediment Control Planning and Design Manual* (NCDENR.01), Appendix 8.05.

**DESIGN CRITERIA SUMMARY**

- ❒ Swales should be designed with longitudinal slopes between 0.3 and 4%.
- ❒ The recommended maximum swale base width is 6 feet. Exact base width is determined by the desired flow depth.
- ❒ Swale side slopes should be 3:1 or flatter.
- ❒ Swale length of 100 feet per contributing acre of drainage area is recommended.
- ❒ The maximum design velocity for the $Q_2$ is 2.0 ft/s.
- ❒ The permissible velocity for the $Q_{10}$ is 4.0 ft/s for a channel with established vegetation.

## VEGETATION CRITERIA

Vegetation used in swales should reasonably tolerate standing water, resist erosion, and resist bending when subject to runoff flows. To maximize treatment efficiency of the swale, the vegetation should be as dense as possible. Guidance on vegetative considerations, specifications for seeding mixtures, and a description of various grasses for use in each of North Carolina's physiographic regions are provided in NCDOT's *Vegetation Management Manual* (NCDOT.02) and in the NCDENR *Erosion and Sediment Control Planning and Design Manual* (NCDENR.01) (refer to Chapter 3, Chapter 6, and Appendix 8.02).

## ALTERNATIVE DESIGN CRITERIA

If site constraints do not allow for the required longitudinal slopes or design storm velocities, water quality rock checks may be used as an alternative design. Water quality rock checks are permanent structures that reduce the effective slope of the swale and create small pools, dissipating the energy of flow and increasing hydraulic residence time. The rock checks should be used in series, with the toe of the upstream check at the same elevation as the top of the downstream check. Design criteria for water quality rock checks are provided in the Alternative Design Criteria Summary.

**ALTERNATIVE DESIGN CRITERIA SUMMARY (WATER QUALITY ROCK CHECK)**

- ❒ Rock check should be 1 foot high along the wetted perimeter of the swale.
- ❒ Rock check should be constructed of Class B riprap.
- ❒ A 12-inch layer of No. 57 stone should be placed upstream of the Class B riprap to provide sediment control.
- ❒ Width of the check should be 4.5 feet in the direction of flow, including the layer of No. 57 stone.
- ❒ Toe of the upstream check should be the same elevation as the top of the downstream check.

### DESIGN AND CONSTRUCTION CONSIDERATIONS

Before vegetation is established in the swale (see Figure 6-6), significant erosion and scour can occur. The exposed swale should be protected with a temporary erosion-resistant lining. Typically, Manning's n-value can be determined for various temporary liners from the manufacturer's specifications. Complete procedures for designing a temporary erosion-resistant liner are provided in Appendix 8.05 in the NCDENR *Erosion and Sediment Control Planning and Design Manual* (NCDENR.01), as well as in FHWA's HEC-15 (FHWA.04).

**Figure 6-6.** Swales before vegetation is established

## 6.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance. Maintaining vegetative cover is essential to superior performance in swales. Headcuts or other scour issues can result in reduced or negative performance. Alternative grasses or seeding mixtures should be considered in the event that the selected vegetation does not become established.

# CHAPTER 7 Forebay

## OVERVIEW

A **FOREBAY** is a pretreatment best management practice (BMP) to be used in conjunction with other BMPs and designed to dissipate energy and capture sediment, trash, and debris.

### PURPOSE AND DESCRIPTION

- A forebay is a basin designed to dissipate the energy of concentrated flows and provide diffuse flow to a downgrade BMP.
- A forebay promotes sedimentation and captures trash and debris.

### APPLICATIONS

- Forebays provide pretreatment for other BMPs, such as infiltration basins, wet and dry detention basins, stormwater wetlands, bioretention basins, filtration basins, and level spreaders.
- Forebays are appropriate where concentrated runoff from a highway project is conveyed by roadside ditches and/or storm pipes to a BMP.

### WATER QUALITY BENEFITS

- Forebays dissipate energy, thereby reducing the velocity of the flow to allow suspended particles to settle before discharging runoff into downstream BMPs.
- Forebays provide diffuse flow to downgrade BMPs.
- Forebays capture trash and debris.
- Forebays enhance the function of downgrade BMPs.

## 7.1 Description

A forebay is an essential component of most impoundment and infiltration BMPs, including infiltration basins, wet and dry detention basins, stormwater wetlands, bioretention basins, filtration basins, and level spreaders (Figure 7.1). The forebay dissipates the energy of the flow from a point discharge, allowing suspended particles to settle and trapping trash and debris. This minimizes clogging of the downgrade outlet control device and prevents sedimentation in the receiving water body. The water exits the forebay through a nonerosive outlet control device.

**Figure 7-1**. Riprap-lined forebay upgrade of a dry detention basin

The main components of a forebay follow:

- Basin
- Liner material
- Outlet control device

Forebay basins are typically lined using riprap with filter fabric; however, other liner materials, including grass and concrete, can be used at the designer's discretion. If riprap is used, the filter fabric acts as a barrier between the basin floor and the riprap. The transition berm, generally a shallow weir, routes stormwater to a downgrade BMP. Forebays can be excavated basins or can be constructed with earthen berms, gabions, or riprap walls. Some forebays may include a combination of these features. Forebays may be rectangular or circular, and may have pipe or swale inlets. For forebays with swale inlets, the swale should be flared around the forebay to match the forebay width. Circular forebays are typically used only with pipes. A typical example of a forebay layout and components is presented in Figure 7-2. Figure 7-3 shows a forebay cross section.

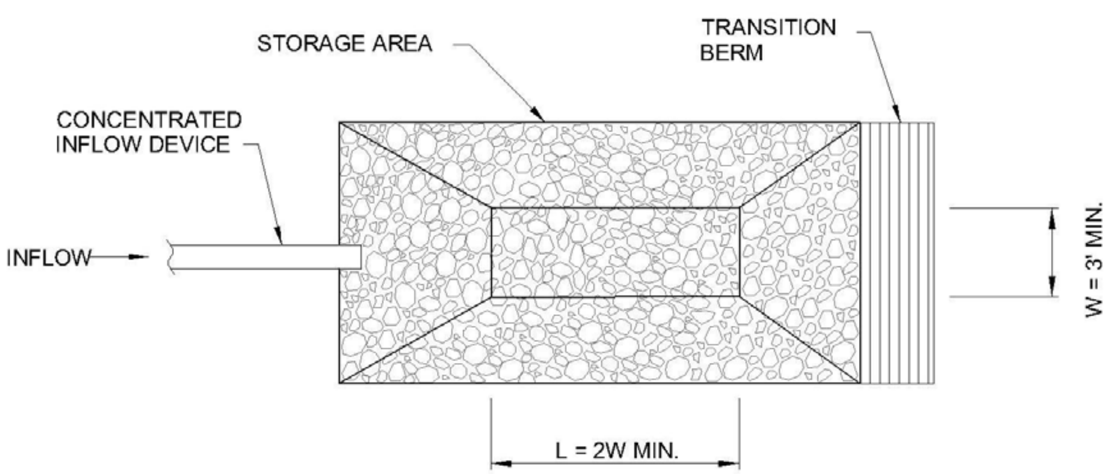



**Figure 7-2.** Plan view: typical riprap forebay layout and components

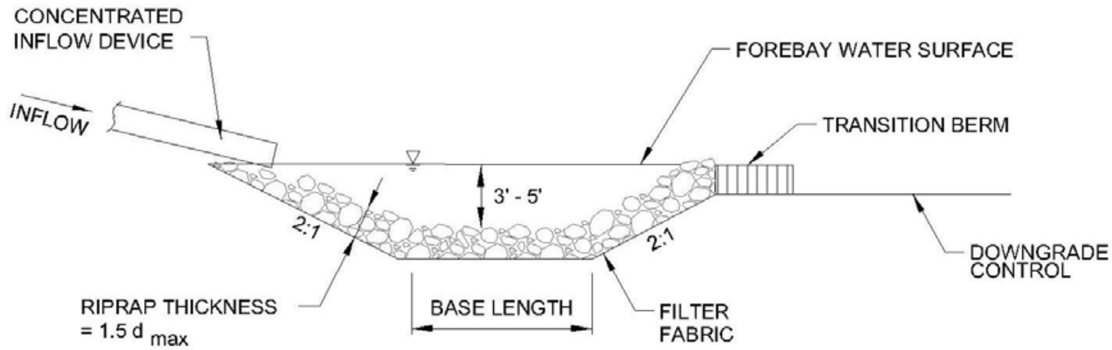



**Figure 7-3.** Profile view: riprap forebay cross section

## 7.2 Applications

Forebays are suitable for many highway applications where the footprint space is available. Forebays are appropriate when concentrated highway runoff from a project is conveyed by roadside swales or conveyances and/or storm pipes to a downstream BMP or water body. A forebay typically serves as a pretreatment control for one BMP or is integrated into a system of BMPs. By trapping sediment and debris, a forebay enhances the performance and longevity of BMP systems. Structural BMPs that are typically combined with a forebay include, but are not limited to, infiltration basins, dry detention basins, stormwater wetlands, bioretention basins, and level spreaders. An example of a forebay used in combination with a bioretention basin is shown in Figure 7-4.

**Figure 7-4.** Forebay with bioretention basin

## 7.3 Design

### SIZING CRITERIA

The forebay size is based on the volume associated with 0.1 inches of runoff for the impervious area within the contributing drainage area. Once the required forebay volume is determined, the forebay configuration is determined using the design criteria provided in the next section.

### DESIGN CRITERIA

The velocity of the flow entering the forebay will be reduced by the liner material to prevent scour and undermining. Outlet stabilization is necessary to absorb the impact of flow and reduce the velocity to nonerosive levels. The outlet stabilization material should line the forebay and be determined by the velocity produced by the $Q_{10}$ discharge. It is recommended that the entire forebay bottom and side slopes be lined with the selected liner material. If riprap is used, it should consist of a well-graded mixture of field stone or quarry stone. The majority of the stone mix should consist of larger stones, with smaller stones filling the voids. The maximum stone diameter, $d_{max}$, should be no greater than 1.5 times the median size of the riprap, $d_{50}$.

The minimum thickness of the riprap should be 1.5 times $d_{max}$. The filter fabric is placed between the riprap and soil foundation to prevent soil movement through the openings of riprap. For requirements regarding the class and size distribution of riprap, see Table 1042-1 in Section 1042 of the NCDOT Standard Specifications (NCDOT.08). Design criteria for the forebay are summarized in the Design Criteria Summary box.

### DESIGN CRITERIA SUMMARY

- ❒ Contributing drainage area should be delineated to determine the $Q_{10}$ discharge.
- ❒ Forebay should be sized for 0.1 inches of runoff from the impervious area within the contributing drainage area.
- ❒ Rectangular forebays should have a minimum length-to-width ratio of 2:1, where practical, to promote sedimentation, with a maximum ratio of 6:1.
- ❒ Rectangular forebay width should be a minimum of 3 feet.
- ❒ Circular forebays should have a minimum diameter of 5 feet.
- ❒ Depth of the forebay should be between 3 and 5 feet.
- ❒ Forebay side slopes should be flatter than or equal to 2:1.

Other design recommendations for a forebay and its components are as follows:

- The size of the riprap or liner material should be selected with respect to pipe outlet velocities.
- Forebay transition berms should have a minimum top width of 5 feet (in the direction of flow).
- The transition berm between the forebay and the downstream BMP should be made of a nonerodible material designed to minimize exit velocities and diffuse flow to the associated BMP.

- Forebays should be located at each inflow point to the BMP. The conveyance system may be aligned to discharge into one forebay or several, as appropriate for the particular site.
- An integrated BMP system, including the forebay and any downstream BMPs, should be capable of passing the 10-year storm event without erosion or failure of the system.

### ALTERNATIVE DESIGN CRITERIA

Forebays in offline systems may be oversized if designed using the guidance previously presented. Forebays in offline systems should be sized using accepted engineering principals and best professional judgment. Sizing should take into consideration the peak flow diverted to the BMP via the flow bypass structure and the associated velocity exiting the forebay.

### DESIGN AND CONSTRUCTION CONSIDERATIONS

When selecting a forebay location, the designer must take into account topography. The forebay should be oriented to conform to the contours of the site. Typically, the forebay is placed at the highway drainage system outlet. Alternatives should be considered when steep slopes are located at a discharge point. For example, a riprap lined channel can be constructed at a pipe outlet to then discharge into a forebay. This method is sometimes applied in gore areas at highway interchanges.

Additional design recommendations follow:

- Locate the forebay outside of clear recovery zones.
- Confirm that the forebay has easy access for maintenance.
- Check the available right-of-way when determining the forebay footprint and orientation.
- Direct off-site diffuse flow around or away from the forebay, where practical.

## 7.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance. Figure 7-5 illustrates the difference between a maintained forebay and a forebay in need of cleaning.

**Figure 7-5.** Maintained forebay (left) and forebay in need of sediment removal (right)

Where possible, provide an area on site where sediment removed from the forebay can be disposed. The area should be relatively flat to promote stabilization after sediment is deposited. The sediment disposal area should also be gently sloped away from the forebay to prevent deposited sediment from reentering. The sediment disposal area should be configured in a manner that prevents adverse effects to receiving waters or adjacent properties.

## 7.5 Safety Considerations

Forebays located in residential or public areas may present a drowning hazard. Consider fencing and signage around the area to ensure safety. Refer to Section 866 of the NCDOT Standard Specifications (NCDOT.08) for fencing options.

# CHAPTER 8 Hazardous Spill Basin

## OVERVIEW

A HAZARDOUS SPILL BASIN is a BMP designed to protect surface water quality by detaining hazardous materials accidentally released on roadways near designated sensitive water supplies and concentrated truck usage areas.

### PURPOSE AND DESCRIPTION

- Hazardous spill basins are structural BMPs designed to temporarily detain hazardous materials.
- Inflow to the basin is trapped by an outlet structure until emergency response activities are complete and the hazardous material is removed.
- Under normal operation, hazardous spill basins do not restrict the free flow of runoff.

### APPLICATIONS

- Hazardous spill basins can be implemented at concentrated truck usage areas and along certain roadways.
- For linear highway applications, hazardous spill basins are provided at stream crossings on rural and urban arterials for specific classifications of streams.
- Hazardous spill basins can be integrated into an BMP system with other structural BMPs that target removal of solids and dissolved pollutants.

### WATER QUALITY BENEFITS

- Hazardous spill basins provide both a public safety and an environmental service by preventing the contamination of receiving waters.

## 8.1 Description

Hazardous materials to support various industries are transported on North Carolina roadways. To protect against the accidental release of hazardous material into receiving waters, hazardous spill basins are implemented at select locations. A hazardous spill basin is a permanent structural BMP with an outlet structure capable of blocking the normal free flow of runoff to retain a spill of hazardous material. Hazardous spill basins provide surface water quality benefits by preventing the contamination of critical water supplies. Figure 8-1 is a photo of a typical hazardous spill basin.

**Figure 8-1**. Typical hazardous spill basin

Emergency response to a hazardous material release is coordinated through the North Carolina Division of Emergency Management (NCEM). NCDOT supports NCEM spill containment efforts involving vehicular accidents on state roads, rights-of-way, and adjacent properties when requested. Further, NCEM regional response teams are trained in various hazardous spill containment techniques and maintain portable equipment for that purpose. More information on emergency response can be found at the NCEM website. Hazardous spill basins are intended to support NCEM response efforts by acting as a secondary BMP when standard emergency response protocols are not adequate to contain a spill.

Hazardous spill basins have the following main components:

- Basin
- Outlet structure
- Obstruction materials (optional)

Runoff and hazardous material typically enter a hazardous spill basin as a point discharge from the roadway or parking lot stormwater drainage system. However, runoff may enter the hazardous spill basin as diffuse flow or as discharge from a pretreatment BMP. Hazardous spill basins are sized to contain the runoff volume from a portion of small, frequently occurring storm events plus additional volume to contain a spill. During normal operation, stormwater runoff flows through the system without detention. In the event of a hazardous material spill, the outlet pipe is obstructed by various mechanisms to prevent the release of hazardous material into a receiving stream.

Typical examples of a hazardous spill basin layout and its components are shown in Figures 8-2 and 8-3.

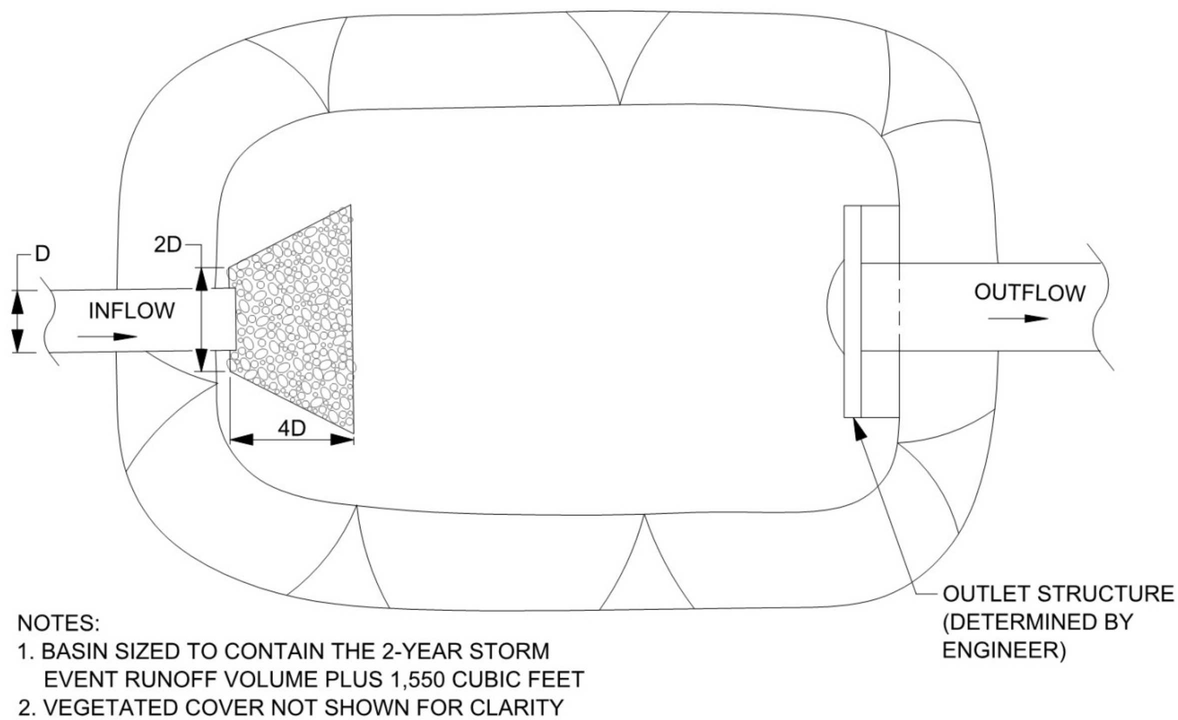



**Figure 8-2.** Plan view: typical hazardous spill basin layout and components

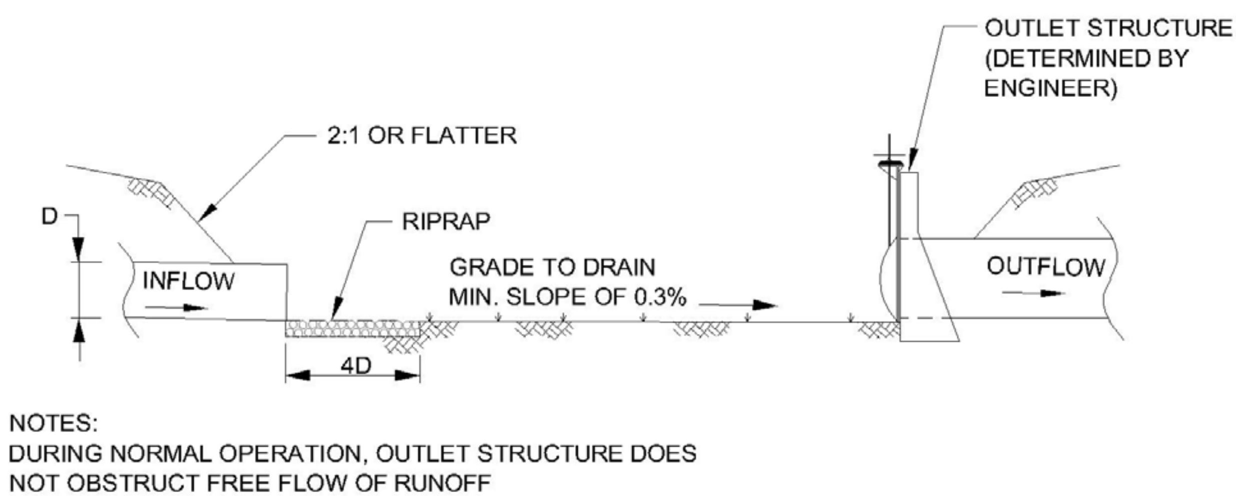



**Figure 8-3.** Profile view: hazardous spill basin cross section

## 8.2 Applications

Hazardous spill basins are applicable at NCDOT industrial facilities and in priority linear highway applications (see Figure 8-4). Hazardous spill basins have been implemented at weigh stations, runaway truck ramps, and rest area truck parking lots. Refer to the NCDOT *Guidelines for Drainage Studies and Hydraulic Design* (NCDOT.03) for guidance on determining if a hazardous spill basin is appropriate.

**Figure 8-4.** A hazardous spill basin at a rest area (left) and in a linear highway setting (right)

Once it is determined that a hazardous spill basin is applicable based on the roadway classification and proximity to an applicable receiving stream, site-specific factors should be evaluated. For example, if a rural arterial does not support tanker truck or other hazardous material transport vehicle of adequate volume to pose a significant risk of a hazardous spill, a hazardous spill basin may not be necessary. The accident potential related to highway geometrics, ease of human access to the basin, and feasibility of basin construction should also be considered.

For Transportation Improvement Projects (TIPs), designers should consult the NCDOT TIP planning document for general recommendations on the use of hazardous spill basins.

## 8.3 Design

The hazardous spill basin comprises a naturally depressed or excavated basin and an outlet structure that can be closed during a hazardous spill event. Hazardous spill basins do not detain stormwater and are not necessarily designed to remove suspended solids; therefore, the standard 3:1 length-to-width ratio for most stormwater control basins does not apply.

All runoff from truck parking lots at NCDOT industrial facilities must be collected via curb and gutter and conveyed to the hazardous spill basin via impervious conveyance, such as a pipe, gutter, or flume.  At these facilities, surface flow into the hazardous spill basin via swale or filter strip is not allowed.

## BASIN SIZING CRITERIA

Hazardous spill basins are sized to temporarily store the runoff volume from the 2-year, 10-minute storm event plus an additional 1,550 $ft^3$ (approximately 11,600 gallons). The following equation should be used to calculate the basin volume.

$$V_{HSB} = 60CIAt_d + 1{,}550$$

Where

| | | |
|---|---|---|
| $V_{HSB}$ | = | volume of the hazardous spill basin ($ft^3$) |
| C | = | rational method runoff coefficient (dimensionless) |
| I | = | average rainfall intensity (in./hr) for the 2-yr storm event with a $t_c$ = 10 minutes (minimum) |
| A | = | size of the drainage area (acres) |
| $t_d$ | = | time of duration (minutes) = 5 minutes |

In addition to the above volume requirement, a freeboard of one foot or greater should be incorporated into the design. Like most BMPs, the entire system should have the capacity to convey the 10-year storm event without system failure or degradation of the receiving stream. The actual shape of the basin is limited only by site-specific constraints. All efforts should be made to orient the hazardous spill basin to facilitate ease of operation and maintenance and to minimize the required right-of-way area. The basin design can be determined by using the criteria outlined in the box entitled Basin Design Criteria Summary.

### BASIN DESIGN CRITERIA SUMMARY

- ❒ The basin side slopes should be 2:1 or flatter.
- ❒ The basin should be designed to contain the runoff volume from the 2-year, 5-minute duration storm event plus 1,550 $ft^3$ (approximately 11,600 gallons).
- ❒ At a minimum, the basin should be designed with 1 foot of freeboard.
- ❒ At a minimum, the basin should be capable of conveying the 10-year storm event without failure or downstream erosion.

## OUTLET STRUCTURE DESIGN CRITERIA

Typically, the hazardous spill basin outlet structure consists of an outlet pipe, a sluice gate, and a concrete head wall supporting the sluice gate. Any mechanical or nonmechanical means that stops and contains the flow within the basin can be implemented. The outlet structure should be designed to quickly and readily contain hazardous materials. Whether the hazardous spill basin will be under close scrutiny (i.e., at rest areas) or infrequently visited should be considered when choosing the outlet structure. Non-mechanical means of blocking the outlet pipe include the storage of an obstruction material, such as sandbags, near the hazardous spill basin.

The traditional sluice gate and concrete end-wall option is discussed in this section. An example of a sluice gate in a hazardous spill basin is shown in Figure 8-5. All alternative designs are subject to approval by the NCDOT Hydraulics Unit.

**Figure 8-5**. A sluice gate in a hazardous spill basin

### *Outlet Pipe*

The invert of the outlet pipe should be located as near the invert of the basin as possible to prevent the detention of runoff and the buildup of sediment. At a minimum, the outlet pipe should be sized to convey flow from the 10-year storm event. All riprap used for energy dissipation purposes should be placed beneath the pipe in accordance with NCDOT Standard Drawing No. 876.02 (NCDOT.07).

### *Sluice Gate*

A sluice gate is a vertically sliding valve typically mounted to a concrete wall with anchor bolts. The purpose of the sluice gate is to stop the flow of runoff. The sluice gate is left open during normal operation. In the event of a spill, the gate is closed by the hazardous material transporter or an emergency responder. The sluice gate should form a watertight seal. Steel sluice gates are commonly applied in hazardous spill basins, although alternative materials can be considered. All sluice gates should be designed in accordance with NCDOT Standard Drawing No. 838.02 (NCDOT.07). Sluice gate dimensions, including gate diameter and frame height, are provided in the standard drawing as a function of the outlet pipe diameter. General design criteria are provided in the Outlet Structure Design Criteria Summary.

### *Concrete End Wall*

The concrete end wall around the outlet pipe is constructed with Class B concrete to support the sluice gate. The design of concrete end walls for use with sluice gates is also shown in NCDOT Standard Drawing No. 838.02 (NCDOT.07). The thickness of the base will vary as a function of the outlet pipe diameter.

Modification of the concrete end wall may be required, depending on the sluice gate dimensions and attachment method. The designer should consult the manufacturer's instructions for installation of the sluice gate before constructing the end wall.

## OUTLET STRUCTURE DESIGN CRITERIA SUMMARY

***Sluice Gate***

- The sluice gate diameter should be a minimum of 7 inches larger than the outlet pipe diameter.
- The manufacturer's dimensions and specifications should be used to properly install the sluice gate.
- Refer to NCDOT Standard Drawing No. 838.02 (NCDOT.07).

***Concrete End Wall***

- Class B concrete should be used.
- The height of the concrete end wall should be 10 feet or less and is dependent on the pipe diameter.
- The concrete end wall should be chamfered 1 inch on all exterior corners.
- Refer to NCDOT Standard Drawing No. 838.02 (NCDOT.07).

## DESIGN AND CONSTRUCTION CONSIDERATIONS

One measure of a successful hazardous spill basin application is the ease with which someone could locate and close the outlet device during an emergency. In addition, the hazardous spill basin should allow access for appropriate maintenance equipment. Alternative hazardous spill containment options should be considered if the basin cannot be accessed for operation and maintenance. Additional design and construction recommendations follow:

- Consider whether bypass or diversion of off-site drainage is necessary based on site constraints.
- Verify soil types using soil survey maps or existing geotechnical reports.
- Use impermeable liners in regions with karst topography (southeastern Coastal Plain) to prevent collapse of underlying soils.
- Locate the outlet structure outside of clear recovery zones.
- Check the available right-of-way when determining the basin footprint and orientation.
- Use proper energy dissipation where perpendicular or angular inflows to the hazardous spill basin are necessary.
- Specify rust-resistant outlet control structure components.
- Use forms to construct the bottom slab of the concrete end wall. When the base is poured separately, leave the concrete surface rough.
- Stabilize all basin system outlets to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042 (NCDOT.08) and NCDOT Standard Drawing No. 876.02 (NCDOT.07).
- Consider a flush-bottom sluice gate to prevent the buildup of debris beneath the gate. If a nonmechanical means is chosen to obstruct the outlet pipe, select materials that can

be quickly moved into the basin without the aid of a shovel, such as sandbags. The materials should be relatively lightweight so they can be easily lifted by the average person.

- Consider covering obstruction materials with a tarp to prevent grass growth.
- Evaluate the impact that a fence will have on the ability to operate the hazardous spill basin in an emergency. At some sites, a fence may be necessary to prevent public access and vandalism. However, emergency responders and emergency equipment must be able to quickly access the hazardous spill basin.

## 8.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance.

# CHAPTER 9 Bridge Best Management Practices

## OVERVIEW

BRIDGE BEST MANAGEMENT PRACTICES often involve both bridge drainage systems and BMPs to dissipate energy, minimize bank erosion, and reduce pollutant loads before runoff enters surface waters.

### PURPOSE AND DESCRIPTION

- Bridge BMPs are designed to integrate roadway and bridge drainage conveyances and overbank areas to provide stable discharge conveyance and facilitate stormwater management.
- Bridge BMPs are designed to meet highway safety standards and minimize stormwater pollution at environmentally sensitive areas.
- The configuration of drainage conveyances can vary, depending on bridge type, available shoulder width, receiving water body, available right-of-way, and topography.

### WATER QUALITY BENEFITS

- Bridge BMPs reduce sediment loads to receiving waters by employing techniques that minimize erosion from drainage conveyances.
- Bridge BMPs often include other BMPs, such as preformed scour holes, hazardous spill basins, and infiltration basins to reduce pollutants.

### APPLICATIONS

- Bridge BMPs are applied to all new bridge projects and all bridge replacement projects.
- Managing stormwater runoff from bridges presents a unique challenge due to structural constraints and the limited space available for conveyance and treatment.

## 9.1 Description

Due to their close proximity to receiving waters, bridges present a unique combination of opportunities and challenges for protecting the safety of the traveling public while concurrently protecting instream water qualty. Bridge best management practices are stormwater management techniques employed to convey stormwater to receiving waters while minimizing impacts in these challenging areas. An example of a bridge BMP is the practice of considering both roadway and bridge deck runoff and providing adequate conveyances, slope stabilization, and energy dissipation to accommodate these flows. Value engineering and environmental site design (i.e., identifiying opportunities to maximize the use of existing site features to achieve stormwater management goals) are encouraged to achieve the desired water quality results in a safe and cost-effective manner.

Bridge BMPs utilize a combined runoff management approach that may include one or a combination of the following: (1) land-based BMPs receiving bridge runoff; and (2) BMPs on the bridge structure. Figures 9-1 and 9-2 provide examples of bridge conveyance configurations employing various BMPs.

**Figure 9-1.** An example of a bridge configuration that employs some common bridge BMPs: dense ground cover, integrated road and bridge drainage conveyances

**Figure 9-2.** An example of a bridge configuration that employs common bridge BMPs: adequate ground cover and slope stabilization; as well as less frequently used BMPs: a closed deck drainage system and a downstream BMP

As rain falls on the bridge, it is routed to the gutter and exits through the deck drains or drainage structures at the end of the bridge. In some drainage conveyance configurations, runoff will free fall from the deck drains onto the area or water body (i.e., direct discharge) below. Note that direct discharge is only allowed in a few situations and requires approval from the State Hydraulics Engineer. Alternatively, runoff may be conveyed to the end(s) of the bridge to the roadway drainage system. If the bridge gutter is not sufficiently wide to convey runoff, a closed deck drainage system may be used. Closed deck drainage systems have a longitudinal pipe that collects runoff from the deck drains and transports it to a downstream collection system, another BMP, or an energy dissipation device. Design information about BMPs that can be applied downstream of a bridge drainage system is presented in other chapters of this toolbox. The purpose of this chapter is to introduce varying methods used to effectively manage stormwater runoff from bridges and minimize impacts.

The configuration of the bridge drainage conveyance depends on the bridge type and size and the characteristics of the water body. Some examples of bridge drainage conveyance configurations follow:

- No deck drains
- Deck drains over land and none over the water body
- Deck drains discharging directly over the water body
- A closed system with a longitudinal drain pipe spanning sections or the entire length of the bridge

Figures 9-3 and 9-4 show various bridge drainage conveyance components and configurations.

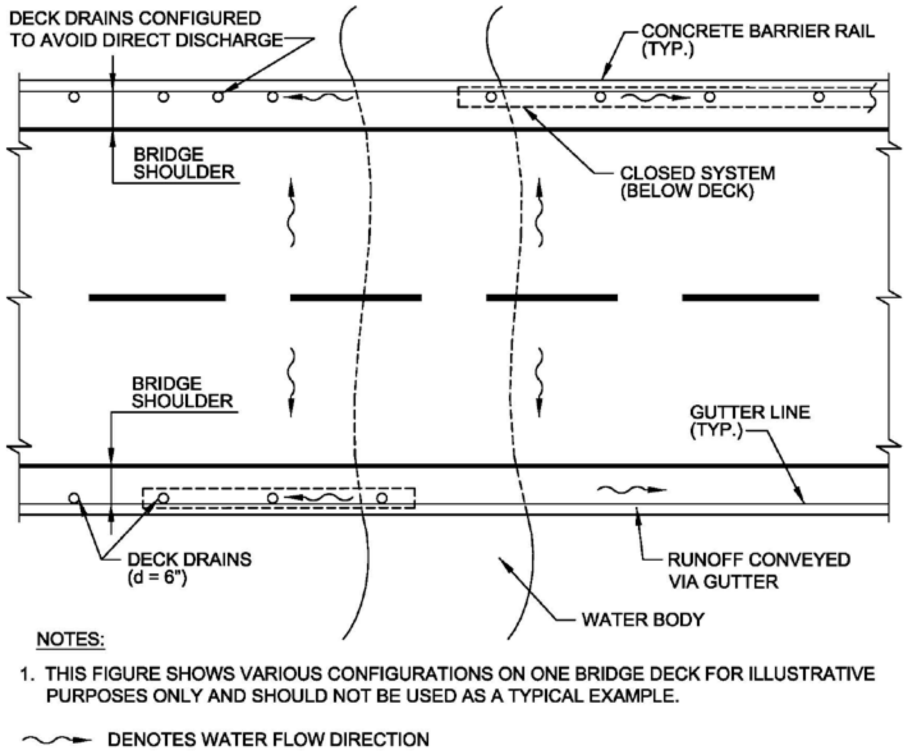
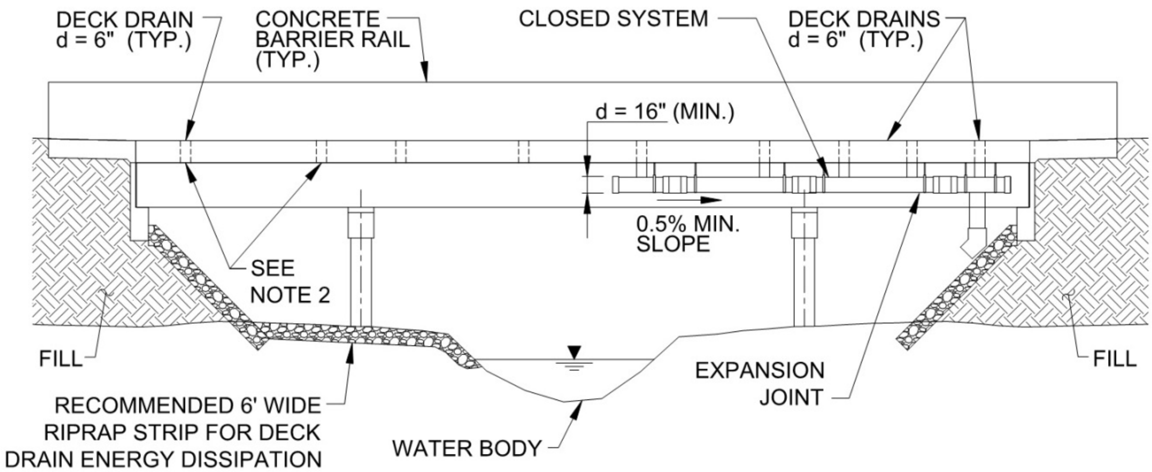



**Figure 9-3.** Plan view: varying bridge drainage conveyance configurations for a girder bridge




NOTE:

1. THIS FIGURE SHOWS MULTIPLE CONFIGURATIONS ON ONE BRIDGE DECK FOR ILLUSTRATIVE PURPOSES ONLY AND SHOULD NOT BE USED AS A TYPICAL EXAMPLE.
2. DECK DRAINS SHOULD BE AT LEAST 5 FEET FROM END BENTS AND EITHER SIDE OF EACH INTERIOR BENT.

**Figure 9-4.** Profile view: varying bridge drainage conveyance configurations for a girder bridge

There are several BMPs that may be applied to achieve road and bridge drainage configurations that safely convey stormwater from the transportation facility and help to protect instream water quality. Bridge BMPs may be applied directly to the bridge structure or to the adjacent land area below and surrounding the bridge. Table 9-1 gives an overview of some common bridge BMPs.

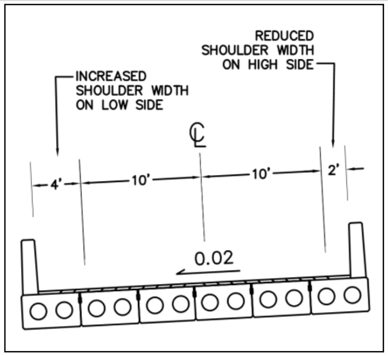
**Table 9-1.** Bridge BMP overview

**Bridge Deck Drainage Design (BDDD)**
A DESIGN-BASED BMP THAT MINIMIZES AND HYDRAULICALLY DISCONNECTS IMPERVIOUS AREA AND REDUCES DIRECT DISCHARGE TO RECEIVING WATERS.

BDDD is a design practice where hydraulic design decisions are made to reduce impervious area on the bridge deck, to minimize direct discharge to the receiving water, or to separate runoff into smaller drainage areas for ease of management.

**Key Considerations**

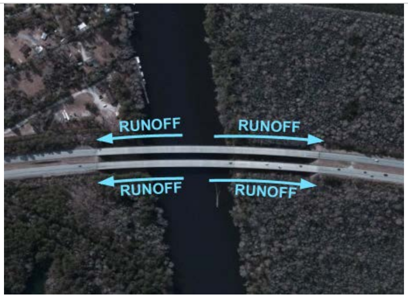
- NCDOT flow spread criteria must be considered in the widening design.
- Appropriate collection, conveyance, and BMP(s) should be provided where deck conveyance reaches the end of the bridge.
- Maintenance activities include removal of sediment, trash, and debris in the flow path.
- Existing well-vegetated areas around and underneath the bridge are ideal release areas for runoff and should influence the location of discharge points when possible.
- Safety of the travelling public must always be the foremost design concern. The designer should carefully consider the effects of water on the bridge and must meet NCDOT flow spread criteria.




**Adjusted Shoulders on Superelevated Bridges**

- Reducing the width of the high side shoulder on superelevated bridges to allow for a wider low side shoulder to eliminate deck drains and subsequently reduce direct discharge.
- Runoff can then be routed to pervious areas where infiltration and settling of solids can occur.

*Photo caption: Shoulder adjusted on superelevated bridge*



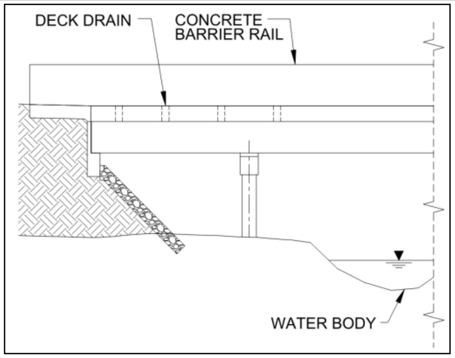

**Bridge Designed to Crest in Center**

- Designing the bridge to crest in the center (of the vertical curve) to create two smaller drainage areas in order to decrease the volume of concentrated stormwater runoff to a given discharge point.
- Provides greater area to treat a smaller volume of runoff resulting in better pollutant removal.

*Photo caption: Crest in center of structure*

**Table 9-1.** Bridge BMP overview (continued)

**Bridge Deck Drainage Design (BDDD) (continued)**




**Eliminate Deck Drains Over Water Body**

- Eliminating deck drains over a portion of the bridge deck to route runoff to natural areas and minimize direct discharge.
- Designer should verify that there is adequate dispersion, vegetative cover, or erosion protection below deck drains.

*Photo caption: Deck drains eliminated over stream*

**Widen Bridge to Convey Runoff Via the Shoulder**

- Increasing the overall width of the bridge to accommodate wide shoulders for runoff conveyance so that deck drains and direct discharge may be avoided.
- Given the additional costs, this may be the least desirable BDDD option.

*Photo caption: Bridge width increased to convey runnoff via shoulder*

**Table 9-1.** Bridge BMP overview (continued)

## Closed Deck Drainage Systems

A SYSTEM THAT INCLUDES A LATERAL TRUNK LINE AND DECK DRAINS TO COLLECT AND CONVEY RUNOFF IN A MANNER THAT AVOIDS DIRECT DISCHARGE TO THE RECEIVING WATER.

Closed deck drainage systems are designed to collect runoff from the bridge deck during a design storm event and convey the runoff to an area beneath or adjacent to the bridge.

**Key Considerations**

- Appropriate BMPs should be considered at the outlet location to dissipate energy and prevent erosion.
- Expansion fittings should be considered in the design at bridge beam joints and other locations.
- Significant maintenance burden should be anticipated, including removal of solids, trash, and debris; and the repair of separated or broken sections of pipe.
- Closed deck drainage systems are expensive to construct and maintain, and have a short lifespan. For these reasons closed deck drainage systems should only be applied when one or more of the other bridge BMPs described in this chapter are deemed insufficient to protect instream water quality standards.

## Environmental Site Design (ESD)

UTILIZATION OF EXISTING SITE FEATURES TO ACHIEVE STORMWATER MANAGEMENT GOALS.

Environmental Site Design (ESD) uses existing natural features on a project to help maintain predevelopment runoff characteristics with minimum modification. Examples of ESD techniques include dispersing runoff through existing wooded areas and vegetation and using naturally depressed areas for runoff storage.

**Key Considerations**

- Additional right-of-way or easements may be required to utilize natural topography.
- The natural topography should match the final graded needs of the BMP to which ESD is being applied.
- Applying ESD practices to a BMP should not increase the required design.
- In most cases, energy dissipation will be needed upgrade of a natural ESD. In addition to energy dissipation, other ESDs may require retrofitting (e.g., installing an outlet structure).
- ESDs reduce construction effort and cost as well as require less maintenance in most cases.

**Table 9-1.** Bridge BMP overview (continued)

### Energy Dissipation

STRUCTURAL POLLUTION-PREVENTION BMPS THAT REDUCE THE ENERGY OF FLOWING RUNOFF BY SLOWING VELOCITY AND ENCOURAGING DIFFUSE FLOW, THEREBY REDUCING EROSION AND SCOUR POTENTIAL.

Energy dissipators can be implemented downgrade of a bridge deck and can receive stormwater from several sources including bridge deck drains, closed conveyance systems, and open channels. Common energy dissipators include preformed scour holes and rock aprons.

**Key Considerations**

- Energy dissipators should be considered during right-of-way acquisition.
- Energy dissipators should be designed to reduce velocity of the discharge point to a non-erosive rate for the design storm of the contributing facility, typically the 10-year event.
- Energy dissipators should be sited on level grade, where possible. At minimum, the downgrade edge of the dissipator must be level and perpendicular to the flow line.
- Maintenance activities include removal of sediment, trash, and debris. Riprap may need to be replaced periodically.

**Table 9-1.** Bridge BMP overview (continued)

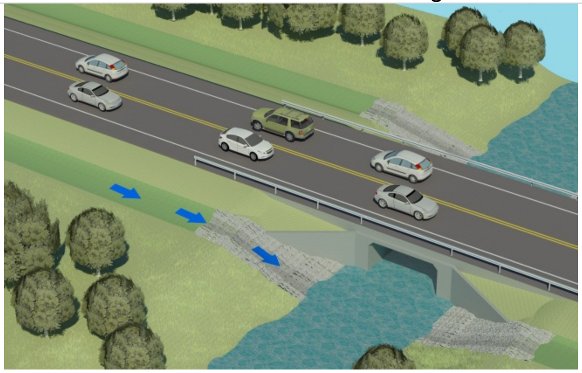
## Stream Bank Drop Structure

STRUCTURAL POLLUTION-PREVENTION BMPS DESIGNED TO SAFELY CONVEY BRIDGE DECK AND/OR ROADWAY RUNOFF INTO A WATERWAY.

The objective of a stream bank drop structure is to minimize erosion caused by concentrated stormwater flows when vegetative cover does not provide adequate protection. Stream bank erosion can result in structural instability of the banks and sedimentation in the receiving water thus increasing the impact on the stream. Stream bank drop structures generally consist of riprap, closed conveyances, or drainage structures.

**Key Considerations**

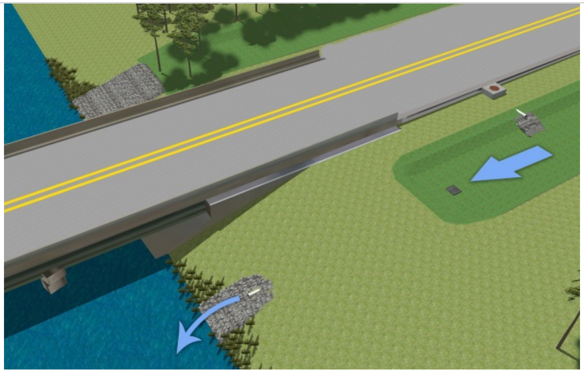
- Approval and applicable permits will be required from governing environmental agencies to allow construction on the stream bank.
- The contributing factors to stream bank erosion must be evaluated and identified in order to select the most appropriate stabilization method.
- Vegetative stabilization in conjunction with structural stabilization should be evaluated.
- At minimum, structures should be designed for the 10-year storm event. The hydraulic capacity of upstream conveyances and the high water surface elevation of the existing stream should be considered in the design.



**Riprap Bank Drop Structure**

- Riprap channels are commonly used to effectively convey runoff from roadway and bridge drainage conveyances to the water body.
- Standard open channel design procedure should be used with an emphasis on providing adequate stabilization.

*Photo caption: Riprap utilized as bank drop structure at bridge*



**Concrete Box Drop Structure**

- Concrete box drop structures are often used to drain low areas or depressions.
- Proper outlet protection should be provided.
- The outlet should be designed to achieve diffuse flow where practicable.

*Photo caption: Runoff coveyed via concrete box drop structure near bridge*

**Table 9-1.** Bridge BMP overview (continued)

## Slope Stabilization

PERMANENT MEASURES USED TO MINIMIZE EROSION PARTICULARLY ON GRADED AND DISTURBED SLOPES

Slope stabilization measures are targeted to areas around the bridge approach where the slope of the embankment or overbank area is such that vegetated ground cover may not be enough to prevent erosion. Riprap slopes and permanent erosion control matting are both examples of post-construction slope stabilization measures.

**Key Considerations**

- Riprap used for slope stabilization should be selected so that the gradient of the slope to be stabilized is less than the riprap's natural angle of repose.
- Excessively steep slopes may require special stability analysis.
- Selection of slope stabilization technique should consider ways to reduce costs and long-term maintenance needs.
- Rock and permanent matting should be installed to avoid erosion around and underneath the area of stabilization. Permanent matting should be keyed into the upgrade slope and other edges properly secured.

## Adequate Ground Cover

A DESIGN-BASED BMP WHERE APPROPRIATE GROUND COVER IS SELECTED TO MINIMIZE EROSION

A dense and vigorous vegetative cover provides cost-effective protection to surficial soils from the erosive impacts of rainfall and runoff, maintains good soil moisture, and can increase soil porosity to improve infiltration.

**Key Considerations**

- Different species of vegetation have varying permissible velocities.
- Steeper slopes require more vigorous vegetative cover, temporary soil stabilization measures, and longer establishment periods.
- Planting season and regional climatic and soil variations will also affect vegetation selection.
- When selecting plant species and supplements to seed mixtures for ground cover in the linear environment, consider the degree of maintenance expected. More information on species selection can be found in Chapter 3 of the *Erosion and Sediment Control Planning and Design Manual* (NCDENR .01).

**Table 9-1.** Bridge BMP overview (continued)

## Dispersed Discharge

DISPERSED DISCHARGE IS INTENDED TO PROVIDE RAPID MIXING AND GREATER DILUTION WITH THE RECEIVING WATER BODY.

Dispersed discharge typically includes multiple deck drains located above the water body such that runoff is distributed over a large area allowing for rapid mixing and dilution with the receiving water.

**Key Considerations**

- Most appropriate on long bridges over large water bodies.
- Some policies and regulations may restrict the use of dispersed discharge in some locations.
- Use of dispersed discharge requires cost analysis and approval by the State Hydraulics Engineer.

*Photo caption: An example of dispersed discharge*

## 9.2 Applications

The bridge BMPs described in this chapter may be implemented to protect water quality standards. At a minimum, BMPs that provide adequate outlet protection and slope stabilization should be applied to every bridge project.

Bridges often present unique challenges and design constraints when compared to other transportation projects. Spread along the bridge structure should be limited to the shoulder width to minimize the potential for roadway hazards such as hydroplaning or icing. Direct discharges are permissible provided that water quality standards are protected.

## 9.3 Design

This section summarizes design information for bridge drainage conveyances only. For more information on design criteria and considerations for BMPs, the designer is directed to the appropriate chapter in this toolbox.

For shorter bridges, the bridge gutter may be adequate to handle bridge runoff without the use of deck drains. In these cases, runoff may be routed to a drainage structure at the end(s) of the bridge. Longer span bridges may require deck drains and/or closed deck drainage systems. The configuration of a closed deck drainage system can be unique, depending on the existing roadway drainage collection system and other structural components of the bridge. In general, it is preferable to avoid closed deck drainage systems, if possible, because of their increased cost, short lifespan, and maintenance requirements. An assessment should be made to determine whether installing a closed deck drainage system or constructing a wider bridge to accommodate runoff is more cost-effective.

The designer should reference the *NCDOT Structure Design Unit–Design Manual* (NCDOT.06) for information about structural components of bridges. For a comprehensive review of bridge drainage design methods, the designer is directed to the FHWA Hydraulic Engineering Circular No. 21 (HEC 21) entitled *Design of Bridge Deck Drainage* (FHWA.01).

### DECK DRAINS

#### *Deck Drain Spacing*

Deck drain spacing is a function of the allowable spread on the bridge and discharge location with respect to the receiving water. To determine deck drain spacing, the designer should calculate the peak rate of runoff using the rational formula with a design storm intensity of 4 in/hr and an appropriate runoff coefficient (C). The procedure and equations for calculating deck drain spacing are provided in HEC 21. Regardless of whether a closed deck drainage system is implemented, the constant distance between deck drains is calculated and adjusted to account for structural constraints.

Standard deck drain spacing can be found in the *NCDOT Structure Design Unit–Design Manual* (NCDOT.06. Generally, a standard spacing of 12-foot centers for girder bridges and 6-foot centers for cored slab and box beam bridges may be used. These standards should be confirmed for each individual project based on calculated spread width using the spacing methodology outlined in HEC 21. Minor adjustments in spacing should be made as needed to accommodate structural and other bridge features such as reinforcing steel. Deck drains should be at least 5 feet from end bents and either side of each interior bent.

### *Deck Drain Orientation*

For girder bridges, deck drains should be 6 inches in diameter, oriented vertically through the bridge deck. Steel girder bridges have an additional requirement that deck drains extend 3 inches below the bottom elevation of the girder. Deck drain orientation is illustrated in Figure 9-5.

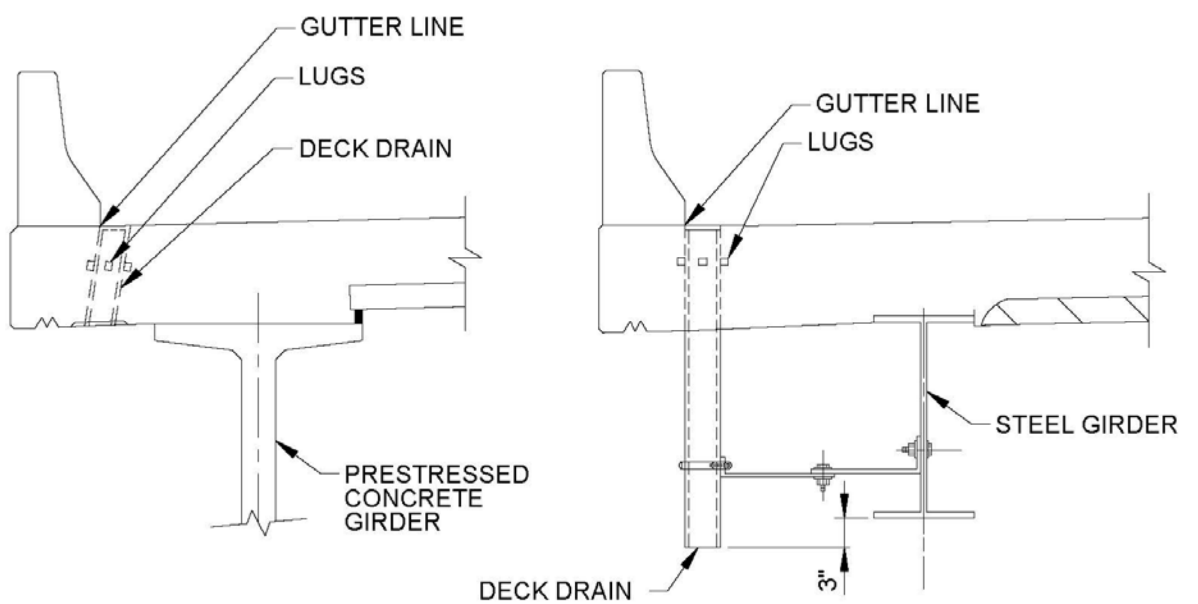



**Figure 9-5.** Deck drain orientation for prestressed concrete (left) and steel (right) girder bridges

Deck drains for cored slab bridges should be 8 inches wide by 6 inches tall, oriented horizontally through the barrier rail. This will result in an approximate opening size of 8 inches by 4 inches after final paving. Similarly, deck drains for box beam bridges should be 5 inches wide by 6 inches tall, oriented horizontally through the barrier rail. This will result in an opening of 5 inches by 4 inches after final paving. Deck drains for cored slab and box beam bridges are illustrated in Figures 9-6 and 9-7, respectively.

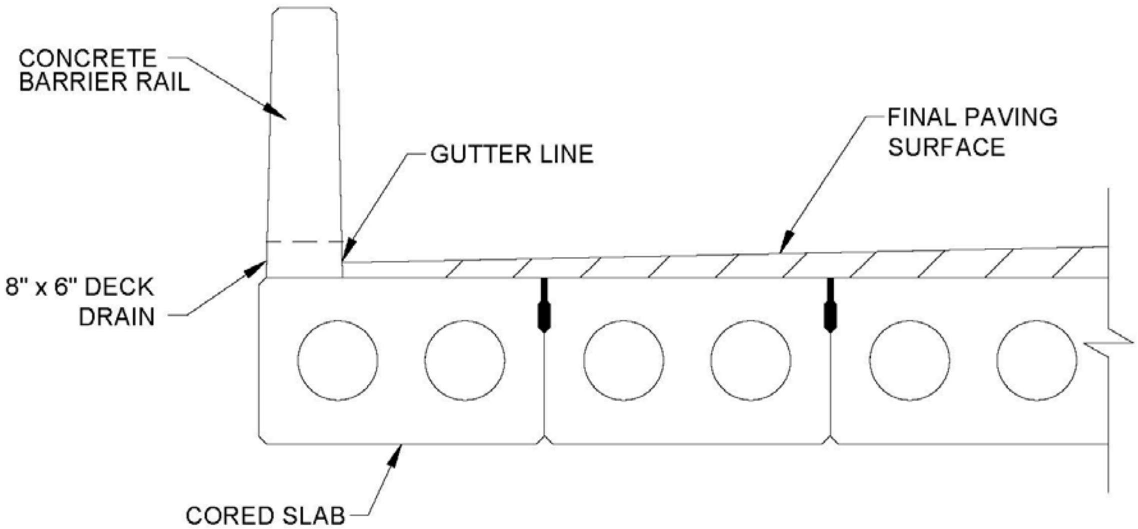



**Figure 9-6.** Deck drain orientation for cored slab bridges

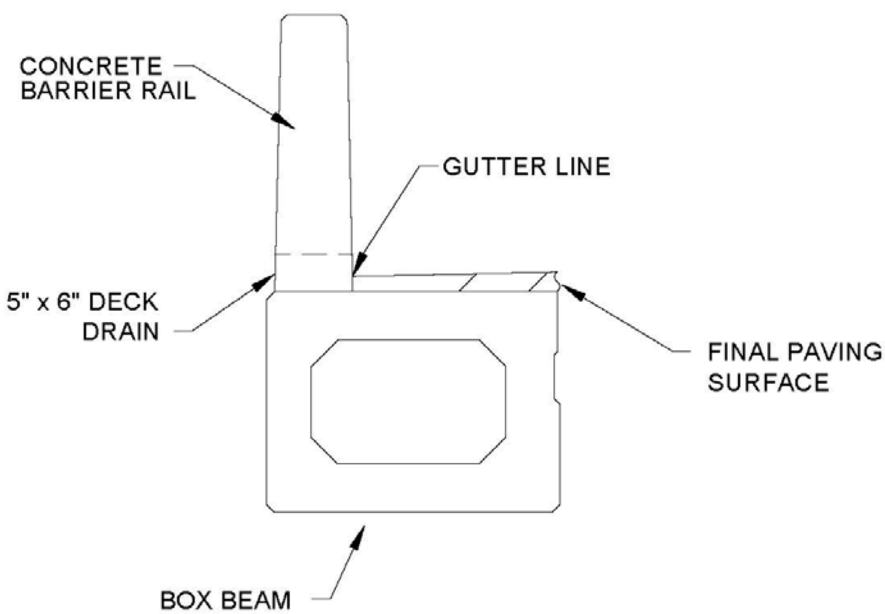



**Figure 9-7.** Deck drain orientation for box beam bridges

Design criteria are outlined in the box entitled Deck Drain Criteria Summary.

## DECK DRAIN CRITERIA SUMMARY

### ***Spacing***

- ❒ Runoff discharge on the bridge should be determined using the rational method with appropriate runoff coefficient.
- ❒ The design storm is the 4 in/hr intensity storm.
- ❒ Gutter spread and deck drain spacing should be determined as provided in HEC 21.

### ***Drain Dimensions and Orientation***

- ❒ Deck drain diameter for girder bridges should be 6 inches.
- ❒ For girder bridges, deck drains should be oriented vertically through the bridge deck (see Figure 9-5).
- ❒ For steel girder bridges, deck drains should extend a minimum of 3 inches vertically below the bottom elevation of the girder (see Figure 9-5).
- ❒ For cored slab and box beam bridges, deck drains should be oriented horizontally through the barrier rail (see Figure 9-6 and 9-7).
- ❒ Deck drains for cored slab should be 8 x 6 (W x H) inches minimum.
- ❒ Deck drains for box beam bridges should be 5 x 6 (W x H) inches minimum.

## CLOSED DECK DRAINAGE SYSTEMS

While avoiding direct discharge may be important in some cases, closed deck drainage systems have high capital and operating (maintenance) costs and a short lifespan. The varying coefficients of expansion between the bridge and the closed deck drainage system and degradation from ultraviolet light also present unique challenges. Closed deck drainage systems provide an area for trash and debris to buildup which can attract rodents and introduce an additional source of bacteria to stormwater runoff. Further, there are additional safety concerns associated with the maintenance required for closed systems. For these reasons, the closed deck drainage system BMP should only be used when the application of one or more of the other bridge BMPs described in this chapter are deemed insufficient to protect instream water quality standards.

Closed deck drainage systems have a longitudinal conveyance pipe attached underneath or alongside the bridge. This pipe may span partial sections or the entire length of the bridge. A closed deck drainage system that spans the entire bridge length may be more appropriate if (1) the longitudinal pipe can be tied into an existing roadway collection system, (2) there is limited land area beneath the bridge to implement energy dissipation controls, or (3) runoff must be routed to a BMP off of the bridge. If the overbank will be used to filter and infiltrate runoff or if runoff will be routed to a BMP beneath the bridge, a pipe that spans only the water body may be more appropriate. Standard deck drain spacing is 12 feet on center; however, use of this standard should be confirmed based on calculated spread widths using the deck drain spacing methodology presented in HEC 21.

Minimum longitudinal pipe diameter for NCDOT projects is 16 inches. To promote positive drainage, the minimum pipe slope should be 0.5%, unless otherwise directed by the Hydraulics Unit. Slotted openings should be incorporated at the connection between the deck drain and the longitudinal pipe to allow larger storm events to overflow the system. This pipe configuration is illustrated in Figure 9-8.

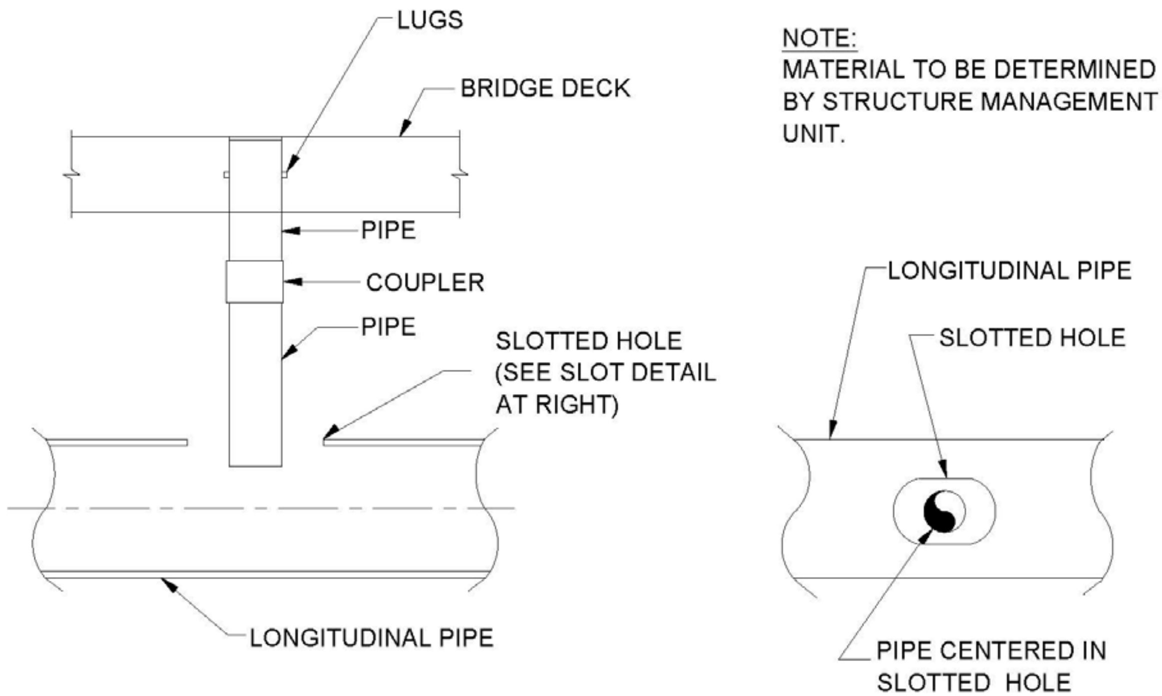



**Figure 9-8.** Elevation view (left) and plan view (right) of deck drain and longitudinal pipe connection

Longitudinal pipes may connect to adjacent roadway drainage collection systems, discharge to a riprap pad or preformed scour hole (refer to Chapter 4 of this toolbox) beneath the bridge, or outlet to another BMP adjacent to the bridge. Runoff should never be discharged onto an area that is erodable without sufficient protection. Design criteria are presented in the box entitled Closed Deck Drainage System Design Criteria Summary.

### Closed Deck Drainage System Design Criteria Summary

- ❒ The longitudinal pipe should have a minimum diameter of 16 inches.
- ❒ The longitudinal pipe should have a minimum slope of 0.5% unless otherwise directed by the Hydraulics Unit.
- ❒ Determine deck drain spacing according to allowable spread and water body characteristics.

### Energy Dissipation and Slope Stabilization

The potential erosive effects of deck drain configuration and spacing should be considered. The effect of any single deck drain is typically minimal; however, flow from multiple deck drains can reconcentrate, channelize, and erode the overbank. For this reason, deck drains should not be located over unprotected soils. A 6-foot wide strip of riprap is recommended below deck drains to protect against erosion. Overbanks should be stabilized by vegetation, riprap, or other materials and designed to convey stormwater from the bridge deck and any other contributing area such as adjacent roadway. Provisions for diffuse flow should be integrated into the bridge drainage conveyance design for buffers and other vegetated areas receiving runoff, where practicable.

Preformed scour holes or energy dissipators should be provided at closed system and roadway drainage system discharge outlets. Refer to Chapter 4 of this Toolbox for guidance on preformed scour hole design and FHWA Hydraulic Engineering Circular No. 14 (HEC 14) entitled *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA.05) for energy dissipation guidance.

### Design and Construction Considerations

The design of bridge drainage conveyances should be initiated early in the hydraulic and bridge design process. Drainage constraints may dictate the width or grades of the bridge. Further, it is important to ensure the roadway and bridge drainage system designs are integrated and that the overbank has proper erosion protection. Additional design and construction recommendations follow:

- Account for bridge structural components when determining the final deck drain spacing. In general, deck drains should be upslope and near expansion joints.
- Avoid routing longitudinal pipes through the bridge abutment, when possible.

## 9.4 Inspection and Maintenance

Proper inspection and maintenance is critical to the performance of bridge closed deck drain systems. Deck drains and longitudinal pipes are highly prone to clogging with solids, trash, and debris. Once the system becomes sufficiently clogged, the system does not efficiently remove stormwater runoff from the bridge as designed and the safety of motorists may be compromised.

NCDOT bridges are routinely inspected by NCDOT's Bridge Management Unit. Any identified maintenance needs are performed by the appropriate NCDOT Highway Division. It may be useful to discuss the probable cleaning methods for the drainage conveyances with the appropriate highway division personnel. Additional recommendations follow:

- Avoid unnecessary bends and T-connections that may become clogged with debris.
- Consider the access required for maintenance crews to safely work on and below the bridge.
- Identify and communicate any deficient surface cover, slope stabilization, or energy dissipation devices.

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for additional inspection and maintenance guidance.

# CHAPTER 10 Infiltration Basin

## OVERVIEW

An INFILTRATION BASIN is a water impoundment in permeable soils that detains and infiltrates stormwater runoff.

### PURPOSE AND DESCRIPTION

- Infiltration basins are created by forming a berm or excavation in areas where the native soil is sufficiently permeable.
- The primary outlet of the infiltration basin is percolation into the basin bottom.
- Infiltration basins are typically preceded by some form of pretreatment, such as a forebay, designed to remove larger particles before stormwater enters the basin.

### APPLICATIONS

- Infiltration basins are applicable only under specific site conditions. Adequate pretreatment, hydraulic conductivity, and depth to groundwater are critical for proper functioning of the basin.
- In North Carolina, infiltration basins are most widely implemented in the Coastal Plain due to the highly permeable soils in this region, but may be installed in other areas where soils permit.
- Infiltration basins function best in an offline configuration for drainage areas of 5 acres or less.

### WATER QUALITY BENEFITS

- By using infiltration as the primary outlet, infiltration basins reduce peak discharge to surface waters and recharge groundwater.
- The native soils in an infiltration basin act as a filter media, straining out solids and adsorbing dissolved pollutants.

## 10.1 Description

An infiltration basin is a permanent structural best management practice (BMP) that treats stormwater runoff by allowing it to percolate into the ground. Infiltration basins do not have underdrain systems and are located in areas where the hydraulic conductivity of the site soils is adequate for infiltration. Infiltration basins provide water quality control for runoff from storms equivalent to and smaller than the design storm. Because the design storm volume does not leave the basin and pollutants are adsorbed by surficial soils, infiltration basins are considered to have a high pollutant removal capacity.

Infiltration basins may have the following components:

- Bypass structure
- Pretreatment BMP
- Basin
- Embankment
- Emergency outlet control structure
- Access road

Runoff first enters a pretreatment device via a flow bypass structure. Once the larger stormwater particulates have been removed, the runoff is conveyed to the infiltration basin. For storm events equivalent to the water quality storm or smaller, runoff remains in the infiltration basin until it has percolated into the soil. Even though infiltration basins are implemented offline, some basins may have an emergency outlet control structure composed of a riser and an outlet pipe. In these cases, the height of the riser is equivalent to the water quality volume (WQv) elevation; therefore, the riser will discharge any storm event greater than the WQv.

The infiltration basin is created either by excavating the native soil to form a depression or by using earthen material to make a basin whose invert is equal to the natural ground elevation. A typical infiltration basin layout is shown in plan and profile views in Figures 10-1 and 10-2, respectively.

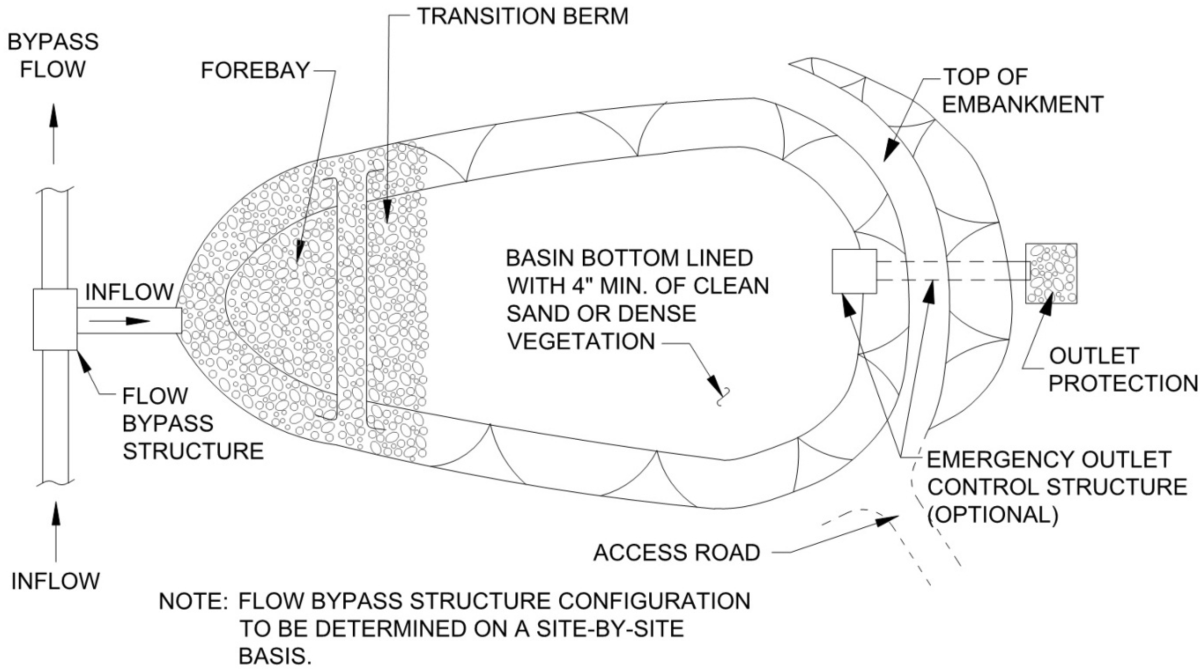



**Figure 10-1.** Plan view: infiltration basin and its components

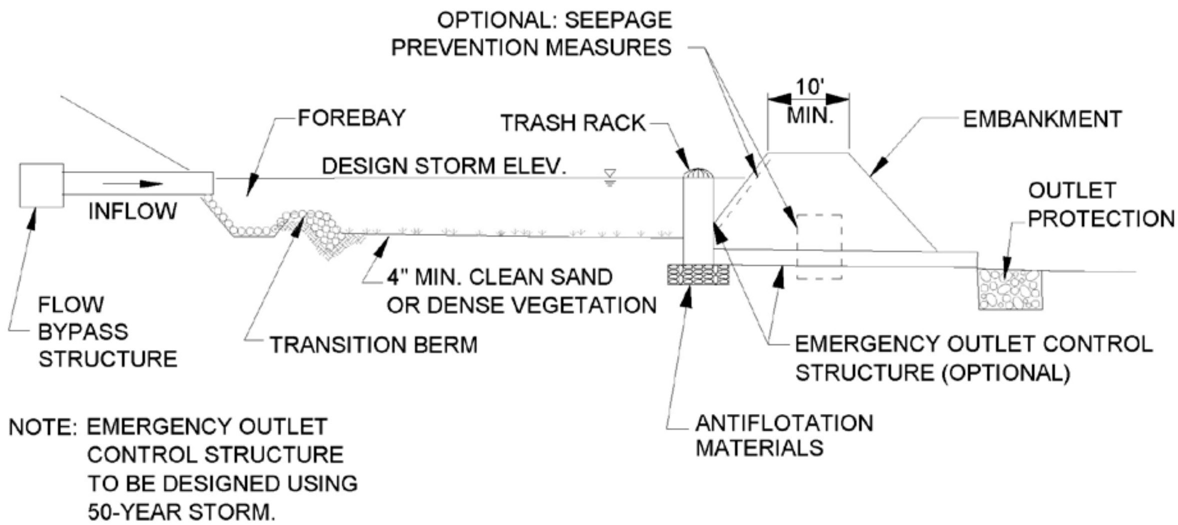



**Figure 10-2.** Profile view: infiltration basin and its components

## 10.2 Applications

Proper site selection is critical to the successful functioning of an infiltration basin. First, infiltration basins should not be placed within 50 feet of Class SA waters, within 30 feet of all other waters, and within 100 feet of water supply wells. Second, the site soils must have adequate hydraulic conductivity to draw down the level of stormwater in the basin within a 5-day period. Finally, the invert of the infiltration basin must be a minimum of 2 feet above the seasonal high groundwater table and a minimum of 3 feet above any bedrock or impervious soil horizon. If the distance between the natural ground elevation and the groundwater table or bedrock does not meet these criteria, the site is not suitable for an infiltration basin.

The hydraulic conductivity and the depth to the seasonal groundwater table must be evaluated by a subsurface investigation, typically performed by the NCDOT Geotechnical Engineering Unit. Using best engineering judgment, the designer should determine the number of borings necessary to evaluate a particular site. Infiltration basins should not be sited in fill material or in areas of karst topography.

Infiltration basins are applicable when objectives are to reduce peak flow rates and remove suspended solids and dissolved pollutants. Figure 10-3 depicts the pollutant removal processes for an infiltration basin.

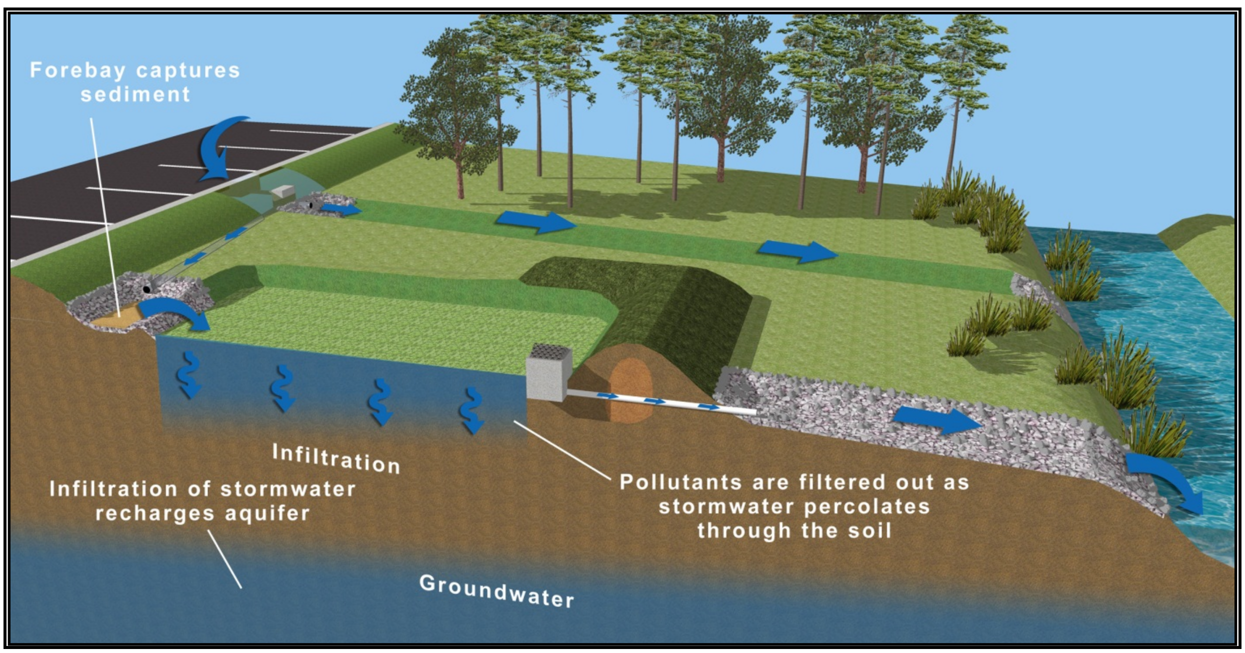



**Figure 10-3.** Typical infiltration basin configuration and pollutant removal processes

**SITING CRITERIA SUMMARY**

- ❒ Infiltration basins function best for drainage areas of 5 acres or less.
- ❒ The basin should be located a minimum of 50 feet from Class SA waters and 30 feet from other surface waters.
- ❒ The basin should be a minimum of 100 feet from water supply wells.
- ❒ A minimum of 2 feet is required between the infiltration basin bottom and the seasonal high water table.
- ❒ A minimum of 3 feet is required between the infiltration basin bottom and any bedrock or impervious soil horizon.
- ❒ The minimum hydraulic conductivity for the native soils is 0.52 inch per hour. This value must be verified by subsurface investigation.

## 10.3 Design

Infiltration basins are implemented in an offline configuration. All runoff in excess of the design storm criteria must be bypassed to a filter strip or swale. Therefore, orientation and siting of the infiltration basin should consider the area required for the entire infiltration basin system. In addition, the basin must be sized to account for runoff at the ultimate built-out potential from all surfaces draining to the system. This section provides general criteria and guidance on infiltration basin design. The designer should confirm whether the proposed design criteria satisfy project-specific permit conditions.

### FLOW BYPASS

All stormwater that is generated from the drainage area in excess of the design storm criteria should be routed to a stable conveyance (e.g., pipe, lined ditch, filter strip, swale) via a bypass structure. The designer should select the appropriate bypass structure configuration on a site-by-site basis. The bypass structure should be designed to safely convey the 10-year storm event at a minimum. In addition, the filter strip or swale should be capable of filtering the 10-year storm event without erosion with a slope of 4% or less. The required minimum length of the filter strip or swale is 50 feet for SA waters and 30 feet for all other waters.

For some bypass configurations, the elevation in the pond must exceed the WQv before bypass will occur. In addition, some bypass structures regulate only flow rates, not volume. In these cases, the emergency outlet control structure protects against failure of the infiltration basin.

### PRETREATMENT

Infiltration basins are prone to failure when inundated by solids carried by stormwater. Stormwater that has not been pretreated to remove large solids will quickly clog the first few inches of soil, reducing the infiltration rate of the basin. Once the basin is clogged, it will begin to retain water, potentially causing mosquito hazards and erosion of the emergency spillway from overuse. Adequate pretreatment is critical to maintain the infiltration rate. For a summary of pretreatment criteria, see Chapter 6, Swale, and Chapter 7, Forebay.

## BASIN SIZING CRITERIA

Infiltration basins are sized to temporarily hold a given volume of runoff known as the water quality volume (WQv). A common benchmark is to capture and treat all runoff from the new built-upon area for 80 to 90% of the average annual rainfall. This results in a water quality design storm of 1 inch for most of the state. For coastal areas or projects that occur within one-half mile of and drain to SA waters, infiltration basins are generally sized to store the runoff from the 1.5-inch storm. The actual WQv for each infiltration basin should be maximized based on site conditions and project constraints. More information on the WQv is available in Chapter 2.

The infiltration rate of the basin should be capable of drawing down the runoff volume from the design storm within 5 days. It is acceptable to assume an infiltration rate equal to the hydraulic conductivity of the site soils, as confirmed by the geotechnical investigation. The designer may choose to apply a safety factor to the hydraulic conductivity to determine the infiltration rate. To promote infiltration along the entire basin bottom, the grade of the infiltration basin should be relatively flat. The basin orientation will be governed by site constraints.

### BASIN SIZING CRITERIA SUMMARY

- ❒ In general, infiltration basins should capture and infiltrate runoff generated from the water quality storm.
- ❒ The basin should infiltrate all runoff from the design storm within 5 days.
- ❒ Basin side slopes should be 3:1 or flatter.

## BASIN COMPONENT DESIGN CRITERIA

Basin components can include the emergency outlet control structure, the embankment, and the basin floor lining material discussed in this section. More information on outlet control structures and embankments is available in Chapter 2.

### *Emergency Outlet Control Structure*

The inclusion of an emergency outlet control structure is at the discretion of the designer. The outlet control structure functions to remove runoff in excess of the design storm from the infiltration basin when the bypass structure overflows. The primary outlet for an infiltration basin is the basin bottom. For most infiltration basins designed to serve small drainage areas, the infiltration basin embankment will be adequate to temporarily contain the 50-year storm event before infiltration. However, additional basin outlets may be necessary under certain conditions. Some bypass structures can allow volumes greater than the water quality volume into the basin. For larger drainage areas, an emergency outlet control structure may be necessary to protect the integrity of the embankment.

The emergency outlet control structure is composed of a riser and a discharge pipe. The riser structure is typically made of concrete for durability. The designer should determine the design storm frequency used to size the outlet control structure based on the flow bypass configuration. The entire infiltration basin should be capable of handling the 50-year storm event without failure.

### *Embankment*

The top width of the embankment should be at least 10 feet to provide access for maintenance. The height of the embankment should be at least 1 foot above the water surface elevation of the 50-year storm event. The embankment should be less than 12 feet in height. For most applications, a simple homogeneous earthen embankment is sufficient. However, the size of the embankment and the type of soil should be evaluated to determine if anti-seep collars, a clay core, impervious liners, diaphragms, or internal drains are needed. Anti-seep collars and clay cores are generally the NCDOT-preferred options. Other seepage prevention measures typically require additional engineering. The NRCS Agriculture Handbook 590 provides guidance on embankment design (USDA.02). Consult the NCDOT Geotechnical Unit for embankment designs. Refer to Chapter 2 for further guidance.

### BASIN BOTTOM

The bottom of infiltration basins should be lined with a layer of clean sand to an average depth of 4 inches or greater. Alternatively, a dense vegetative cover on the bottom of the basin can be substituted for the sand layer. These practices help maintain the infiltration rate.

### BASIN COMPONENT DESIGN CRITERIA SUMMARY

#### ***Emergency Outlet Control Structure***

- ❒ Emergency outlet control structure should be designed to allow the infiltration basin to handle the 50-year storm without failure.

#### ***Embankment***

- ❒ Embankment height should be less than 12 feet.
- ❒ Embankment structure should have a minimum top width of 10 feet with side slopes of 3:1 or flatter.
- ❒ Minimum of 1 foot of freeboard must be provided between the surface water elevation of the 50-year storm event and the top of the embankment.

#### ***Basin Bottom***

- ❒ Basin bottom should be a 4-inch minimum layer of clean sand or a dense cover of vegetation.

### DESIGN AND CONSTRUCTION CONSIDERATIONS

Because infiltration basins are prone to failure when inundated with coarse particles, advance consideration should be given to construction sequencing and erosion and sediment control practices during site construction. Often, inlet protection is not adequate during construction of an infiltration basin. The best protection is bypassing stormwater away from the facility until vegetation is established and all construction-related sediment has been controlled. Otherwise, the infiltration basin may be unusable immediately after implementation.

In North Carolina, the Underground Injection Control (UIC) Program regulates stormwater injection or the emplacement of stormwater into the subsurface soil layers through methods such as a piped subsurface distribution system. As the guidance in this chapter does not include subsurface distribution systems, this BMP is exempt from these regulators. However, if an injection or subsurface distribution system is included in the design of an infiltration system, a “Notification for Stormwater Drainage Wells” should be sent to the NCDENR-Aquifer Protection section. Other examples of BMPs requiring notification include commercially manufactured stormwater infiltration devices and open bottom arches intended to distribute stormwater into the subsurface.

Additional design and construction recommendations follow:

- Consider the consequences of groundwater interaction with runoff.
- Locate the infiltration basin outside of clear recovery zones.
- Check the available right-of-way when determining the BMP footprint and orientation.
- Consider the space needed for the filter strip or swale required for bypassed flow.
- Avoid using heavy equipment in the basin bottom to maintain the infiltration rate.
- Determine proper ballast for the outlet control structure to prevent flotation as needed.
- Stabilize all basin system discharge points to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042 (NCDOT.08).
- Provide a debris screen or trash rack over the riser structure to prevent clogging.
- Include a minimum 10-foot wide maintenance access road to the media filter for cleanup and repair.

## 10.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance.

Where possible, provide an area on site where sediment removed from the BMP can be disposed. The area should be relatively flat to promote stabilization after sediment is deposited. The sediment disposal area should also be gently sloped away from the BMP to prevent deposited sediment from reentering the BMP. The sediment disposal area should be configured in a manner that prevents adverse effects to receiving waters or adjacent properties.

## 10.5 Safety Considerations

Because infiltration basins are typically dry, the components of the basin are accessible. Trash racks and other structures should be designed to prevent entry by the public.

# CHAPTER 11 Media Filters

## OVERVIEW

A MEDIA FILTER is a best management practice that impounds stormwater, allowing it to percolate through permeable media to an underdrain system before it is conveyed off site. Media filters include filtration and bioretention basins.

### PURPOSE AND DESCRIPTION

- Media filters are structural best management practices designed to temporarily capture stormwater runoff, filter and retain pollutants, and reduce peak flows.
- Runoff is detained and filtered through natural, manufactured, or engineered media.
- Media filters are designed with an underdrain that typically conveys filtered runoff to an outlet control structure.
- Media filters promote infiltration where supported by underlying soils.

### APPLICATIONS

- Flexibility in the design of media filters (i.e., size, shape, media, vegetation, etc.) allow them to be installed in various locations.
- The use of media filters is typically restricted to drainage areas of 5 acres or less.

### WATER QUALITY BENEFITS

- Media filters capture and release stormwater over a period of approximately 48 hours, reducing peak flows and minimizing downgrade erosion.
- The media removes solids and adsorbs dissolved pollutants, reducing total suspended solids, nutrients, metals, hydrocarbons, and pathogens. Bioretention basins provide increased removal of nutrients.

## 11.1 Description

A media filter is a structural BMP that treats runoff by filtering it through a layer of natural, manufactured, or engineered media, which can include amended soil, sand, or other material. As runoff percolates through the media, solids are filtered out and pollutants are adsorbed to the media. After filtration, runoff is collected in an underdrain and conveyed off site. Media filters are typically planted with grass or with shrubs and other landscape vegetation.

This chapter addresses two types of media filters:

- Filtration basins – grassed media filters
- Bioretention basins – landscaped media filters

Although the overall layout, components, and design strategies are similar for both types of media filters, there are a few differences. Filtration basin media is primarily composed of coarse sand or recycled aggregate with organic material and is covered with turfgrass. Bioretention basin media is a mix of sand, fines, and organic material, to support the growth of ornamental plants, with a mulched groundcover. The minimum required media depth is shallower in filtration basins where nitrogen and temperature reduction are not primary design goals. Lastly, bioretention basins are designed to draw down impounded stormwater more rapidly than filtration basins to avoid adverse impacts on beneficial vegetation.

Media filters typically have the following components:

- Bypass structure (optional)
- Forebay
- Basin
- Media
- Landscaping (bioretention basin)
- Underdrain system
- Outlet control structure
- Embankment
- Emergency spillway
- Access road

The general flow path of stormwater runoff through both types of media filters is the same. Runoff typically enters at the forebay through an open channel or conveyance pipe, where larger stormwater particulates are removed. Stormwater then exits the forebay and enters the basin. For storm events equivalent to the water quality design storm or smaller, runoff remains in the media filter until it has percolated through the media and out through the underdrain. Stormwater quantities exceeding the water quality volume (WQv) typically overflow through the outlet control structure and exit the basin. Alternatively, a flow bypass structure may be used to bypass runoff in excess of the WQv. A typical media filter layout is shown in plan and profile views in Figures 11-1 and 11-2, respectively.

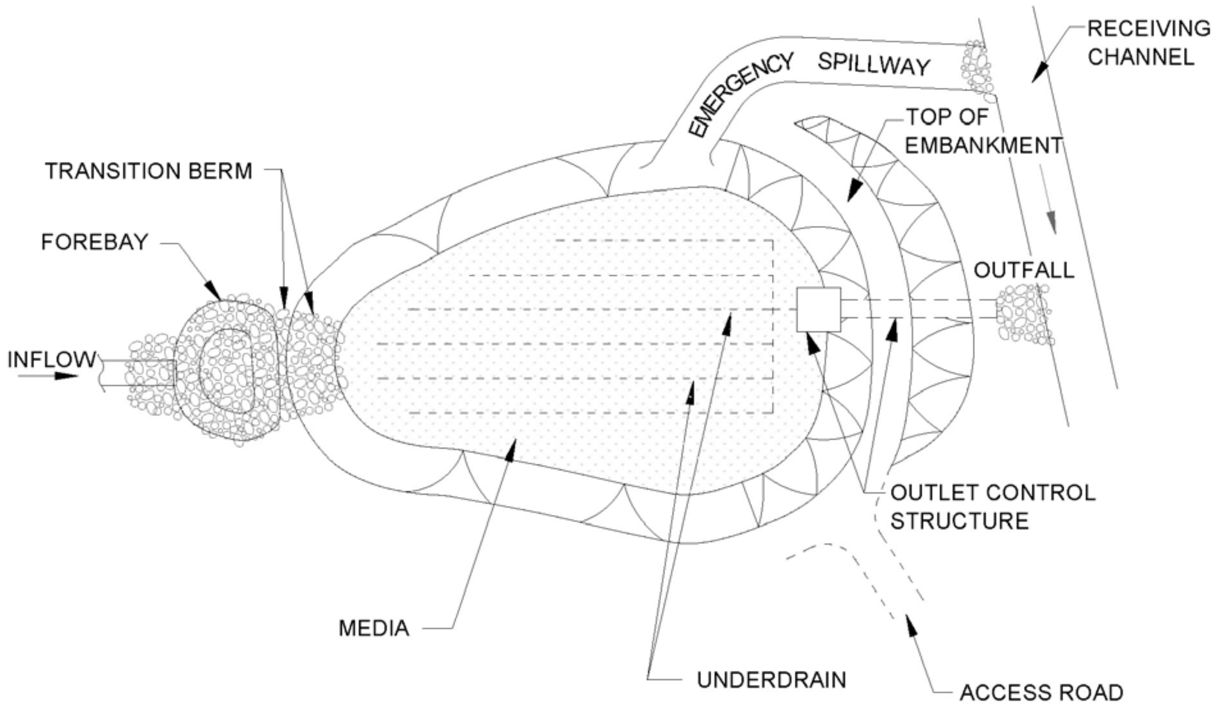



**Figure 11-1.** Plan view: media filter and its components

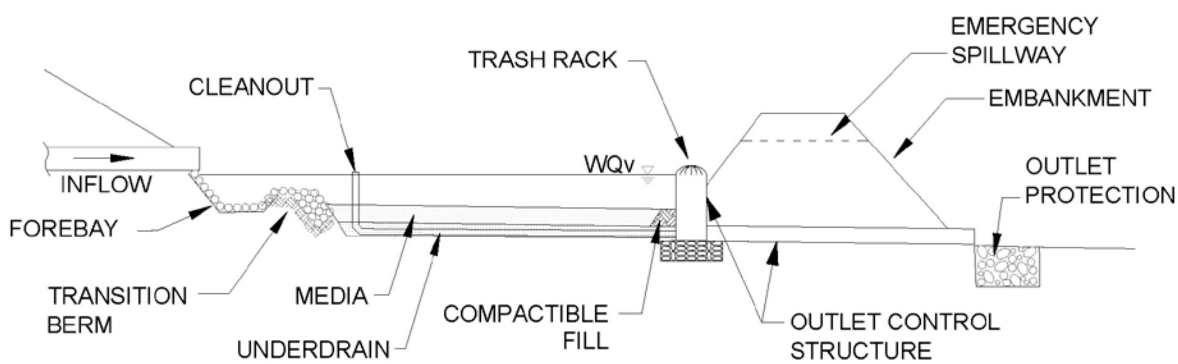



**Figure 11-2.** Profile view: media filter and its components

## 11.2 Applications

Media filters can be shaped in various geometric patterns and may be incorporated into existing topography. Thus, they can be used in various applications, such as at highway industrial facilities, rest areas, and linear systems where space permits. Media filters are not suited for unstable drainage areas. High sediment loads that cannot be effectively reduced through pretreatment by the forebay or a vegetated conveyance can quickly clog the media, rendering it ineffective. The drainage area for media filters is often limited to 5 acres or less, and drainage area slopes greater than 20% are not ideal in the vicinity of this BMP.

Media filters are applicable when the primary objective is to reduce pollutants, as these BMPs treat a broad spectrum of water quality parameters of concern. As stormwater is temporarily detained in the BMP, suspended sediments and some phosphorus are captured through sedimentation. During infiltration and other chemical processes, metals and additional phosphorus are removed. Microbial activity that occurs in the media helps to reduce nitrogen and hydrocarbons. As the surface layer of the BMP is exposed to sunlight and allowed to dry, pathogens are treated. Media filters with relatively deep media layers can help abate runoff temperatures. Additionally, media filters provide peak flow attenuation for smaller watersheds.

Filtration and bioretention are similar in design and pollutant removal mechanisms. Bioretention basins are characterized by mulched landscape vegetation, which incorporates shrubbery and other plants to provide robust root systems that enhance the soil structure. Subsequently, they provide improved filtration rates and increased pollutant removal. Filtration basins are generally more economical to construct and maintain. Bioretention basins will likely be installed in areas where aesthetics are desirable and manpower is available to perform routine maintenance on ornamental plants and control weeds and pests in the mulched landscape bed. Filtration basins are preferred where a grassed surface that can be maintained by routine mowing is desired.

Figures 11-3 and 11-4 illustrate the treatment processes and target depths associated with different pollutants for filtration basins and bioretention basins, respectively (Hunt.01).

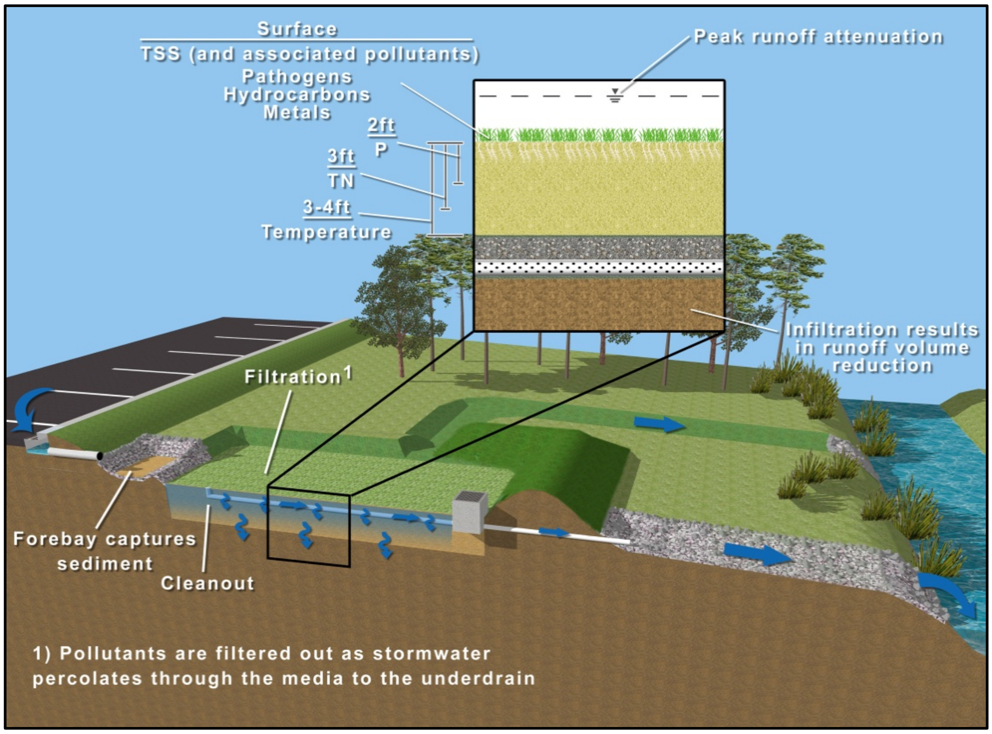



**Figure 11-3.** Typical filtration basin configuration, pollutant removal processes, and depths required for given constituents

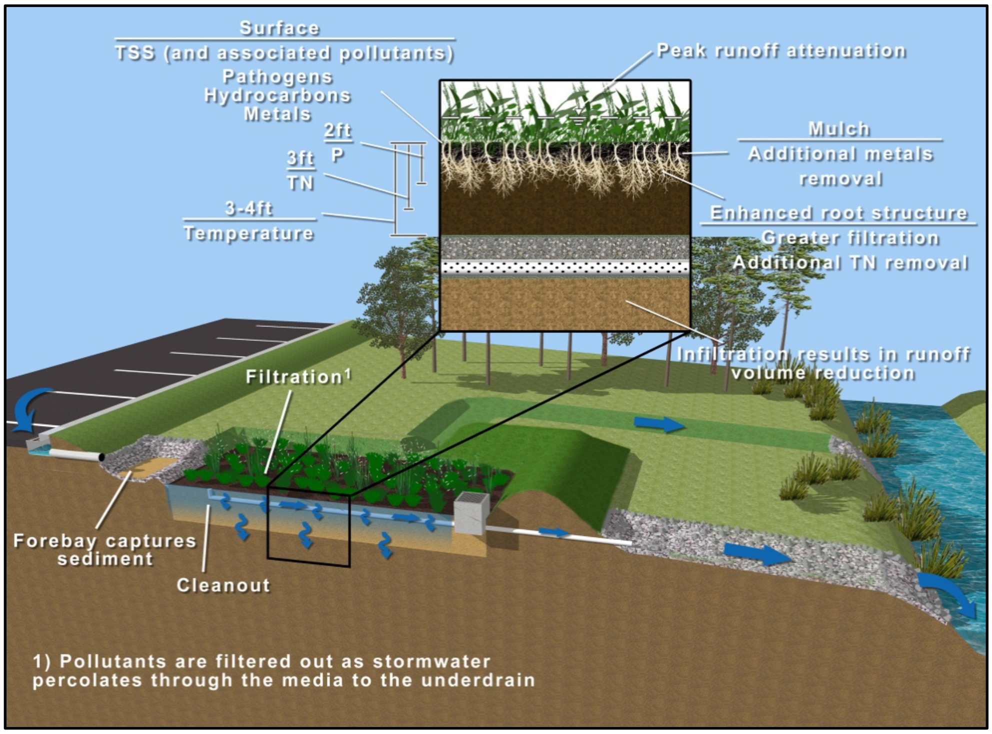



**Figure 11-4.** Typical bioretention basin configuration, pollutant removal processes, and depths required for given constituents

Where possible, media filters should not be located within 50 feet of Class SA waters, within 30 feet of all other waters, and within 100 feet of water supply wells. Surface water classifications can be confirmed using NCDENR's Basinwide Assessment Information Management Systems Reports (BIMS) database available at NCDENR's website. The bottom of the media filter (invert of the underdrain) should be a minimum of 2 feet above the seasonal high groundwater table. Closer proximity to surface waters and wells and a smaller separation from the water table may be acceptable if there is sufficient justification.

The hydraulic conductivity of in situ soils and the depth to the seasonal groundwater table must be evaluated by a subsurface investigation, typically performed by the NCDOT Geotechnical Engineering Unit. Media filters should not be sited in areas of karst topography. Criteria to guide basin siting and orientation are summarized in the Siting Criteria Summary box. The final orientation of the basin will be determined by site-specific constraints.

**SITING CRITERIA SUMMARY**

- ❒ Media filter drainage areas are often limited to 5 acres or less.
- ❒ Drainage area slopes in the vicinity of the media filter should generally be less than 20%.
- ❒ The basin should be located a minimum of 50 feet from Class SA waters and 30 feet from other surface waters, where possible.
- ❒ The basin should be a minimum of 100 feet from water supply wells, where possible.
- ❒ A minimum of 2 feet is desired between the media filter bottom and the seasonal high water table, where possible.

## 11.3 Design

Media filters are sized to capture and filter a volume of runoff known as the water quality volume (WQv). A common benchmark is to capture and treat all runoff from the new built-upon area for 80 to 90% of the average annual rainfall. This results in a water quality design storm of 1 inch for most of North Carolina and 1.5 inches for coastal areas. Although this is a common benchmark, the actual volume treated will depend on the existing site conditions. In some cases, treatment will exceed the target benchmark; others may fall short due to site constraints. Refer to Chapter 2 for further guidance. Media filters may be designed in an online or offline configuration depending on site constraints. Guidance for sizing media filters follows.

### MEDIA FILTER SIZING CRITERIA

Water quality benefits should be maximized by sizing the basin based on existing site conditions and hydrologic design parameters. Consideration should be given for runoff from the entire drainage area at ultimate build-out, as well as run-on from off-site, if it cannot be isolated. Analyses should be performed to determine existing hydrologic conditions to aid in identifying and meeting site-specific context objectives.

To determine the largest possible WQv that can be treated, the existing site conditions should be analyzed by considering the space available, the type of media filter, the depth of the media, maximum ponding depth, maximum side slopes (3:1), and the configuration of the outlet control structure and emergency spillway. The top of the outlet control structure is set at the WQv elevation. The emergency spillway is generally set 0.5 feet above the water surface elevation for the 10-year storm. One foot of freeboard should be provided above the water surface elevation of the 50-year storm event. Refer to the Basin Component Design Criteria section for additional information relevant to determining the WQv based on site constraints.

Design of media filters often includes the use of a flow bypass structure to avoid erosion or inundation of the basin by frequent or intense storm events. In determining if a flow bypass structure is necessary, consideration should be given for the following:

- **Available footprint and site constraints:** This will determine the volume and shape of the basin, and how much runoff it can accept.
- **Site-specific context objectives:** If peak flow attenuation is needed, consider omitting the flow bypass structure.
- **Type and layout of project**: This will dictate the amount of new built-upon area and the runoff hydrograph.
- **Hydraulics of the system:** The peak flow rate will determine whether runoff velocities into the basin are excessive.

The media filter should be designed to drain to a level 24 inches below the media surface (or drain completely for shallower basins) within 48 hours. The required drawdown time depends on the type of media filter installed:

- **Filtration basins**: All ponded water visible above the surface of the filtration basin should be drawn down within **24 hours**. The depth of ponded water, as measured from the surface of the media to the water quality elevation, should be 12 to 36 inches for filtration basins. Depths in excess of 36 inches may result in excessive head that can cause fouling or piping of media.

- **Bioretention basins**: All ponded water should draw down within **12 hours** to minimize stress on ornamental plants from submergence. Also for this reason, the depth of ponded water, as measured from the surface of the media to the water quality elevation, should be restricted to 12 inches for bioretention basins.

Darcy's law can be applied to calculate hydraulic conductivity (K) given WQv, drawdown time, ponding depth, media depth, and basin footprint. Acceptable values for hydraulic conductivity are 0.52-6 inches/hour, but 1-2 inches/hour is desired. Given this information, Darcy's law should be used to confirm the dimensions of the basin are within the acceptable range. Guidance on Darcy's law follows:

$$q = \frac{KhA}{12L}$$

where

q = flow rate ($ft^3$/hr)

| | | |
|---|---|---|
| K | = | hydraulic conductivity of the media (in/hr) |
| h | = | average head during drawdown period (ft) |
| A | = | cross-sectional area of flow ($ft^2$) |
| L | = | length of flow path (ft) |

The flow rate is governed by the WQv and the drawdown time. The average head during the drawdown period is the depth of ponded water associated with the WQv divided by 2. The cross-sectional area of flow is the area occupied by the media as viewed from above or below (plan view). Finally, the length of the flow path is the depth of the media.

To promote filtration along the entire basin surface, the finished grade should be relatively flat. The basin orientation will be governed by site constraints.

### BASIN SIZING CRITERIA SUMMARY

- ❒ Media filters should be sized to maximize water quality benefits to the extent that site constraints will allow.
- ❒ One foot of freeboard should be provided above the 50-year storm elevation.
- ❒ Basin side slopes should be 3:1 or flatter.
- ❒ A minimum length-to-width ratio of 2:1 is recommended.
- ❒ The desirable hydraulic conductivity of the media is 1-2 inches per hour.
- ❒ The top 24 inches of media (entire media if depth ≤ 24 inches) should be drained of stormwater within 48 hours.
- ❒ All ponded water should drain into the media within the following time frames:
  - Filtration basins: within 24 hours
  - Bioretention basins: within 12 hours

## MEDIA FILTER COMPONENT DESIGN CRITERIA

Basin components typically include a forebay, media, vegetation, an underdrain system, an outlet control structure, an embankment, and an emergency spillway, as discussed below. More information on outlet control structures and embankments is available in Chapter 2.

### *Forebay*

Pretreatment forebays extend the life of media filters and facilitate maintenance. A pretreatment forebay removes some sediment and trash through energy dissipation and gravitational settling before the runoff enters the basin. If excessive sediment is allowed to reach the basin, it can quickly clog the media. The velocity out of the forebay should be low to avoid damage to the media bed. Carefully consider providing a bypass structure for larger watersheds. The transition berm between the forebay and the media filter should be designed to prevent erosion. The transition berm should have an impermeable liner installed under the riprap. Also, the transition berm must be constructed level to avoid areas of concentrated flow that could damage the berm and damage the media bed. The forebay should be sized based on the volume associated with 0.1 inches of runoff from the impervious area within the contributing drainage area. More information on forebays is provided in Chapter 7.

### *Media*

The media chosen depends on the type of media filter installed. To support turfgrass systems, filtration basins are primarily composed of coarse sand and organic material. Bioretention basins require a media composition that will support landscape plantings. Acceptable values for hydraulic conductivity are 0.52-6 inches/hour, but 1-2 inches/hour is preferred. Specific media design criteria is provided below for each type of basin.

***Filtration Basin***

Filtration basin media typically consists of the following materials measured on a volume basis:

- 95-97% Type 2S or 2MS coarse sand (passes a No. 10 sieve, retained on a No. 40 sieve).
    - Sand should be of nonlimestone or similarly sourced material to prevent solidification of the media. Other media, such as expanded slate, may be considered.
- 3-5% organic matter, typically consisting of finely ground pine bark.

The media depth is dependent upon the pollutants targeted for treatment. Figure 11-3 shows the depths at which treatment occurs for various pollutants. The minimum required media depth is 18 inches. If phosphorus is targeted for removal, the media should be analyzed by a soils laboratory to determine the phosphorus content and corresponding phosphorus index (P-index). Media with high phosphorus levels can export this nutrient into the runoff instead of reducing this potential pollutant. A P-index less than 30 is desirable.

***Bioretention Basin***

Bioretention basin media should consist of the following USDA Soil Textural Classification (measured on a volume basis):

- 85-88% coarse sand (nonlimestone), Type 2S or 2MS
- 8-12% fines (silt and clay passing No. 200 sieve)
    - 12% to obtain 1 in/hr hydraulic conductivity for increased nitrogen removal
    - 8% to obtain 2 in/hr hydraulic conductivity for phosphorus, metals, and other pollutant removal
- 3-5% organic matter

The media depth is dependent upon the pollutants targeted for treatment. Figure 11-4 shows the depths at which treatment occurs for various pollutants. The minimum required media depth is 24 inches. If phosphorus is targeted for removal, a P-index of 10–30 is desired; otherwise, a P-index of 25–40 is better suited to support growth of landscape plants.

### *Vegetation*

Vegetation planted in the basin will depend on the type of media filter being installed. Filtration basins are sodded with turfgrass species. Bioretention basins are planted with a variety of ornamental selections. The use of woody species within the basin should be avoided for operation and maintenance reasons.

### *Filtration Basin*

Filtration basins are typically sodded with grass for rapid soil stabilization and improved pollutant removal. Filtration basins constructed in the Mountain and Piedmont geographic regions are typically sodded with cool season turfgrass species, such as fescue and bluegrass. Zoysiagrass, a warm season turfgrass, may also be considered. Filtration basins in the Coastal Plain geographic region are typically sodded with warm season species, such as centipedegrass or bermudagrass. Topsoil is generally not needed. Sod should be obtained from a supplier that grows in nonclay soils where possible. Sod grown in clayey soils can reduce infiltration into the media, causing the basin to retain water longer than desired. Generally, sod should be ‘half cut’ or ‘thin cut’ whereby the soil thickness is approximately half of conventionally available sod to maximize infiltration. Consult with the Roadside Environmental Unit on turfgrass selection.

### *Bioretention Basin*

In bioretention basins, vegetation is essential in preventing erosion in the basin and plays an important role in treatment mechanisms. The bioretention basin design should include a landscaping plan prepared by a qualified professional. Soil moisture can vary greatly in bioretention basins. Therefore, plants tolerant of both wet and dry conditions are ideal. Plants selected should also be suited for the anticipated pollutants from the drainage area. Finally, a mulch layer should be provided in the basin, typically consisting of 3–4 inches of triple-shredded hardwood mulch.

## *Underdrain System*

Underdrains are used to drain the media and to convey treated runoff from the site. Underdrains are typically constructed of 6-inch perforated plastic pipe with filter socks to prevent clogging. Each branch should span the approximate length of the basin. Spacing between branches should not exceed 10 feet. Larger diameter pipe may be used if conditions warrant. Maximum flow through the media and into the underdrain should be determined using Darcy’s law as previously described. Manning’s formula can then be used to determine whether 6-inch pipe is adequate. The size and spacing of holes in the underdrain is usually predetermined. The holes are 3/8 inches in diameter and spaced 6 inches on center, longitudinally. Underdrain piping typically has four rows of holes running longitudinally that are evenly spaced radially. With this information, the orifice equation can be used to evaluate whether the total length of underdrain provided is sufficient. Additional guidance on the orifice equation is provided in Chapter 2.

The branches of the underdrain should connect to a single stub-out from the outlet control structure to minimize penetrations into the outlet structure, where possible. Figure 11-1 shows a typical underdrain configuration. The bottom of the basin should be relatively flat to promote exfiltration. The underdrain pipe should have a minimum slope of 0.5% toward the outlet control structure.

Below the underdrain, a permeable filter fabric should be provided that extends along the entire footprint of the basin, including the side slopes. The underdrain is generally bedded on a thin layer of washed coarse aggregate (i.e., #5 stone, #57 stone, or alternate) to achieve the desired slope, and then backfilled to a total aggregate depth of 12 inches. Limestone-based aggregates are not acceptable for this application. A second layer of high flow permeable filter fabric should be provided over the aggregate to prevent media and stormwater pollutant particulates from migrating into the aggregate.

Cleanouts should be provided at the end of each underdrain branch and should extend to a height that minimizes (1) inflow in the event that a cap is removed or damaged, (2) burial by sediment, and (3) damage by maintenance equipment. The top of cleanouts should extend above scheduled mowing height for filtration (grass) basins and above the WQv for bioretention basins.

### *Outlet Control Structure*

The outlet control structure typically functions as an overflow device that removes runoff in excess of the WQv from the media filter. Typically, the underdrain is also connected to the outlet control structure as a means of conveying treated stormwater downstream. The outlet control structure is often composed of a riser, trash rack, valve, and a discharge pipe. The top of the riser is set at the WQv elevation. The riser structure is typically made of concrete for durability. The material for the barrel or the pipe outlet structure is selected based on the outlet velocity and slope. The outlet structure is typically sized to convey the 10-year storm if a separate emergency spillway channel is provided, and the emergency spillway is sized to convey the 50-year storm. If no emergency spillway is provided, the outlet control structure should be sized for the 50-year storm. For larger basins, a valve or sluice gate is often provided at the surface elevation of the media to allow the basin to be drained for maintenance. The valve or sluice gate should have a minimum opening of 8 inches. To avoid seepage around the outside surface of the outlet control structure, a compactable material should be provided around the perimeter of the structure for the full depth of the media.

### *Embankment*

The height of the embankment is determined by providing a minimum of 1 foot of freeboard above the water surface elevation of the 50-year storm event. The embankment should be less than 12 feet in height. Refer to Chapter 2 for guidance on measuring embankment height. The top width of the embankment should be 10 feet to provide maintenance access.

### *Emergency Spillway*

The emergency spillway is typically constructed in natural ground to serve as an overflow structure to safely discharge runoff during large storm events. The channel is usually designed to convey the discharge for the 50-year storm event. The invert of the emergency spillway is typically set 0.5 feet above the water surface elevation for the 10-year storm. If there is not enough available right-of-way to construct the emergency spillway, an alternative design can be used. Further, for small basins, the emergency spillway is often eliminated by sizing the outlet control structure to convey the 50-year storm.

## BASIN COMPONENT DESIGN CRITERIA SUMMARY

### ***Forebay***

- Forebay should be sized for 0.1 inches of runoff from the impervious area within the contributing drainage area. Refer to Chapter 7 for more guidance.
- Forebay should have a minimum length-to-width ratio of 2:1 where practical to promote sedimentation.
- Depth of the forebay should be between 3 and 5 feet.
- Forebay side slopes should be flatter than or equal to 2:1.

### ***Media***

**Filtration Basin**

- K values of 0.52–6 in/hr are acceptable, 1–2 in/hr is desired.
- Media should consist of the following materials measured on a volume basis:
  - 95-97% Type 2S or 2MS coarse sand (passes a No. 10 sieve, but retained on a No. 40 sieve).
  - 3-5% organic matter consisting of finely ground pine bark.
- Media should have a P-index of less than 30.
- Minimum depth is 18 inches.
- Other nonlimestone based media may be considered.
- Media depth is dependent upon pollutants targeted for treatment.

**Bioretention Basin**

- K values of 0.52–6 in/hr are acceptable, 1–2 in/hr is desired.
- Media should consist of the following materials measured on a volume basis:
  - 85-88% Type 2S or 2MS coarse sand.
  - 8-12% fines (silt and clay passing a No. 200 sieve):
    - 12% to obtain 1 in/hr hydraulic conductivity for increased nitrogen removal.
    - 8% to obtain 2 in/hr hydraulic conductivity for phosphorus, metals, and other pollutant removal.
  - 3-5% organic matter.
- Media should have a P-index of 10–30 if P targeted for removal; otherwise, P-index should be 25–40.
- Minimum depth is 24 inches.
- Media depth is dependent upon pollutants targeted for treatment.

## BASIN COMPONENT DESIGN CRITERIA SUMMARY (CONTINUED)

### *Landscaping*

**Filtration Basin**

- Grass sod generally consisting of cool season species in the Piedmont and Mountain geographic regions and warm season species in the Coastal Plain geographic region. Consult the Roadside Environmental Unit.

**Bioretention Basin**

- Include a 3- to 4-inch mulch layer of triple-shredded hardwood mulch.
- A landscaping plan should be prepared by a qualified professional.
- Vegetation should be suited for expected pollutants and moisture conditions.

### *Underdrain System*

- Underdrain should be sloped toward the outlet control structure, 0.5% minimum slope.
- Underdrain with filter sock should consist of 6-inch plastic pipe with four rows of 3/8-inch holes, 6 inches on center.
- Backfill underdrain with washed coarse aggregate to a depth of 12 inches.
- Provide cleanouts at the end of each underdrain branch. Cleanouts should protrude from the bottom to a height that minimizes the risk of inflow, burial, and damage by maintenance equipment.

### *Outlet Control Structure*

- Outlet control structure should be designed to allow the basin to store the WQv.
- Outlet control structure typically designed to convey the 10-year storm; if an emergency spillway channel is not provided, it should be designed to convey the 50-year storm.
- An emergency sluice gate or valve should be provided for larger basins. The sluice gate invert should be set at the surface elevation of the media with a minimum opening of 8 inches.

### *Embankment*

- Height should be less than 12 feet. Refer to Chapter 2 for guidance on measuring embankment height.
- Embankment structure should have a minimum top width of 10 feet with side slopes of 3:1 or flatter.
- A minimum of 1 foot of freeboard must be provided between the surface water elevation of the 50-year storm event and the top of the embankment.

## BASIN COMPONENT DESIGN CRITERIA SUMMARY (CONTINUED)

***Emergency Spillway***

- Emergency spillway invert elevation is typically set 0.5 feet above the top of the outlet control structure.
- Emergency spillways should be sized to safely convey the 50-year storm event and prevent flooding of the roadway.
- Emergency spillway liner material should be designed to handle the peak velocity from the 50-year storm event.

## DESIGN OPTIONS CRITERIA

### *Internal Water Storage (IWS) Zone*

An IWS zone can be created by adding an up-turned elbow type configuration to the end of the underdrain pipe within the outlet control structure (Brown.01). The elbow should have an extension that rises a minimum of 24 inches vertically. Figure 11-5 illustrates this configuration.

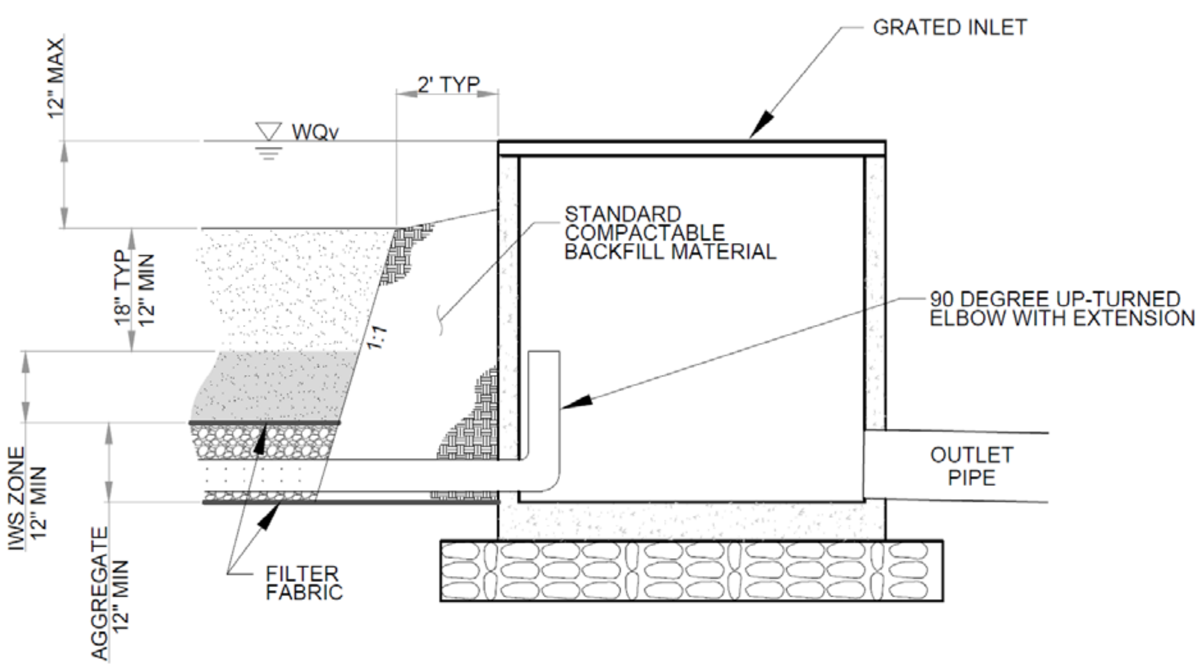



**Figure 11-5.** Profile view: internal water storage zone configuration

The elbow creates an area at the bottom of the media that remains saturated. Anaerobic conditions are created in this saturated zone that increase nitrogen removal (Passeport.01). The IWS zone should be 12 inches or greater in depth, measured from the elevation of the top of the up-turned elbow to the bottom of the media. The media above the IWS zone must be at least 12 inches deep; 18 inches is recommended. For systems with IWS zones, the drawdown requirements differ slightly in that runoff should drain to the level of the IWS zone within 48 hours, rather than draining to a level 24 inches below the surface of the media. When using Darcy's law to calculate flow through media filters with IWS zones, the length of flow path, L, is still the depth of media (i.e., the IWS zone plus the 12 or more inches of media above it).

Alternatively, a tee configuration can be used inside the outlet control structure. A pipe can be attached to the top of the tee to achieve the desired height. An end cap on the bottom of the tee can be removed to drain the media, if desired.

### *Flow Bypass Structure*

Flow bypass structures may be used to bypass runoff in excess of the WQv. The velocity discharging the forebay should also be a factor considered when designing a bypass structure. The designer should select the appropriate bypass structure configuration on a site-by-site basis. The weir and pipes associated with the bypass structure should be sized to convey all runoff generated by the water quality design storm into the basin. Hydrograph generation and routing calculations are recommended to size the weir and pipes; however, peak discharge and pipe flow capacity calculations are also acceptable sizing methods. In addition, considerations for backwater conditions in the basin must be given. An outlet control structure and emergency spillway may still be needed with some flow bypass configurations. Refer to Chapter 2 for more detailed guidance.

## DESIGN AND CONSTRUCTION CONSIDERATIONS

Because the media may become clogged if inundated by sediment, advanced consideration should be given to construction sequencing and erosion and sediment control practices during site construction. Avoid excavation operations during or immediately following a storm event that generates runoff. Perimeter erosion and sediment control is paramount during construction to avoid contamination of media by sediment. Consider bypassing stormwater away from the facility until vegetation is established and all construction-related sediment has been controlled.

Additional design and construction recommendations follow:

- Locate the media filter outside of clear recovery zones.
- Check the available right-of-way when determining the BMP footprint and orientation.
- Consider anticipated construction methods and equipment, and provide adequate space for construction of basin components.
- Avoid using heavy equipment in the basin bottom to maintain the hydraulic conductivity of in situ soils and media, and to avoid damaging the underdrain.
- Scarify the basin bottom with an excavator bucket to promote in situ soil infiltration prior to placing filter fabric.
- Provide watertight connections at all pipe connections to concrete structures. Connections for nonconcrete pipes should be made using flexible boot, gasket, or similar device.
- Backfill around outlet control structure with compactable material.

- Determine proper ballast for the outlet control structure to prevent flotation, as needed.
- Stabilize all basin system outlets to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042 (NCDOT.08).
- Provide a grated inlet, debris screen, or trash rack over the riser structure to prevent clogging.
- Include a minimum 10-foot wide maintenance access road to the media filter for cleanup and repair.

## 11.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance.

Where possible, provide an area on site where sediment removed from the BMP can be disposed. The area should be relatively flat to promote stabilization after sediment is deposited. The sediment disposal area should also be gently sloped away from the BMP to prevent deposited sediment from reentering the BMP. The sediment disposal area should be configured in a manner that prevents adverse effects to receiving waters or adjacent properties.

## 11.5 Safety Considerations

Because media filters are typically dry, the components of the basin are accessible. Trash racks and other structures should be designed to prevent entry by the public.

# CHAPTER 12 Wet Detention Basin

## OVERVIEW

A WET DETENTION BASIN is a structural BMP that maintains a permanent pool of water, attenuates peak stormwater flows, promotes settlement of suspended solids and biological uptake of pollutants, and reduces erosive velocities downstream of the outlet structure.

### PURPOSE AND DESCRIPTION

- Wet detention basins are stormwater ponds that maintain a permanent pool of water and have additional capacity for temporarily storing runoff.
- Stormwater runoff that is captured is slowly released over a target period of 2 to 5 days through a drawdown component positioned at the permanent pool surface elevation.

### APPLICATIONS

- Wet detention basins are often installed at highway industrial facilities, rest areas, and other locations where space permits and an aesthetically pleasing water feature is desirable.
- Wet detention basins are best suited for low-lying areas with a high water table.
- Wet detention basins may not be suitable for areas with water temperature concerns, such as areas draining to trout streams.

### WATER QUALITY BENEFITS

- By reducing peak discharges, wet detention basins prevent downgrade erosion and hydrologic impacts to receiving water bodies.
- Wet detention basins promote sedimentation of suspended solids and pollutant removal through biological uptake by plants, algae, and bacteria.
- Incorporation of a vegetated shelf promotes wetland vegetation growth and, in turn, further promotes sedimentation and biological uptake of nutrients.

## 12.1 Description

A wet detention basin is a permanent structural BMP with an outlet structure that captures and temporarily detains stormwater runoff, while maintaining a permanent pool of water. Captured runoff is slowly released over a period of time through a drawdown device or orifice associated with the outlet structure.

**Figure 12-1**. Typical wet detention basin adjacent to roadway

Wet detention basins provide water quality benefits through quantity control, settling of suspended solids, and biological uptake of nutrients. By controlling the release of stormwater flows, wet detention basins mitigate the erosive impacts of frequent or intense storm events. Some evapotranspiration and infiltration may also occur. Figure 12-1 shows a typical wet detention basin.

The main components of a wet detention basin follow:

- Forebay
- Basin
- Vegetated shelf
- Outlet control structure
- Drawdown device
- Embankment
- Emergency spillway
- Access road

Runoff typically enters a wet detention basin at the forebay via an open channel or conveyance pipe. Inflowing stormwater runoff causes the water level in the basin to rise above the level of the drawdown device until it reaches the water quality volume (WQv) elevation, generally defined by the top of the outlet control structure. For storm events less than or equal to the water quality design storm, stormwater runoff is detained in the basin. Discharge is controlled through the drawdown device, discharging over the next 2 to 5 days, if possible. For larger storm events, an emergency spillway is necessary to minimize the potential for overtopping the basin and causing downgrade flooding. The emergency spillway serves as an overflow structure that is typically constructed as a channel in natural ground, but the outlet control structure may be sized to perform this function if site constraints warrant.

Wet detention basins should be designed with the goal of maintaining or returning the drainage area to existing hydrologic conditions. The WQv should be based upon hydrologic design parameters as well as site-specific context objectives, but will ultimately be constrained by the existing site conditions. For further information on BMP design concepts, refer to Chapter 2.

Typical examples of a wet detention basin layout and its components are shown in Figures 12-2 and 12-3.

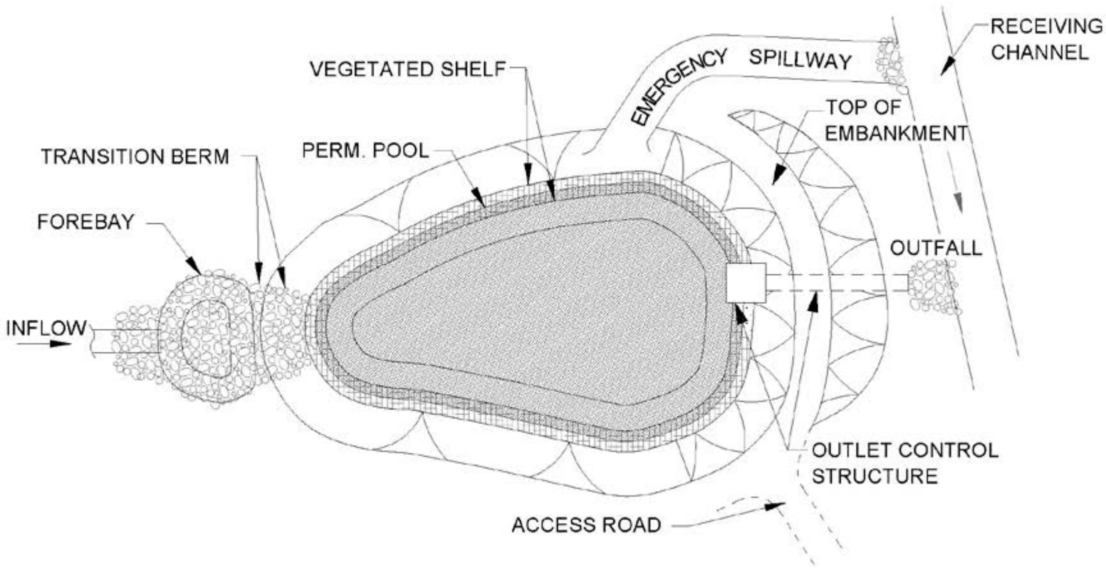



**Figure 12-2.** Plan view: typical wet detention basin layout and components

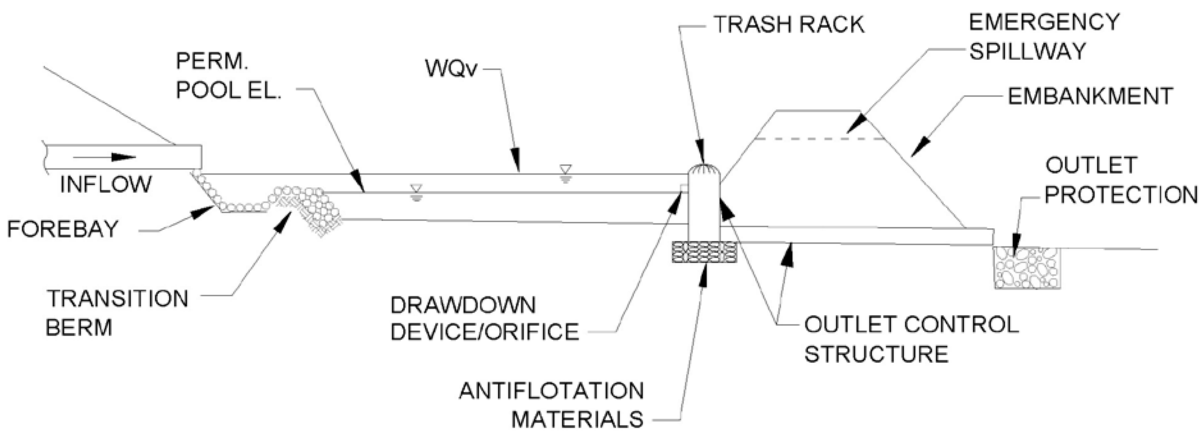



**Figure 12-3.** Profile view: wet detention basin cross section

## 12.2 Applications

Wet detention basins are suitable for collecting and detaining runoff from a variety of highway applications, such as linear rights-of-way on new location projects, facility areas, and interchanges. Compared to other structural BMPs, the basin footprint can be relatively large, making some linear right-of-way applications impractical. A relatively large contributing drainage area or a low-lying site with a high water table is desirable in order to maintain the permanent pool. Wet detention basins are often designed so that the permanent pool elevation is at or near the average water table elevation.

The wet detention basin is applicable when objectives are to reduce peak flow rates into receiving water bodies; remove suspended solids and associated pollutants through settling; and reduce pollutant loads through biological uptake by plants, algae, and bacteria. Because stormwater is detained in the basin, the settling of particles and particulate-bound pollutants is the primary pollutant removal mechanism. Figure 12-4 shows the pollutant removal processes in a typical wet detention basin configuration. Wet detention basins can also be implemented in series with other structural BMPs, such as filter strips or swales, to meet pollutant removal requirements. It should be noted that wet detention basins can negatively impact runoff temperatures. Careful consideration should be given in areas where elevated water temperatures are a concern, such as areas draining to trout waters (NCDENR.03). Avoid areas where wet detention basins have the potential to adversely impact water levels in adjacent wetlands or properties.

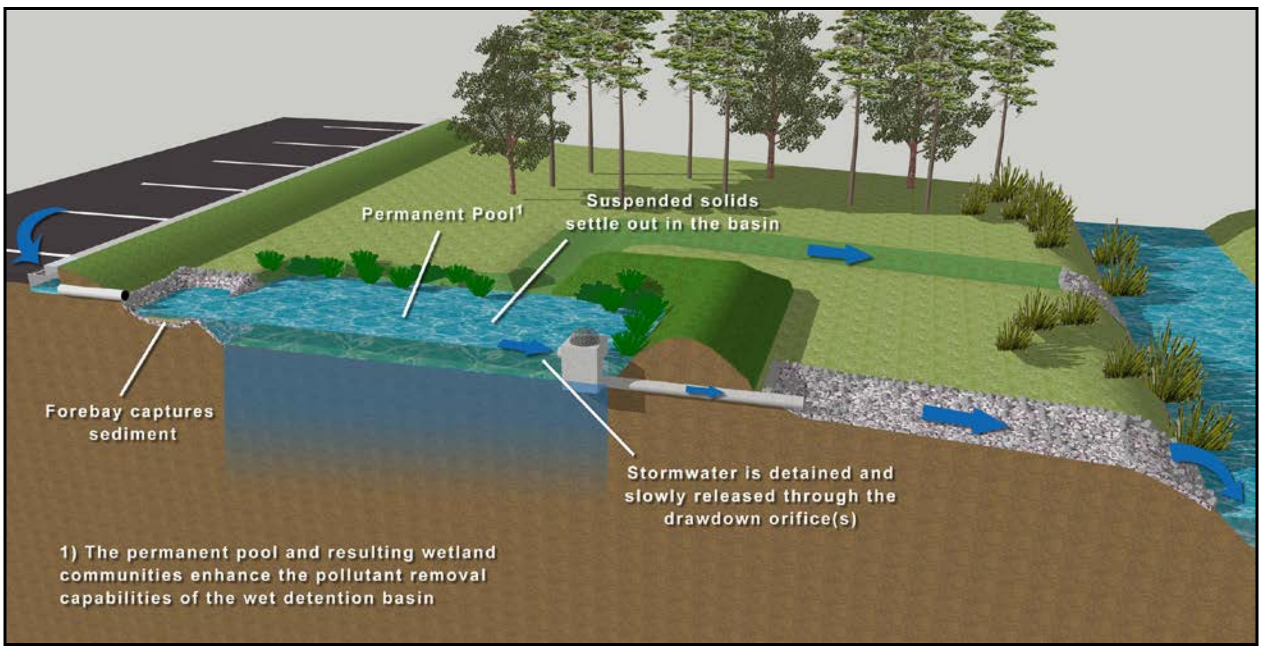



**Figure 12-4.** Typical wet detention basin configuration and pollutant removal processes

## 12.3 Design

The design of the wet detention basin must account for the drainage area hydrology and the BMP component hydraulics. The inflow and outflow hydrographs for all design storms (e.g., WQv and 50-year storm events) must be determined and considered during design. Outlet structure and emergency spillway hydraulics must also be evaluated. The routing procedure and hydrograph computation can be performed by a variety of methods and procedures contained in spreadsheets or modeling programs. The routing must be completed for each design storm under consideration to determine the water surface elevation of that storm as well as the overall functionality of the system. In addition, the design should take into consideration the existing hydrologic conditions. More information on hydrologic analysis and design methods is presented in Chapter 2.

## BASIN SIZING CRITERIA

Wet detention basins are designed to maintain a permanent pool of water and provide additional storage for the WQv. A common benchmark for this additional storage is to capture and treat all runoff from the new built-upon area for 80 to 90% of the average annual rainfall. This results in a water quality design storm of 1 inch for most of North Carolina and 1.5 inches for coastal areas. Although this is a common benchmark, the actual volume treated will depend on the existing site conditions. In some cases, treatment will exceed the target benchmark; others may fall short due to site constraints. Refer to Chapter 2 for further guidance.

Water quality benefits should be maximized by sizing the basin based on existing site conditions and hydrologic design parameters. Consideration should be given for runoff from the entire drainage area at ultimate build-out. Run-on from off site should also be considered if it cannot be isolated. Refer to Chapter 2 for additional information.

To determine the largest possible permanent pool and WQv that can be captured, the existing site conditions should be analyzed by considering the space available and the configuration of the outlet control structure, emergency spillway, and vegetated shelf. Specific criteria for each component are provided below in the Basin Component Design Criteria section. In addition, 1 foot of freeboard should be provided above the 50-year storm water surface elevation. One foot of extra depth is typically provided for storage of sediment.

After the total volume of the basin is determined, consideration should be given for how it will be divided between the permanent pool and the WQv (i.e., at what elevation will the drawdown device be located). Most research indicates that a larger permanent pool will result in better reduction of suspended solids and nutrients (USEPA.01). A larger WQv will provide for better attenuation of peak flows and flood control. However, the permanent pool volume should be at least equal to the WQv. Characteristics of receiving waters and watershed hydrology will dictate which parameters are of greater concern. Where possible, the permanent pool should be two to three times the WQv (or larger if space, topography, and budget allow) to maximize suspended solid and nutrient removal.

With site-specific context objectives in mind, the following references may be used to help determine the ideal division between WQv and permanent pool volume:

- **Peak flow and flood control:** Determine the appropriate design storm or water quality design storm, and use the National Resources Conservation Service (NRCS) Runoff Curve Number Method or WQv equation in conjunction with the orifice equation to determine the proper WQv.
- **Total suspended solids (TSS):** Removal of TSS depends on particle size distribution, varying particle settling velocities, and hydraulic residence time. TSS removal in wet detention basins can be estimated using Driscoll's model (USEPA.01).

- **Nutrients:** Total nitrogen (TN) and total phosphorus (TP) removal in wet detention basins can be estimated using Reckhow's model (Reckhow.01; Borden.01).

To improve the removal efficiency of solids using gravitational settling, the distance between the basin inlet and the outlet control structure should be maximized. The minimum recommended length-to-width ratio of the basin is 2:1 as measured from the termination of the inlet pipe or channel to the outlet control structure. Criteria to guide basin sizing and orientation are provided below in the Basin Sizing Criteria Summary box. The final orientation of the basin will be determined by site-specific constraints.

### Basin Sizing Criteria Summary

- ❒ Permanent pool average depth should be between 3 and 8 feet.
- ❒ An additional 1 foot of depth (minimum) should be provided for sediment storage.
- ❒ Basin is typically sized so that permanent pool volume is between 1 and 3 times the WQv.
- ❒ Basin should capture the runoff from the WQv storm and allow it to draw down over a period of 2–5 days, if possible.
- ❒ 1 foot of freeboard should be provided above the 50-year storm elevation.
- ❒ Minimum recommended flow length-to-width ratio is 2:1.
- ❒ Vegetated and submerged side slopes should be 3:1 or flatter. For steeper slopes, slope stabilization should be considered.

## Landscaping Plan

The wet detention basin design should include a landscaping plan prepared by a qualified professional. Vegetation is essential in preventing erosion on basin side slopes and plays an important role in stormwater management and treatment. Landscaping is also important for the overall aesthetic appeal of the basin. Shallow water, wetland, and moisture-tolerant species should be planted on the vegetated shelf. The use of woody species on the vegetated shelf should be avoided. However, taller herbaceous species planted around the perimeter may deter waterfowl by preventing easy access to the water from land. Canopy trees planted around the perimeter of the basin can also deter unwanted waterfowl from visiting the basin. However, trees should not be planted on the embankment, and consideration for maintenance access should be given when developing the landscaping plan.

## Basin Component Design Criteria

Basin components include the forebay, vegetated shelf, outlet control structure, drawdown device, embankment, and emergency spillway.

### *Forebay*

Pretreatment forebays can improve the performance of wet detention basins and facilitate maintenance. A pretreatment forebay removes some sediment and trash through energy dissipation and gravitational settling before the runoff enters the detention basin. The forebay decreases the incidence of drawdown orifice clogging, improves overall pollutant removal efficiencies, and reduces the required frequency of maintenance. The forebay should be sized based on the volume associated with 0.1 inches of runoff from the impervious area within the contributing drainage area. The transition berm between the forebay and the wet detention basin should be designed to prevent erosion. A fixed vertical sediment depth marker should be installed to measure sediment deposition over time. More information on forebays is provided in Chapter 7.

### *Vegetated Shelf*

A vegetated shelf is a shallow area around the perimeter of the basin designed to promote safety, wetland vegetation growth, and enhance pollutant removal through biological uptake. The vegetated shelf is recommended to be at least 10 feet wide. The inside edge of the shelf should be 6 inches below the permanent pool elevation, and the outside edge should be 6 inches above the permanent pool elevation. For a 10-foot wide shelf, this results in the recommended 10:1 slope (NCDENR.03). For areas where the shelf is constrained to be narrower than 10 feet, the shelf should be at a 10:1 slope and extend no deeper than 6 inches below the permanent pool elevation. The landscaping plan should include multiple shallow water and wetland species located on the vegetated shelf. If the site is constrained such that the shelf must be omitted or reduced, consider fencing the area to promote safety.

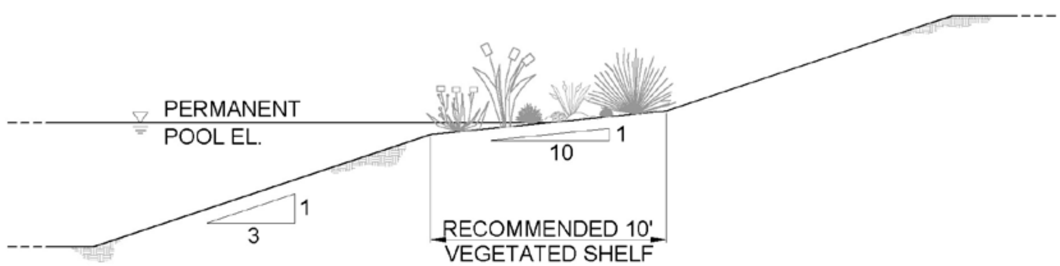



**Figure 12-5.** Vegetated shelf cross section

### *Outlet Control Structure*

The outlet control structure is typically composed of a riser, drawdown device, trash rack, valve or sluice gate, and discharge pipe (refer to Figures 12-3 and 12-6). The drawdown device is set at the permanent pool elevation. The top of the riser is set at the WQv elevation. The riser structure is typically made of concrete for durability. The material for the barrel or the pipe outlet structure is selected based on the outlet velocity and slope. Typically, an outlet control structure and emergency spillway are provided. The outlet structure is sized to convey the 10-year storm, and the emergency spillway is sized to convey the 50-year storm. If no emergency spillway channel is provided, the outlet control structure should be sized to convey the 50-year storm. The discharge pipe should be sized with consideration of tailwater conditions. A gate valve or sluice gate should be provided at the top of the sediment storage area to allow the basin to be drained for maintenance. The outlet structure should be made easily accessible by providing a berm from the side of the basin or the embankment, if possible.

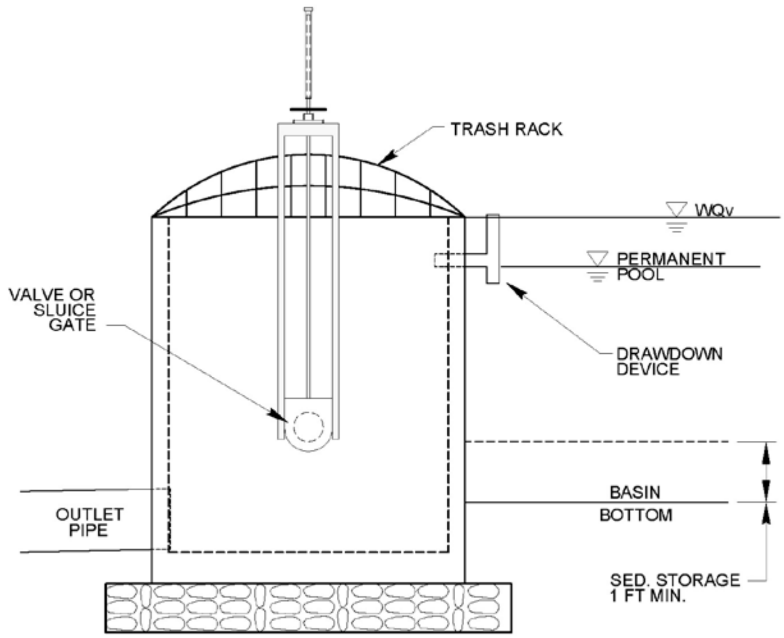



**Figure 12-6.** Wet detention basin outlet control structure

### *Drawdown Device*

The drawdown device is used to slowly drain the WQv that is temporarily stored following a storm event. Drawdown devices are typically designed so that the opening is below the level of the permanent pool to prevent clogging by floating debris. Usually this is accomplished by installing a small diameter pipe with a tee turned so that the branches extend vertically. The branch of the tee pointing up is typically extended above the water quality volume and sealed at the end with a threaded cap or plug. The cap or plug can easily be removed providing access to clear the open orifice at the bottom should it become clogged with debris. For drawdown purposes, it is preferable to use an orifice diameter between 2 and 3 inches. If a larger opening is required, installation of two or more orifices is recommended. The orifice should be designed to draw down the WQv within 2 to 5 days where possible. Drawdown orifice size can be calculated using a routing spreadsheet or the orifice equation. The routing spreadsheet will include the changing head elevation; the orifice equation alone should use an average height equal to one-half of the WQv depth.

### *Embankment*

The height of the embankment is determined by providing a minimum of 1 foot of freeboard above the water surface elevation of the 50-year storm event. The embankment should be less than 12 feet in height and have an impoundment capacity of less than 10 acre-feet. Refer to Chapter 2 for guidance on measuring embankment height. The top width of the embankment should be 10 feet to provide access for maintenance. For most applications, a simple homogeneous earthen embankment is sufficient. However, the size of the embankment and the type of soil should be evaluated to determine if anti-seep collars, a clay core, impervious liners, diaphragms, or internal drains are needed. Anti-seep collars and clay cores are generally the

NCDOT-preferred options. Other seepage prevention measures typically require additional engineering. The NRCS Agriculture Handbook 590 provides guidance on embankment design (USDA.02). Consider consulting a geotechnical engineer for large or complex embankment designs. Refer to Chapter 2 for further guidance.

### *Emergency Spillway*

The emergency spillway is typically constructed in natural ground to serve as an overflow structure to safely discharge storm runoff during large storm events. The channel is usually designed to convey the peak discharge for the 50-year storm event without considering flow through the outlet control structure. The invert of the emergency spillway should be set 0.5–1 foot above the top of the outlet control structure. If there is not enough available right-of-way to construct the emergency spillway, an alternative design can be used.

Often the top of the riser is converted into an emergency overflow device, such as an open-throat riser. If the riser serves as the emergency spillway, it must be designed to pass the discharge from the 50-year storm. All alternative design options are subject to review by the NCDOT Hydraulics Unit. Additional design criteria for basin components are provided below in the Basin Component Design Criteria Summary box.

### BASIN COMPONENT DESIGN CRITERIA SUMMARY

#### ***Forebay***

- ❒ Forebay should be sized for 0.1 inches of runoff from the impervious area within the contributing drainage area.
- ❒ Forebay should have a minimum length-to-width ratio of 2:1, where practical, to promote sedimentation.
- ❒ Depth of the forebay should be between 3 and 5 feet.
- ❒ Forebay side slopes should be flatter than or equal to 2:1.

#### ***Vegetated Shelf***

- ❒ Vegetated shelf should be at least 10 feet wide where possible.
- ❒ Inner edge should be 6 inches below the permanent pool elevation. Outer edge should be 6 inches above the permanent pool elevation, typically resulting in a 10:1 slope.
- ❒ Areas of the shelf less than 10 feet wide should have a 10:1 slope and extend no lower than 6 inches below the permanent pool elevation.

## BASIN COMPONENT DESIGN CRITERIA SUMMARY (CONTINUED)

### ***Outlet Control Structure***

- ❒ Outlet control structure should be designed to allow the basin to store the permanent pool and temporarily detain the WQv.
- ❒ Outlet control structure should typically be designed to handle the 10-year storm. If an emergency spillway is not provided, it should be designed for the 50-year storm.
- ❒ An emergency sluice gate or valve should be provided. Sluice gate or valve invert should be set at the top of the sediment storage level with a minimum opening of 8 inches.

### ***Drawdown Device***

- ❒ Drawdown device should be designed to prevent clogging by floating debris.
- ❒ Preferred orifice size is between 2 and 3 inches.
- ❒ Drawdown device should be sized to provide a 2–5 day drawdown time of the WQv where possible.

### ***Embankment***

- ❒ Height should be less than 12 feet and impoundment capacity less than 10 acre-feet. Refer to Chapter 2 for guidance on measuring embankment height.
- ❒ Embankment structure should have a minimum top width of 10 feet with side slopes of 3:1 or flatter.
- ❒ A minimum of 1 foot of freeboard must be provided between the surface water elevation of the 50-year storm event and the top of the embankment.

### ***Emergency Spillway***

- ❒ Emergency spillway invert elevation is typically set 0.5–1 foot above the top of the outlet control structure.
- ❒ Emergency spillway should be sized to safely convey the 50-year storm event and prevent flooding of the roadway.
- ❒ Emergency spillway liner material should be designed to handle the peak velocity from the 50-year storm event.

## DESIGN OPTIONS CRITERIA

A flow bypass structure may be needed for cases where the basin is undersized due to site constraints or drainage area characteristics. Also, constructing a flow bypass structure may be more economical than an outlet control structure or emergency spillway sized to convey the 10- and 50-year storm events.

The designer should select the appropriate bypass structure configuration on a site-by-site basis. The weir and pipes associated with the bypass structure should be sized to convey all runoff generated by the water quality design storm into the basin. Hydrograph generation and pond routing calculations are recommended to size the weir and pipes; however, peak discharge and pipe flow capacity calculations are also acceptable sizing methods. In addition, considerations for backwater conditions in the basin must be given. An outlet control structure and emergency spillway may still be needed with some flow bypass configurations. Refer to Chapter 2 for more detailed guidance.

## DESIGN AND CONSTRUCTION CONSIDERATIONS

When determining the location of a wet detention basin, the designer must take into account the topography, soils, and drainage patterns. The detention basin's shape will be subject to the contours of the site in some locations. The orientation should maximize the length-to-width ratio of 2:1 or more.

Rainwater harvesting and reuse should also be considered during the design phase. Other state transportation departments develop agreements with adjacent property owners to harvest rainwater from wet detention basins. The rainwater can be used for irrigation and other non-potable uses.

Careful consideration should be given to the size of the drainage area and the water table early in the design process. Large drainage areas or a high water table is needed to maintain the permanent pool level. Alternatively, liners can be installed to help maintain the permanent pool. Liners can also be used to prevent interaction with groundwater in special situations where it is a concern, or in regions with karst topography (southeastern coastal plain) to prevent collapse of underlying soils. Soil types and water table information can be obtained from geotechnical reports generated during subsurface investigation that is typically performed by the NCDOT Geotechnical Engineering Unit.

Additional design and construction recommendations follow:

- Locate the basin outside of the clear recovery zone.
- Check the available right-of-way when determining the basin footprint and orientation.
- Place detention basins in undisturbed soil, not in fill material.
- Determine proper ballast for the outlet control structure to prevent flotation as needed.
- Consider whether bypass or diversion of off-site drainage is necessary based on site constraints.
- Stabilize all basin system outlets to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042 (NCDOT.08).
- The basin should remain offline until all areas contributing to the basin are stabilized.
- Provide a debris screen or trash rack over the riser structure to prevent clogging and human entry.
- Include a minimum 10-foot wide access road to the wet detention basin for maintenance.
- Provide watertight connections at all pipe connections to concrete structures. Connections for nonconcrete pipes should be made using flexible boot, gasket, or similar device.

## 12.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance.

Where possible, provide an area on site where sediment removed from the BMP can be disposed. The area should be relatively flat to promote stabilization after sediment is deposited. The sediment disposal area should also be gently sloped away from the BMP to prevent deposited sediment from reentering the BMP. The sediment disposal area should be configured in a manner that prevents adverse effects to receiving waters or adjacent properties.

## 12.5 Safety Considerations

Wet detention basins are typically large, and water depths may be deep enough to present a drowning hazard, especially in residential or public areas. Trash racks and other structures should be designed to prevent entry by children. A vegetated shelf should be provided as previously described where possible. Consider fencing and signage around the BMP if the vegetated shelf does not meet the guidelines previously presented, the basin is surrounded by steep side slopes, or if children are expected to be in the area (i.e., nearby schools or playgrounds). Refer to NCDOT Standard Specifications, Section 866 (NCDOT.08), for fencing options.

# CHAPTER 13 Stormwater Wetland

## OVERVIEW

A STORMWATER WETLAND is an engineered marsh or swamp with dense wetland vegetation designed to remove stormwater pollutants primarily through biological processes.

### PURPOSE AND DESCRIPTION

- Stormwater wetlands are constructed BMPs that mimic natural wetlands and provide an efficient biological method for removing a variety of pollutants by temporarily storing stormwater runoff in shallow pools that support emergent and riparian vegetation.
- Stormwater runoff that is captured is slowly released over a target period of 2 to 5 days through a drawdown component positioned at the permanent pool surface elevation.

### APPLICATIONS

- Stormwater wetlands are often installed at highway industrial facilities, rest areas, and other locations where space permits and an aesthetically pleasing water feature is desirable.
- Stormwater wetlands are best suited for low-lying areas with a high water table.
- Stormwater wetlands can provide an excellent habitat for wildlife and waterfowl but must meet critical water balance requirements to function properly.

### WATER QUALITY BENEFITS

- By reducing peak discharges, stormwater wetlands prevent downgrade erosion and hydrologic impacts to receiving water bodies.
- The complex microtopography, storage, and vegetative community in stormwater wetlands combine to form an ideal matrix for the removal of suspended solids, nitrogen, and phosphorus.
- Stormwater wetlands provide conditions that facilitate the chemical and biological processes that cleanse water and promote effective sedimentation.

## 13.1 Description

A stormwater wetland is a permanent structural BMP designed with multiple treatment zones of varying water depths. An outlet structure captures and temporarily detains stormwater runoff, while maintaining a permanent pool of water. Impounded runoff is slowly released over a period of time through a drawdown device or orifice associated with the outlet structure.

**Figure 13-1**. Typical stormwater wetland

Stormwater wetlands provide water quality benefits through quantity control, settling of suspended solids, and biological uptake of nutrients. By controlling the release of stormwater flows, stormwater wetlands mitigate the erosive impacts of frequent or intense storm events. Some evapotranspiration and infiltration may also occur. Figure 13-1 shows a typical stormwater wetland.

The main components of a stormwater wetland include the following:

- Forebay
- Shallow water zone
- Shallow land zone
- Deep pools
- Landscaping
- Drawdown device
- Outlet control structure
- Embankment
- Emergency spillway
- Access road

Runoff typically enters a stormwater wetland at the forebay via an open channel or conveyance pipe. From the forebay, runoff enters a low flow channel consisting of a long sinuous path of wetland features including shallow water, shallow land, and deep pools before reaching the outlet control structure. Inflowing stormwater runoff causes the water level in the wetland to rise above the level of the drawdown device until it reaches the water quality volume (WQv) elevation, generally defined by the top of the outlet control structure. For storm events less than or equal to the water quality design storm, stormwater runoff is detained in the wetland. Stormwater is slowly discharged through the drawdown device over a period of 2 to 5 days, if possible. For larger storm events, an emergency spillway is necessary to minimize the potential for overtopping the wetland and causing downgrade flooding. The emergency spillway serves as an overflow structure that is typically constructed as a channel in natural ground, but the outlet control structure may be sized to perform this function if site constraints warrant.

Stormwater wetlands should be designed with the goal of maintaining or returning the drainage area to existing hydrologic conditions. The WQv should be based upon hydrologic design parameters as well as site-specific context objectives, but will ultimately be constrained by the existing site conditions. For further information on BMP design concepts, refer to Chapter 2.

Typical examples of a stormwater wetland layout and its components are shown in Figures 13-2 and 13-3.

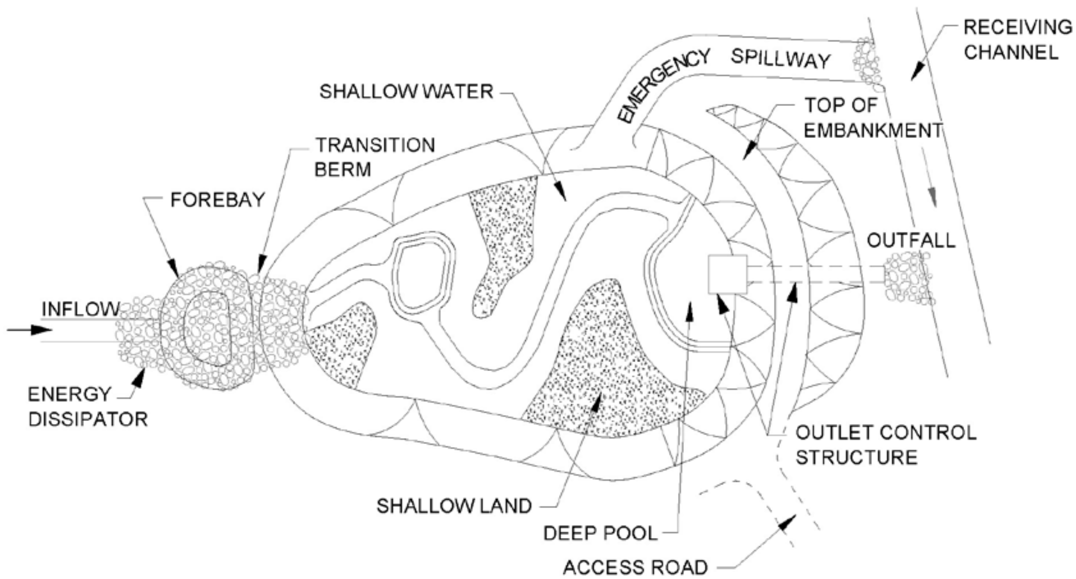



**Figure 13-2.** Profile view: typical stormwater wetland layout and components

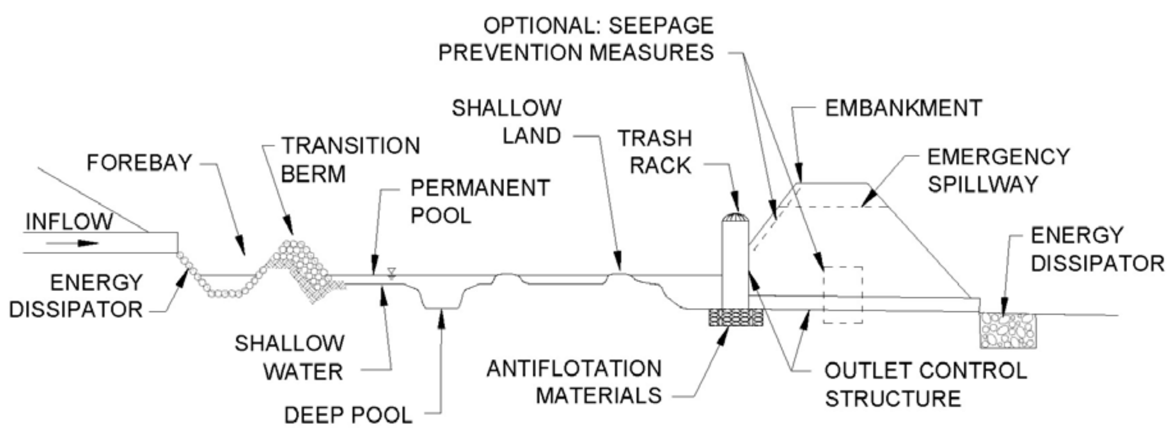



**Figure 13-3.** Plan view: stormwater wetland cross section

## 13.2 Applications

Stormwater wetlands are suitable for collecting and detaining runoff from a variety of highway applications, such as linear rights-of-way, facility areas, and interchanges. Generally, a lowing-lying site with a high water table is required to maintain the permanent pool. Stormwater wetlands function best for drainage areas of 5 acres are more. Stormwater wetlands are often designed so that the permanent pool elevation is at or near the seasonal high water table (SHWT) elevation. A water balance calculation can be performed to verify site applicability. Additional guidelines on ideal locations for stormwater wetlands are provided in the Siting Criteria Summary box.

A stormwater wetland is applicable when objectives are to reduce peak flow rates into receiving water bodies; remove suspended solids and associated pollutants through settling; and reduce pollutant loads through biological uptake by plants, algae, and bacteria. The storage capability, complex microtopography, and vegetative community of a stormwater wetland make it ideal for removing pollutants including total suspended solids, various forms of nitrogen and phosphorus, some metals, and fecal coliform. Figure 13-4 shows the pollutant removal processes in a typical stormwater wetland configuration. Stormwater wetlands can also be implemented in series with other structural BMPs, such as filter strips or swales, to meet pollutant removal requirements. It should be noted that a filter strip is recommended for overflows or discharges from the stormwater wetland for areas within one-half mile of and draining to SA waters or unnamed tributaries of SA waters. Areas where stormwater wetlands have the potential to adversely impact water levels in adjacent wetlands or properties should be avoided.

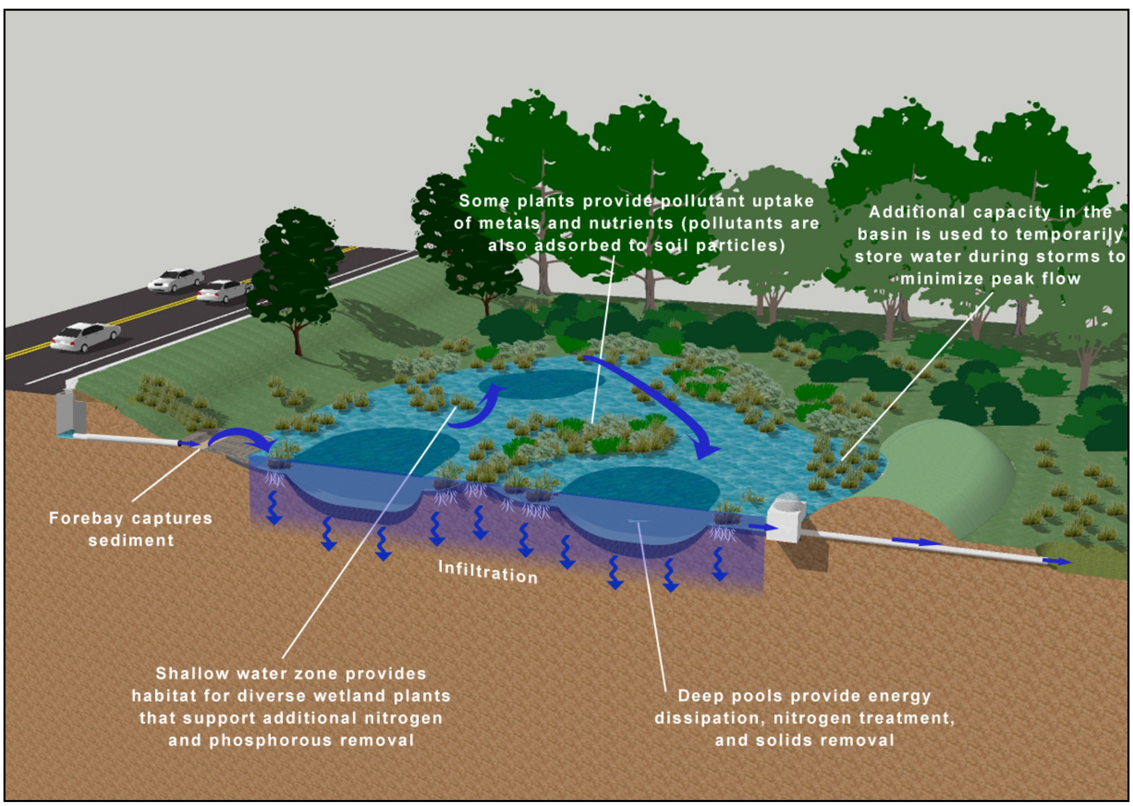


**Figure 13-4.** Typical stormwater wetland configuration and pollutant removal processes

### SITING CRITERIA SUMMARY

- ❒ Wetlands function best for drainage areas of 5 acres or more.
- ❒ Runoff volume, water table, or a combination of the two must be capable of sustaining the permanent pool.
- ❒ If the water table is used to sustain the permanent pool, the permanent pool elevation should be within 6 inches of the seasonal high water table.
- ❒ A water balance calculation may be used to determine site applicability.

### WATER BALANCE

Best professional judgment should be used in determining when and how water balance calculations are performed. Generally, water balances are performed for the driest month (i.e., least amount of rain coupled with the highest evaporation). In North Carolina, the driest months are typically in the summer. A water balance calculation can be performed by summing the inflows and subtracting the outflows. Inflows include:

- Direct precipitation over the wetland area
- Runoff from the drainage area
- Baseflow

Outflows include:

- Infiltration
- Evapotranspiration
- Overflow

Average precipitation data is available from the National Oceanic and Atmospheric Administration (NOAA) website. Wetlands are rarely constructed in perennial streams; therefore, baseflow can usually be omitted from the calculation. However, the elevation of the water table should be considered. Infiltration can be calculated using Darcy's Law, explained in Chapter 11. Data for evapotranspiration can be obtained from the State Climate Office of North Carolina website. Because the calculation is being performed for the monthly average, overflow is typically omitted (Hunt.01; CM.01). If water cannot be maintained in the permanent pool, a stormwater wetland may not be suited for the site.

## 13.3 Design

The design of the stormwater wetland must account for the drainage area hydrology and the BMP component hydraulics. The inflow and outflow hydrographs for all design storms (e.g., WQv and 50-year storm events) must be determined and considered during design. Outlet structure and emergency spillway hydraulics must also be evaluated. The routing procedure and hydrograph computation can be performed by a variety of methods and procedures contained in spreadsheets or modeling programs. The routing must be completed for each design storm under consideration to determine the water surface elevation of that storm as well as the overall functionality of the system. In addition, the design should take into consideration the existing hydrologic conditions. More information on hydrologic analysis and design methods is presented in Chapter 2.

## STORMWATER WETLAND SIZING CRITERIA

Stormwater wetlands are designed to maintain a permanent pool of water and provide additional storage for the WQv. A common benchmark for this additional storage is to capture and treat all runoff from the new built-upon area for 80 to 90% of the average annual rainfall. This results in a water quality design storm of 1 inch for most of North Carolina and 1.5 inches for coastal areas. Although this is a common benchmark, the actual volume treated will depend on the existing site conditions. In some cases, treatment will exceed the target benchmark; others may fall short due to site constraints. Refer to Chapter 2 for further guidance.

Water quality benefits should be maximized by sizing the wetland based on existing site conditions and hydrologic design parameters. Consideration should be given for runoff from the entire drainage area at ultimate build-out. Run-on from off site should also be considered if it cannot be isolated. Refer to Chapter 2 for additional information.

To determine the largest possible permanent pool and WQv that can be captured, the existing site conditions should be analyzed by considering the space available, and the configuration of the outlet control structure and emergency spillway. The WQv elevation should be a maximum of 1 foot above the permanent pool elevation. Specific criteria for each component are provided below in the Stormwater Wetland Component Design Criteria section. In addition, 1 foot of freeboard should be provided above the 50-year storm water surface elevation.

To improve the removal efficiency of solids using gravitational settling, the distance between the wetland inlet and the outlet control structure should be maximized. The minimum recommended length-to-width ratio of the wetland is 1.5:1 (3:1 is recommended) as measured from the termination of the inlet pipe or channel to the outlet control structure. Criteria to guide wetland sizing and orientation are provided below in the Stormwater Wetland Sizing Criteria Summary box. The final orientation of the wetland will be determined by site-specific constraints.

### STORMWATER WETLAND SIZING CRITERIA SUMMARY

- ❒ Wetland will be sized to handle all runoff at ultimate build-out including off-site drainage.
- ❒ Minimum WQv size of 3,630 cubic feet.
- ❒ Maximum WQv elevation should be 1 foot above the permanent pool elevation.
- ❒ Minimum elevation change needed between inflow and outflow of the wetland is typically between 2 and 5 feet.
- ❒ Wetland should capture the runoff from the WQv storm and allow it to draw down over a period of 2–5 days, if possible.
- ❒ One-foot of freeboard should be provided above the 50-year storm elevation.
- ❒ Minimum recommended flow length-to-width ratio is 1.5:1 (3:1 recommended).
- ❒ Vegetated and submerged side slopes should be 3:1 or flatter. For steeper slopes, slope stabilization should be considered.

## LANDSCAPING PLAN

The stormwater wetland design should include a landscaping plan prepared by a qualified professional. The effectiveness of a stormwater wetland to remove pollutants from stormwater runoff is dependent upon a dense cover of emergent plant vegetation. Vegetation is also essential in preventing erosion on wetland side slopes, for the overall aesthetic appeal of the wetland, to limit solar exposure of open water areas, and to promote greater wildlife use within the wetland. Plant species should be used that are non-invasive, can establish large areas that continue through the winter dormant season, have high colonization and growth rates, are robust in continuously or periodically flooded environments, and have a high potential for pollutant removal. Native plant species are desirable. Cattails should not be used in the landscaping plan as they can quickly predominate the site, limit biodiversity, and cause mosquito concerns. Consult with the NCDOT Roadside Environmental Unit for landscape plant selection and design.

## STORMWATER WETLAND COMPONENT DESIGN CRITERIA

Stormwater wetland components include the forebay, shallow water, shallow land, deep pool, outlet control structure, drawdown device, embankment, and emergency spillway.

### *Forebay*

Pretreatment forebays are required for stormwater wetland designs. Forebays can improve the performance of stormwater wetlands, help to facilitate maintenance, and remove some sediment and trash through energy dissipation and gravitational settling before the runoff enters the wetland. The forebay decreases the incidence of drawdown orifice clogging, improves overall pollutant removal efficiencies, and reduces the required frequency of maintenance. The forebay should be sized based on the volume associated with 0.1 inches of runoff from the impervious area within the contributing drainage area. The transition berm between the forebay and the wetland should be designed to prevent erosion. A fixed vertical sediment depth marker should be installed to measure sediment deposition over time. More information on forebays is provided in Chapter 7.

### *Shallow Water*

The shallow water zone acts as a constant hydraulic connection between the inlet and outlet structure of a stormwater wetland and provides habitat for diverse wetland plants that aid in pollutant removal. The shallow water zone should be between 3 and 6 inches deep with the top of the zone representing the permanent pool elevation. Over designing this zone to be too deep can be a cause of wetland failure. In addition, the shallow water zone should make up 40 percent of the stormwater wetland’s total surface area.

### *Shallow Land*

The shallow land zone provides temporary storage volume as it is only submerged for short periods of time due to storm events. This zone should make up 30 to 40 percent of the stormwater wetland’s total surface area. The shallow land zone elevation should be at the elevation of the permanent pool. The shallow land zone provides shade, wildlife habitat, and pollutant removal via biological uptake. This zone should be planted with vegetation that can withstand occasional drought and irregular inundation.

### *Deep Pool*

Deep pools are comprised of permanently deep depressions that retain water even during drought conditions. There are two types of deep pools; forebay deep pools and non-forebay deep pools. A forebay is required for a stormwater wetland and design specifics are discussed in the “Forebay” section noted previously. Non-forebay deep pools should be evenly dispersed throughout a stormwater wetland with the exception of a non-vegetated deep pool that is required at the outlet of the wetland to prevent clogging of the orifice. Deep pools provide pollutant removal, storage volume, energy dissipation, habitat for aquatic wildlife (including fish that consume mosquitos), and promote infiltration. Deep pools should be between 1.5 and 3 feet in depth and comprise 15 to 20 percent (5 to 10 percent for non-forebay deep pools) of the stormwater wetland’s total surface area. Rooted plants will not live in deep pools; however, submerged or floating plants may be used in this zone except around the wetland outlet device.

### *Outlet Control Structure*

The outlet control structure regulates the release of stormwater and maintains the shallow water level in the wetland. Flashboard riser style outlet control structures should be used for stormwater wetlands to allow adjustment of the permanent pool level as needed for the health of vegetation and to facilitate maintenance needs. A flashboard riser consists of a riser with one wall or edge composed of movable boards to create adjustable water levels. One or more drawdown orifices in the form of holes in the boards allow stormwater that has accumulated above the permanent pool level to slowly drawdown from the wetland. The material for the barrel or the pipe outlet structure is selected based on the outlet velocity and slope. Typically, an outlet control structure and emergency spillway are provided. The outlet structure is sized to convey the 10-year storm, and the emergency spillway is sized to convey the 50-year storm. If no emergency spillway channel is provided, the outlet control structure should be sized to convey the 50-year storm. The discharge pipe should be sized with consideration of tailwater conditions. The outlet structure should be made easily accessible by providing a berm from the side of the wetland or the embankment, if possible. Figure 13-5 illustrates the configuration of a flashboard riser.

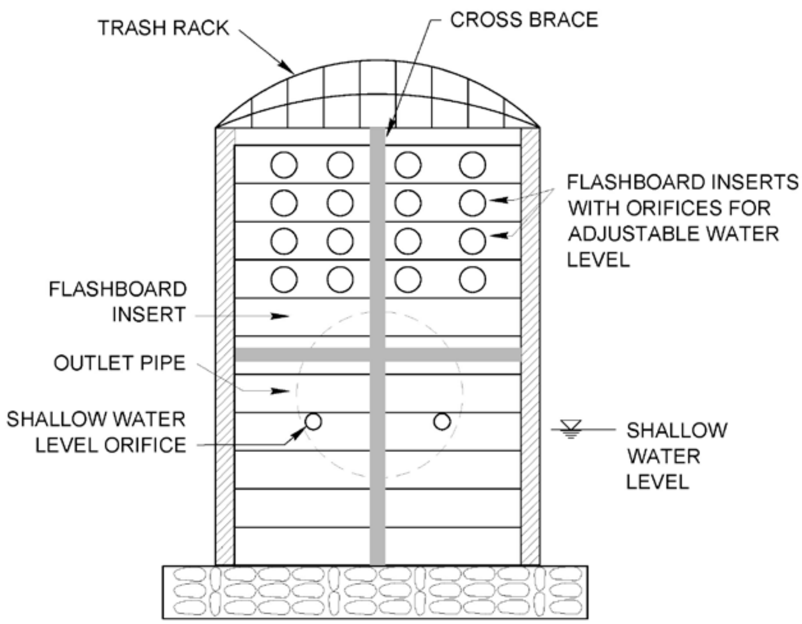



**Figure 13-5.** Typical flashboard riser outlet control structure

### *Drawdown Orifice*

The drawdown orifice is used to slowly drain the WQv that is temporarily stored following a storm event. For drawdown purposes, it is preferable to use an orifice diameter between 2 and 3 inches. If a larger opening is required, installation of two or more orifices is recommended. The orifice should be designed to draw down the WQv within 2 to 5 days where possible. Drawdown orifice size can be calculated using a routing spreadsheet or the orifice equation. The routing spreadsheet will include the changing head elevation; the orifice equation alone should use an average height equal to one-half of the WQv depth.

### *Embankment*

The height of the embankment is determined by providing a minimum of 1 foot of freeboard above the water surface elevation of the 50-year storm event. The embankment should be less than 12 feet in height and have an impoundment capacity of less than 10 acre-feet. Refer to Chapter 2 for guidance on measuring embankment height. The top width of the embankment should be 10 feet with side slopes of 3:1 or flatter to provide access for maintenance. For most applications, a simple homogeneous earthen embankment is sufficient. However, the size of the embankment and the type of soil should be evaluated to determine if anti-seep collars, a clay core, impervious liners, diaphragms, or internal drains are needed. Anti-seep collars and clay cores are generally the NCDOT-preferred options. Other seepage prevention measures typically require additional engineering. The *NRCS Agriculture Handbook 590* provides guidance on embankment design (USDA.02). Consider consulting a geotechnical engineer for large or complex embankment designs. Refer to Chapter 2 for further guidance.

### *Emergency Spillway*

The emergency spillway is typically constructed in natural ground to serve as an overflow structure to safely discharge storm runoff during large storm events. The channel is usually designed to convey the peak discharge for the 50-year storm event without considering flow through the outlet control structure. The liner material used in the spillway should be designed to handle the peak velocity from the 50-year storm event. The invert of the emergency spillway should be set 0.5–1 foot above the top of the outlet control structure. If there is not enough available right-of-way to construct the emergency spillway, an alternative design can be used.

Often the top of the riser is converted into an emergency overflow device, such as an open-throat riser. If the riser serves as the emergency spillway, the riser and outlet pipe must be designed to pass the discharge from the 50-year storm. All alternative design options are subject to review by the NCDOT Hydraulics Unit. Additional design criteria for stormwater wetland components are provided below in the Basin Component Design Criteria Summary box.

#### BASIN COMPONENT DESIGN CRITERIA SUMMARY

***Forebay***

- ❒ Forebay should be sized for 0.1 inches of runoff from the impervious area within the contributing drainage area.
- ❒ Forebay should have a minimum length-to-width ratio of 2:1, where practical, to promote sedimentation.
- ❒ Depth of the forebay should be 3−5 feet.
- ❒ Forebay side slopes should be flatter than or equal to 2:1.

***Shallow Water Zone***

- ❒ Depth of shallow water zone should be 3−6 inches.
- ❒ Shallow water zone should make up 40% of the total stormwater wetland surface area.

***Shallow Land Zone***

- ❒ Shallow land zone elevation should be equal to the permanent pool elevation.
- ❒ Shallow land zone should make up 30−40% of the total stormwater wetland surface area.

***Deep Pool***

- ❒ Maximum depth of deep pools should be 1.5−3 feet.
- ❒ Deep pools should make up 15−20% of the total stormwater wetland surface area.

## BASIN COMPONENT DESIGN CRITERIA SUMMARY (CONTINUED)

### ***Outlet Control Structure***

- ❒ Outlet control structure should be designed to allow the wetland to store the permanent pool and temporarily detain the WQv.
- ❒ Outlet control structure should typically be designed to handle the 10-year storm. If an emergency spillway is not provided, it should be designed for the 50-year storm.

### ***Drawdown Orifice***

- ❒ Preferred orifice size is 2−3 inches.
- ❒ Drawdown device should be sized to provide a 2–5 day drawdown time of the WQv where possible.

### ***Embankment***

- ❒ Height should be less than 12 feet and impoundment capacity less than 10 acre-feet. Refer to Chapter 2 for guidance on measuring embankment height.
- ❒ Embankment structure should have a minimum top width of 10 feet with side slopes of 3:1 or flatter.
- ❒ A minimum of 1 foot of freeboard must be provided between the surface water elevation of the 50-year storm event and the top of the embankment.

### ***Emergency Spillway***

- ❒ Emergency spillway invert elevation is typically set 0.5−1 foot above the top of the outlet control structure.
- ❒ Emergency spillway should be sized to safely convey the 50-year storm event and prevent flooding of the roadway.
- ❒ Emergency spillway liner material should be designed to handle the peak velocity from the 50-year storm event.

## DESIGN OPTIONS CRITERIA

A flow bypass structure may be needed for cases where the wetland is undersized due to site constraints or drainage area characteristics. Also, constructing a flow bypass structure may be more economical than an outlet control structure or emergency spillway sized to convey the 10- and 50-year storm events.

The designer should select the appropriate bypass structure configuration on a site-by-site basis. Energy dissipation or dispersion of flow must be utilized for concentrated discharges. The weir and pipes associated with the bypass structure should be sized to convey all runoff generated by the water quality design storm into the wetland. Hydrograph generation and pond routing calculations are recommended to size the weir and pipes; however, peak discharge and pipe flow capacity calculations are also acceptable sizing methods. In addition, considerations for backwater conditions in the wetland must be given. An outlet control structure and emergency spillway may still be needed with some flow bypass configurations. Refer to Chapter 2 for more detailed guidance.

### Design and Construction Considerations

When determining the location of a stormwater wetland, the designer must take into account the topography, soils, and drainage patterns. The wetland's shape will be subject to the contours of the site in some locations. The orientation should maximize the length-to-width ratio of 1.5:1 or greater.

Careful consideration should be given to the size of the drainage area and the water table early in the design process. Large drainage areas and a high water table are needed to maintain the permanent pool level. Soil types and water table information can be obtained from geotechnical reports generated during a subsurface investigation that is typically performed by the NCDOT Geotechnical Engineering Unit.

Additional design and construction recommendations follow:

- Locate the wetland outside of the clear recovery zone.
- Check the available right-of-way when determining the stormwater wetland footprint and orientation.
- Place stormwater wetlands in undisturbed soil, not in fill material.
- Coordinate with the NCDOT Roadside Environmental Unit when developing the landscaping plan.
- Determine proper ballast for the outlet control structure to prevent flotation as needed.
- Consider whether bypass or diversion of off-site drainage is necessary based on site constraints.
- Stabilize all stormwater wetland system outlets to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042 (NCDOT.08).
- The stormwater wetland should remain offline until all areas contributing to the wetland are stabilized.
- The stormwater wetland must be stabilized immediately following its construction.
- In order to preserve soil moisture and workability, the stormwater wetland drain should be fully opened for no more than 3 days prior to the planting date.
- Provide a debris screen or trash rack over the riser structure to prevent clogging and human entry.
- Include a minimum 10-foot wide access road to the stormwater wetland for maintenance.
- Provide watertight connections at all pipe connections to concrete structures. Connections for nonconcrete pipes should be made using flexible boot, gasket, or similar device.

## 13.4 Inspection and Maintenance

Refer to the NCDOT *Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for inspection and maintenance guidance.

Where possible, provide an area on site where sediment removed from the BMP can be disposed. The area should be relatively flat to promote stabilization after sediment is deposited. The sediment disposal area should also be gently sloped away from the BMP to prevent deposited sediment from reentering the BMP. The sediment disposal area should be configured in a manner that prevents adverse effects to receiving waters or adjacent properties.

## 13.5 Safety Considerations

Stormwater wetlands are typically large, and water depths may be deep enough to present a drowning hazard, especially in residential or public areas. Shallow safety benches may be constructed around the perimeter of the wetland. Trash racks and other structures should be designed to prevent entry by children. Consider fencing and signage around the BMP if the stormwater wetland is surrounded by steep side slopes, or if children are expected to be in the area (e.g., nearby schools or playgrounds). Refer to NCDOT Standard Specifications, Section 866 (NCDOT.08), for fencing options.

# CHAPTER 14 Filter Strip

## OVERVIEW

A FILTER STRIP is a uniformly sloped and vegetated area designed to treat diffuse stormwater flow by filtering, slowing, and infiltrating runoff.

### PURPOSE AND DESCRIPTION

- A filter strip reduces pollutants as stormwater runoff uniformly flows over a slightly graded densely vegetated slope.

### APPLICATIONS

- A filter strip is generally used adjacent to the linear roadside environment, maintenance facility parking areas, or rest area parking lots.
- A filter strip can also be used in conjunction with level spreaders, preformed scour holes, and other BMPs as part of a BMP system.

### WATER QUALITY BENEFITS

- By reducing velocity, filter strips promote particulate settling and infiltration.
- Filter strips can improve stormwater quality by reducing suspended solids, metals, and in some cases nutrients through sedimentation and interception, vegetated filtration, and biological uptake.

## 14.1 Description

A filter strip is a uniformly graded and densely vegetated BMP that provides diffuse flow to effect pollutant removal from stormwater runoff through increased sedimentation, vegetative filtering, and infiltration. Filter strips are engineered BMPs, although research indicates that roadside ditches not designed for stormwater treatment also present water quality benefits. They can be comprised of a variety of shrubs, grasses, and native vegetation to facilitate filtration, increase roughness and benefit water quality and are typically used along linear road systems, parking lots, and other pervious and impervious areas. Filter strips are often used in conjunction with level spreaders, preformed scour holes, and other BMPs as part of a best management practice system. Filter strips provide groundwater recharge in areas with pervious soils. Figure 14-1 shows a typical filter strip.

**Figure 14-1.** Typical filter strip along a roadway shoulder section

## 14.2 Applications

Site conditions that are most fitting for filter strips are along highways and rural roadways where there is enough shoulder to provide diffuse flow off the road and over the filter strip before entering the receiving stream. A filter strip may also be used in conjunction with other BMPs such as level spreaders and preformed scour holes to enhance stormwater treatment. Filter strips may be limited on linear projects in urban areas due to constraints associated with right-of-way availability in providing effective lengths of vegetative cover to treat stormwater runoff. For frequent small storms, filter strips are effective at treating runoff. The ability to convey large runoff rates from roadways during high-intensity events is limited by the flow depth over the system.

A primary consideration for filter strips is to treat small drainage areas. A drainage area to filter strip surface area ratio of 10:1 is considered conservative for North Carolina. Studies at North Carolina State University have shown good total suspended solids (TSS) removal and volume reduction at ratios of 20−40:1. The appropriate size of the filter strip relative to the drainage area will depend on contributing sources, with a larger ratio of drainage area relative to filter strip size permissible when there is no off-site drainage than when other contributing sources are present.

The overland flow length upgrade of the filter strip should be evaluated to prevent reconcentration of flow. In general, overland flow lengths for pervious surfaces are greater than those for impervious surfaces. If the upgrade flow length is excessive, use a level spreader to redistribute flow. A maximum slope of 5% is desirable for the upgrade overland flow path; however, steeper slopes may be used if suitable non-erodible grasses can be established. To maximize the potential for infiltration, the seasonal high water table should be at least one foot lower than any point along the filter strip. The lateral slope perpendicular to the flow should be as close to zero as practicable, as even relatively mild slopes can allow for reconcentration of runoff. Figure 14-2 shows the typical filter strip configurations and pollutant removal processes. Guidance for the location and applicability of filter strips is presented in the Siting Criteria Summary box.

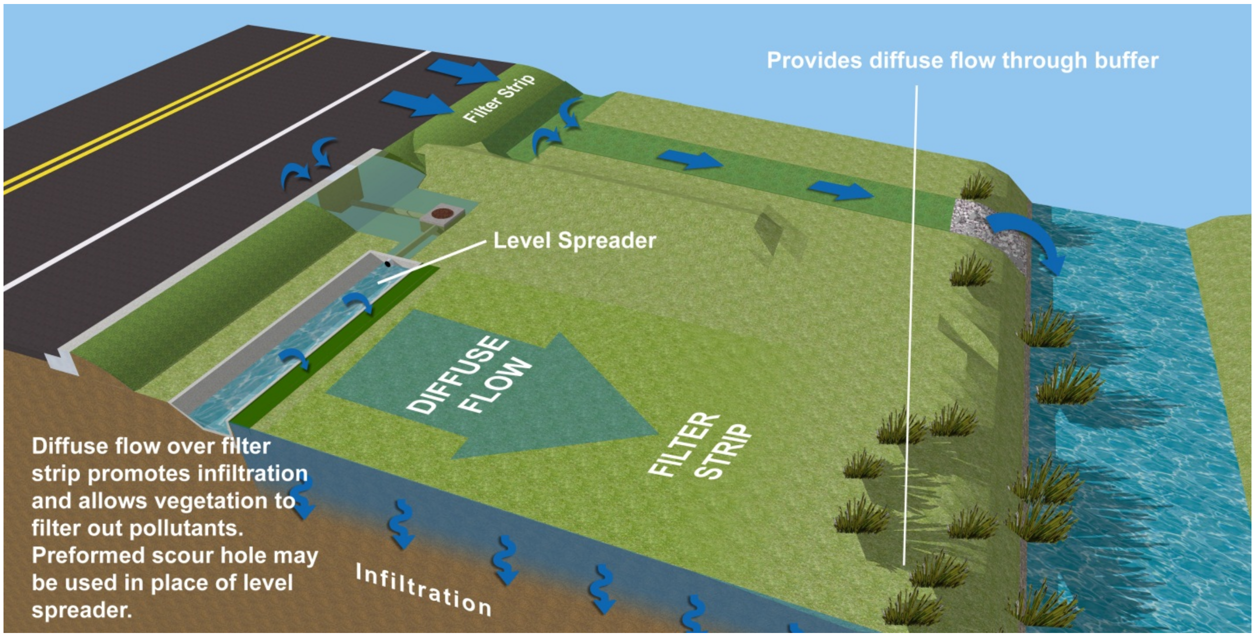



**Figure 14-2.** Typical filter strip configurations and pollutant removal processes

### Siting Criteria Summary

- ❒ Locate filter strip on right-of-way or in a permanent drainage easement with appropriate access.
- ❒ Filter strip should be used to treat small drainage areas; a maximum ratio of 10:1 (drainage area to filter strip surface area) is recommended.
- ❒ Evaluate the overland flow length upgrade of filter strip to prevent reconcentration of flow unless redistributed using a level spreader.
- ❒ Maximum slope of the upgrade overland flow path should not exceed 5%.
- ❒ Seasonal high water table should be at least 1 foot lower than any point along the filter strip.
- ❒ In the linear environment, utilize available vegetated roadway shoulder as a roadside filter strip.

## 14.3 Design

The design of a filter strip is based on site conditions to include, soil type, slope, length, and drainage area served. One of the most critical design features is to ensure diffuse flow over the filter strip. A filter strip design with the top and toe being as flat as possible will promote this flow regime.

## SIZING CRITERIA

A longitudinal slope of 2 to 5 percent is optimal for diffuse flow and to prevent ponding and to promote enhanced sedimentation, vegetative filtering, and infiltration. However, filter strips with slopes greater than 5% can be effective at removing sediment (Caltrans.01). Permissible velocities for filter strips should be ≤ 4 feet per second for grass and ≤1 feet per second for native herbaceous vegetation. The lateral slope should be as flat as possible; however, filter strips along the shoulder sections will follow the topography of the roadway. Filter strips should be at least 30 feet in length and 50 feet is the preferred minimum length for SA waters (NCDENR.03). However, research has shown that road shoulders less than 30 feet have been effective in removing sediment (Caltrans.01). Typical filter strip design components for non-road and roadway applications are depicted in Figures 14-3 and 14-4, respectively.

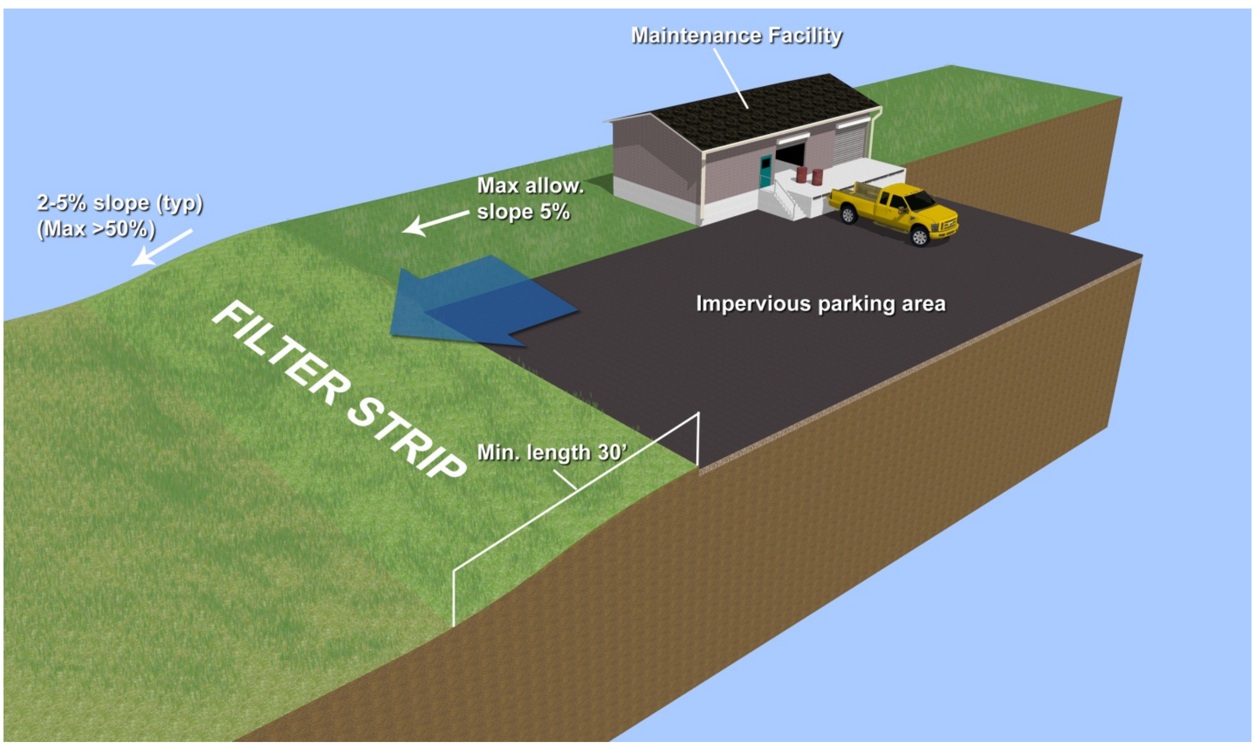



**Figure 14-3.** Typical non-road filter strip design components

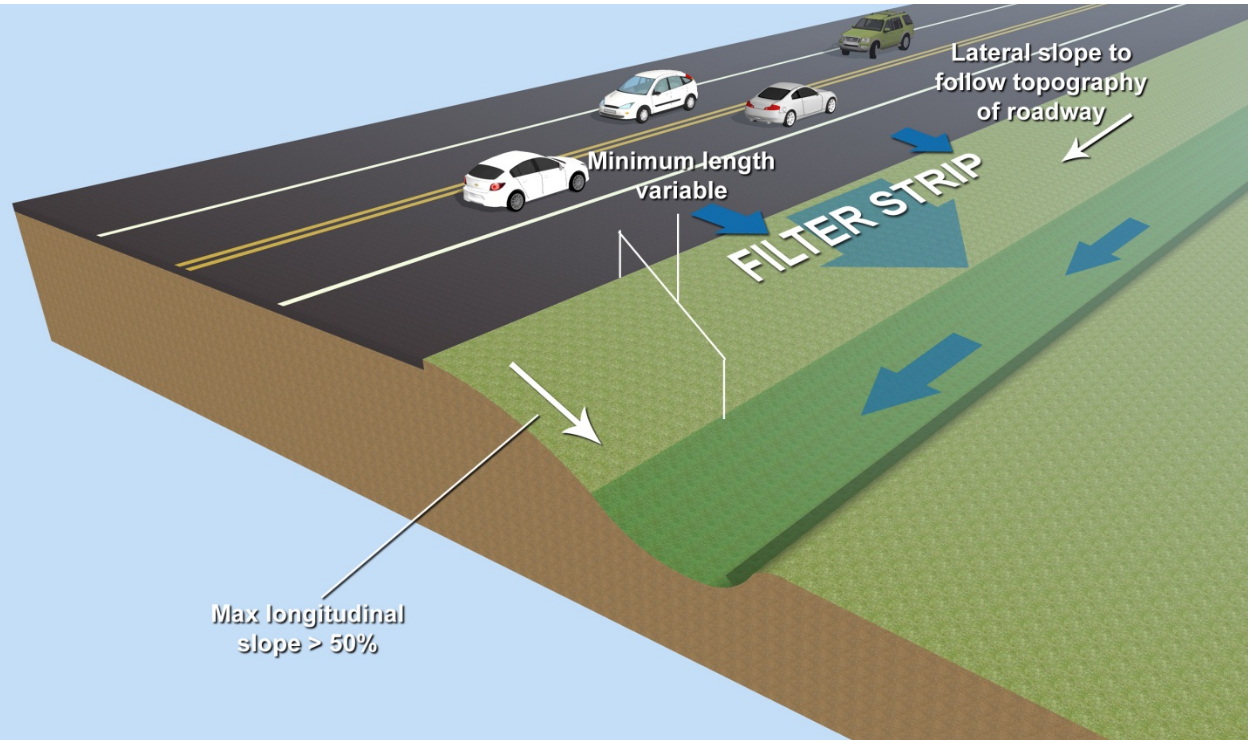



**Figure 14-4.** Typical roadway filter strip design components

## DESIGN CRITERIA SUMMARY

- ❒ The longitudinal slope (parallel to flow) of a filter strip should optimally be 2−5%, when feasible; slopes steeper than 5% are permissible when non-erosive velocities can be maintained.
- ❒ The lateral slope (perpendicular to flow) of a filter strip should be as flat as possible.
- ❒ The preferred minimum length (parallel to flow) of a filter strip adjacent to SA waters is 50 feet; 30 feet is desirable for other locations, but shorter lengths can be effective.
- ❒ Both the top and toe of slope for a filter strip should be as flat as possible to encourage diffuse flow.

## VEGETATION CRITERIA

Dense vegetative cover is critical to ensure treatment of stormwater runoff in filter strips. Research indicates that inferior treatment performance has been observed when the aerial vegetative cover is less than 80 percent (NCDOT.08). Vegetative cover and height (relative to water depth) is a critical parameter that affects removal efficiencies. Also, as vegetative retardance increases, the detention time for settling of suspended solids increases, which is the primary removal mechanism for particulates.

The underlying soils for the filter strip's root system should be tested and amended to ensure appropriate levels of plant nutrients and soil pH. The designer may specify an engineered soil media where existing site conditions are not favorable or conducive to good vegetative establishment. The soils should be able to sustain a dense grass cover with high retardance capabilities.

The filter strip should consist of densely covered sod. Bermudagrass and Centipede grass are selections for the coastal plain region; fescue, bluegrass, and zoysiagrass are considerations for the piedmont and mountain regions. If sod is not used, the seeded filter strip should utilize appropriate erosion control matting based on maximum permissible shear and velocity threshold values.

## ALTERNATIVE DESIGN CRITERIA

Filter strips used in conjunction with other BMPs may incorporate the installation of a high flow bypass system. This bypass channel directs flow around the BMPs without causing erosion to either the channel itself or to the receiving drainage conveyances or stream. Ensure that the bypass channel does not discharge perpendicular to the flow of the stream to minimize the potential for streambed erosion.

In areas of incised stream systems, the filter strip system may include a berm or other method of collecting runoff at the toe of the slope to direct runoff into a channel for discharge to avoid head cutting. Figure 14-5 is an illustration of this condition.

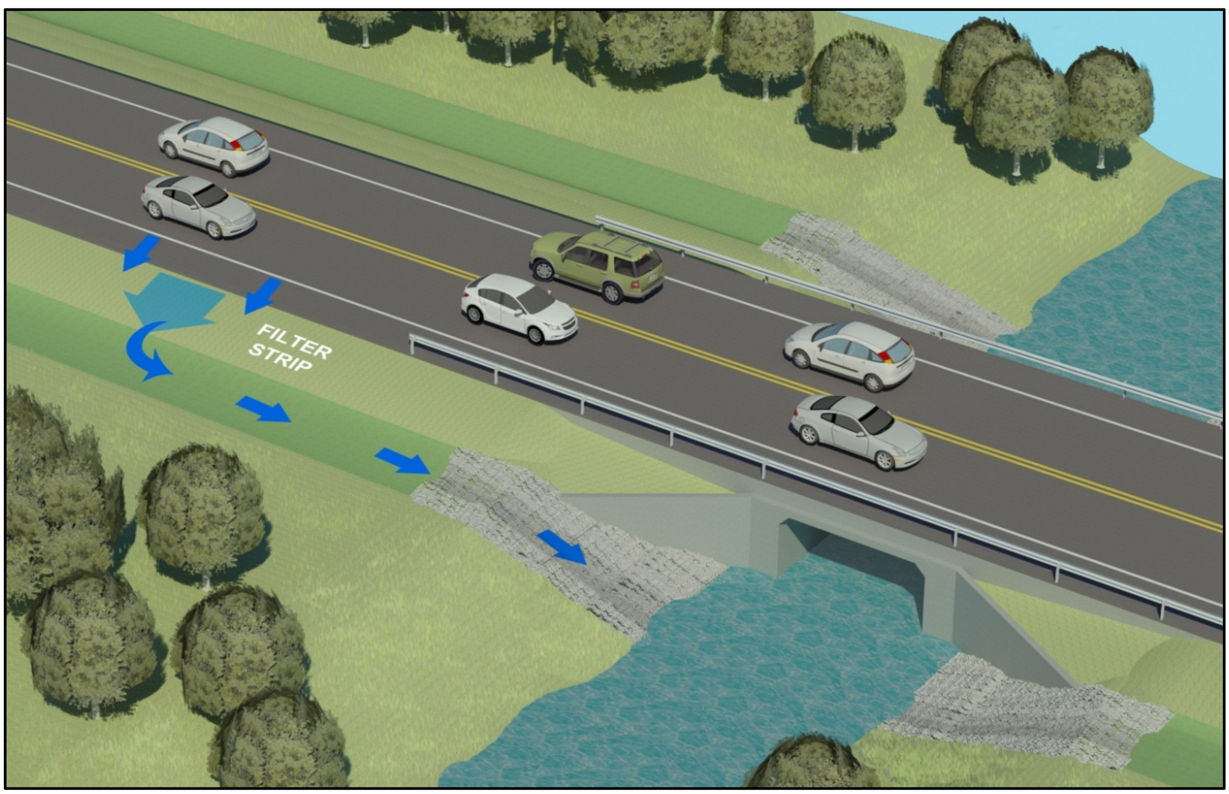



**Figure 14-5.** Example of conveyance designed downstream of filter strip to protect buffer and streambank from erosion

### DESIGN AND CONSTRUCTION CONSIDERATIONS

Before vegetation is established in the filter strip, significant erosion and scour can occur. The exposed filter strip should be protected with a temporary erosion-resistant lining and perimeter sediment controls, as needed. Manning's 'n' values typically can be determined for various temporary liners from the manufacturer's specifications. Complete temporary erosion-resistant liner design procedures are provided in Appendix 8.05 in the NCDENR (NCDENR.01) *Erosion and Sediment Control Planning and Design Manual*, as well as in FHWA's HEC-15 (FHWA.04). Figure 14-4 shows a roadside filter strip prior to seeding (left) and a filter strip used in combination with a level spreader prior to vegetation establishment (right).

**Figure 14-6.** Filter strips prior to vegetation establishment

Additional design and construction recommendations follow:

- Evaluate the impacts of ponded water in the filter strip. Ponded water and wetland vegetation may occur when longitudinal slopes are less than 1.0%.
- Mowing constraints should be considered during the design process. The maximum slope that can be safely mowed with conventional equipment is 3:1.
- When applying the filter strip in a best management practice system, design the transitions to other best management practices to prevent short-circuiting.
- When pratical, route off-site runoff away from the filter strip.
- Consider alternative grasses or seeding mixtures in the event the selected vegetation does not become established.
- Avoid driving heavy equipment on the filter strip to prevent compaction.

## 14.4 Inspection and Maintenance

The filter strip requires routine mowing and visual inspection to ensure densely populated vegetation exists and no erosion or channelization is occurring at the site. Grass length should be no less than 4 to 6 inches and should not exceed 12 inches. Filter strip components that receive or trap sediment should be inspected for clogging, density of vegetation, damage by vehicle or foot traffic, and excessive accumulation of debris. General maintenance includes repair of eroded areas, repair seeding, supplemental seeding, and fertilizer topdressing to maintain dense vegetative growth.

Refer to the *NCDOT Stormwater Control Inspection and Maintenance Manual* (NCDOT.05) for additional inspection and maintenance guidance for filter strips used at level spreaders.

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# APPENDIX A CHECKLISTS

North Carolina Department of Transportation
Highway Stormwater Program

## LEVEL SPREADER CHECKLIST



Project: ______ TIP No: ______

Prepared by: ______ Date: ______ Checked by: ______ Date: ______

NCDOT Division: ______ River Basin: ______

City: ______ NCDWR Stream Classification

County: ______ Primary: ______

CAMA County: Yes No Supplemental: ______

303(d) Stream: Yes No

Buffer Required: Yes No

**PROJECT DESCRIPTION**

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Were different level spreader locations and orientations considered to optimize water quality benefit? Explain. | ☐ | ☐ | ☐ | |
| 2 | Was a field visit made to the proposed level spreader site? | ☐ | ☐ | ☐ | |
| 3 | Was the level spreader positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 4 | Were off-site drainage areas verified and accommodated? | ☐ | ☐ | ☐ | |
| 5 | Was care taken to prevent hydraulic encroachment on nearby properties from flow bypass structure and level spreader design? | ☐ | ☐ | ☐ | |
| 6 | Was a geotechnical investigation performed for the level spreader location? | ☐ | ☐ | ☐ | |
| 7 | Was adequate maintenance ingress and egress provided within the right-of-way? | ☐ | ☐ | ☐ | |
| 8 | During design, was flow entering the level spreader slowed or dissipated to avoid concentrating the flow and exiting the lip at one area? | ☐ | ☐ | ☐ | |
| 9 | Was topography downgrade of the level spreader reviewed for ability to diffuse flow? | ☐ | ☐ | ☐ | |
| 10 | Does the entire level spreader system safely pass the 10-year storm event? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

**LEVEL SPREADER CHECKLIST** | 

**Project:** ______ **TIP No:** ______

**Prepared by:** ______ **Date:** ______ **Checked by:** ______ **Date:** ______

**NCDOT Division:** ______ **River Basin:** ______

**City:** ______ **NCDWR Stream Classification**

**County:** ______ **Primary:** ______

**CAMA County:** **Yes** **No** **Supplemental:** ______

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

**PROJECT DESCRIPTION**

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 11 | Was the level spreader implemented in a system with another BMP? Explain. | ☐ | ☐ | ☐ | |
| 12 | Was a forebay considered? Why or why not? | ☐ | ☐ | ☐ | |
| 13 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

## PREFORMED SCOUR HOLE CHECKLIST



**Project:** ______________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWR Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** **Yes** **No** **Supplemental:** __________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

**PROJECT DESCRIPTION**

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Was a field visit made for the proposed preformed scour hole site/location? | ☐ | ☐ | ☐ | |
| 2 | Was the preformed scour hole positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 3 | Were off-site drainage areas verified and accommodated? | ☐ | ☐ | ☐ | |
| 4 | Were adequate ingress and egress for maintenance provided within right-of-way? | ☐ | ☐ | ☐ | |
| 5 | Were different preformed scour hole locations and orientations considered to optimize water quality benefits? Explain. | ☐ | ☐ | ☐ | |
| 6 | Was topography downgrade of the preformed scour hole reviewed for ability to diffuse flow? | ☐ | ☐ | ☐ | |
| 7 | Is the PSRM apron shown on the plans flush with the natural ground? | ☐ | ☐ | ☐ | |
| 8 | Is the discharge pipe an allowable size for use with a preformed scour hole (15 in. or 18 in.)? | ☐ | ☐ | ☐ | |
| 9 | Have maximum allowable discharges based on the $Q_{10}$ discharge been verified? | ☐ | ☐ | ☐ | |
| 10 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

## DRY DETENTION BASIN CHECKLIST



### GENERAL PROJECT INFORMATION

**Project:** ______________________ **TIP No:** __________

**Prepared by:** ______________ **Date:** ________ **Checked by:** ____________ **Date:** ________

**NCDOT Division:** ______________ **River Basin:** ______________

**City:** ______________ **NCDWR Stream Classification**

**County:** ______________ **Primary:** ______________

**CAMA County:** **Yes** **No** **Supplemental:** ______________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

### PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Was a field visit made to the proposed dry detention basin site? | ☐ | ☐ | ☐ | |
| 2 | Is the dry detention basin positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 3 | Was maintenance access provided? | ☐ | ☐ | ☐ | |
| 4 | Were off-site drainage areas verified and accommodated? | ☐ | ☐ | ☐ | |
| 5 | Was a pretreatment BMP used in series with the dry detention basin? If a forebay was used, the Chapter 7 Checklist should be completed. | ☐ | ☐ | ☐ | |
| 6 | Was soil compaction information provided in the project specifications? | ☐ | ☐ | ☐ | |
| 7 | Was energy dissipation required for the emergency spillway (if used)? | ☐ | ☐ | ☐ | |
| 8 | Was the buoyancy of the outlet structure calculated? | ☐ | ☐ | ☐ | |
| 9 | Was the vegetative cover specified? | ☐ | ☐ | ☐ | |
| 10 | Was the grade of the basin bottom shown to slope and drain toward the orifice? | ☐ | ☐ | ☐ | |
| 11 | Was topography downgrade of the dry detention basin outlet reviewed for ability to handle flow? | ☐ | ☐ | ☐ | |
| 12 | Were velocities evaluated for scour and erosion potential? | ☐ | ☐ | ☐ | |
| 13 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

**SWALE CHECKLIST**



**GENERAL PROJECT INFORMATION**

**Project:** ______________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWR Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** **Yes** **No** **Supplemental:** __________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

**PROJECT DESCRIPTION**

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Was a field visit made to the proposed swale site? | ☐ | ☐ | ☐ | |
| 2 | Were off-site drainage areas verified and accommodated? | ☐ | ☐ | ☐ | |
| 3 | Were different swale locations and orientations considered to optimize water quality benefits? Explain. | ☐ | ☐ | ☐ | |
| 4 | Was NCDENR Erosion and Sediment Control Planning and Design Manual reviewed for proper vegetative cover selection? | ☐ | ☐ | ☐ | |
| 5 | Is selected vegetation specified? | ☐ | ☐ | ☐ | |
| 6 | Were adequate ingress and egress for maintenance provided within the right-of-way? | ☐ | ☐ | ☐ | |
| 7 | Were water quality rock checks used in the swale design? | ☐ | ☐ | ☐ | |
| 8 | Was temporary erosion-resistant lining specified? | ☐ | ☐ | ☐ | |
| 9 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

| FOREBAY CHECKLIST | Page 1 of 1 |
|---|---|

**GENERAL PROJECT INFORMATION**

**Project:** ______ **TIP No:** ______
**Prepared by:** ______ **Date:** ______ **Checked by:** ______ **Date:** ______
**NCDOT Division:** ______ **River Basin:** ______
**City:** ______ **NCDWR Stream Classification**
**County:** ______ **Primary:** ______
**CAMA County:** **Yes** **No** **Supplemental:** ______
**303(d) Stream:** **Yes** **No**
**Buffer Required:** **Yes** **No**

**PROJECT DESCRIPTION**

| Check the correct response. | | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Was a field visit made to the proposed forebay site? | ☐ | ☐ | ☐ | |
| 2 | Was forebay positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 3 | Were off-site drainage areas verified and accommodated? | ☐ | ☐ | ☐ | |
| 4 | Were adequate ingress and egress for maintenance provided within right-of-way? | ☐ | ☐ | ☐ | |
| 5 | Is a forebay provided at each inflow point at this site? How many? | ☐ | ☐ | ☐ | |
| 6 | Was the sizing criteria in Chapter 7 used for estimating the volume of the forebay? | ☐ | ☐ | ☐ | |
| 7 | Was the forebay liner material specified? | ☐ | ☐ | ☐ | |
| 8 | Was the liner designed to meet velocity requirements? | ☐ | ☐ | ☐ | |
| 9 | Is the forebay in series with another BMP? If so, what type? | ☐ | ☐ | ☐ | |
| 10 | Does the forebay safely pass the 10-year storm event? | ☐ | ☐ | ☐ | |
| 11 | Is the depth of the forebay set between 3 and 5 feet? | ☐ | ☐ | ☐ | |
| 12 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

## HAZARDOUS SPILL BASIN CHECKLIST



### GENERAL PROJECT INFORMATION

**Project:** ____________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWR Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** Yes No **Supplemental:** __________

**303(d) Stream:** Yes No

**Buffer Required:** Yes No

### PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Were the planning documents reviewed and information therein verified to determine whether a hazardous spill basin is applicable? | ☐ | ☐ | ☐ | |
| 2 | Was a field visit made to the proposed hazardous spill basin site? | ☐ | ☐ | ☐ | |
| 3 | Is the hazardous spill basin positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 4 | Was maintenance access provided to accommodate appropriate maintenance equipment? | ☐ | ☐ | ☐ | |
| 5 | Were off-site drainage areas verified and accommodated? | ☐ | ☐ | ☐ | |
| 6 | Was energy dissipation required? | ☐ | ☐ | ☐ | |
| 7 | Is the outlet structure (i.e., sluice gate) or obstruction material (i.e., sand bags) specified? | ☐ | ☐ | ☐ | |
| 8 | Was the grade of the basin bottom designed to slope and drain toward the outlet pipe? | ☐ | ☐ | ☐ | |
| 9 | Was topography downgrade of the hazardous spill basin outlet assessed for its ability to handle flow? | ☐ | ☐ | ☐ | |
| 10 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

| BRIDGE BEST MANAGEMENT PRACTICES CHECKLIST | Page 1 of 1 |
|---|---|

**GENERAL PROJECT INFORMATION**

**Project:** ______________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWR Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** **Yes** **No** **Supplemental:** __________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

**PROJECT DESCRIPTION**

| Check the correct response. | | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Were the planning documents reviewed to determine which bridge drainage system configuration is applicable? | ☐ | ☐ | ☐ | |
| 2 | Is a closed deck drainage system required? | ☐ | ☐ | ☐ | |
| 3 | Are the bridge drainage conveyances combined with another BMP?<br>If yes, what BMP?<br>If no, document justification. | ☐ | ☐ | ☐ | |
| 4 | Is a hazardous spill basin required (refer to Chapter 8)? | ☐ | ☐ | ☐ | |
| 5 | Is erosion protection provided at piped outlets? | ☐ | ☐ | ☐ | |
| 6 | Has the material for the closed deck drainage system been determined by the Structure Management Unit? | ☐ | ☐ | ☐ | |
| 7 | Is there adequate erosion protection specified for overbank areas below open deck drains? | ☐ | ☐ | ☐ | |
| 8 | Were instances of longitudinal pipes through the abutment avoided where possible? | ☐ | ☐ | ☐ | |
| 9 | Does the bridge drainage design account for runoff received from the roadway drainage system? | ☐ | ☐ | ☐ | |
| 10 | Is slope stabilization provided? | ☐ | ☐ | ☐ | |
| 11 | Has the design been provided to the Structure Management Unit? | ☐ | ☐ | ☐ | |
| 12 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

**INFILTRATION BASIN CHECKLIST**



**Project:** ____________ **TIP No:** ____________

**Prepared by:** ____________ **Date:** ________ **Checked by:** ____________ **Date:** ________

**NCDOT Division:** ____________ **River Basin:** ____________

**City:** ____________ **NCDWR Stream Classification**

**County:** ____________ **Primary:** ____________

**CAMA County:** **Yes** **No** **Supplemental:** ____________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

**PROJECT DESCRIPTION**

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Is the project area within one-half mile of and draining to a Class SA water or tributary of a Class SA water? | ☐ | ☐ | ☐ | |
| 2 | Is system located a minimum of 50 feet from a Class SA water and 30 feet from other surface waters? | ☐ | ☐ | ☐ | |
| 3 | Has the site been reviewed to confirm that the basin is a minimum of 100 feet from any water supply wells? | ☐ | ☐ | ☐ | |
| 4 | Was a field visit made to the proposed infiltration basin site? | ☐ | ☐ | ☐ | |
| 5 | Is the drainage area less than 5 acres? | ☐ | ☐ | ☐ | |
| 6 | Is the infiltration basin positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 7 | Is the infiltration basin proposed to be excavated from existing material? | ☐ | ☐ | ☐ | |
| 8 | Has a subsurface geotechnical investigation been performed on the site? | ☐ | ☐ | ☐ | |
| 9 | After final grading, will the infiltration basin bottom be at least 2 feet above the seasonal high water table? | ☐ | ☐ | ☐ | |
| 10 | After final grading, will the infiltration basin bottom be at least 3 feet above bedrock or any impervious soil horizon? | ☐ | ☐ | ☐ | |
| 11 | Is the hydraulic conductivity (verified by subsurface investigation) greater than 0.52 inch per hour? | ☐ | ☐ | ☐ | |
| 12 | Do the WQv calculations account for the ultimate built-out potential of the drainage area? | ☐ | ☐ | ☐ | |

**North Carolina Department of Transportation**
**Highway Stormwater Program**

| INFILTRATION BASIN CHECKLIST | Page 2 of 2 |
|---|---|

**Project:** ______________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWR Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** **Yes** **No** **Supplemental:** __________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

| Check the correct response. | | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 13 | Has the infiltration rate been set equal to the hydraulic conductivity? If a safety factor has been used, please specify. | ☐ | ☐ | ☐ | |
| 14 | Will the infiltration basin draw down the design storage volume under seasonal high water conditions within five days? | ☐ | ☐ | ☐ | |
| 15 | Was a pretreatment BMP implemented to remove coarse solids? If a forebay was used, the Chapter 7 Checklist should be completed. | ☐ | ☐ | ☐ | |
| 16 | Was at least a 4-inch layer of clean sand or a vegetative cover specified for the bottom of the infiltration basin? | ☐ | ☐ | ☐ | |
| 17 | Are all basin side slopes equal to or flatter than 3:1? | ☐ | ☐ | ☐ | |
| 18 | Was energy dissipation provided for the emergency outlet control structure (if used)? | ☐ | ☐ | ☐ | |
| 19 | Has adequate anchoring been provided for the emergency outlet control structure (if used)? | ☐ | ☐ | ☐ | |
| 20 | Has access been provided to the basin for inspection and maintenance? | ☐ | ☐ | ☐ | |
| 21 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

# MEDIA FILTER CHECKLIST



## GENERAL PROJECT INFORMATION

Project: ______________________ TIP No: ________

Prepared by: ____________ Date: ________ Checked by: ____________ Date: ________

NCDOT Division: ____________ River Basin: ____________

City: ____________ NCDWR Stream Classification

County: ____________ Primary: ____________

CAMA County: Yes No Supplemental: ____________

303(d) Stream: Yes No

Buffer Required: Yes No

## PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Is the media filter a bioretention area? | ☐ | ☐ | ☐ | |
| 2 | Is the media filter a filtration basin? | ☐ | ☐ | ☐ | |
| 3 | Is the project area within one-half mile of and draining to a Class SA water or tributary of a Class SA water? | ☐ | ☐ | ☐ | |
| 4 | Was a field visit made to the proposed media filter site? | ☐ | ☐ | ☐ | |
| 5 | Has a subsurface geotechnical investigation been performed on the site? | ☐ | ☐ | ☐ | |
| 6 | Is the drainage area less than 5 acres? | ☐ | ☐ | ☐ | |
| 7 | Are drainage area slopes in the vicinity of the media filter less than 20%? | ☐ | ☐ | ☐ | |
| 8 | Is the site located a minimum of 50 feet from a Class SA water and 30 feet from other surface waters? | ☐ | ☐ | ☐ | |
| 9 | Has the site been reviewed to confirm that the basin is a minimum of 100 feet from any water supply wells? | ☐ | ☐ | ☐ | |
| 10 | After final grading, will the media filter bottom be at least 2 feet above the seasonal high water table? | ☐ | ☐ | ☐ | |
| 11 | Are all basin side slopes equal to or flatter than 3:1? | ☐ | ☐ | ☐ | |
| 12 | Is the length-to-width ratio of the basin greater than or equal to 2:1? | ☐ | ☐ | ☐ | |
| 13 | For the embankment, was 1 ft of freeboard provided above the 50-year storm elevation? | ☐ | ☐ | ☐ | |
| 14 | For bioretention basins, does all ponded water visible above the surface of the media filter draw down within 12 hours? | ☐ | ☐ | ☐ | |

**MEDIA FILTER CHECKLIST**



**GENERAL PROJECT INFORMATION**

**Project:** ______________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWQ Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** Yes No **Supplemental:** __________

**303(d) Stream:** Yes No

**Buffer Required:** Yes No

**PROJECT DESCRIPTION**

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 15 | For filtration basins, does all ponded water visible above the surface of the media filter draw down within 24 hours? | ☐ | ☐ | ☐ | |
| 16 | Was a pretreatment BMP implemented to remove coarse solids? If a forebay was used, the Chapter 7 Checklist should be completed. | ☐ | ☐ | ☐ | |
| 17 | For filtration basins, is there a minimum media depth of 18 in? | ☐ | ☐ | ☐ | |
| 18 | For bioretention basins, is there a minimum media depth of 24 in? | | | | |
| 19 | Is the filter media depth above the internal water storage zone a minimum of 12 in (if used)? | ☐ | ☐ | ☐ | |
| 20 | For bioretention basins, does the media composition meet specifications listed in Chapter 11? | ☐ | ☐ | ☐ | |
| 21 | Is the internal water storage zone depth a minimum of 24 in (if used)? | ☐ | ☐ | ☐ | |
| 22 | Does the underdrain have a minimum slope of 0.5% toward the outlet control structure? | ☐ | ☐ | ☐ | |
| 23 | Does the underdrain system meet criteria specified in Chapter 11 (if used)? | ☐ | ☐ | ☐ | |
| 24 | Was the media filter appropriately sized to allow drawdown within a 2-5 day period? | ☐ | ☐ | ☐ | |
| 25 | For an internal water storage zone, does the upturned elbow extend a minimum of 24 in vertically (if used)? | ☐ | ☐ | ☐ | |
| 26 | Was the outlet control structure sized to convey the 10-year storm at a minimum and allow the basin to store the WQv? | ☐ | ☐ | ☐ | |

| Highway Stormwater Program (NCDOT) | North Carolina Department of Transportation<br>Highway Stormwater Program | |
|---|---|---|
| **MEDIA FILTER CHECKLIST** | |  |

**GENERAL PROJECT INFORMATION**

**Project:** ____________________ **TIP No:** ________

**Prepared by:** ____________ **Date:** ______ **Checked by:** ____________ **Date:** ______

**NCDOT Division:** ____________ **River Basin:** ____________

**City:** ____________ **NCDWQ Stream Classification**

**County:** ____________ **Primary:** ____________

**CAMA County:** **Yes** **No** **Supplemental:** ____________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

**PROJECT DESCRIPTION**

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 27 | Is the emergency spillway sized to convey the 50-year storm and prevent flooding of the roadway? | ☐ | ☐ | ☐ | |
| 28 | Is the emergency spillway invert elevation set 0.5 ft above the top of the outlet control structure? | ☐ | ☐ | ☐ | |
| 29 | Is the emergency spillway liner material designed to handle the peak velocity from the 50-year storm event? | ☐ | ☐ | ☐ | |
| 30 | Is the top width of the embankment a minimum of 10 ft? | ☐ | ☐ | ☐ | |
| 31 | Is the embankment less than 12 ft in height? | ☐ | ☐ | ☐ | |
| 32 | Was energy dissipation provided for the outlet control structure? | ☐ | ☐ | ☐ | |
| 33 | Has adequate anchoring been provided for the outlet control structure? | ☐ | ☐ | ☐ | |
| 34 | Has access been provided to the basin for inspection and maintenance? | ☐ | ☐ | ☐ | |
| 35 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |
| 36 | Is the media filter positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 37 | Do the WQv calculations account for the ultimate built-out potential of the drainage area? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

## WET DETENTION BASIN CHECKLIST



### GENERAL PROJECT INFORMATION

**Project:** ____________ **TIP No:** ____________

**Prepared by:** ____________ **Date:** ________ **Checked by:** ____________ **Date:** ________

**NCDOT Division:** ____________ **River Basin:** ____________

**City:** ____________ **NCDWR Stream Classification**

**County:** ____________ **Primary:** ____________

**CAMA County:** **Yes** **No** **Supplemental:** ____________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

### PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Is the project area within one-half mile of and draining to a Class SA water or tributary of a Class SA water? | ☐ | ☐ | ☐ | |
| 2 | Is system located a minimum of 50 feet from a Class SA water and 30 feet from other surface waters? | ☐ | ☐ | ☐ | |
| 3 | Has the site been reviewed to confirm that the basin is a minimum of 100 feet from any water supply wells? | ☐ | ☐ | ☐ | |
| 4 | Was a field visit made to the proposed wet detention basin site? | ☐ | ☐ | ☐ | |
| 5 | Is the wet detention basin positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 6 | Has a subsurface geotechnical investigation been performed on the site? | ☐ | ☐ | ☐ | |
| 7 | Do the WQv calculations account for the ultimate built-out potential of the drainage area? | ☐ | ☐ | ☐ | |
| 8 | Was a pretreatment BMP implemented to remove coarse solids? If a forebay was used, the Chapter 7 Checklist should be completed. | ☐ | ☐ | ☐ | |
| 9 | Are vegetated and submerged side slopes 3:1 or flatter? | ☐ | ☐ | ☐ | |
| 10 | Was energy dissipation provided for the emergency outlet control structure (if used)? | ☐ | ☐ | ☐ | |
| 11 | Has adequate anchoring been provided for the emergency outlet control structure (if used)? | ☐ | ☐ | ☐ | |
| 12 | Has access been provided to the basin for inspection and maintenance? | ☐ | ☐ | ☐ | |
| 13 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |

## WET DETENTION BASIN CHECKLIST



### GENERAL PROJECT INFORMATION

**Project:** ______________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWQ Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** **Yes** **No** **Supplemental:** __________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

### PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 14 | Was the basin sized such that the permanent pool volume is 1 - 3 times the WQv? | ☐ | ☐ | ☐ | |
| 15 | Was the basin designed such that a minimum of 1 ft of extra depth was provided for sediment storage? | ☐ | ☐ | ☐ | |
| 16 | Was the basin embankment designed to allow for 1 ft of freeboard above the 50-year storm elevation? | ☐ | ☐ | ☐ | |
| 17 | Is the basin embankment less than 12 ft high and have an impoundment capacity of less than 10 acre-ft? | ☐ | ☐ | ☐ | |
| 18 | Does the basin embankment have a minimum top width of 10 ft with side slopes of 3:1 or flatter? | ☐ | ☐ | ☐ | |
| 19 | Was the basin designed so that the distance between the basin inlet and outlet control structure was maximized in order to improve the removal efficiency of solids? | ☐ | ☐ | ☐ | |
| 20 | Is the permanent pool average depth between 3 and 8 ft? | ☐ | ☐ | ☐ | |
| 21 | Is drawdown time for WQv between 2 and 5 days? | ☐ | ☐ | ☐ | |
| 22 | Is the vegetated shelf around the perimeter of the basin at least 10 ft wide? | ☐ | ☐ | ☐ | |
| 23 | Is the inside edge of the vegetated shelf 6 in below the permanent pool elevation and the outside edge 6 in above the permanent pool elevation? | ☐ | ☐ | ☐ | |
| 24 | Was the outlet control structure designed to handle the 10-year storm? If an emergency spillway was not provided was | ☐ | ☐ | ☐ | |

| | North Carolina Department of Transportation<br>Highway Stormwater Program | |
|---|---|---|
| WET DETENTION BASIN CHECKLIST | |  |

## GENERAL PROJECT INFORMATION

**Project:** ____________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWQ Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** **Yes** **No** **Supplemental:** __________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

## PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| | it designed for the 50-year storm? | | | | |
| 25 | Is the emergency spillway sized to convey the 50-year storm and prevent flooding of the roadway? | ☐ | ☐ | ☐ | |
| 26 | Is the emergency spillway invert elevation set 0.5 to 1 ft above the top of the outlet control structure? | ☐ | ☐ | ☐ | |
| 27 | Is the emergency spillway liner material designed to handle the peak velocity from the 50-year storm event? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

## STORMWATER WETLAND CHECKLIST



### GENERAL PROJECT INFORMATION

**Project:** ____________________ **TIP No:** __________

**Prepared by:** __________ **Date:** ______ **Checked by:** __________ **Date:** ______

**NCDOT Division:** __________ **River Basin:** __________

**City:** __________ **NCDWR Stream Classification**

**County:** __________ **Primary:** __________

**CAMA County:** **Yes** **No** **Supplemental:** __________

**303(d) Stream:** **Yes** **No**

**Buffer Required:** **Yes** **No**

### PROJECT DESCRIPTION

| Check the correct response. | | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Is the project area within one-half mile of and draining to a Class SA water or tributary of a Class SA water? | ☐ | ☐ | ☐ | |
| 2 | Was a field visit made to the proposed stormwater wetland site? | ☐ | ☐ | ☐ | |
| 3 | Is the stormwater wetland positioned outside the roadway clear recovery zone? | ☐ | ☐ | ☐ | |
| 4 | Has a subsurface geotechnical investigation been performed on the site? | ☐ | ☐ | ☐ | |
| 5 | Do the WQv calculations account for the ultimate built-out potential of the drainage area? | ☐ | ☐ | ☐ | |
| 6 | Is the WQv a minimum of 3,630 cubic feet? | ☐ | ☐ | ☐ | |
| 7 | Is the WQv elevation a maximum of 1 foot above the permanent pool elevation? | ☐ | ☐ | ☐ | |
| 8 | Is the minimum elevation change between inflow and outflow of the wetland 2 to 5 feet? | ☐ | ☐ | ☐ | |
| 9 | Is the flow length-to-width ratio a minimum of 1.5:1? | ☐ | ☐ | ☐ | |
| 10 | Are vegetated and submerged side slopes 3:1 or flatter? | ☐ | ☐ | ☐ | |
| 11 | Has a minimum 10 foot wide access road been implemented to allow inspection and maintenance of the wetland? | ☐ | ☐ | ☐ | |
| 12 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |
| 13 | Is the drainage area of the stormwater wetland a minimum of 5 acres? | ☐ | ☐ | ☐ | |
| 14 | Is runoff volume and/or the water table capable of sustaining the permanent pool? | ☐ | ☐ | ☐ | |

| | | |
|---|---|---|
| North Carolina Department of Transportation<br>Highway Stormwater Program | | |
| STORMWATER WETLAND CHECKLIST |  | |

## GENERAL PROJECT INFORMATION

Project: ______________________ TIP No: __________

Prepared by: __________ Date: ______ Checked by: __________ Date: ______

NCDOT Division: __________ River Basin: __________

City: __________ NCDWQ Stream Classification

County: __________ Primary: __________

CAMA County: Yes No Supplemental: __________

303(d) Stream: Yes No

Buffer Required: Yes No

## PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 15 | Is the permanent pool elevation within 6 inches of the seasonal high water table? (Only applies If the water table is used to sustain the permanent pool) | ☐ | ☐ | ☐ | |
| 16 | Was the wetland embankment designed to allow for 1 ft of freeboard above the 50-year storm elevation? | ☐ | ☐ | ☐ | |
| 17 | Is the wetland embankment less than 12 ft high and have an impoundment capacity of less than 10 acre-ft? | ☐ | ☐ | ☐ | |
| 18 | Does the wetland embankment have a minimum top width of 10 ft with side slopes of 3:1 or flatter? | ☐ | ☐ | ☐ | |
| 19 | Is drawdown time for WQv between 2 and 5 days? | ☐ | ☐ | ☐ | |
| 20 | Was a pretreatment BMP implemented to remove coarse solids? If a forebay was used, the Chapter 7 Checklist should be completed. | ☐ | ☐ | ☐ | |
| 21 | Is the outlet control structure designed as a flashboard riser? | ☐ | ☐ | ☐ | |
| 22 | Is the outlet control structure designed to handle the 10-year storm? If an emergency spillway was not provided, is it designed for the 50-year storm? | ☐ | ☐ | ☐ | |
| 23 | Is the outlet control structure designed to allow the wetland to store the permanent pool and temporarily detain the WQv? | ☐ | ☐ | ☐ | |
| 24 | Was a debris screen or trash rack installed over the flashboard riser outlet structure to prevent clogging and human entry? | ☐ | ☐ | ☐ | |
| 25 | Is the emergency spillway sized to convey the 50-year storm and prevent flooding of the roadway? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

## STORMWATER WETLAND CHECKLIST



### GENERAL PROJECT INFORMATION

Project: ______________________ TIP No: __________

Prepared by: __________ Date: ______ Checked by: __________ Date: ______

NCDOT Division: __________ River Basin: __________

City: __________ NCDWQ Stream Classification

County: __________ Primary: __________

CAMA County: Yes No Supplemental: __________

303(d) Stream: Yes No

Buffer Required: Yes No

### PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 26 | Is the emergency spillway invert elevation set 0.5 to 1 ft above the top of the outlet control structure? | ☐ | ☐ | ☐ | |
| 27 | Is the emergency spillway liner material designed to handle the peak velocity from the 50-year storm event? | ☐ | ☐ | ☐ | |
| 28 | Is the drawdown orifice sized to be between 2 and 3 inches in diameter? | ☐ | ☐ | ☐ | |
| 29 | Is the depth of the shallow water zone between 3 and 6 inches deep? | ☐ | ☐ | ☐ | |
| 30 | Do shallow water zone areas make up 40 percent of the total stormwater wetland surface area? | ☐ | ☐ | ☐ | |
| 31 | Is the shallow land zone elevation the same as the permanent pool elevation? | ☐ | ☐ | ☐ | |
| 32 | Do shallow land zone areas make up 30 to 40 percent of the total stormwater wetland surface area? | ☐ | ☐ | ☐ | |
| 33 | Is the maximum depth of deep pools between 1.5 and 3 feet? | ☐ | ☐ | ☐ | |
| 34 | Do deep pools make up 15 to 20 percent of the total stormwater wetland surface area? | ☐ | ☐ | ☐ | |

North Carolina Department of Transportation
Highway Stormwater Program

## FILTER STRIP CHECKLIST



### GENERAL PROJECT INFORMATION

Project: ______________________ TIP No: __________

Prepared by: ______________ Date: ________ Checked by: ______________ Date: ________

NCDOT Division: ______________ River Basin: ______________

City: ______________ NCDWR Stream Classification

County: ______________ Primary: ______________

CAMA County: Yes No Supplemental: ______________

303(d) Stream: Yes No

Buffer Required: Yes No

### PROJECT DESCRIPTION

| | Check the correct response. | Yes | No | Not Applicable | Comments/Design Assumptions |
|---|---|---|---|---|---|
| 1 | Is the filter strip located a minimum of 50 feet from a Class SA water and 30 feet from other surface waters? | ☐ | ☐ | ☐ | |
| 2 | Was the filter strip constructed outside of the riparian buffer (Zone 1)? | ☐ | ☐ | ☐ | |
| 3 | Is the filter strip located on the right-of-way or in a permanent drainage easement with appropriate access? | ☐ | ☐ | ☐ | |
| 4 | Is the drainage area to filter strip surface area ratio less than or equal to 10:1? | ☐ | ☐ | ☐ | |
| 5 | Is overland flow length upgrade of the filter strip excessive to the point that reconcentration of flow is a concern? Consider redistributing flow using a level spreader. | ☐ | ☐ | ☐ | |
| 6 | Is the slope of the overland flow path upgrade of the filter strip less than or equal to 5 percent? | ☐ | ☐ | ☐ | |
| 7 | Is the longitudinal slope of the filter strip between the optimal 2 and 5 percent? (slopes steeper than 5% are permissible when non-erosive velocities can be maintained) | ☐ | ☐ | ☐ | |
| 8 | Is the minimum length of the filter strip 50 ft (if adjacent to SA waters)? | ☐ | ☐ | ☐ | |
| 9 | Were all design assumptions documented? | ☐ | ☐ | ☐ | |
| 10 | Is the seasonal high water table at least 1 ft lower than any point along the filter strip? | ☐ | ☐ | ☐ | |

# APPENDIX B NCDOT-SPONSORED RESEARCH PROJECTS INVESTIGATING STORMWATER BEST MANAGEMENT PRACTICE EFFECTIVENESS

# Appendix B – NCDOT-Sponsored Research Projects Investigating Stormwater Best Management Practice Effectiveness

| Project ID | Report Title | Institution | Summary | Implications/Conclusions |
|---|---|---|---|---|
| N/A | Stormwater Runoff From Bridges | -NC Department of Transportation (NCDOT)<br>-URS, Inc.<br>-NC Department of Environmental and Natural Resources (NCDENR)<br>-NCSU – Biological and Agricultural Engineering<br>-Lenat Consulting Services, Inc<br>-ETS, Inc<br>-Center for Transportation and the Environment (CTE) | In response to Session Law 2008-107, NCDOT conducted a characterization study of the quality and quantity of bridge deck runoff, and the effectiveness of treatment best management practices (BMP) in reducing the impacts of this runoff. Sampling was performed at a variety of bridge sites, including instream and runoff water quality sampling, bridge deck solids, sediment sampling, and bioassessments upstream and downstream of bridge deck sites with either direct discharge or discharge after treatment by a BMP. The study included an analysis of the costs associated with implementing treatment BMPs for existing and new bridges over waterways in North Carolina. The study concluded that impacts from bridge deck runoff are generally minimal. | The study helped demonstrate that bridges do not cause adverse impacts on receiving streams. There was no material difference in water quality upstream or downstream of bridges, or between bridges with and without a treatment BMP. The study helped demonstrate to the legislature that requiring treatment for bridge deck runoff would not be an efficient use of resources. |

| Project ID | Report Title | Institution | Summary | Implications/Conclusions |
|---|---|---|---|---|
| 2011-12<br>2009-29 | Monitoring of Prospective Bridge Deck Runoff BMPs: Bioretention and Bioswale at Mango Creek/I-540 | -NCSU – Biological and Agricultural Engineering | This research project focused on retrofit stormwater BMPs for bridge deck runoff management. Two bioretention cells and a swale were constructed in the easement of a bridge deck on I-540 at Mango Creek in eastern Wake County, NC. One bioretention cell was sized according to NCDENR design guidelines, while a second cell was deliberately undersized by one-half. The study found that all BMPs were effective at treating stormwater runoff from the bridge. The undersized bioretention cell performed more effectively than its relative size, which indicates that treatment performance might be asymptotic, and even undersized BMPs present value for treatment of stormwater runoff. | Undersized bioretention basins were still effective in treating runoff. Swales were effective in reducing total suspended solids (TSS). |
| 2010-11<br>2009-21<br>2005-29 | Long-term Water Quality Performance of a Coastal Infiltration System – Kure Beach Dune Infiltration System | -NCSU – Biological and Agricultural Engineering | Dune Infiltration Systems (DIS) have been implemented at three sites in Kure Beach, NC. The goal of this project was to develop a low-cost solution to reduce beach closures due to fecal bacteria exceedances at beach outfalls. Stormwater that used to discharge directly into the ocean was rerouted through open-bottom chambers installed in existing dunes, which provided equalization volume until runoff could be infiltrated. Monitoring results indicate the DIS systems captured 80-100 % of stormwater volume, and reduced bacterial concentrations by as much as 98%. | Project demonstrated that DIS are a viable option for reducing exceedances of fecal coliform standards due to stormwater when permeable soils and elevation change are available. |
| 2007-21 | Evaluation of Permeable Friction Course, Roadside Filter Strips, Dry Swales, and Wetland Swales for Treatment of Highway Stormwater Runoff | - NCSU – Biological and Agricultural Engineering | This study monitored vegetated filter strips and dry swales at two sites and wet swales at two sites on I-40 in the Piedmont region of North Carolina. Edge-of-pavement concentrations were relatively low due to the presence of an open-graded friction course overlay over the pavement. The researchers compared the effluent quality to benchmarks obtained from healthy Piedmont streams, and found that well-maintained vegetative conveyance was able to produce effluent quality consistent with these benchmarks. | The study showed that a permeable friction course (PFC) can result in dramatic reductions in TSS at the edge of pavements (EOP). Nutrients in runoff treated by vegetated swales was found to be below benchmarks developed that were reflective of healthy Piedmont streams. Wetland swales were found to be more effective at reducing nutrients than dry swales. |

| Project ID | Report Title | Institution | Summary | Implications/Conclusions |
|---|---|---|---|---|
| 2007-04 | Evaluation of Nutrient Loading Rates and Effectiveness of Roadside Vegetative Connectivity for Managing Runoff from Secondary Roadways | -University of North Carolina at Charlotte (UNCC)-Civil Engineering (CE)<br>-UNCC-Geography | Identification of major sources of nutrients in the highway environment; calculation of annual unit area nutrient loading rates; identification of factors that contribute to variability in loading rates; development of monitoring protocol recommendations; development of a highway nutrient loading database; monitoring; recommendations of percent removal efficiency of grass filters/swales. | This study characterized the quality of runoff from secondary roads, and compared them to primary roads in an earlier study (1998-08). These datasets were pivotal in the development of NCDOT-specific EMCs for the Jordan and Falls Lake Accounting Tools. |
| 2003-19 | Evaluation and Implementation of BMPs for NCDOT's Highway and Industrial Facilities | UNCC-CE<br>UNCC-Geography | This project involved monitoring of three structural BMPs over a period of 3-6 months – a grass filter strip in Clayton, a filtration swale in Troy and a grassed shoulder in Charlotte. The grass filter strip was able to achieve 56-94% Total Suspended Solids (TSS) concentration reduction and 68-97% TSS load reduction. The filtration swale, which is a swale underlain with a short bed of permeable soil with an underdrain, achieved TSS load reductions of 56-100% and was effective in treating NH4-N. The grassed shoulder on W.T. Harris Blvd in Charlotte achieved median TSS concentration reductions of 75% and 35%, based on highly variable influent concentrations. This research project also developed pump capacity curves for the operation of stilling basins treating borrow pit wastewater, to serve as a guide for operator to adjust pumping rates during high turbidity surges. | This study determined the effectiveness of grass filter strips and filtration swales in treating highway runoff, and demonstrated that vegetated areas were effective at reducing TSS. |

| Project ID | Report Title | Institution | Summary | Implications/Conclusions |
|---|---|---|---|---|
| 2001-07 | Evaluating BMPs for Treating Stormwater and Wastewater from North Carolina Highways, Industrial Facilities, and Borrow Pits | NCSU-Water Quality (WQ) | This study involved monitoring runoff and BMP efficiencies at 3 industrial sites (Wilson, Orange, and Alexander county maintenance yards [CMY]) and a borrow pit. Monitoring included characterizing runoff from a steam cleaning operation, a salt storage area, a soil storage area, a gravel truck wash pad, and the general maintenance yard while the BMPs included a wetland, level spreader, and extended detention pond. | Monitoring results documented that a large sediment trap reduced sediment load and turbidity in effluent from a borrow pit by 63 and 48%, respectively. Limited monitoring results suggest that the effectiveness of the extended detention pond was improved by adding a rock baffle and a floating effluent drain. Monitoring of effluent from steam cleaning 10 vehicles documented relatively high concentrations of metals, oil and grease, many inorganic nonmetals. Monitoring of effluent and runoff from a gravel washpad where trucks are washed had slightly elevated levels of sediment and chloride, but other pollutants were similar to urban stormwater. Runoff from a salt storage area had elevated levels of chloride indicating the need for improved containment of salt. |
| 1999-06 | Sampling and Testing of Stormwater Runoff from North Carolina Highways | UNCC-Geography.<br>UNCC-CE | This project presents research findings pertaining to the implementation of a comprehensive monitoring program for characterization of North Carolina highway runoff. The effectiveness of vegetative BMPs was assessed. A database was established for estimation of seasonal and annual pollutant loads and event-mean-concentrations. The study was part of NCDOT's effort to comply with National Pollutant Discharge Elimination System (NPDES) requirements. | The effectiveness of vegetative BMPs was assessed by comparing pollutant exports from 3 groups of paired monitoring sites. A database was established for estimation of seasonal and annual pollutant loads and the event mean concentrations (EMC). |

| Project ID | Report Title | Institution | Summary | Implications/Conclusions |
|---|---|---|---|---|
| N/A | Preformed Scour Hole Study | NCDOT Hydraulics | Due to the small drainage areas associated with the typical preformed scour hole (PSH), and the large number of PSH's statewide, a maintenance agenda has not been developed by NCDOT. NCDOT will investigate and develop a strategy for PSH's through evaluations of a representative sample. The project's main goal will be to determine maintenance needs, protocol, and maintenance schedules (if needed) for PSH as a stormwater control. | As a result of this study, a maintenance schedule was developed for PSH's. |