# Job Messages

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## Administrator

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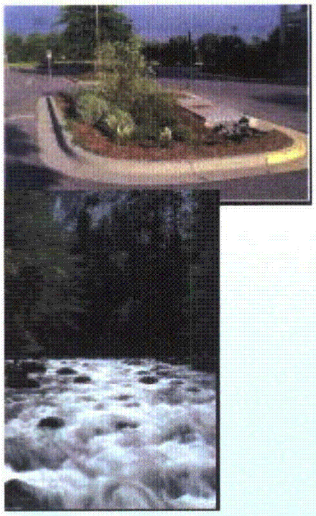


North Carolina
Division of Water Quality

# Stormwater Best Management Practices Manual

July 2007*

NCDENR

*Individual chapters of the BMP Manual will be updated periodically. Individual chapters may be more recent than July 2007.

# Table of Contents

# 1. Introduction

## 1.1. Background

As land is developed, the impervious surfaces that are created increase the amount of runoff during rainfall events, disrupting the natural hydrologic cycle. Without stormwater controls, the increased runoff can erode stream channels, increase pollutant loadings, cause downstream flooding, and prevent groundwater recharge. The increased runoff can degrade water quality in all types of waters, including those classified as water supply watersheds, shellfish areas, and nutrient-sensitive waters. Protecting these waters is vital for a number of reasons, including the protection of fish and wildlife habitat, human health, recreation, and drinking water supplies.

The management of all water pollution sources is a stated goal of the 1987 amendments to the Clean Water Act. To fulfill the requirements of the Clean Water Act, the North Carolina Department of Environment and Natural Resources, Division of Water Quality (DWQ) has examined water pollution in each of its 17 river basins and has developed corresponding plans to address that pollution. Some of the plans have resulted in the promulgation of specific stormwater regulations to address overall water pollution issues. In addition, there are several county and local governments that have also implemented stormwater regulations to address specific local water pollution issues. Most of these programs attempt to protect, maintain, and restore water uses to the surface waters through the use of narrative based effluent limitations in the form of "best management practices" (BMPs).

## 1.2. Introduction to BMPs

Stormwater BMPs are implemented as a way of treating or limiting pollutants and other damaging effects of stormwater runoff in order to meet legislative and North Carolina Administrative Code requirements. There are two major categories of BMPs: non-structural and structural. In North Carolina, the management of stormwater runoff through non-structural BMPs is the preferred method of reducing pollution from developing urban and suburban areas. In cases where the preferred methods are not feasible or sufficient, or where stormwater controls are being used to retrofit existing development, engineered or structural BMPs are viable solutions to reducing pollution. Both non-structural and structural BMPs are discussed in more detail in the following sections.

### 1.2.1. Non-Structural BMPs

Non-structural BMPs are typically passive or programmatic and tend to be source control or pollution prevention BMPs that reduce pollution in runoff by reducing the opportunity for the stormwater runoff to be exposed to the pollutants. In many circumstances it may be easier and less costly to prevent the pollutants from entering the drainage system rather than to control them with end-of-pipe structural BMPs. Used properly, the non-structural BMPs can be very effective in controlling pollutants and in greatly reducing the need for structural BMPs. In addition, non-structural BMPs tend to be less costly and easier to design and implement. Typically, the measures do not require maintenance but do require administrative resource commitments to ensure that they are continually implemented. Non-structural BMPs normally do not have technical or engineering designs associated with them. Some typical non-structural BMPs are listed below:

- Public education and participation.
- Land use planning and management (vegetative controls, reduced impervious areas, disconnected impervious areas).
- Material use controls (housekeeping practices, safer alternative products, pesticide and fertilizer use).
- Material exposure controls (material storage control, vehicle-use reduction).
- Illegal dumping controls (storm drain stenciling, household hazardous waste collection, used oil collection).
- Spill prevention and cleanup (vehicle spill control, aboveground tank spill control).
- Connection controls (illicit connection detection, removal, and prevention, leaking sanitary sewer control).
- Street and storm drain maintenance (roadway cleaning, catch basin cleaning, vegetation controls, storm drain flushing, roadway/bridge maintenance, , drainage channel and creek maintenance).

### 1.2.2. Structural BMPs

Structural BMPs refer to physical structures designed to remove pollutants from stormwater runoff, reduce downstream erosion, provide flood control, and promote groundwater recharge. Structural BMPs typically require engineering design and engineered construction. The several types of structural BMPs vary greatly in their design and they each have advantages and disadvantages relative to each other. Some structural BMPs provide considerable stormwater quantity handling capability through the use of infiltration and/or detention/retention facilities (e.g. infiltration devices, stormwater wetlands, wet detention basins). Others provide many types of pollutant removal mechanisms such as sedimentation, filtration, microbial action, and plant uptake (e.g. bioretention, stormwater wetlands). Some BMPs provide high levels of both stormwater quantity handling and pollutant removal ability. In addition, structural BMPs can be divided into those that help reduce the pollutants or quantity of stormwater entering a collection system (e.g. permeable pavement, filter strips, rooftop runoff management), and those that treat the stormwater at the "end of pipe" (e.g. sand filter, stormwater wetlands, wet detention basins). The following structural BMPs are discussed in detail within this design manual:

- Bioretention
- Sand Filter
- Stormwater Wetlands
- Wet Detention Basin

- Filter Strip
- Grassed Swale
- Infiltration Devices
- Restored Riparian Buffer
- Dry Extended Detention Basin
- Permeable Pavement Systems
- Rooftop Runoff Management
- Proprietary Systems

## 1.3. About This Manual

The purpose of this manual is to assist designers, developers, owners, contractors, and local officials in determining what stormwater regulations apply to their situation, what the best stormwater BMP to meet those regulations might be, and how to then design and maintain that particular stormwater BMP. It is intended to provide the competent design professional with the information necessary both to properly meet the minimum requirements of the various North Carolina stormwater programs, and to be able to design a stormwater BMP that meets the water quality objectives. However, it does not cover every aspect of the civil engineering and structural design necessary for proper BMP system design and construction , nor does it cover every site situation that may occur, or every possible stormwater solution. The design professional is responsible for the design and construction of a properly functioning stormwater BMP that meets all of the applicable regulations, including the water quality objectives, and that considers all the unique conditions of an individual site. Where the designer determines that conformance with this manual would create an unreasonable hardship or where an alternative design may be more appropriate, alternative designs, materials, and methodologies will be considered on a case-by-case basis.

This manual is meant to supplement (not supplant) North Carolina's stormwater regulations by explaining the stormwater BMPs that will be allowed, their design criteria, and their assumed pollutant removal efficiencies in an easy-to-understand manner. In addition, local communities are free to adopt more stringent requirements than those presented in this manual (local standards that are more stringent do not result in increased removal credits). In general, if any part of this manual lists requirements different from those imposed by any other ordinance, rule, regulation, or other provision of law, whichever provision is more restrictive or imposes higher protective standards for human or environmental health, safety, and welfare, shall control. It should be noted, however, that some Environmental Management Commission rules, such as the Universal Stormwater Management Program, do allow substitution of portions of one program for another.

There are figures, example calculations, operation and maintenance items, etc., used throughout this manual. The intention is to provide the reader with visual assistance in device functions, siting, and concepts, as well as guidance on designing, operating, and maintaining specific BMPs. The figures, example calculations, operation and maintenance items, etc., will not represent the proper solution for every situation, and they may contain items that may not exactly fit the requirements listed in the section. The user of this manual must look at these items and use his or her professional judgment as to their proper use in a specific situation (however, any variance from a requirement must be clearly indicated). In the event of a conflict or inconsistency between the text of this manual and any heading, caption, figure, illustration, table, map, etc., the text shall control.

Throughout the text of this manual, the words "should" and "recommended" are used for items that are recommended for good design practices and optimum performance of the BMP. The words "shall", "must", and "required" are used for items that are required for receiving approval of the design and for that design to receive the listed pollutant removal rates. In each design section, the required items are broken into 2 groups: those that are required for approval of a design based on requirements in the North Carolina Administrative Code, and those that are required for a design to receive full credit listed in this manual for pollutant removal rates. Those designs not meeting all of the requirements of the first group will not be approved for construction, and those designs not meeting all of the requirements of both the first and second group will not receive the stated removal rates.

Also used throughout this manual is the phrase "design professional". This phrase is a generic title for a qualified, registered, North Carolina professional engineer, surveyor, soil scientist, or landscape architect, performing services only in his or her area of competence. Other individuals may be authorized as a "design professional", if they can demonstrate proper knowledge and ability to DWQ.

Knowledge about stormwater management is continually advancing. This manual, or individual sections of this manual, will be regularly updated to keep up with advances in research and practice. Each section has a date on the header of each page so that all users can be sure which version of the manual they are using. At the end of each chapter, there will a "Revisions" note added when changes are made which notes the reason for the change. Please refer to the DWQ Stormwater Permitting Unit webpage on a regular basis to check for the most current version of each section. There is also an opportunity provided on the Division's stormwater web site to add your email address so you will be notified of updates to this manual.

## 1.4. Must the Manual be Followed Explicitly?

The Stormwater BMP Manual contains what the Division of Water Quality believes to be the technologies and specifications that: 1) will meet the state minimum regulatory requirements for stormwater BMPs, 2) will perform in a manner most likely to protect the state's water quality standards and 3) will continue to function as designed to protect water quality.

The specifications contained in this Manual were based on the most recent and recognized research and guidance from professionals in academia, research organizations, regulatory agencies and design practitioners across the state. Although we believe that following the conditions of the Manual will provide compliant and permittable design, some professionals may desire to design stormwater treatment devices in a manner different from that specified in this Manual. This is acceptable if the design and implementation meets the state's minimum regulatory requirements and can be shown to provide equal or better protection than those specified in the Manual. Design professionals desiring to deviate from the provisions contained in this Manual must provide full technical justification that their recommendation is as protective as or better than the recommendations contained in this Manual. Although at times, unique situations provide obvious evidence that a deviation from the Manual is justified, most recommendations for deviations will require technical documentation that provides convincing evidence of the acceptability of the alternative. Vague, anecdotal or isolated evidence of the acceptability of an alternative solution cannot be used to supplant the considered recommendations of this Manual.

Because our review staff must consider all deviations from this Manual on a case-by-case basis, requesting approval of BMP designs different from those recognized in the Manual will almost always slow down the permit review process. One benefit of having a Manual is to provide BMP recommendations that have been recognized and accepted and can be readily approved. Projects requesting deviations from the specifications contained in the Manual will require additional staff resources for review. Therefore, project proponents desiring an expedited review should strive to use the accepted specifications in the Manual.

## 1.5. Acknowledgements

This manual was prepared with the help of many individuals from a variety of affiliations, including: NCDENR, North Carolina State University, private consultants, and various North Carolina municipalities. It also relies on concepts, presentation style, and even text material that were found in BMP design manuals from other states, regional authorities, and municipalities. Most of this material has been reworked extensively and is therefore difficult to reference precisely. Exact referencing has been attempted when possible, and those documents that have been utilized in general have been included in the reference list.

## 1.6. Disclaimer

To the best of their ability, the authors have insured that material presented in this manual is accurate and reliable. The design of engineered facilities, however, requires considerable judgment on the part of designer. It is the responsibility of the design professional to insure that techniques utilized are appropriate for a given situation. Therefore, neither the State of North Carolina, Department of Environment and Natural Resources, nor any author or other individual, group, business, etc., associated with production of this manual, accepts any responsibility for any loss, damage, or injury as a result of the use of this manual.

# 2. North Carolina's Stormwater Requirements

## 2.1. Overview

North Carolina's Division of Water Quality (DWQ) under the authority of the Environmental Management Commission (EMC) has developed a variety of stormwater programs to protect the waters of the State. The primary strategy for these programs is to minimize impervious surfaces and to treat stormwater runoff using BMPs. BMPs in this manual, if appropriately applied, receive credit towards meeting the requirements of these programs.

The following sections provide a summary of North Carolina's various stormwater programs. These sections are general in nature and intended to provide an overview of the requirements that could potentially affect BMP selection and design. Tables 2-2 and 2-3, at the end of this section, summarize the basic design requirements for all of the stormwater programs in the State. The summaries and tables are not intended to provide a comprehensive account of all the requirements for a given program. Consult the permitting authority (DWQ or local government, depending on the program) and/or the relevant statute or rule for specific program requirements. Figures 2-1 and 2-2, also at the end of this section, show a map delineating the applicable areas of the various stormwater programs throughout the State, and a map showing the DWQ Regions (including contact information), respectively.

## 2.2. NPDES Stormwater Program (Phases I and II)

In 1972, the National Pollutant Discharge Elimination System (NPDES) program was established under the authority of the Clean Water Act. Phase I of the NPDES stormwater program was established in 1990. It required NPDES permit coverage for municipalities that had populations of 100,000 or more. In North Carolina, there are six permitted local governments that have municipal separate storm sewer systems (MS4s) serving populations of 100,000 or more (Raleigh, Durham, Fayetteville/Cumberland County, Charlotte, Winston-Salem, Greensboro). Each subject local government was required to develop and implement a stormwater management program that includes public education, illicit discharge detection and elimination, storm sewer system and land use mapping, and analytical monitoring.

Under Session Law 2004-163, the Phase II program builds upon the existing Phase I program by requiring certain smaller communities (<100,000) and public entities that own and operate an MS4 to apply and obtain an NPDES permit for stormwater discharges. The session law defines the communities that are required to obtain a Phase II permit, the process for including new communities, and the general requirements for compliance with a Phase II permit. Each community that is subject to Phase II is required to meet the following six minimum measures:

- Public education and outreach on stormwater impacts.
- Public involvement/participation.
- Illicit discharge detection and elimination.
- Construction site stormwater runoff control.
- Post-construction stormwater management in new development and redevelopment.
- Pollution prevention/good housekeeping for municipal operations.

It is under the "Post-construction stormwater management in new development and redevelopment" requirement that subject communities must adopt ordinances that could require the use of structural BMPs to meet stormwater quality objectives. The Phase I communities will also adopt the minimum stormwater requirements in Phase II as part of their comprehensive stormwater program. Both Phase I and II communities are free to adopt more stringent requirements, but there are minimum standards for post-construction stormwater management that are given below.

The requirements for post-construction stormwater management apply to developments (or redevelopments) in which the total land disturbance is greater than one acre. The NPDES program classifies development into two categories: low-density and high-density.

A project may be permitted as low density if:

1) It has no more than two dwelling units per acre, or
2) It meets the following requirements:
    - Density:
        - Non-SA waters: 24% built upon area
        - SA waters (within a half mile of and draining to): 12% built upon area
    - Use of vegetated conveyances to the maximum extent practicable;
    - All built-upon areas are at least 30 feet landward of perennial and intermittent surface waters; and
    - Deed restrictions and protective covenants are required by the locally issued permit and incorporated by the development to ensure that subsequent development activities maintain the development (or redevelopment) consistent with the approved plans.

A project not consistent with the requirements for a low density project may be permitted as a high density project if it meets the following requirements:

- Treatment volume: Volume is specific to the project's location:
    - Non-coastal counties: Control and treat the first 1.0" of rain.
    - Coastal counties: The coastal counties are listed in Section 2.4.1. Portions of these counties are within a half-mile of and drain to special resource waters (SR), which have additional requirements. SR waters are shellfish waters (SA) that have an average concentration of 500 ppm of natural chloride ion. The Division considers all SA waters to be SR waters unless

laboratory testing has determined otherwise through the procedure outlined in Session Law 2006-246.
  - Non-SR (non-SA) waters: Control and treat the first 1.5" of rain.
  - SR (SA) waters:
    - Control and treat the first 1.5" of rain, and
    - Control and treat the difference in depth of the stormwater runoff between pre-development and post-development.
- Discharge rate: Discharge the storage volume at a peak rate equal to or less than the pre-development discharge peak rate for the 1-year 24-hour storm;
- Drawdown time: Session Law 2006-246 requires that BMPs drawdown the treatment volume between 48 and 120 hours. 15A NCAC 02H .1008(d)(5) requires that infiltration devices drawdown within 120 hours. The Division requires that BMPs drawdown within the following timeframes. *Additional requirements may be specified in each BMP chapter:*
  - Wet ponds, wetlands, and dry detention: Drawdown between 48 and 120 hours
  - Infiltration devices, bioretention cells, sand filters: Drawdown within 120 hours
  - Grassed swales, restored riparian buffers, filter strips, level spreaders, permeable pavement, rooftop management, and proprietary systems: These BMPs do not use treatment mechanisms that result in "drawdown" rates as the other BMPs previously listed. Therefore, there is no set drawdown time for these systems. However, these BMPs must be compliant with the engineering criteria specified in each respective chapter.
- TSS removal: All structural stormwater treatment systems must be designed to achieve 85% average annual removal of total suspended solids. Two or more BMPs can be used in series to achieve this requirement.;
- Engineering design: Stormwater management measures must comply with the General Engineering Design Criteria For All Projects requirements listed in 15A NCAC 2H .1008(c);
- Distance to surface waters: All built-upon areas are at least 30 feet landward of perennial and intermittent surface waters; and,
- Deed restrictions: Deed restrictions and protective covenants are required by the locally issued permit and incorporated by the development to ensure that subsequent development activities maintain the development (or redevelopment) consistent with the approved plans.

The local communities are responsible for the implementation of the NPDES program under their jurisdictions, and all plan approvals should be submitted to the appropriate local authorities. Development in the extra-jurisdictional area of each municipality (1-3 miles around municipal boundaries, depending on population) is also subject to the minimum NPDES requirements for post-construction listed above. In these areas, plan approvals should be submitted to the appropriate DWQ Regional Office (see Figure 2-2 at the end of this section for DWQ Regional Office information).

## 2.3. Nutrient Management Programs

### 2.3.1. Neuse River Basin (15A NCAC 2B .0235)

The Neuse River Basin Nutrient Sensitive Waters Management Strategy (or Neuse Stormwater Program) targets nitrogen pollution in stormwater runoff as specified in 15A NCAC 2B .0235. The Neuse Stormwater Program affects the 15 most populous communities in the Neuse River basin: Cary, Durham, Garner, Goldsboro, Havelock, Kinston, New Bern, Raleigh, Smithfield, Wilson, Durham County, Johnston County, Orange County, Wake County, and Wayne County. New development in these communities must meet the requirements listed below (although local communities are free to adopt more stringent requirements).

For the purposes of the Neuse Stormwater Program, new development shall be defined as to include the following:

- Any activity that disturbs greater than one acre of land in order to establish, expand or modify a single family or duplex residential development or a recreational facility.
- Any activity that disturbs greater than one-half an acre of land in order to establish, expand or modify a multifamily residential development or a commercial, industrial or institutional facility.
- New development does not include agriculture, mining, or forestry activities. Land disturbance is defined as grubbing, stump removal, and/or grading.

The computed post-development nitrogen load (see Section 3 for information on how to calculate nutrient loads) must be reduced to 3.6 lb/ac/yr. This can be done by either installing nitrogen-reducing BMPs that receive credit by reducing the total nitrogen export by a certain percentage (depending on the BMP), and/or through offset payments to the Ecosystem Enhancement Program (EEP). Contact DWQ or EEP for information regarding nitrogen buy-down options.

In addition to the nutrient reduction requirements, there must also be no net increase in peak flow leaving the site from the predevelopment conditions for the 1-year, 24-hour storm.

### 2.3.2. Tar-Pamlico River Basin (15A NCAC 2B .0258)

The Tar-Pamlico River Basin Nutrient Sensitive Waters Management Strategy (or Tar-Pamlico Stormwater Program) targets both nitrogen and phosphorus pollution in stormwater runoff as specified in 15A NCAC 2B .0258. The Tar-Pamlico Stormwater Program affects the 11 most populous communities in the Tar-Pamlico River basin: Greenville, Henderson, Oxford, Rocky Mount, Tarboro, Washington, Beaufort County, Edgecombe County, Franklin County, Nash County, and Pitt County. New development in these communities must meet the requirements listed below (although local communities are free to adopt more stringent requirements).

For the purposes of the Tar-Pamlico Stormwater Program, new development shall be defined as to include the following:

- Any activity that disturbs greater than one acre of land to establish, expand, or replace a single family or duplex residential development or recreational facility. For individual single family residential lots of record that are not part of a larger common plan of development or sale, the activity must also result in greater than ten percent built-upon area.
- Any activity that disturbs greater than one-half an acre of land to establish, expand, or replace a multifamily residential development or a commercial, industrial or institutional facility.
- Projects meeting the above criteria that replace or expand existing structures or improvements and that do *not* result in a net increase in built-upon area shall not be required to treat stormwater runoff for nitrogen or phosphorus removal.
- Projects meeting the above criteria that replace or expand existing structures or improvements and that result in a net increase in built-upon area shall achieve a 30 percent reduction in nitrogen loading and no increase in phosphorus loading relative to the previous development.
- Land disturbance is defined as grubbing, stump removal, grading, or removal of structures. New development shall not include agriculture (including intensive livestock operations), mining, or forestry activities.

The computed post-development nitrogen and phosphorus loads (see Section 3.3 for information on how to calculate nutrient loads) must be reduced to 4.0 lb/ac/yr and 0.4 lb/ac/yr, respectively. This can be done by either installing nutrient-reducing BMPs, on- or offsite, that receive credit by reducing the total nutrient export by a certain percentage (depending on the BMP), and/or through offset payments to the Ecosystem Enhancement Program (EEP). Contact the local community for information regarding off-site treatment options and DWQ or EEP for information regarding nutrient buy-down options.

In addition to the nutrient reduction requirements, there must also be no net increase in peak flow leaving the site from the predevelopment conditions for the 1-year, 24-hour storm.

## 2.4. State Stormwater Program (15A NCAC 2H .1000)

The State Stormwater Program is administered by the DWQ Regional Offices (see Figure 2-2 at the end of this section for DWQ Regional Office information). Any development that requires a CAMA major permit or a Sedimentation/Erosion Control Plan and falls under the jurisdiction of the State Stormwater Program (Coastal Counties, High Quality Waters, or Outstanding Resource Waters) must obtain a stormwater management permit.

### 2.4.1. Coastal Counties (15A NCAC 2H .1005)

Development in the 20 coastal counties that requires a Coastal Area Management Act (CAMA) major permit or a Sedimentation/Erosion Control Plan falls under the State Stormwater program. Permits must be obtained from either of the two regional offices (Washington or Wilmington) that serve the 20 coastal counties. The counties served by the Wilmington regional office include: Brunswick, Carteret, New Hanover, Onslow, and Pender. The counties served by the Washington regional office include: Beaufort, Bertie, Camden, Chowan, Craven, Currituck, Dare, Gates, Hertford, Hyde, Pamlico, Pasquotank, Perquimans, Tyrrell, and Washington.

The State Stormwater Program in the Coastal Counties falls under two main categories: development that drains to class SA waters and development that drains to non-SA waters. SA waters are the highest quality designation for salt waters and correspond primarily to waters that have shellfishing as a designated use. Non-SA waters include lower class saltwaters (SB and SC, e.g.) and all classes of freshwaters.

Please note: At the time of publication of this Chapter (07-01-07), the Environmental Management Commission is considering modification to the stormwater rules for coastal counties (2H .01005). If these rule changes were to be adopted, there is a potential that stormwater requirements for coastal counties could be different than what is discussed below.

#### 2.4.1.1. SA Waters

In order to be considered as draining to SA waters, development must be within one-half mile of and drain to SA waters or unnamed tributaries of SA waters. For such development, there are two options: low density and high density.

Low-density development is defined as having a 25% or less built-upon area. For low-density development the following stormwater requirements apply:

- Stormwater runoff must be transported primarily by vegetated conveyances.
- Conveyance systems shall not include a discrete stormwater collection system.
- The development must maintain a 30-ft wide vegetative buffer.

High-density development is defined as having greater than 25% built-upon area. For high-density development the following stormwater requirements apply:

- There must be no direct outlet channels or pipes to SA waters unless permitted in accordance with 15A NCAC 2H .0126.
- BMPs must be infiltration systems designed to control the runoff from all surfaces generated by one and one-half inches of rainfall.
- Runoff in excess of the design volume must flow overland through a vegetative filter with a minimum length of 50 ft measured from mean high water of SA waters.

#### 2.4.1.2. Non-SA Waters

For development in the coastal counties that does not drain to SA waters, there are also two options for development: low density and high density.

Low-density development is defined as having a 30% or less built-upon area. For low-density development the following stormwater requirements apply:

- Stormwater runoff must be transported primarily by vegetated conveyances.
- Conveyance systems shall not include a discrete stormwater collection system.
- The development must maintain a 30-ft wide vegetative buffer.

High-density development is defined as having greater than 30% built-upon area. For high-density development the following stormwater requirements apply:

- BMPs must be infiltration systems, wet detention ponds, or alternative stormwater management systems as defined in 15A NCAC 2H .1008.
- BMPs must be designed to control runoff from all surfaces generated by one inch of rainfall.

### 2.4.2. High Quality Waters (15A NCAC 2H .1006) and Outstanding Resource Waters (15A NCAC 2H .1007)

The State has designated that certain bodies of water in North Carolina should be considered High Quality Waters (HQW) and Outstanding Resource Waters because of the high natural resource value of these waters. As such, DWQ is tasked with providing protection for these waters through stormwater management strategies. The areas that are designated as HQW and ORW are shown in Figure 2-1. If development occurs in these areas and either requires a CAMA major permit or a Sedimentation/Erosion Control Plan, a permit must be obtained from the appropriate DWQ Regional Office. The minimum requirements for the permit are given below, although more stringent measures may be required on a case-by-case basis.

For proposed projects affected by HQW or ORW requirements, there are two options for development: low density and high density. (See Tables 2-2 and 2-3 for details.)

Low-density development is defined as having a 12% or less built-upon area. For low-density development the following stormwater requirements apply:

- Stormwater runoff must be transported primarily by vegetated conveyances.
- The conveyance system must not include a discrete stormwater distribution system.
- The development must maintain a 30-ft wide vegetative buffer.

High-density development is defined as having greater than 12% built-upon area. For high-density development the following stormwater requirements apply:

- BMPs must be wet detention ponds or alternative stormwater management systems as defined in 15A NCAC 2H .1008.
- BMPs must be designed to control runoff from all surfaces generated by one inch of rainfall.

Development activities that require a stormwater management permit and drain to saltwaters classified as ORW must meet the following requirements:

- Within 575 ft of the mean high water line of designated ORW areas, development activity must comply with the low-density ORW option, as described above.
- Contact the appropriate Regional Office for further requirements that may be applicable (see Figure 2-2).

## 2.5. Water Supply Watershed Protection Program (15A NCAC 2B .0212-.0216)

As the name implies, the water supply watershed protection program is designed to protect the surface water sources of the State. The water supply watersheds are delineated in Figure 2-1, and within this program there are several categories of protection. The program designates the water supply (WS) watersheds as WS-I (most stringent stormwater requirements), WS-II, WS-III, and WS-IV (least stringent requirements). For WS-II, WS-III, and WS-IV, there are also separate requirements for the area directly adjacent to the water supply intake point (known as the "critical area").

For each of these categories there are stormwater requirements that must be met for development. The local community governments have the authority to implement this program and have adopted these requirements by ordinance. The requirements for the water supply program are summarized in Table 2-1; additional requirements and development options may apply.

**Table 2-1**

Water Supply Watershed Protection Program – Minimum Design Requirements

| Water Supply Classification | Low-density Threshold | Low-density Design Requirements | High-density Design Requirements |
|---|---|---|---|
| **WS-I** | N/A | No development permitted | No development permitted |
| **WS-II (Critical Area)** | 6% built-upon area or one single-family residential development per 2 acres | Stormwater runoff from development transported by vegetated conveyances to the maximum extent | Control runoff from the first inch of rainfall. New development density not to exceed |

| Water Supply Classification | Low-density Threshold | Low-density Design Requirements | High-density Design Requirements |
|---|---|---|---|
| | | practicable. | 24% built-upon area. |
| **WS-II (Balance of Watershed)** | 12% built-upon area or one single-family residential development per acre | Stormwater runoff from development transported by vegetated conveyances to the maximum extent practicable. | Control runoff from the first inch of rainfall. New development density not to exceed 30% built-upon area. |
| **WS-III (Critical Area)** | 12% built-upon area or one single-family residential development per acre | Stormwater runoff from development transported by vegetated conveyances to the maximum extent practicable. | Control runoff from the first inch of rainfall. New development density not to exceed 30% built-upon area. |
| **WS-III (Balance of Watershed)** | 24% built-upon area or two single-family residential developments per acre | Stormwater runoff from development transported by vegetated conveyances to the maximum extent practicable. | Control runoff from the first inch of rainfall. New development density not to exceed 50% built-upon area. |
| **WS-IV (Critical Area)** | 24% built-upon area or two single-family residential developments per acre | Stormwater runoff from development transported by vegetated conveyances to the maximum extent practicable. | Control runoff from the first inch of rainfall. New development density not to exceed 50% built-upon area. |
| **WS-IV (Protected Area)** | 24% built-upon area or two single-family residential development per acre | Stormwater runoff from development transported by vegetated conveyances to the maximum extent practicable. | Control runoff from the first inch of rainfall. New development density not to exceed 70% built-upon area. |

## 2.6. Randleman Lake Water Supply Watershed Program (15A NCAC 2B .0251)

The Randleman Lake Water Supply Watershed Program applies to the upper and lower portions of the Randleman Lake Watershed. The upper portion of the watershed is defined as those waters and lands of the Deep River watershed that drain to the Oakdale-Cotton Mill Dam. The lower portion of the watershed is those waters and lands of the Deep River upstream and draining to the Randleman Lake Dam, from the Oakdale-Cotton Mill Dam to the Randleman Dam.

### 2.6.1. Lower Portion

Low-density development in the lower portion of the Randleman watershed is defined as no more than 12% built-upon area or one single-family residential development per acre. For low-density development the following stormwater requirements apply:

- Stormwater runoff must be transported primarily by vegetated conveyances.
- The conveyance system must not include a discrete stormwater collection system as defined in 15A NCAC 2B .0202.

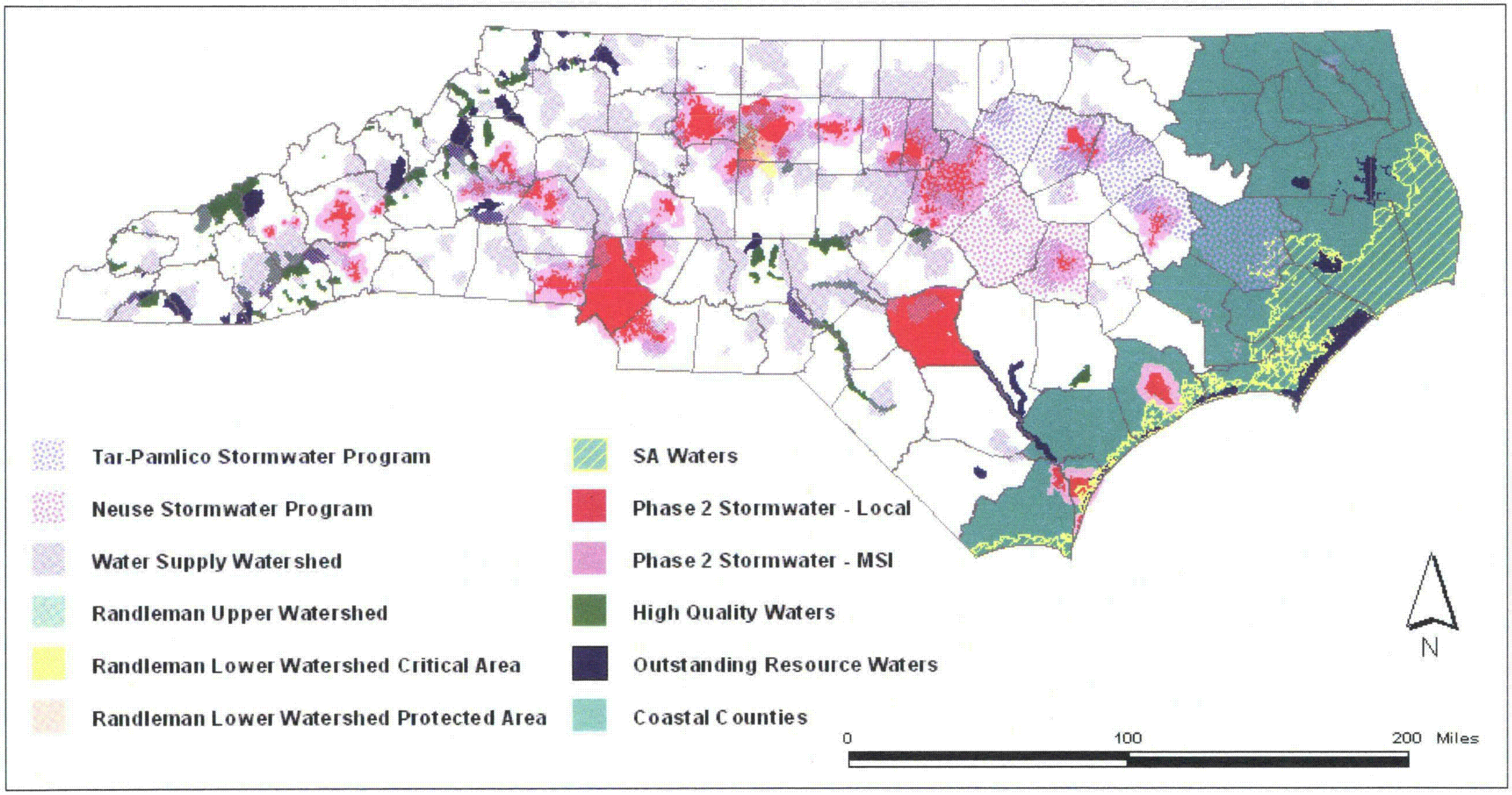
High-density development in the lower portion of the Randleman watershed is any development that does not meet the requirements for low density, and the following requirements apply:

- Engineered stormwater controls must be used to control runoff from the first inch of rainfall.
- Engineering controls may consist of wet detention ponds or alternative stormwater management systems in accordance with the requirements of 15A NCAC 2B .0104(g).

### 2.6.2. Upper Portion

Development in the upper portion of the Randleman watershed must meet the State's rules for a WS-IV classification as described 15A NCAC 2B .0104, .0202, and .0216. The primary stormwater management requirements that affect BMP design are in .0216, and these requirements are summarized in Section 2.5 of this document.

**Figure 2-1**
Stormwater Programs in North Carolina (9/2006)



## Figure 2-2

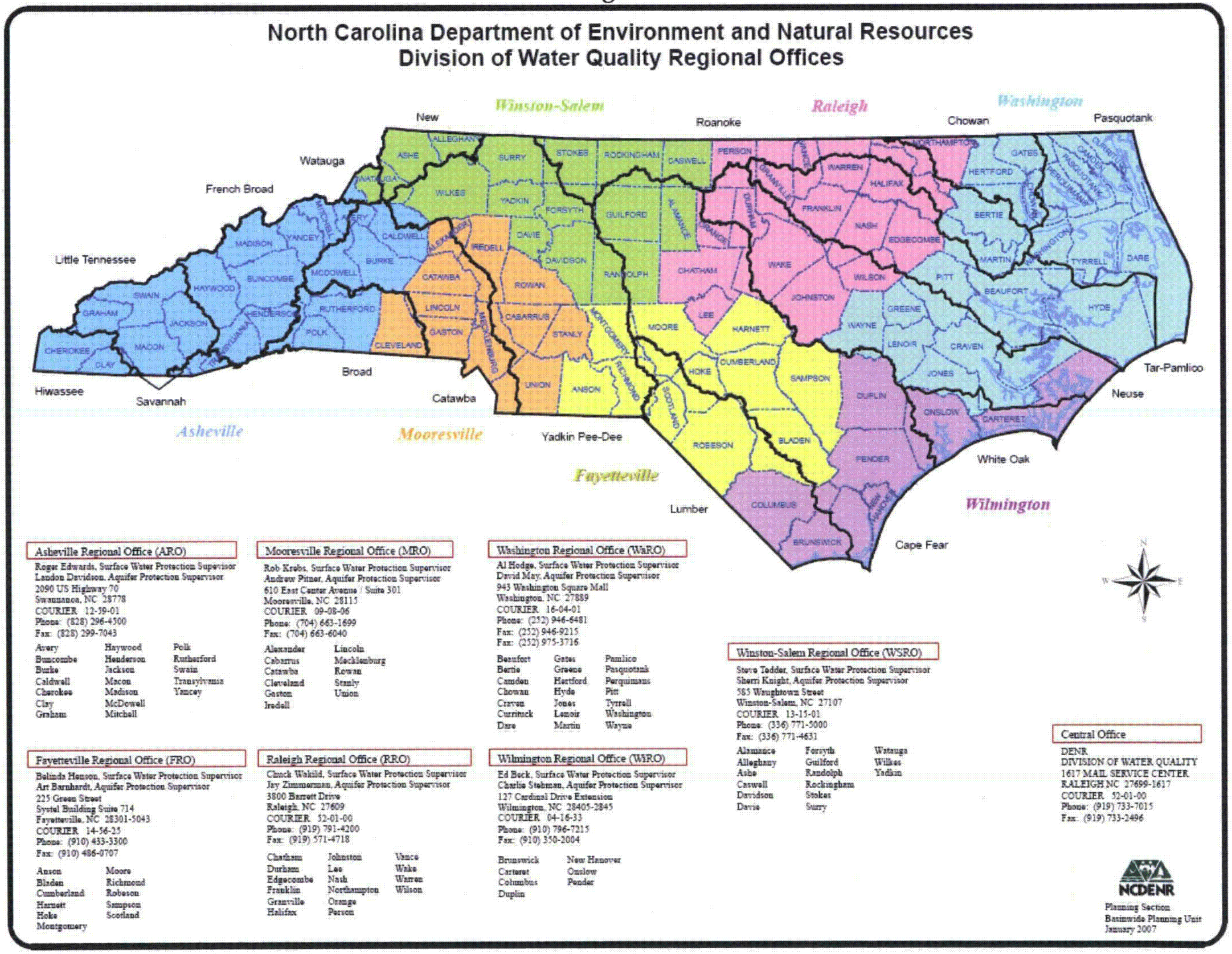

North Carolina Department of Environment and Natural Resources
Division of Water Quality Regional Offices
Winston-Salem
Raleigh
Washington
Asheville
Mooresville
Fayetteville
Wilmington
New
Watauga
French Broad
Little Tennessee
Hiwassee
Savannah
Broad
Catawba
Yadkin Pee-Dee
Roanoke
Chowan
Pasquotank
Tar-Pamlico
Neuse
White Oak
Cape Fear
Lumber
Asheville Regional Office (ARO)
Roger Edwards, Surface Water Protection Supervisor
Landon Davidson, Aquifer Protection Supervisor
2090 US Highway 70
Swannanoa, NC 28778
COURIER 12-59-01
Phone: (828) 296-4500
Fax: (828) 299-7043
Avery Haywood Polk
Buncombe Henderson Rutherford
Burke Jackson Swain
Caldwell Macon Transylvania
Cherokee Madison Yancey
Clay McDowell
Graham Mitchell
Mooresville Regional Office (MRO)
Rob Krebs, Surface Water Protection Supervisor
Andrew Pitner, Aquifer Protection Supervisor
610 East Center Avenue / Suite 301
Mooresville, NC 28115
COURIER 09-08-06
Phone: (704) 663-1699
Fax: (704) 663-6040
Alexander Lincoln
Cabarrus Mecklenburg
Catawba Rowan
Cleveland Stanly
Gaston Union
Iredell
Washington Regional Office (WaRO)
Al Hodge, Surface Water Protection Supervisor
David May, Aquifer Protection Supervisor
943 Washington Square Mall
Washington, NC 27889
COURIER 16-04-01
Phone: (252) 946-6481
Fax: (252) 946-9215
Fax: (252) 975-3716
Beaufort Gates Pamlico
Bertie Greene Pasquotank
Camden Hertford Perquimans
Chowan Hyde Pitt
Craven Jones Tyrrell
Currituck Lenoir Washington
Dare Martin Wayne
Winston-Salem Regional Office (WSRO)
Steve Tedder, Surface Water Protection Supervisor
Sherri Knight, Aquifer Protection Supervisor
585 Waughtown Street
Winston-Salem, NC 27107
COURIER 13-15-01
Phone: (336) 771-5000
Fax: (336) 771-4631
Alamance Forsyth Watauga
Alleghany Guilford Wilkes
Ashe Randolph Yadkin
Caswell Rockingham
Davidson Stokes
Davie Surry
Fayetteville Regional Office (FRO)
Belinda Henson, Surface Water Protection Supervisor
Art Barnhardt, Aquifer Protection Supervisor
225 Green Street
Systel Building Suite 714
Fayetteville, NC 28301-5043
COURIER 14-56-25
Phone: (910) 433-3300
Fax: (910) 486-0707
Anson Moore
Bladen Richmond
Cumberland Robeson
Harnett Sampson
Hoke Scotland
Montgomery
Raleigh Regional Office (RRO)
Chuck Wakild, Surface Water Protection Supervisor
Jay Zimmerman, Aquifer Protection Supervisor
3800 Barrett Drive
Raleigh, NC 27609
COURIER 52-01-00
Phone: (919) 791-4200
Fax: (919) 571-4718
Chatham Johnston Vance
Durham Lee Wake
Edgecombe Nash Warren
Franklin Northampton Wilson
Granville Orange
Halifax Person
Wilmington Regional Office (WiRO)
Ed Beck, Surface Water Protection Supervisor
Charlie Stehman, Aquifer Protection Supervisor
127 Cardinal Drive Extension
Wilmington, NC 28405-2845
COURIER 04-16-33
Phone: (910) 796-7215
Fax: (910) 350-2004
Brunswick New Hanover
Carteret Onslow
Columbus Pender
Duplin
Central Office
DENR
DIVISION OF WATER QUALITY
1617 MAIL SERVICE CENTER
RALEIGH NC 27699-1617
COURIER 52-01-00
Phone: (919) 733-7015
Fax: (919) 733-2496
NCDENR
Planning Section
Basinwide Planning Unit
January 2007

**Table 2-2**
Applicable Stormwater Requirements for Sites that Drain to Saltwaters

| **Requirement** - Based on Classification | **State S/W** 20 Coastal Counties | **SA** (1/2 Mile and Draining To) | **SR** (1/2 Mile and Draining To) | **ORW** (Within 575' MHW Line) | **Neuse NSW** | **Tar-Pamlico NSW** | **Phase II** | **USMP** |
|---|---|---|---|---|---|---|---|---|
| *Permitting Authority* | DWQ - RO | DWQ - RO | DWQ - RO | DWQ - RO | Local Gov't | Local Gov't | Note 13 | Local Gov't |
| Low Density Maximum BUA **(1)** | 30% | 25% | 12% | 25% | N/A | N/A | 24% | Note 12 |
| High Density Maximum BUA **(2)** | No Max | No Max | No Max | Not Allowed | N/A | N/A | No Max | |
| Low Density Setback | 30' | 30' | 30' | 30' | 50' RB | 50' RB | 30' | 30' * |
| High Density Setback | N/A | 50' | 30' | N/A | 50' RB | 50' RB | 30' | |
| S/W Control Req. for High Density **(3)** | 1" R/O | 1.5" R/O | Note 3 | N/A | Peak Reduc. | Peak Reduc. | Note 3 | 1.5" R/O |
| TSS removal Requirement | 85% | 85% | 85% | N/A | N/A | N/A | 85% | 85% |
| Stormwater Drawdown Requirement **(4)** | Note 4 | Note 4 | Note 4 | N/A | Note 4 | Note 4 | Note 4 | Note 4 |
| Vegetated Conv. For Low Density **(5)** | Yes | Yes | Yes | Yes | N/A | N/A | Yes | N/A |
| Deed Restrictions Required **(6)** | Yes | Yes | Yes | Yes | N/A | N/A | Yes | Yes |
| Infiltration Systems Required for S/W Control **(8)** | | Yes | Yes | | | | | |
| No New or Expanded Stormwater Discharges **(9)** | | Yes | Yes | | | | | |
| Nitogen Loading Limits **(10)(11)** | | | | | Yes | Yes | Note 10, 11 | Note 10, 11 |
| Phosphorus Loading Limits **(11)** | | | | | No | Yes | Note 11 | Note 11 |

**BUA** - Built-upon area, **DWQ-RO** - Division of Water Quality - Regional Office, **NSW** - Nutrient Sensitive Waters, **ORW** - Outstanding Resource Waters, **RB** - Riparian Buffer, **R/O** - Runoff, **SA** - Saltwater "A" Classification (Shellfishing), **S/W** - Stormwater, **TSS** - Total Suspended Solids, **USMP** - Universal Stormwater Management Program, **SR** - Shellfish Resource Waters, **HQW** - High Quality Waters

## Footnotes for Table 2-2

**(1)** Low-density limits are represented in the table in terms of maximum built upon area percentage. In addition, a two-dwelling-units-per-acre limit may be used in lieu of this percentage.
**(2)** High-density limits are represented in maximum built upon area percentages only. No dwelling-unit-per-acre limits apply.
**(3)** Stormwater Control Requirement: 1.5-inch storm, except SR waters must control and treat the difference in volume of runoff between the pre-development and post-development conditions for the 1-year 24-hour storm. For ORW Stormwater Control requirements for 25% BUA see 15A NCAC 2H .1005(2)(a)(ii). For the Neuse and Tar-Pamlico stormwater programs (Peak Reduc.), there shall be no increase in peak flow leaving the site from the predevelopment conditions for the 1-year, 24-hour storm.
**(4)** Drawdown Requirement: Runoff volume drawdown time varies between programs but must be a minimum of 24-48 hours (depending on the program), but not more than 120 hours; may differ based on BMP selected.
**(5)** The low-density option requires the use of vegetated conveyances to the maximum extent practicable.
**(6)** Where applicable, deed restrictions and protective covenants are required by the locally issued permit and incorporated by the development to ensure that that subsequent development activities maintain the development (or redevelopment) consistent with the approved plans.
**(7)** Cluster development is defined in 15A NCAC 02B .0202 (16) as the following: "the grouping of buildings in order to conserve land resources and provide for innovation in the design of the project including minimizing stormwater runoff impacts."
**(8)** The use of infiltration systems is required for projects draining to shellfishing waters.
**(9)** No new or expanded stormwater discharges are allowed for projects draining to shellfishing waters.
**(10)** The Neuse stormwater nutrient loading limits specified in 15A NCAC 2B .0235 apply in the applicable affected local governments within the Neuse River Basin.
**(11)** The Tar-Pamlico stormwater nutrient loading limits specified in 15A NCAC 2B .0258 apply in the applicable affected local governments within the Tar-Pamlico River Basin.
**(12)** No Low/High density designations for USMP; No maximum BUA, *except* if within 575' of SA waters, maximum BUA is 36%.
**(13)** DWQ-RO or Local government (see http://h2o.enr.state.nc.us/su/msi_maps.htm)
* Neuse and Tar-Pamlico setbacks are a 50-foot riparian buffer.

**Table 2-3**
Applicable Stormwater Requirements for Sites that Drain to Freshwaters

| Requirement - Based on Classification | WS-II CA | WS-II BW | WS-III CA | WS-III BW | WS-IV CA | WS-IV PA | HQW or ORW | USMP | Neuse NSW | Tar-Pamlico NSW | Randle Upper Portion | Randle Lower CA | Randle Lower PA | Phase II | State SW Coastal Counties |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Permitting Authority* | Local Gov't | Local Gov't | Local Gov't | Local Gov't | Local Gov't | Local Gov't | DWQ - RO | Local Gov't | Local Gov't | Local Gov't | Local Gov't | Local Gov't | Local Gov't | Local Gov't | DWQ - RO |
| Low Density Max. Built Upon Area (BUA) **(1)** | 6% | 12% | 12% | 24% | 24% | 24% | 12% | Note 11 | N/A | N/A | 24% | 6% | 12% | 24% | 30% |
| High Density Max BUA **(2)** | 24% | 30% | 30% | 50% | 50% | 70% | None | | N/A | N/A | 70% | 30% | 50% | None | None |
| Low Density Setback | 30′ | 30′ | 30′ | 30′ | 30′ | 30′ | 30′ | 30′ | 50′ RB | 50′ RB | 50′ RB | 50′ RB | 50′ RB | 30′ | 30′ |
| High Density Setback | 100′ | 100′ | 100′ | 100′ | 100′ | 100′ | None | | 50′ RB | 50′ RB | 50′ RB | 100′ | 100′ | 30′ | None |
| S/W Control Req. for High Dens **(3)** | 1″ R/O | 1″ R/O | 1″ R/O | 1″ R/O | 1″ R/O | 1″ R/O | 1″ R/O | 1″ R/O | Peak reduc. | Peak reduc. | 1″ R/O | 1″ R/O | 1″ R/O | 1″ R/O | 1″ R/O |
| TSS Removal Requirement | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | None | None | 85% | 85% | 85% | 85% | 85% |
| Stormwater Drawdown **(4)** | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 | Note 4 |
| Vegetated Conv, for Low Dens **(5)** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | N/A | N/A | N/A | Yes | Yes | Yes | Yes | Yes |
| Deed Restrictions Required **(6)** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | N/A | N/A | Yes | Yes | Yes | Yes | Yes |
| Cluster Dev. Allowed **(7)** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | N/A | N/A | Yes | Yes | Yes | Yes | Yes |
| 10/70 Provision Allowed **(8)** | No | Yes | No | Yes | No | Yes | No | N/A | N/A | N/A | Yes | No | Yes | No | N/A |
| NSW Load Limits **(10)** | | | | | | | | Note 10 | Yes | Yes | | | | | |

**CA** - Critical Area, **BW** - Balance of Watershed, **HQW** - High Quality Waters, **ORW** - Outstanding Resource Waters, **NSW** - Nutrient Sensitive Waters, **PA** - Protected Area, **Randle** - Randleman Reservoir Watershed, **RB** - Riparian Buffer, **RO** - Runoff, **TSS** - Total Suspended Solids, **WS** - Water Supply watershed, **USMP** - Universal Stormwater Management Program

## Footnotes for Table 2-3

**(1)** Low-density limits are represented in the table in terms of maximum built upon area percentages. In addition, the following dwelling unit per acre limits may be used in lieu of these percentages:

- 6% BUA is equivalent to 1 dwelling unit per every two acres.
- 12% BUA is equivalent to 1 dwelling unit per acre.
- 24% BUA is equivalent to 2 dwelling units per acre.

**(2)** High-density limits are represented in maximum built upon area percentages only. No dwelling-unit-per-acre limits apply.
**(3)** Stormwater Control Requirement: The '1" R/O' requirement as specified in the table corresponds to capturing the runoff from a 1-inch storm. For the Neuse and Tar-Pamlico stormwater programs (Peak Reduc.), there shall be no increase in peak flow leaving the site from the predevelopment conditions for the 1-year, 24-hour storm.
**(4)** Drawdown Requirement: Runoff volume drawdown time varies between programs but must be a minimum of 24-48 hours (depending on the program), but not more than 120 hours; may differ based on BMP selected.
**(5)** The low-density option requires the use of vegetated conveyances to the maximum extent practicable.
**(6)** Where applicable, deed restrictions and protective covenants are required by the locally issued permit and incorporated by the development to ensure that that subsequent development activities maintain the development (or redevelopment) consistent with the approved plans.
**(7)** Cluster development is defined in 15A NCAC 02B .0202 (16) as the following: "the grouping of buildings in order to conserve land resources and provide for innovation in the design of the project including minimizing stormwater runoff impacts."
**(8)** The "10/70 Provision" is defined in 15A NCAC 02B .0214 (3)(b)(i)(E) and, in general, allows a local community to set aside 10% of their jurisdiction in the water supply watershed to be developed up to 70% BUA.
**(9)** This provision allows projects to be classified as low density for built-upon areas up to 36%, provided that no curb and gutter is used.
**(10)** The Neuse stormwater nutrient loading limits specified in 15A NCAC 2B .0235 apply in the applicable affected local governments within the Neuse River Basin. The Tar-Pamlico stormwater nutrient loading limits specified in 15A NCAC 2B .0258 apply in the applicable affected local governments within the Tar-Pamlico River Basin.
**(11)** No Low/High density designations for USMP; No maximum BUA.
**(12)** Local government or DWQ Central Office (see http://h2o.enr.state.nc.us/su/msi_maps.htm)
* Neuse and Tar-Pamlico setbacks are a 50-foot riparian buffer.

## 2.7. 401 Water Quality Certifications

Section 401 of the Clean Water Act delegates authority to the states to issue a 401 Water Quality Certification for all projects that require a Federal Section 404 Permit due to impacts to wetlands or waters of the State. A 401 Water Quality Certification is also required to impact isolated wetlands, which are not covered under Section 404. The 401 Certification is a verification by the Division of Water Quality that a given project will not degrade waters of the State or otherwise violate water quality standards. The stormwater requirements associated with receiving a 401 Certification can be found on the Division of Water Quality's web site at: http://h2o.enr.state.nc.us/ncwetlands/rd_wetlands_certifications.htm.

## 2.8 Universal Stormwater Management Program

A voluntary program went into effect January 1, 2007 that enables local governments to administer state stormwater programs within their jurisdiction while providing more effective environmental protections. The Universal Stormwater Management Program (USMP) represents a new approach to stormwater management in North Carolina in that it will allow local governments to adopt and implement a single, simplified set of stormwater rules within their jurisdiction. This will eliminate the confusion that can be posed by the overlapping requirements of up to 16 different stormwater pollution prevention programs. The program also incorporates the latest research regarding the most effective control and treatment of stormwater pollution.

The USMP is available to local governments that adopt an ordinance that complies with the rule and receives approval from the Environmental Management Commission. For those entities that adopt the program, the rule outlines requirements that apply to development and redevelopment activities that meet defined thresholds. In the 20 coastal counties, the threshold is projects that disturb 10,000 square feet or more, or disturb less than 10,000 square feet but are part of a larger common plan of development or sale. For the 80 non-coastal counties, the thresholds are: residential development activity that disturbs an acre or more, residential development activity that disturbs less than an acre but is part of a larger common plan of development or sale and non-residential development activities that disturb one-half acre or more. The USMP rule requires stormwater controls, such as the detention of stormwater to settle solids and modify its force and volume, for projects that meet or exceed the thresholds. In areas where stormwater drains to shellfish harvesting waters, measures must be taken to control fecal coliform and new or expanded outfalls are prohibited.

For more information about the USMP and the text of the rule, go to the Division of Water Quality's Web site, http://h2o.enr.state.nc.us/su/usmp.htm.

September 28, 2007 Changes:

1. 2.2: Corrected the volume and peak flow requirements.
2. 2.2: Clarified the drawdown requirements specified in the Administrative Code and Session Law 2006-246 (Phase II).
3. Table 2-2: Updated this table summarizing the stormwater requirements for sites that drain to saltwaters.
4. Table 2-3: Updated this table summarizing the stormwater requirements for sites that drain to freshwaters.

# 3. Stormwater Calculations

## 3.1. Stormwater Management Objectives

The objective of BMPs is to minimize the adverse effects of development by mimicking, as closely as possible, the runoff characteristics of the site in its undeveloped state. These characteristics include:

- Moderation of runoff peak flows and volumes to minimize downstream erosion and damage to in-stream aquatic habitat.
- Removal of pollutants such as sediment, nutrients, pathological bacteria and heavy metals.
- Infiltration of rainfall to replenish the water table and provide stable base flow to streams.

The preferred stormwater management approach is to preserve the natural storage, infiltration, and pollutant-treatment functions of each drainage area where practical, and where not practical to construct BMPs that mimic those natural functions as closely as possible.

Stormwater calculations are required to analyze a proposed new development for its impacts on peak flows and volumes. Stormwater programs in North Carolina typically include provisions to control and treat a certain volume of stormwater runoff and/or provisions to control the peak stormwater discharge rate. Additional calculations are required to design BMPs with appropriate treatment capacity and correctly sized outlet structures. Table 3-1 summarizes the stormwater calculations and allowable methods that will be presented in this chapter.

**Table 3-1**
Summary of Stormwater Calculations

| **Calculation of:** | **Section** | **Allowable Methods** |
|---|---|---|
| Peak Flow | 3.2 | Rational Method |
| Runoff Volume | 3.3 | Simple Method<br>Discrete SCS Curve Number Method |
| Storage Volume | 3.4 | Stage-Storage Table |
| Hydraulic Performance of the Outlet Device | 3.5 | Weir Equations<br>Orifice Equation |
| Stage-Storage-Discharge | 3.6 | Chainsaw Routing<br>Others: HEC-HMS, WinTR-55, SWIMM |
| Channel Geometry | 3.7 | Manning Equation |
| Nutrient Loading | 3.8 | DWQ Neuse TN Export Worksheet<br>DWQ Tar-Pamlico Nutrient Export Worksheet |
| Pollutant Removal of BMPs | 3.9 | Stand-alone BMPs<br>Multiple Drainage Areas<br>BMPs in Parallel<br>BMPs in Series |

**Note:** Designers may adopt different calculation methods, but the method chosen must provide equivalent or greater protection than the methods presented here.

## 3.2. Peak Flow Calculations

Some of the state's stormwater programs require providing attenuation of peak runoff; for example, that the post-development flow rate for the one-year, 24-hour storm may not exceed the pre-development flow rate (Neuse and Tar-Pamlico NSW Programs). In addition, it is also important to compute flow rates from the watershed when designing BMPs such as grassed swales, filter strips, and restored riparian buffers.

The primary method that is used to determine peak runoff rate for North Carolina's stormwater programs is the Rational Method. The Rational equation is given as:

$$Q = C * I * A$$

Where:
- $Q$ = Estimated design discharge (cfs)
- C = Composite runoff coefficient (unitless) for the watershed
- $I$ = Rainfall intensity (in/hr) for the designated design storm in the geographic region of interest
- $A$ = Watershed area (ac)

The composite runoff coefficient reflects the surface characteristics of the contributing watershed. The range of runoff coefficient values varies from 0 – 1.0, with higher values corresponding to greater runoff rate potential. The runoff coefficient is determined by estimating the area of different land uses within each drainage area. Table 3-2 presents values of runoff coefficients for various pervious and impervious surfaces. The Division believes that the Rational Method is most applicable to drainage areas approximately 20 acres or less.

**Table 3-2**

Rational runoff coefficients (ASCE, 1975; Viessman, et al., 1996; and Malcom, 1999)

| Description of Surface | Rational Runoff Coefficients, C |
|---|---|
| Unimproved Areas | 0.35 |
| Asphalt | 0.95 |
| Concrete | 0.95 |
| Brick | 0.85 |
| Roofs, inclined | 1.00 |
| Roofs, flat | 0.90 |
| Lawns, sandy soil, flat (<2%) | 0.10 |
| Lawns, sandy soil, average (2-7%) | 0.15 |
| Lawns, sandy soil, steep (>7%) | 0.20 |
| Lawns, heavy soil, flat (<2%) | 0.15 |
| Lawns, heavy soil, average (2-5%) | 0.20 |
| Lawns, heavy soil, steep (>7%) | 0.30 |
| Wooded areas | 0.15 |

The appropriate value for ***I***, precipitation intensity in inches per hour, can be obtained from the NOAA web site at: http://hdsc.nws.noaa.gov/hdsc/pfds/. This web site

allows the user to select from one of NOAA's numerous data stations throughout the state. Then, the user can ask for precipitation intensity and view a table that displays precipitation intensity estimates for various annual return intervals (ARIs) (1 year through 1000 years) and various storm durations (5 minutes through 60 days).
The requirements of the applicable stormwater program will determine the appropriate values for ARI and storm duration. If the design is for a level spreader that is receiving runoff directly from the drainage area, then the value for *I* should simply be one inch per hour (more information on level spreader design in Chapter 8).

## 3.3. Runoff Volume

Many stormwater programs have a volume control requirement; that is, capturing the first 1 or 1.5 inches of stormwater and retaining it for 2 to 5 days. There are two primary methods that can be used to determine the volume of runoff from a given design storm: the Simple Method (Schueler, 1987) and the discrete SCS Curve Number Method (NRCS, 1986). Both of these methods are intended for use at the scale of a single drainage area. Stormwater BMPs shall be designed to treat a volume that is at least as large as the volume calculated using the Simple Method. If the SCS Method yields a greater volume, then it can also be used.

### 3.3.1. Simple Method

The Simple Method uses a minimal amount of information such as watershed drainage area, impervious area, and design storm depth to estimate the volume of runoff. The Simple Method was developed by measuring the runoff from many watersheds with known impervious areas and curve-fitting a relationship between percent imperviousness and the fraction of rainfall converted to runoff (the runoff coefficient). This relationship is presented below:

$$R_V = 0.05 + 0.9 * I_A$$

Where:
$R_V$ = Runoff coefficient [storm runoff (in)/storm rainfall (in)], unitless
$I_A$ = Impervious fraction [impervious portion of drainage area (ac)/ drainage area (ac)], unitless.

Once the runoff coefficient is determined, the volume of runoff that must be controlled is given by the equation below:

$$V = 3630 * R_D * R_v * A$$

Where:
$V$ = Volume of runoff that must be controlled for the design storm ($ft^3$)
$R_D$ = Design storm rainfall depth (in) *(Typically, 1.0" or 1.5")*
$A$ = Watershed area (ac)

### 3.3.2. Discrete SCS Curve Number Method

The SCS method (SCS, 1985; NRCS, 1986) is an alternative method for calculating the volume of stormwater runoff that is generated from a given amount of rainfall. **It may only be used when the site design is a Low Impact Development (LID).**

The SCS runoff equation is given below:

$$Q^* = \frac{(P-0.2S)^2}{P+0.8S}$$

Where: $Q^*$ = Runoff depth (in)
$P$ = Rainfall depth (in)
$S$ = Potential maximum retention after rainfall begins (in)

S is related to the soil and surface characteristics of the drainage area through the curve number (CN) by the following equation:

$$S = \frac{1000}{CN} - 10$$

Where: CN is the curve number, unitless.

The curve number, CN, describes the characteristics of the drainage area that determine the amount of runoff generated by a given storm: hydrologic soil group and ground cover. Soils are classified into four hydrologic soil groups (A, B, C, and D) based on their minimum infiltration rate, with A having the highest infiltration potential and D having the lowest. The four soil groups are summarized in Table 3-3.

The required treatment volume is determined by multiplying the runoff depth (Q*) by the drainage area.

**Table 3-3**

Four Hydrologic Soil Groups as Defined by the SCS (1986)

| | |
|---|---|
| Group A | A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr). The textures of these soils are typically sand, loamy sand, or sandy loam. |
| Group B | B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr). The textures of these soils are typically silt loam or loam. |
| Group C | C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr). The texture of these soils is typically sandy clay loam. |
| Group D | D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr). The textures of these soils are typically clay loam, silty clay loam, sandy clay, silty clay, or clay. |

Table 3-4 lists the hydrologic soil grouping for most soil series in North Carolina. Some soils may reside in two groups depending on the presence of a high water table that limits infiltration. If these soils are effectively drained, they are placed in the group with lower runoff potential. For example, Cape Fear soil is classified as B/D, which indicates that it is in group B if drained and in group D if undrained. If a soil at a given site is not listed in Table 3-4, the surface layer soil texture may be used to determine the hydrologic soil group. The texture may be determined by soil analysis or from the local soil survey.

**Table 3-4**

Hydrologic soil groups for soil types found in North Carolina (Malcom, 1989)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Alaga | A | Dragston | D/C | Louisa | B | Ridgeland | C |
| Alamance | B | Dunbar | D/B | Louisburg | B | Rimini | C |
| Albany | C/A | Duplin | C/B | Lucy | A | Roanoke | D |
| Altavista | C/B | Durham | B | Lumbee | D/C | Rosman | B |
| Americus | A | Dykes | B | Lynchburg | C/B | Rumford | B |
| Appling | B | Edneyville | B | Lynn Haven | D/C | Ruston | B |
| Ashe | B | Elbert | D | Madison | B | Ruttege | D/B |
| Augusta | C | Elioak | B | Magnolia | B | Saluda | C/B |
| Avery | B | Elsinboro | B | Mantachie | C/B | Scranton | D/B |
| Aycock | B | Enon | C | Manteo | D | Seneca | C/B |
| Barclay | C | Eustis | A | Marlboro | B | Starr | B |
| Barth | C | Exum | C/B | Masada | B | State | B |
| Bayboro | D/C | Faceville | B | Maxton | B | Suncook | A |
| Bertie | C/B | Fannin | B | Mayodan | B | Surry | B |
| Bibb | D/B | Fletcher | B | McColl | D/C | Talladega | C |
| Bladen | D/C | Fuquay | B | Mecklenburg | C | Tallepoosa | C |
| Blaney | B | Georgeville | B | Meggett | D/C | Tate | B |
| Blanton | A | Gilead | C | Molena | A | Taturn | B |
| Bowie | B | Goldsboro | C/B | Musella | B | Thurmont | B |
| Braddock | B | Goldston | C | Myatt | D/C | Toccoa | B |
| Bradley | B | Granville | B | Nahunta | C/B | Toisnot | C/B |
| Brandywine | B | Grover | B | Nason | C | Torhuna | C/A |
| Brevard | B | Guin | A | Nixonton | B | Toxaway | D |
| Bucks | B | Gwinnett | B | Norfolk | B | Transylvania | B |
| Buncombe | A | Hartsells | B | Ochlockonee | B | Troup | A |
| Burton | B | Hatboro | D/C | Ocilla | C/B | Tuckerman | D/C |
| Byars | D | Hayesville | B | Olustee | D/C | Tusquitee | B |
| Cahaba | B | Haywood | B | Onslow | B | Unison | B |
| Cape Fear | D/B | Helena | C | Orange | D | Vance | C |
| Caroline | C | Herndon | B | Orangeburg | B | Varina | C |
| Cartecay | C | Hiwassee | B | Osier | D | Vaucluse | C |
| Cataula | C | Hoffman | C | Pacolet | B | Wadesboro | B |
| Cecil | B | Hulett | B | Pactolus | C/A | Wagram | A |
| Chandler | B | Hyde | D/C | Pamlico | D/C | Wahee | D/C |
| Chastain | D | Invershiel | C | Pantego | D/C | Wake | D |
| Chester | B | Iredell | D | Pasquotank | D/B | Watauga | B |
| Chesterfield | B | Iuka | C | Pelham | D/C | Wedowee | B |
| Chewacla | C | Izagora | C | Pender | D | | |
| Chipley | C/A | Johnston | D/B | Penn | C/B | | |
| Clifton | B | Johus | C/B | Pinkston | C | | |
| Codurus | C | Kalmia | B | Plummer | D/B | | |
| Colfax | C | Kenansville | A | Pocalla | A | | |
| Comus | B | Kershaw | A | Pocomoke | D/B | | |
| Congaree | B | Kinston | D/C | Pomello | C/A | | |
| Cowarts | C | Lakeland | A | Ponzer | D/C | | |
| Coxville | D/C | Leaf | D/C | Porters | B | | |
| Craven | C | Lenoir | D/B | Portsmouth | D/C | | |
| Davidson | B | Leon | C/B | Rabun | B | | |
| Delanco | C | Liddell | D/C | Rains | D/B | | |
| Dorovan | D | Lloyd | B | Ramsey | D | | |
| Dothan | B | Lockhart | B | Ranger | C | | |

The type of ground cover at a given site greatly affects the volume of runoff. Undisturbed natural areas, such as woods and brush, have high infiltration potentials whereas impervious surfaces, such as parking lots and roofs, will not infiltrate runoff at all. The ground surface can vary extensively, particularly in urban areas, and Table 3-5 lists appropriate curve numbers for most urban land use types according to hydrologic soil group. Land use maps, site plans, and field reconnaissance are all effective methods for determining the ground cover.

**Table 3-5**

Runoff curve numbers in urban areas for the SCS method (SCS, 1986)

| Cover Description | Curve Numbers for Hydrologic Soil Group | | | |
|---|---|---|---|---|
| *Fully developed urban areas* | A | B | C | D |
| Open Space (lawns, parks, golf courses, etc.) | | | | |
| Poor condition (< 50% grass cover) | 68 | 79 | 86 | 89 |
| Fair condition (50% to 75% grass cover) | 49 | 69 | 79 | 84 |
| Good condition (> 75% grass cover) | 39 | 61 | 74 | 80 |
| Impervious areas: | | | | |
| Paved parking lots, roofs, driveways, etc. | 98 | 98 | 98 | 98 |
| Streets and roads: | | | | |
| Paved; curbs and storm sewers | 98 | 98 | 98 | 98 |
| Paved; open ditches | 83 | 89 | 98 | 98 |
| Gravel | 76 | 85 | 89 | 91 |
| Dirt | 72 | 82 | 85 | 88 |
| *Developing urban areas* | | | | |
| Newly graded areas | 77 | 86 | 91 | 94 |
| Pasture (< 50% ground cover or heavily grazed) | 68 | 79 | 86 | 89 |
| Pasture (50% to 75% ground cover or not heavily grazed) | 49 | 69 | 79 | 84 |
| Pasture (>75% ground cover or lightly grazed) | 39 | 61 | 74 | 80 |
| Meadow - continuous grass, protected from grazing and generally mowed for hay | 30 | 58 | 71 | 78 |
| Brush (< 50% ground cover) | 48 | 67 | 77 | 83 |
| Brush (50% to 75% ground cover) | 35 | 56 | 70 | 77 |
| Brush (>75% ground cover) | 30 | 48 | 65 | 73 |
| Woods (Forest litter, small trees, and brush destroyed by heavy grazing or regular burning) | 45 | 66 | 77 | 83 |
| Woods (Woods are grazed but not burned, and some forest litter covers the soil) | 36 | 60 | 73 | 79 |
| Woods (Woods are protected from grazing, and litter and brush adequately cover the soil) | 30 | 55 | 70 | 77 |

Most drainage areas include a combination of land uses. The SCS Curve Number Model should be applied separately: once for areas where impervious cover is directly connected to surface water via a swale or pipe and a second time for the remainder of the site. The runoff volumes computed from each of these computations should be added to determine the runoff volume for the entire site.

For the portion of the site that is NOT directly connected impervious surface, a composite curve number can be determined to apply in the SCS Curve Number Model. The composite curve number must be area-weighted based on the distribution of land uses at the site. Runoff from impervious areas that is allowed to flow over pervious areas has the potential to infiltrate into the soil (for example, where roof downspouts are diffused over a lawn). Disconnected impervious areas produce less runoff than impervious areas that are directly connected to a storm drainage system.

**Table 3-6**
How to apply the SCS Curve Number Method

| | |
|---|---|
| Step 1. | Divide the drainage area into land uses and assign an appropriate CN to each one (see Table 3.5). |
| Step 2. | Compute Q* for any impervious surfaces that are directly linked to surface waters via a swale or pipe. Find the runoff volume from the directly connected impervious surfaces by multiplying Q* times the area of the directly connected impervious surfaces. |
| Step 3. | Composite a curve number for the remainder of the site by using a weighted average. If the composite CN is equal to or below 64, assume that there is no runoff resulting from either the 1 or 1½ inch storm. If the composite CN is above 64, compute Q* for this area. Find the runoff volume from the remainder of the site by multiplying Q* times the area of the remainder of the site. |
| Step 4. | Find the runoff volume from the whole site by adding the results of Step 2 and Step 3. |

## 3.4. Storage Volume

Volume control is typically provided through detention structures with volume above the water operating level and below the required freeboard. Some BMPs do not have the capability to provide this volume control due to their design, and others can include storage volume within the media of the BMP. Each individual BMP chapter discusses the specific calculations for meeting the volume control requirements. However, since many of the BMPs use storage volume in a detention structure, this section will discuss an acceptable method of calculating that volume.

Storage volume within a detention structure shall be calculated using a stage-storage method. A table shall be provided showing incremental elevations of the BMP with square footage values at the listed elevations. The elevation increments shall be no more than 1 foot. Columns can then be produced showing the incremental volume and cumulative volume of storage provided. See Table 3-7 below for an example of a storage volume calculation. This method can be used for basin shapes as simple as a rectangle or as intricate as a curved, landscape designed wetland feature. It can also be used to calculate sediment storage volume and operating volume within BMPs.

**Table 3-7**
Stage-Storage Volume Calculation Table Example

| Elevation | Surface Area (sf) | Incremental Volume (cf) | Cumulative Volume (cf) |
|---|---|---|---|
| less than 725 | operating volume | 0 | 0 |
| 725 | 10,000 | 0 | 0 |
| 726 | 13,000 | 11,500 | 11,500 |
| 727 | 16,500 | 14,750 | 26,250 |
| 728 | 21,500 | 19,000 | 45,250 |
| 729 | 26,000 | 23,750 | 69,000 |
| over 729 | freeboard | 0 | 69,000 |

## 3.5. Hydraulic Performance of the Outlet Device

In order to successfully design a stormwater treatment system, it is crucial to analyze the way in which the outlet devices release stormwater outflow. Typically, these devices can be considered as either weirs or orifices. A weir is a dam placed horizontally along a stream or channel to raise its level or divert its flow. Some uses for weirs are in the design of stormwater BMPs are:

- Check dams in channels,
- Flow splitter devices,
- Flow into a pipe before it is completely submerged, and
- Level spreaders.

An orifice is simply a hole. In the design of stormwater BMPs, orifices are used to drain a BMP that is detaining stormwater for volume control and pollutant removal. It is important to determine the size an orifice correctly so that the appropriate drawdown rate can be provided.

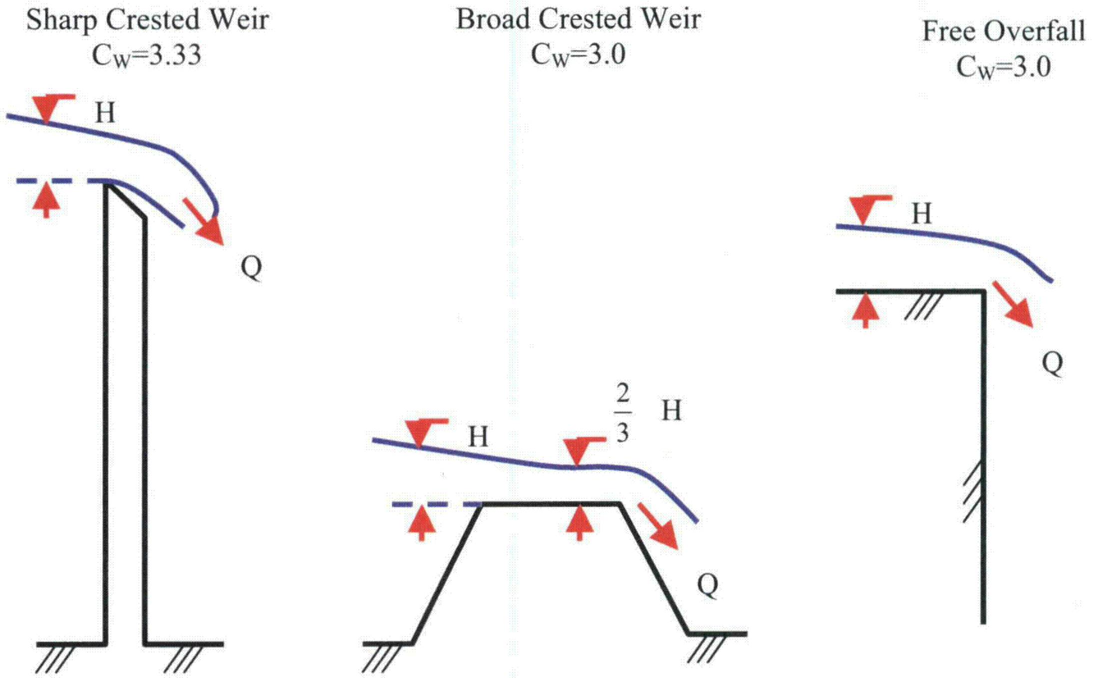
### 3.5.1. Weir Equations

Three kinds of weirs are typically used: sharp-crested, broad-crested and v-notch. For sharp-crested and broad-crested weirs, the basic equation is:

$$Q = C_W L H^{1.5}$$

Where:
- $Q$ = Discharge (cfs)
- $C_W$ = Coefficient of discharge (dimensionless) - see below
- $L$ = Length of weir (ft), measured along the crest
- $H$ = Driving head (ft), measured vertically from the crest of the weir to the water surface at a point far enough upstream to be essentially level

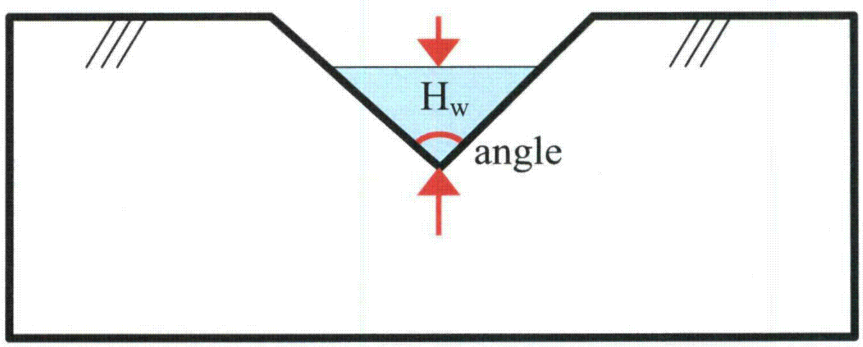
**Figure 3-1**
Schematic sections through weirs (Malcom 1989)




For v-notch weirs, the basic equation is:

$$Q = C_v H_w^{5/2}$$

Where: $Q$ = Discharge (cfs)
$C_v$ = Weir flow coefficient for V-notch weirs
2.50 for 90 degrees
1.44 for 60 degrees
1.03 for 45 degrees
$H_w$ = Difference between pool elevation and notch (ft)



### 3.5.2. Orifice Equation

The basic equation for orifices is:

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

Where:

- $Q$ = Discharge (cfs)
- $C_D$ = Coefficient of discharge (dimensionless) - see Table 3-8
- $A$ = Cross-sectional area of flow at the orifice entrance (sq ft)
- $g$ = Acceleration of gravity (32.2 ft/sec$^2$)
- $H_O$ = Driving head (ft), measured from the centroid of the orifice area to the water surface – **Note: Usually use Ho/3 to compute drawdown through an orifice to reflect the fact that head is decreasing as the drawdown occurs.**

**Figure 3-2**
Schematic section through an orifice

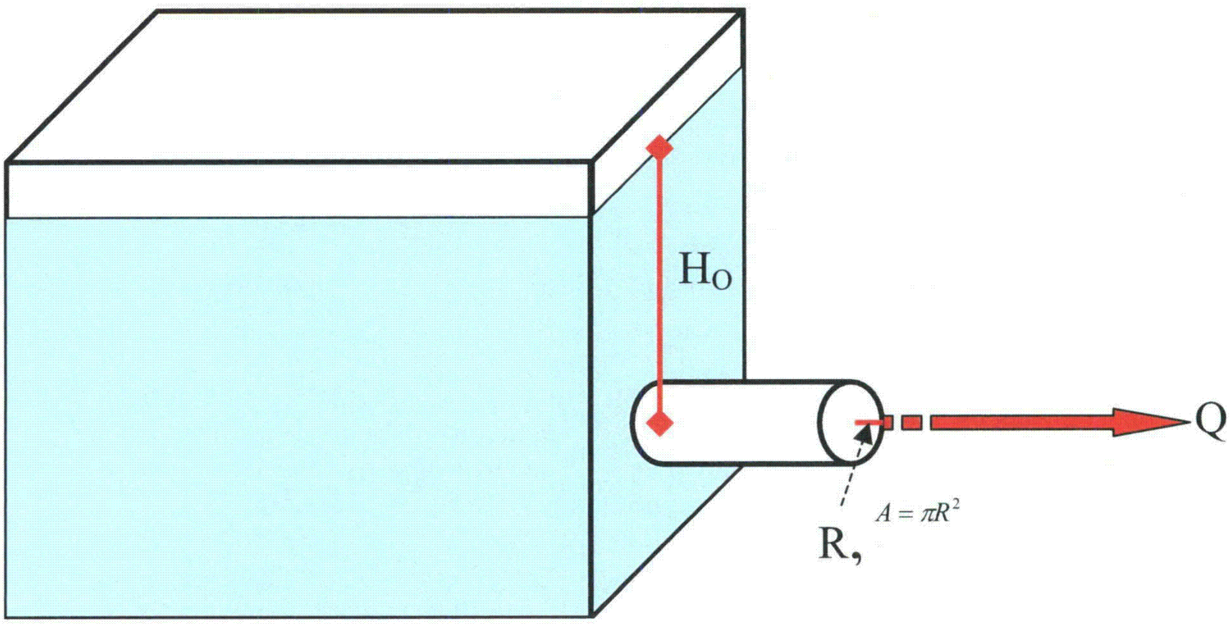



**Table 3-8**
Values of Coefficient of Discharge, $C_D$ (Malcom, 1989)

| Entrance Condition | $C_D$ |
|---|---|
| Typical default value | 0.60 |
| Square-edged entrance | 0.59 |
| Concrete pipe, grooved end | 0.65 |
| Corrugated metal pipe, mitred to slope | 0.52 |
| Corrugated metal pipe, projecting from fill | 1.00 |

## 3.6. Stage-Storage-Discharge Model

Creating a stage-storage-discharge model is crucial for stormwater BMPs that involve detention of stormwater, particularly stormwater wetlands and wet detention basins. These BMPs provide volume control for the specified storm (for example, the 1 or 1½ inch storm) in a temporary pool that is above the permanent pool.

(Please note that some BMPs do not have the capability to provide this volume control due to their design, and others can include storage volume within the media of the BMP. Each BMP Section will discuss the specific calculations for meeting the volume control requirements.)

### 3.6.1. Chainsaw Routing

The Chainsaw Routing method is appropriate for the routine design of small systems. Three sets of source data are needed to apply the Chainsaw Routing method:

- The inflow hydrograph,
- The size and shape of the storage basin, and
- The hydraulics of the outlet device.

The application of the Chainsaw Routing method is described in detail in Elements of Urban Stormwater Design (Dr. H. Rooney Malcom, P.E. 1989). Please refer to Section III, Stormwater Impoundments for a detailed explanation and examples of its use. This reference is available in Appendix B.

### 3.6.2. Other Models

Other models may be used to assist in determining stage-storage-discharge through a detention BMP. These models include:

- HEC-HMS, developed by the U.S. Army Corps of Engineers, provides a variety of options for simulating precipitation-runoff processes. This model can simulate unit hydrograph and hydrologic routing options. The latest version also has capabilities for continuous soil moisture accounting and reservoir routing operations.
  http://www.hec.usace.army.mil/software/hec-hms/download.html
- WinTR-55, develop by the NRCS, can be used to analyze the hydrology of small watersheds. A final version (including programs, sample data, and documentation) is now complete.
  http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html.
- SWIMM, developed by the EPA, can be used to analyze stormwater quantity and quality associated with runoff from urban areas. Both single-event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations.
  http://www.epa.gov/ceampubl/swmm.htm

## 3.7. Channel Geometry

The Manning Equation is the model of choice for determining the cross-section for a trapezoidal stormwater channel. It is applicable where (Malcom 1989):

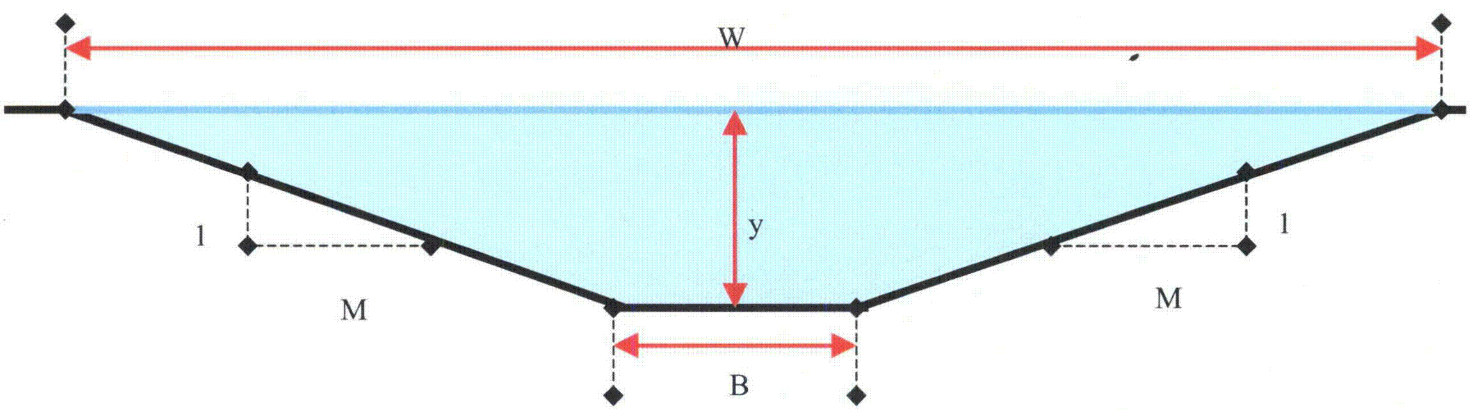
- Stormwater is flowing under the influences of gravity, and
- Flow is steady - it does not vary with time (Although discharge does vary during the passage of a flood wave, it is essentially steady during the time around the peak, the time of interest in channel design.)

The Manning Equation can be stated as:

$$Q = \frac{1.489}{n} A R^{0.667} S^{0.5}$$

Where:
- $Q$ = Peak discharge to the channel (cfs)
- $n$ = Manning roughness coefficient (dimensionless)
- $A$ = Cross-sectional area of flow (sq ft), the area through which flow takes place *(see below)*
- $R$ = Hydraulic radius (ft), found by dividing cross-sectional area, A (sq ft), by wetted perimeter, P (ft) *(see below)*
- $S$ = Longitudinal slope of the invert of the channel (ft fall/ft run).

**Figure 3-3**
Diagram of a trapezoidal channel*




* M is governed by channel side slope requirements, which are typically 3:1 (M=3) unless otherwise specified in this manual.

The Manning roughness coefficient is an experimentally determined value that is a function of the nature of the channel lining.

**Table 3-9**

Rational runoff coefficients (adopted from Munson, et al., 1990 and Chow et al., 1988)

| Channel lining | Manning roughness coefficient, n |
|---|---|
| Asphalt | 0.016 |
| Concrete, finished | 0.012 |
| Concrete, unfinished | 0.014 |
| Grass | 0.035 |
| Gravel bottom with riprap sides | 0.033 |
| Weeds | 0.040 |

The cross-sectional area of flow, A, can be determined by the following equation:

$$A = By + My^2$$

The wetted perimeter, P, is the distance along the cross section against which the water is flowing. It does not include the free water surface. P can be determined by the following equation:

$$P = B + 2y\,(1 + M^2)^{0.5}$$

The hydraulic radius, R, can be determined by the following equation:

$$R = \frac{A}{P}$$

For the three equations above, the variables have the following meanings (also refer to Figure 3-3):

$A$ = Cross-sectional area of flow (sq ft)
$B$ = Bottom width of the channel (ft)
$M$ = Side slope ratio (ft horizontal/ft vertical) *(determined by channel side slope requirements)*
$P$ = Wetted perimeter (ft)
$R$ = Hydraulic radius (ft)
$y$ = Depth of flow (ft)

## 3.8. Nutrient Loading

Nutrient control requirements currently apply to new development and redevelopment projects occurring in the jurisdictions of the largest local governments in the Neuse and Tar-Pamlico River Basins.

In the affected jurisdictions in the Neuse and Tar-Pamlico River Basins, new developments are required to meet specified nutrient export rates. These export rates can be met on site through one or more of the following measures:

- Site planning that reduces land uses that contribute high nutrient loadings,
- Implementation of BMPs that remove nutrients, and
- Offset payments to the Wetland Restoration Fund.

For the Neuse River Basin, the nutrient of concern is total nitrogen (TN). The TN export limit is 3.6 pounds per acre per year (lb/ac/yr). Nitrogen load from new developments that exceeds this performance standard may be offset by payment of a fee to the Wetlands Restoration Fund provided. However, no new residential development may exceed 6.0 lb/ac/yr and no new nonresidential development may exceed 10.0 lb/ac/yr.

For the Tar-Pamlico River Basin, the nutrients of concern are TN and total phosphorus (TP). The TN export limit is 4.0 lb/ac/yr and the TP export limit is 0.40 lb/ac/yr. Just like in the Neuse River Basin, nitrogen load from new developments that exceeds this performance standard may be offset by payment of a fee to the Wetlands Restoration Fund provided. However, no new residential development may exceed 6.0 lb/ac/yr and no new nonresidential development may exceed 10.0 lb/ac/yr.

The above nutrient export limits were determined based on analyzing the nutrient loading coming from undeveloped land within each river basin, which consists mainly of forested land and agricultural land. The nutrient loading limit on new development then represents a 30 percent reduction from the overall average nutrient loading rate of the undeveloped land. The rate for TN is slightly higher in the Tar-Pamlico basin than in the Neuse basin due to the higher ratio between agricultural lands (high nutrient loading rate) and forested lands (low nutrient loading rate).

In addition to the requirements for nutrient loading rates, new developments subject to this program must show that there is no net increase in peak flow leaving the site from the predevelopment conditions for the 1-year, 24-hour storm. The intent of this requirement is to protect the stream channel and adjacent riparian buffer, which help to prevent additional nutrients from entering streams.

For both the Neuse and Tar-Pamlico River Basins, the affected local governments are responsible for reviewing new development plans to see that they comply with the nutrient export limits and peak flow control requirements. The affected jurisdictions are listed in Table 3-10 below. The EMC may also designate additional local governments in the Neuse and Tar-Pamlico basins to comply with the NSW stormwater rule in the future.

**Table 3-10**
Local governments affected by the Neuse and Tar-Pamlico NSW Stormwater Programs

| Neuse River Basin | Tar-Pamlico River Basin |
|---|---|
| Cary | Greenville |
| Durham | Henderson |
| Garner | Oxford |
| Goldsboro | Rocky Mount |
| Havelock | Tarboro |
| Kinston | Washington |
| New Bern | Beaufort County * |
| Raleigh | Edgecombe County * |
| Smithfield | Franklin County * |
| Wilson | Nash County * |
| Durham County * | Pitt County * |
| Johnston County * | |
| Orange County * | |
| Wake County * | |
| Wayne County * | |

* Applicable areas are those under the direct jurisdiction of the respective county.

### 3.8.1. DWQ Neuse TN Export Worksheets

In the Neuse River Basin, there is a Model Stormwater Program for Nutrient Control that was developed as part of a joint effort between the DWQ and the affected local governments.

Two model methodologies that may be used to calculate the TN export rate from a new development are summarized below. However, local governments may propose alternative approaches where it can be demonstrated to be equivalent.

- Method 1 is intended for residential developments where lots are shown but the actual footprint of buildings are not shown on site plans. This method estimates the impervious surface resulting from building footprints on individual lots based on typical impervious areas associated with given lot sizes.

- Method 2 is for residential, commercial and industrial developments when the entire footprint of the roads, parking lots, buildings and any other built-upon area is shown on the site plans. This method is simpler and more accurate since it does not require estimating the impervious surface based on lot size like Method 1.

Worksheets for Methods 1 and 2 are presented on pages 10 through 12 of ***The Neuse River Basin: Model Stormwater Program for Nitrogen Control***. This model program is available at: http://h2o.enr.state.nc.us/su/PDF_Files/Neuse/FinalModel_Plan.pdf

### 3.8.2 DWQ Tar-Pamlico Nutrient Export Worksheets

In order to meet the requirements of the Tar-Pamlico NSW Stormwater Program, each of the affected local governments has developed its own program for Nutrient Control. These programs can be accessed at the DWQ web site at: http://h2o.enr.state.nc.us/nps/Tar-Pamlico_Nutrient_Trading_Program_files/Tar-PamlicoLocalStormwaterPrograms00.htm

There are a number of differences between the Neuse and Tar-Pamlico Nutrient Export Worksheets that are summarized as follows:

- The Tar-Pamlico model computes the export of both TN and TP, whereas the Neuse model is only computes TN.
- The Tar-Pamlico model has a separate version for the Piedmont versus the Coastal Plain; the Neuse model does not.
- The Tar-Pamlico breaks the urban land uses into a greater number of categories than the Neuse model.
- The Tar-Pamlico model combines the Methods 1 and 2 used in the Neuse model into a single method.
- Most importantly, the Tar-Pamlico model is presented as an interactive spreadsheet where the designer can input data about the site of interest and the model will compute the appropriate TN and TP export rates in lb/ac/yr.
- The Tar-Pamlico model also allows the designer to input information about the BMPs used to treat each drainage area and the spreadsheet will compute the new loading rate resulting from the use of the BMP.

The interactive Tar-Pamlico nutrient export worksheets are available on the DWQ's web site at:

- Coastal Plain: http://h2o.enr.state.nc.us/nps/documents/N-PCalcsheetCoastProtected10-04.xls
- Piedmont: http://h2o.enr.state.nc.us/nps/documents/N-PCalcsheetPiedProtected10-04.xls

## 3.9. Pollutant Removal of BMPs

### 3.9.1. Stand-alone BMPs

Throughout this manual, each BMP is assigned a removal rate for TSS, TN and TP. In the case of TSS, the calculation of pollutant removal for a single BMP is not needed because the designer will be required simply to select a BMP that removes 85% of TSS. However, a pollutant removal calculation will be necessary in order to determine whether the nutrient removal requirements of the Neuse and Tar-Pamlico NSW Stormwater Programs have been met.

For a single BMP treating stormwater in an affected area of the Neuse or Tar-Pamlico River Basins, the removal of the a pollutant by a single BMP is shown below:

$$PL_e = PL_i * RE$$

Where:
$PL_e$ = Pollutant Loading in the Effluent (lb/ac/yr)
$PL_i$ = Pollutant Loading in the Influent (lb/ac/yr)
$RE$ = Listed Removal Efficiency of the BMP

### 3.9.2. Multiple Drainage Areas

When a site contains multiple drainage areas, each drainage area must meet the quantity and quality requirements of the applicable stormwater program before leaving the site. Volume and pollutant control may not be averaged between different drainage areas to meet an overall site requirement. In addition, if a drainage area extends upstream from a site, the stormwater volume and pollutant transport calculations must be performed for that upstream section of the drainage area and included in the total volume and loading values for the site for treatment by the appropriate BMP. Calculations for BMPs that are located in separate drainage areas must be performed as presented above for single BMPs.

### 3.9.3. BMPs in Parallel

If designed properly, a parallel placement of multiple BMPs could additively combine the storage volume of each individual BMP to provide a total volume control function that would meet the stormwater program requirements. However, a parallel placement of multiple BMPs would not increase pollutant removal efficiencies but would just provide a flow-weighted removal proportional to the individual removal rate and the fraction of total flow passing through each particular BMP.

### 3.9.4. BMPs in Series

Multiple BMPs may be placed in series within the same drainage area to combine treatment capabilities. If multiple BMPs are placed in series, they can utilize the combined volume control capabilities and increase combined removal efficiency. The volume control capabilities are additive, however, the pollutant removal rates are not. The overall efficiency ($E$) for a given pollutant (TSS, TN or TP) of multiple BMPs in series is computed as follows (Division of Watershed Management, 2004):

$$E = A + B - \left[\frac{(AxB)}{100}\right]$$

Where:
E = Total pollutant removal efficiency (%)
A = Efficiency of the First or Upstream BMP
B = Efficiency of the Second or Downstream BMP

For more than two BMPs in series, the equation can be applied iteratively from upstream to downstream using the calculated total efficiency as the upstream efficiency in each successive iteration.

It has been found that pollutant removal effectiveness does not continue to increase when using the same removal mechanism over and over. For any set of multiple BMPs placed in series, the combined removal efficiency equation can use pollutant removal efficiency values from a maximum of two BMPs with the same removal mechanism. Additional BMPs with the same removal mechanism will not increase the removal efficiency, but they can contribute to volume control capabilities. A categorization of the BMP removal mechanisms is provided in Table 3-11.

**Table 3-11**
BMPs categorized by removal mechanism

| Removal Mechanism | BMPs |
|---|---|
| Detention/Retention | Dry Extended Detention Basin<br>Wet Detention Basin<br>Stormwater Wetlands |
| Filtration | Sand Filters<br>Bioretention |
| Infiltration | Infiltration Devices<br>Porous Pavement |
| Natural Conveyance | Filter Strip<br>Grassed Swale<br>Restored Riparian Buffer |

This discussion of multiple BMPs placed in series in this section is assuming the BMPs are directly successive. If there is additional drainage area between them, the flow volume and pollutant load from that additional drainage area must be added into the calculations between the discharge of the first BMP and the influent of the second BMP.

September 28, 2007 Changes:

1. 3.2: Deleted a sentence (below the Rational Method) that led to confusion in unit conversions.
2. 3.2: Clarified guidance on using the Rational Method on drainage areas over 20 acres.
3. 3.3: Clarified that the calculated treatment volume shall be at least as large as the volume calculated using the Simple Method.
4. 3.3.1: Clarified that the variable, "Design storm depth" is typically 1.0" or 1.5".
5. 3.3.2: Clarified that for Low Impact Development (LID) designs using the Discrete SCS Curve Number Method, the treatment volume is equal to the runoff depth multiplied by the drainage area.
6. 3.5.2: Changed the average drawdown head from $H_o/2$ to $H_o/3$ in, "Note: Usually use $H_o/3$ to compute drawdown through an orifice to reflect the fact that head is decreasing as the drawdown occurs."
7. 3.5.2: Corrected a typo in the orifice equation. "$C_O$" now reads "$C_D$". *(Note: This change is not visible in Track Changes.)*
8. 3.7: Corrected a statement indicated that all channel side slopes were to be 3:1. Side slope requirements are typically 3:1, unless otherwise specified in the manual.

# 4. Selecting the Right BMP

## 4.1 Introduction

Selecting the most appropriate BMPs for a development is an art as well as a science, if done correctly. This Chapter provides the link between stormwater regulatory requirements and physical site constraints, as well as issues of cost and community acceptance.

For several reasons, there is no one BMP that is best for every site. First, different BMPs are better suited for different aspects of stormwater treatment and control (sediment removal, nutrient removal, and volume control). One particular BMP might not provide all of the required treatment goals of the regulations that apply to a site. Additionally, each site has unique features, such as slope, soils, size, and development density that encourage the use of some types of BMPs and eliminate the use of other types of BMPs. Issues of cost and community acceptance are also vital to consider in the BMP selection process.

Whether or not a structural BMP is needed will be determined by the applicable regulatory requirements for the site, which are covered in Chapter 2. For an exact determination of the applicable regulations at a site, please check with local planning and zoning authorities, as well as using the interactive mapping feature on the DWQ Stormwater Web page at http://h2o.enr.state.nc.us/su/msi_maps.htm.

## 4.2. General BMP Selection Guidance

Prior to selecting a structural BMP, a designer should first consider if it is possible to reduce the impervious surfaces on the site. Reducing impervious surfaces can minimize or eliminate the need for structural BMPs. Strategies for reducing impervious surfaces are discussed in Section 4.3.

If structural BMPs will be required, the following process is recommended for selecting the appropriate one to use:

- First, determine the treatment capability (TSS removal, nutrient removal and peak flow control) that is required of the BMP based on the applicable regulatory requirements for the site (see Chapter 2).
- Second, determine which BMPs will meet the treatment capability requirements (Section 4.4) and create a "short list."
- Third, see which of the "short listed" BMPs will be appropriate for the physical site characteristics (Section 4.5).
- Fourth, consider other factors such as construction cost, maintenance effort, community acceptance and wildlife habitat (Section 4.5).

When a site has a lot of physical constraints and the regulatory requirements are stringent, it can be especially challenging to find a BMP that will fit the bill. In this case, it may be necessary to modify the BMP design for the site characteristics (see individual

BMP chapters) or to provide a combination of BMPs that are suitable for the site in series to provide the required level of stormwater treatment.

Getting even further into the art of good BMP design requires blending the BMP into the natural environment to make it an aesthetic enhancement rather than a thing to hide (especially in areas with considerable pedestrian traffic such as residential, commercial, and office locations). This often requires collaboration between various professions such as civil engineers and landscape architects.

When siting BMPs within a site, they should conform to the natural features of the landscape such as drainage swales, terraces, and depressions. Many of the more "natural" BMPs can readily achieve these goals, such as filter strips, grassed swales, and restored riparian buffers. Other natural-looking BMPs such as bioretention and stormwater wetlands can be blended right into natural areas of site designs, or even create new, small sized natural areas within normally barren portions of the site, such as parking lots, walking areas, and outdoor plazas.

DWQ recommends reintroducing runoff from impervious surfaces into the natural environment as close to the surfaces as possible. Ideally, impervious surfaces should be hydrologically divided so that runoff is delivered in smaller volumes that can be accommodated by smaller, less expensive and less obtrusive BMPs. In general, DWQ recommends against constructing large "end-of-pipe" facilities because of their high cost, maintenance requirements, consumption of land, and disruption of the landscape.

## 4.3. Reducing Impervious Surfaces

Most stormwater rules provide an option to meet certain low-density development criteria and then typically no engineered stormwater controls will be required. Keeping the percent impervious surface low when possible is the preferred method of stormwater control. In addition, reducing the percentage of impervious cover in a high-density development will reduce the size of BMPs that are needed.

Some of the options for reducing impervious surfaces are listed below. The local planning jurisdiction will usually determine the flexibility that exists to try them.

- Reducing road widths
- Reducing minimum parking requirements
- Minimizing use of curb and gutter
- Cluster or open-space developments
- Traditional neighborhood developments
- Mixed-use developments

Appendix G of the *Neuse River Basin: Model Stormwater Program for Nitrogen Control* (1999) discusses site design techniques to reduce impervious surfaces in greater detail, available at: http://h2o.enr.state.nc.us/su/PDF_Files/Neuse/FinalModel_App_G.pdf.

## 4.4. Comparison of BMP Treatment Capabilities

If the low-density option is not chosen, then one or more structural BMPs will be needed. For structural BMPs, one or more of the following general requirements will apply:

- There will be a pollutant removal requirement (typically 85% for TSS) or a maximum discharge limit (maximum pollutant export rate for TN and possibly also TP) imposed.
- There will be a volume of stormwater that must be captured and treated prior to release (typically first 1 inch or first 1.5 inches of rainfall).
- The post-construction peak stormwater discharge rate must be reduced to no greater than the pre-construction peak stormwater discharge rate (usually for the 1-year, 24-hour storm).

Table 4-1 presents the TSS, N, and P removal efficiencies of the various BMPs discussed in this manual. These removal efficiencies assume that the BMPs are designed in accordance with the design requirements presented in Chapters 8 through 20. The removal efficiencies presented are in accordance with the September 8, 2004 memorandum *Updates to Stormwater BMP Efficiencies* from the North Carolina Department of Environment and Natural Resources (DENR), Division of Water Quality (DWQ) Stormwater Unit (DWQ, 2004).

Fecal coliform reduction is currently regulated as a narrative requirement rather than a quantitative requirement. Effort must be made to reduce fecal coliform levels in SA waters. The current main mechanism for reducing fecal coliform in stormwater BMPs is through exposure to UV light (sunlight), which happens regularly in devices containing areas which become temporarily inundated with stormwater, deposit fecal coliform bacteria in those areas, and then dry out and expose that fecal coliform bacteria to UV light. BMPs are ranked relatively for fecal coliform removal in Table 4-1.

High temperature of BMP discharges is of concern in HQW waters that support trout. The higher temperatures reduce dissolved oxygen, reduce reproductive rates, hinder growth, and increase disease exposure, among other things. Temperatures are typically increased due to ponded water being exposed to sunlight. BMPs are ranked relatively for temperature issues in Table 4-1.

**Table 4-1**
BMP Ability for Stormwater Quantity Control

| | Quantity Control | TSS Removal Efficiency | TN Removal Efficiency | TP Removal Efficiency | Fecal Removal Ability | High Temperature Concern |
|---|---|---|---|---|---|---|
| Bioretention | Possible | 85% | 35% | 45% | High | Med |
| Stormwater wetlands | Yes | 85% | 40% | 35% | Med | High |
| Wet detention basin | Yes | 85% | 25% | 40% | Med | High |
| Sand filter | Possible | 85% | 35% | 45% | High | Med |
| Filter strip | No | 25-40% | 20% | 35% | Med | Low |
| Grassed swale | No | 35% | 20% | 20% | Low | Low |
| Restored riparian buffer | No | 60% | 30% | 35% | Med | Low |
| Infiltration devices | Possible | 85% | 30% | 35% | High | Low |
| Dry extended detention basin | Yes | 50% | 10% | 10% | Med | Med |
| Permeable pavement system | No | 0% | 0% | 0% | Low | Med |
| Rooftop runoff management | Possible | 0% | 0% | 0% | Low | Med |

## 4.5. Comparison of BMP Site Constraints

The basic nature of stormwater BMPs often places them in low-lying areas and next to existing waterways, which can put them at odds with other regulations. The designer must always be aware of other regulations when siting BMPs. A non-exhaustive list of possible environmental regulatory issues is provided below:

- Jurisdictional wetlands
- Stream channels
- 100-year floodplains
- Stream buffers
- Forest conservation areas
- Critical areas
- Endangered species

BMPs should also be sited in a manner that avoids the following types of infrastructure:

- Utilities
- Roads

- Structures
- Septic drain fields
- Wells

A BMP will not work unless it is sited appropriately. It is very important to visit the site and obtain information about the size of the drainage area, soils and slopes as well as depth to groundwater table and bedrock.

The various site considerations for siting BMPs is presented in Table 4-2 below. Each of these considerations is discussed below.

The **size of drainage area** is a primary consideration in selecting a BMP. Some BMPs will only work with drainage area that is sufficient to provide a permanent pool of water. Other BMPs, such as bioretention areas and sand filters, are specifically designed to handle smaller flows and could easily become overwhelmed if sited at the outlet of a large drainage area.

The **space required** for a BMP is another important consideration, particularly if the site does not have a lot of space to accommodate a BMP. It is important to note, however, that some of the BMPs that require a small space are relatively expensive (i.e., sand filter) or do not have high treatment capabilities (i.e., grassed swale).

The **head required** (elevation difference) will also affect the BMP selected. In areas of low relief excavations are often required for basins, which can be expensive. In addition, some devices require several feet of hydraulic head, which may not be available in low relief areas.

**Steep slopes** will affect the BMP selection process. Larger BMPs, such as wet detention basins and extended detention wetlands, may not fit well on a site where there is not a relatively flat area to site them or result in an impractically large embankment height. Also, steep slopes may create excessive water velocities for some systems (e.g.: filter strips, swales, restored riparian buffer). When an entire site has steep slopes, it may be best to provide a number of smaller BMPs that can fit into the existing contours of the site.

A **shallow water table** can limit some types of BMP systems. For example, bioretention areas require a minimum depth to groundwater of two feet; otherwise, the bioretention area will actually function as a stormwater wetland.

A **shallow depth to bedrock** can greatly limit BMP options. Shallow bedrock can restrict the use of infiltration systems, prevent the excavation of basins, and limit the hydraulic functions of certain BMPs. The BMP options in this scenario may be limited to filter strips, restored riparian buffers and rooftop runoff management.

**High sediment** input can limit the longevity of certain BMPs, especially sand filters, bioretention, infiltration systems, stormwater wetlands, and permeable pavement. These BMPs should not be placed in locations where high sediment loads are expected upstream in the future (typically from future development). Alternatively, high sediment loads that might adversely affect BMPs can be overcome by providing filter strips and sediment basins in upgradient areas.

**Poorly drained soils** are another BMP siting consideration. For example, poorly drained soils may exclude the use of any system relying on infiltration, such as bioretention areas without an underdrain (However, this problem can be corrected with the use of an underdrain.) Poorly drained soils may be very well suited, however, for BMPs that retain water, such as a wet detention basin or a stormwater wetland.

**Table 4-2**
Possible Siting Constraints for BMPs

| BMP | Size of Drainage Area | Space Required | Head Required | Works with Steep Slopes? | Works with Shallow Water Table? | Works with Shallow Depth to Bedrock? | Works with High Sediment Input? | Works with Poorly Drained Soils? |
|---|---|---|---|---|---|---|---|---|
| Bioretention | S | High | Med | Y | N | N | N | Y |
| Stormwater wetlands | S-L | High | Med | N | Y | N | Y | Y |
| Wet detention basin | M-L | High | High | N | Y | N | Y | Y |
| Sand filter | S | Low | Med | Y | N | N | N | Y |
| Filter strip | S | Med | Low | N | Y | Y | N | Y |
| Grassed swale | S | Low | Med | Y | Y | N | N | Y |
| Restored riparian buffer | S-M | Med | Low | N | Y | Y | N | Y |
| Infiltration devices | S-M | High | Low | N | N | N | N | N |
| Dry extended detention basin | S-L | Med | High | N | N | N | Y | Y |
| Permeable pavement system | S-M | N/A | Low | N | N | N | N | Y |
| Rooftop runoff management | S | High | Low | Y | Y | Y | Y | Y |

## 4.6. Comparison of BMP Costs and Community Acceptance

Construction costs and operation and maintenance efforts for each of the BMPs are listed in Table 4-3. However, it is important to note that some of the lowest cost or lowest maintenance level BMPs also have some of the lowest treatment capabilities. Using low-cost BMPs could result in a need for additional BMPs to achieve the requirements, thereby increasing costs and maintenance requirements. In addition, several of the lowest cost BMPs may be difficult to integrate into the natural features of a site or may be the least desirable from an aesthetic or safety point of view. Often, a slightly more expensive or maintenance intensive BMP may be a better choice for overall site design.

Sometimes community and environmental factors seem like the least important, but they can actually have a big impact on the public perception and acceptance of a site development. For instance, a prospective homeowner may think twice before buying a lot or home bordering a large, fenced-in dry extended detention basin with a large corrugated metal riser pipe and occasional mosquito outbreaks after storms. However, if the BMP were designed as a bioretention device or stormwater wetland served as an aesthetic amenity on the site, possibly with birds, frogs, and fish. Table 4-3 provides information on each BMP's safety concerns, community acceptance, and wildlife habitat.

**Table 4-3**

Cost, Community and Environmental Issues for BMPs

| | Construction Cost | Maintenance Level | Safety Concerns | Community Acceptance | Wildlife Habitat |
|---|---|---|---|---|---|
| Bioretention | Med-High | Med-High | N | Med-High | Med |
| Stormwater wetlands | Med | Med | Y | Med | High |
| Wet detention basin | Med | Med | Y | Med | Med |
| Sand filter | High | High | N | Med | Low |
| Filter strip | Low | Low | N | High | Med |
| Grassed swale | Low | Low | N | High | Low |
| Restored riparian buffer | Med | Low | N | High | Med-High |
| Infiltration devices | Med-High | Med | N | Med-High | Low |
| Dry extended detention basin | Low | Low-Med | Y | Med | Low |
| Permeable pavement system | High | Low-Med | N | Med | N/A |
| Rooftop runoff management | High | Med | N | High | Low |

September 28, 2007 Changes:

1. 4.5: Deleted a reference to "pocket wetland". Pocket wetlands are not addressed in the 2007 manual.
2. 4.5: Deleted the list of BMPs with minimum drainage areas. It was inaccurate.
3. Table 4-1: Corrected the bioretention TN removal efficiency from 40% to 35%.

# 5. Common BMP Design Elements

There are many elements of BMP design that are common to most BMP types. Those elements are presented here rather than repeated multiple times in the individual BMP design sections. In addition, the discussion of the design elements covered in this section is not intended to be exhaustive, nor a complete design manual. Many of the subjects (soils, impoundments, etc.) are too complicated or site-specific to cover completely in this document, so the design professional is relied upon to make the correct design choices.

## 5.1 Stone and Landscape Construction Materials

### 5.1.1 Aggregates

Aggregate is natural or manufactured hard, durable, uncoated, inert particles, reasonably free from deleterious substances. Substances such as reactive chert, gypsum, iron sulfide, or amorphous silica are considered deleterious because they reduce the durability of the materials. Fine aggregates are essentially sand materials and coarse aggregates are essentially stone or gravel. Section 1005 of the NCDOT specifications provides grain sizes and durability specifications for several grades of coarse and fine aggregates. Aggregates can be used to increase permeability of soil media, or can be the sole media in a BMP, depending on the situation.

### 5.1.2 Rock Lining (Riprap)

Rock lining or riprap is a constructed layer or facing of stone placed to prevent erosion, scour, or sloughing of an earthen structure or embankment. The term "riprap" also is frequently defined as the stone used to construct such a lining.

Riprap is a special class of very large aggregate. Riprap gradations range in diameter from 2 to 42 inches. Because riprap is typically subject to significant energy, it is important that it be sound and free from defects or entrained substances such as soil shale or organic materials.

The resistance of riprap to displacement by moving water is a function of the weight, size, and shape of the stone; the geometry of the channel or bank it is protecting; the velocity of the water; the magnitude of wave energy; and the filter blanket over which the riprap is placed.

Section 1042 of the NCDOT specifications gives the size, gradation, and durability specifications for several grades of riprap.

### 5.1.3 Gabion Systems

Wire-enclosed riprap or gabion systems consist of mats or baskets fabricated from wire mesh, filled with small riprap, and stacked or anchored to a slope. Wrapping the riprap allows smaller riprap to be used for the same resistance to displacement by water energy as larger unwrapped riprap. This is particularly advantageous when constructing rock lining in areas inaccessible to trucks or large construction equipment. The wire baskets also allow steeper (to nearly vertical) channel linings to be constructed.

Gabion baskets or mattresses can be constructed from commercially available wire units or from available wire fencing material. Suppliers of prefabricated gabions generally provide extensive criteria for using their products. If prefabricated systems are used, manufacturers' guidelines must be followed. If gabions are to be constructed on-site, the designer should reference USDOT HEC 11 (1989).

The life of a gabion structure depends on the mesh material, the durability of the stone, the stability of the infill material, and the exposure conditions on site. For example, coated, galvanized steel wire resists chemical attack typical of earth retaining structures. The durability will also be affected by scour effects in streams. Specific durability information should be obtained from the manufacturer.

### 5.1.4 Landscaping Blocks

Landscaping blocks are typically cast of concrete and come in varying sizes, shapes, colors, and appearances. Small, decorative landscaping blocks are often used to enhance aesthetics and provide minor slope control on BMPs that might be located in high pedestrian traffic areas. Larger landscaping blocks can be used to provide significant landscape elevation differences (large soil retaining walls), or to provide a vertical or near vertical water/soil interface with erosion control, similar to what rip-rap or gabions can provide (e.g. bulkheads). These larger types of applications might require extensive use of manufacturer's recommendations and use of licensed design professionals and installers.

## 5.2 Geosynthetics

It is often the case that the soils located on the site will not fulfill all the necessary functions a BMP design may require. The use of geosynthetics can often supplement, enhance, or replace certain natural materials in a BMP design. Construction materials consisting of synthetic components made for use with or within earth materials generally are referred to as geosynthetics. Because these products are highly variable in both material and geometry, it is difficult to develop design guidelines applicable to all systems. The manufacturer's project-specific design criteria should be followed and documented for each specific application. The following paragraphs discuss the four main categories of geosynthetics: Geotextiles, Geomembranes, Geonets/Geocomposites, and Geocells.

Geotextiles are the most common geosynthetics and consist of woven or non-woven fabric made from polymeric materials, such as polyester or polypropylene, or from natural fibers, such as coir (coconut hull fibers). Four main uses for geotextiles include stabilization, separation, filtration, and in-plane drainage. It should be noted, however, that geotextiles often provide many of the functions listed above at the same time, whether intended or not. Geotextiles primarily used for stabilization to protect soils and seeds from erosion are often referred to as "rolled erosion control products" and can be temporary or permanent (bio- and/or photo-degradation specifications are important). Geotextiles providing separation capabilities are placed between dissimilar materials to prevent migration of one of the materials into the other, or to discourage undesirable root growth into underlying drain systems. Geotextiles providing filtration would typically prevent the movement of fine particles from soil through which seepage occurs. And finally, certain types of geotextiles, in particular thick-needle punched non-woven geotextiles, have sufficient in-plane flow capacity for use as flow conduits in certain applications.

Geomembranes are continuous polymeric sheets that are, for all practical purposes, impermeable. There are many varieties of geomembranes in use today; however, the most frequently used geomembranes for ground applications are thermoplastic products manufactured from high-density polyethylene (HDPE) and polyvinyl chloride (PVC). Different types of geomembranes have significantly different properties, including strength, longevity, resistance to ultraviolet light, thermal expansion and contraction, chemical resistance, and ease of installation. The most appropriate geomembrane to use for a given application is dependent on the application and the environment to which the geomembrane will be exposed.

Geocomposites consist of a combination of geosynthetic components. Geocomposites used in BMP applications are usually sheet- or edge-drains consisting of a prefabricated core to which a geotextile filter is bonded. The core provides void space through which water can flow in-plane while the geotextile filter keeps soil from filling the voids created by the core. Geocomposite sheet drains are available that allow flow in from one or both faces. Geonets are a type of geosynthetic that consists of a continuous extrusion of polymeric ribs. The ribs themselves form void space through which in-plane flow capacity is provided. Geonets are available with or without bonded geotextile filters. Geonets with bonded geotextile filters are sometimes referred to as composite drainage nets (CDNs).

Geocells are three-dimensional prefabricated polymeric systems ranging from 4 to 8 inches high. The geocell systems are collapsed for delivery to the site. Upon arrival at a site, they are spread open and filled to form a three-dimensional reinforced mattress. Originally developed to rapidly stabilize soft subgrades for mobilization of large equipment, they are now frequently used for protection and stabilization of steep slope surfaces and protective linings for channels. Because use of geocells for slope stabilization applications is relatively new, there is little available design guidance beyond that available from the manufacturers.

## 5.3. Flow Splitters

BMPs can either be placed on-line or off-line. An on-line BMP will receive all stormwater flows regardless of the intensity, with the flows beyond the design volume typically passing over an overflow of some type. An off-line BMP is one that typically has a flow splitter of some sort prior to the BMP, which will divert the design volume flows to the BMP and bypass a certain volume of excess flows around the BMP. For most BMPs it is advantageous to install a flow splitter prior to the BMP to bypass stormwater in excess of the design volume around the BMP. This will help minimize resuspension of sediment, hydraulic overload, and/or excessive erosion of the BMP.

Flow splitters must be designed to send all of the flow from every rainfall event into the BMP until the BMP design volume (based on the specific stormwater program requirements) has been reached, at which point the flow splitter may start diverting a portion or all of the additional flow around the BMP. The diverted flow may be routed to an additional BMP (if necessary as part of the overall stormwater plan for the site), or it may be discharged to the receiving waters.

Flow splitters are most often and most simply designed as a weir overflow device placed in a manhole or vault as shown in Figures 5-1, 5-2, and 5-3. The elevation of the overflow weir is most often set at the design volume elevation of the BMP. That will allow all flows less than and up to the design volume to enter the BMP, and the flows over the design volume will split, with a portion being bypassed and a portion being sent to the BMP.

It should be noted that the recommended design of the flow splitter will cause water levels in the BMP to exceed the design volume elevation (see Figure 5-3). This should be accounted for in the design of the BMP structure. The height of the water level increase in the BMP above the design volume elevation is mostly a factor of the bypass flow capacity in the flow splitter device. Ideally, a very wide weir would be used to maximize the flow rate and minimize the head over the weir during bypass, but that also increases the size of the bypass structure. Often a balance is struck between flow splitter design and BMP storage design to best fit the specific situation.

It should also be noted that the recommended design of the flow splitter has the potential to cause a flow reversal and drain a certain volume of the BMP (the volume above the design volume elevation). This occurs if influent flows drop the water level in the flow splitter faster than the outlet drops the water level in the BMP (see Figure 5-3). This is best minimized by designing a wide weir and minimizing the head over the weir as discussed above.

There are many other flow splitter designs available, many of which involve various piping arrangements utilizing upturned overflow pipes and orifices. Although most of these do provide flow splitting functions, they may not meet the requirements of capturing the first 1 inch or 1.5 inches of runoff, or mitigating the peak flow rates that are required in many of the stormwater programs. If a flow splitting device other than that discussed above is proposed, the design professional must prove convincingly that the flow splitting scenarios for all stormwater situations will properly meet the stormwater program requirements.

The hydraulics of the flow splitter and outflow pipes in the flow splitter are particularly important. The outfall pipe to the BMP must be sized so that it will not hydraulically limit the flows of a high intensity storm into the BMP and cause stormwater to prematurely overflow into the bypass before the stormwater capture or peak flow mitigation volumes have been sent to the BMP. Additionally, the flow splitter weir and the outfall for the bypass must be able to hydraulically handle the entire design flow capacity of the upstream conveyance system, not just the design storm of the BMP, otherwise the flow splitter device could hydraulically fail (overflow) during storm events greater than the BMP design storm.

Materials in the flow splitter device shall be corrosion resistant, such as concrete, aluminum, stainless steel, or plastic. Painted, zinc coated, and galvanized metal materials shall not be used due to their corrosion potential (poor longevity) and possible aquatic toxicity impacts.

**Figure 5-1**
Flow Splitter in a Vault
(Adapted from, Minnesota Urban Small Sites BMP Manual, 2001)

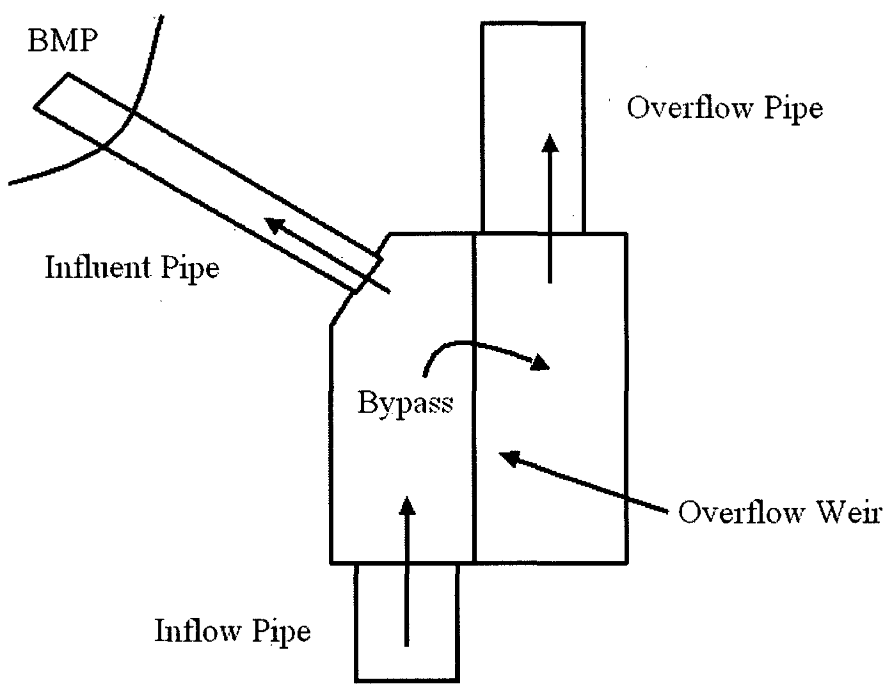
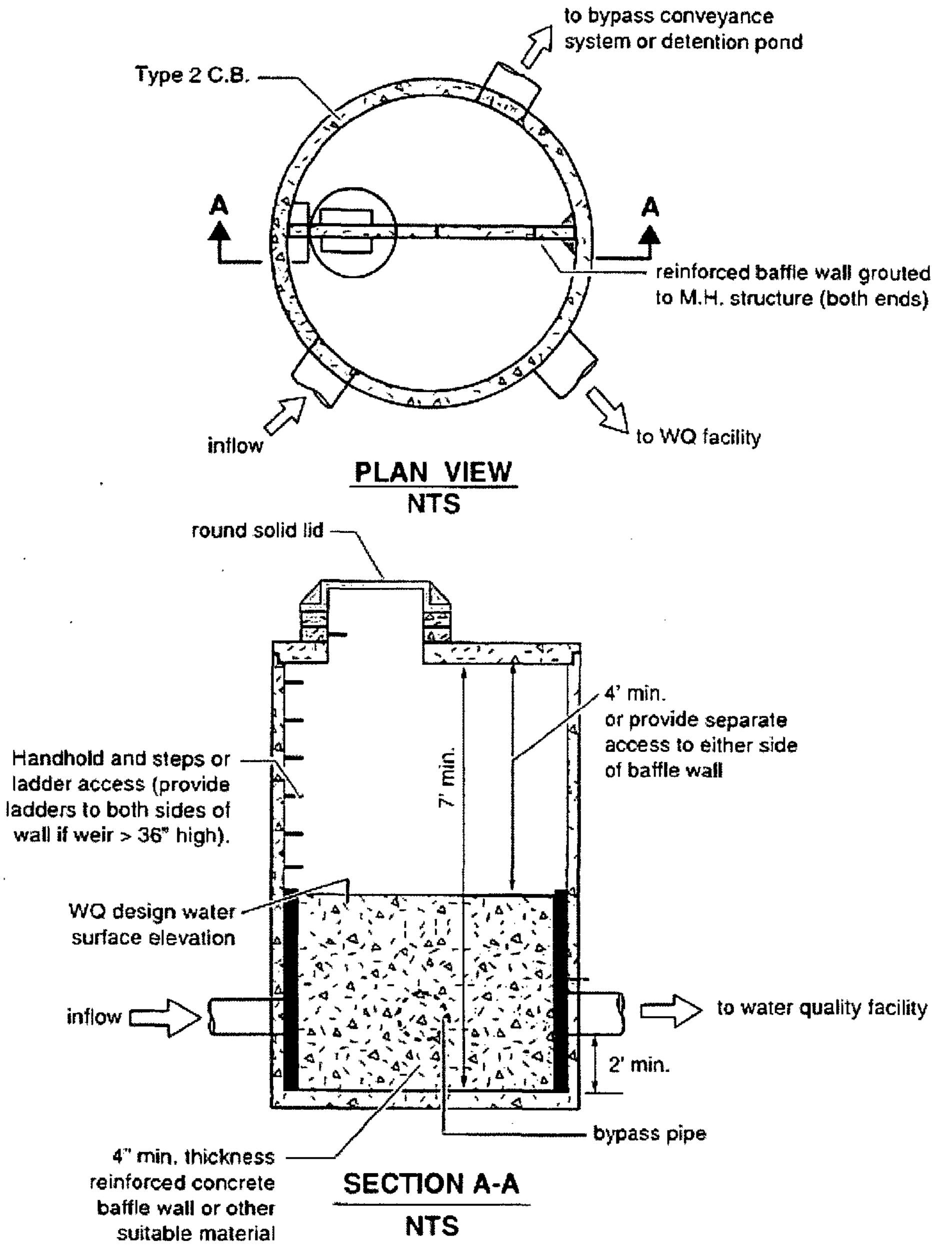
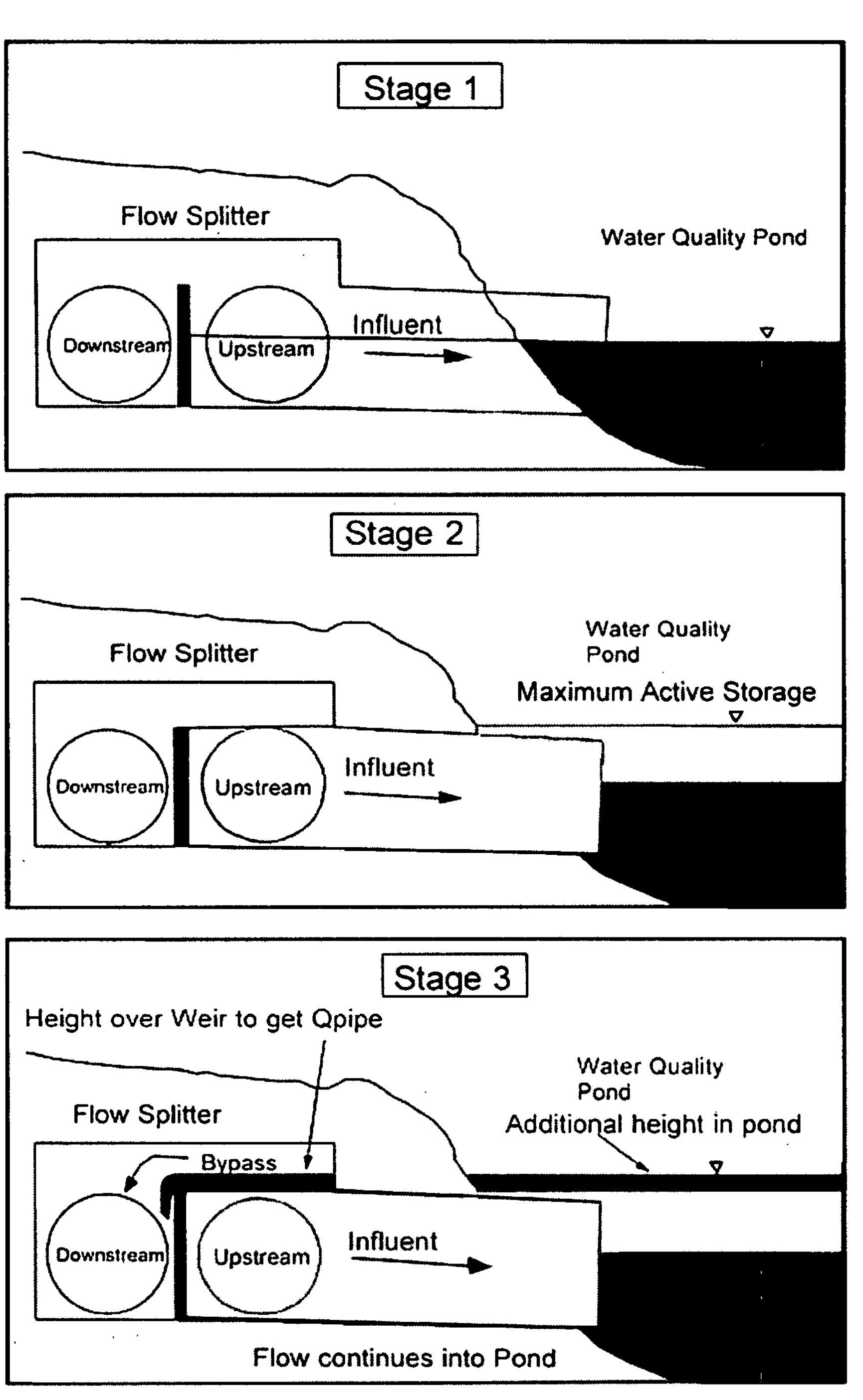


**Figure 5-2**
Flow splitter in Manhole
(Minnesota Urban Small Sites BMP Manual, 2001)




**Note:** The water quality discharge pipe may require an orifice plate be installed on the outlet to control the height of the design water surface (weir height). The design water surface should be set to provide a minimun headwater/diameter ratio of 2.0 on the outlet pipe.

**Figure 5-3**
Water Level Progression in BMP with Flow Splitter
(Minnesota Urban Small Sites BMP Manual, 2001)



## 5.4 Curb Diversion Devices

Curb diversion devices can be used to divert flow from curb-and-gutter type pervious surfaces such as roads and parking lots to a variety of BMPs (e.g. grassed swales, filter strips, restored riparian buffer, bioretention, sand filter, etc.). The use of a curb diversion device can avoid the installation of a piped stormwater collection system, however, it does not guarantee sheet flow or proper flow quantity diversion. This section simply provides information to assist in their design where their use may be beneficial to the overall stormwater management goals.

The stormwater is diverted to the BMP through the use of inlet deflector blocks, which have ridges to help channel the runoff. The gutter and diversion block should meet the guidelines set forth by the relevant local permitting authority. If placed before a BMP other than a natural conveyance type, a 5-foot wide grassed buffer between the diversion device and the BMP is required, unless a forebay or other sediment removal device is required to be placed before the particular BMP (in which case the 5-foot wide grassed buffer does not qualify). This small grassed buffer serves as pretreatment and reduces the possibility of drainage seeping under the pavement section and creating "frost heave" during winter months. The flow diversion method shown is for conceptual purposes and may not meet the volume attainment requirements.

## 5.5 Forebays

A forebay is a settling basin near an inlet of a BMP to dissipate the energy of the incoming stormwater and to settle out the larger incoming sediment particles. With heavy, coarse sediment confined to the forebay area, maintenance is made simpler and less costly and the life of the BMP is extended. A forebay is required for particular BMPs and is optional for others; however, in no case does the use of a forebay provide additional credits towards pollutant removal rates.

One of the main benefits of the forebay is to collect a majority of the volume of sediment in a small area that is specifically designed for easy sediment removal. Sediment removal frequency from the BMP will likely be every 3-5 years for BMPs without forebays, as opposed to every 15-25 years for some BMPs with forebays. Due to the ease of removal of sediment from the forebay, the overall cost should be less over the same period by installing a forebay. In addition, having a forebay with more frequent cleanout makes it is easier for sediment removal to be more of an ongoing operation and maintenance cost that is properly funded rather than a surprise capital expense that was not accounted for.

Sediment forebays shall have direct access provided for appropriate maintenance equipment. The designer of the BMP should consider if a hardened surface (gravel, open concrete pavers, etc.) should be incorporated into the aesthetic design for the access point and a staging pad next to the forebay. This would reduce erosion and vegetation disturbance during sediment removal operations. In addition, the bottom of the forebay should be made of hardened material, if compatible with the design. A forebay that will be permanently submerged could have a solid concrete bottom, and one that is exposed could have open concrete pavers that allow grasses or other small vegetation to grow in the openings.

A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time. In general, sediment shall be removed when 25% of the volume of the forebay is taken up by sediment (this percentage should be converted to a depth which is noted in the maintenance logs and indicated on the sediment depth marker). In wet pond forebay specifications, sediment is to be removed when the one foot additional sediment storage depth is exhausted.

Some sort of separation structure must be provided to separate the forebay from the main body of the BMP. That structure can be an earthen or rip-rap berm, or a wall made of concrete or a gabion system. The forebay could be set at a higher elevation than the main BMP and the separation structure could therefore be set several feet above the design storm water level of the BMP and operate as an overflow structure to the BMP. The elevation of the separation structure can also be as low as (but not to exceed) 1 foot below the design storm water elevation. Regardless of the relative elevation of the separation structure, the water flowing over (and possibly through) it must be at a non-erosive velocity, preferably by designing the entire overflow structure at a single elevation to act as one large weir.

Use of a vegetated shelf is recommended, especially if a vegetated shelf is utilized in the main BMP structure. This shelf will not only increase safety, but it also benefits water quality, and discourages non-migratory Canada geese from establishing.

If the BMP has a volume of permanent water that is required as part of the design for proper treatment, any permanent volume of water within the forebay can be included as part of the overall treatment volume required. If the BMP is required to have storage volume for capturing stormwater during a storm event, any dry storage volume within the forebay that will fill and empty with the storm similar to the main body of the BMP, may be included in the overall storage volume to meet the requirements.

Forebay volume shall be approximately 20% of the total required storage volume (unless noted otherwise in a specific BMP design section). This leaves about 80% of the design volume in the main basin. Multiple inlets may require additional forebay volume (or additional forebays). The depth of a forebay shall be approximately 3 feet, with a deeper section on the inlet side in order to dissipate hydraulic energy entering the forebay.

## 5.6. Earthen Impoundments, Embankments and Dams

Many BMPs will involve construction of some volume of water storage for water treatment and/or water quantity control. The most common type of storage facility is the earthen impoundment. These structures sometimes are simply dug out of existing soil and are below grade, but others involve fill material and dams.

This document only discusses some general considerations when utilizing earthen impoundments in BMPs and does not cover earthen embankment or dam design. A licensed design professional should make sure any impoundments, embankments and/or dams designed as part of a BMP meet any applicable requirements of the dam safety regulations found in 15A 2K Section .0100 through .0500. These rules include detailed information on dam classification (i.e., low, medium and high hazard dams), design information, and review and approval requirements. Water detention basins that meet one or more of the following criteria may be regulated as dams by DENR, Division of Land Resources (DLR):

- Have a high hazard potential, or
- Embankments higher than 15 feet, measured from the highest point on the top of the dam to the lowest point on the downstream toe; and
- Impounded volumes more than 10 acre-feet of runoff to the top of the dam.

Many factors must be taken into consideration when designing an earthen impoundment utilizing embankments and/or dams, including: foundation preparation and treatment, control of seepage, embankment stability, subsidence/settlement, piping, and maintenance. The following points include some specific information to incorporate in the design of impoundments utilizing embankments and/or dams:

- A maximum slope of 3H:1V shall be used on the embankments to allow maintenance equipment and to maintain ground cover. If site conditions require steeper slopes on one side of the basin, slope stability techniques should be used to ensure long-term stability of the slope.
- The height of an embankment dam must consider freeboard and compensation for settlement. The basin's freeboard shall be a minimum of 1 foot above the elevation of the highest stage calculated based on the 100-year storm.
- Pipes and other conduits through the embankment should be avoided if at all possible. If a penetration is necessary through the embankment (typically for the outlet device) then seepage should be minimized through the use of anti-seep collars or filter and drainage diaphragms.
- A grass surface is preferred unless frequent vehicle traffic or foot travel is expected, in which case gravel, modular paving block, or similar surface should be installed to prevent erosion and rutting. If vegetation is used to stabilize the embankment, proper maintenance, including mowing, fertilizing, and reseeding bare-spots, is required to prevent erosion. Other maintenance items are discussed in Section 6.0 BMP Maintenance as well as individual BMP design sections.
- Embankment dams should be nonlinear where possible for aesthetic reasons. Concave embankments are inherently more stable than convex alignments.
- When an impoundment is located in karst topography, gravelly sands, or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options can include: 6 to 12 inches of clay soil (minimum 15 percent passing the #200 sieve and a maximum permeability of $1 \times 10^{-5}$ cm/sec), a 30 mil poly-liner, or a bentonite liner.

## 5.7. Underdrain Systems

Underdrain systems are utilized in several BMP designs, and can have many different configurations. All piping within the underdrain system shall have a minimum slope of 0.5 percent and shall be constructed of Schedule 40 or SDR 35 smooth wall PVC pipe. The underdrain pipes shall be designed to carry 2-10 times the maximum flow exfiltrating from the BMP medium. Choose a value within this range to reflect the expected stability of the drainage area. This maximum flow is computed from Darcy's law and assuming maximum ponding and complete saturation along the depth of the medium. Manning's formula is then used to size the pipe. The minimum size of pipe shall be 4-inch diameter. The spacing of collection laterals shall be no greater than 10 feet center to center, and a minimum of two pipes should be installed to allow for redundancy (Hunt and White, 2001). A minimum of 4 rows of perforations shall be provided around the diameter of the pipe (more for pipes 10 inches in diameter and larger), and the perforations shall be placed 6 inches on center within each row for the entire length of the drainage lateral. Perforations shall be 3/8-inch in diameter.

The underdrain pipes shall have a minimum of 3 inches of washed #57 stone above and on each side of the pipe (stone is not required below the pipe). Above the stone, either filter fabric or two inches of choking stone is required to protect the underdrain from blockage. Avoid filter fabric if there is any question about the future stability of the drainage area. Above the filtering device, a minimum of 2 inches of washed sand shall be installed.

The number of pipes needed for the underdrain system is determined using the following 4-step process.

1. Determine flow rate through the soil media and apply a safety factor of 10 (this is now the underdrain design flow, Q).
2. Use the following equation: Use the following equation: $D = \left(\frac{16 * Q * n}{S^{0.5}}\right)^{\left(\frac{3}{8}\right)}$

   Where D = Diameter of single pipe, n = roughness factor (recommended to be 0.011), s = internal slope (recommended to be 0.5%). Units: Q (cfs), D (in).
3. The only unknown is D. This is the diameter of a single pipe that could carry all the water were it to be the only underdrain. Pipe diameters are typically either 4 inches or 6 inches. Table 5-1 below converts "D" (in inches) to an equal number of 4 or 6 inch underdrains at 0.5% slope.

**Table 5-1**
Number of Pipes Required in the Underdrain

| If D is less than | # of 4" pipes | If D is less than | # of 6" pipes |
|---|---|---|---|
| 5.13 | 2 | 7.84 | 2 |
| 5.95 | 3 | 9.11 | 3 |
| 6.66 | 4 | 10.13 | 4 |
| 7.22 | 5 | | |
| 7.75 | 6 | | |
| 8.20 | 7 | | |

## 5.8 Outlets

Outlets of BMPs are the devices that control the flow of stormwater out of the BMP to the conveyance system (stormwater pipe, natural drainageway, etc.). While most of the water quality treatment takes place within the BMP, the outlet design is often integral to treatment efficiency, as well as being a critical factor in stormwater volume control. Water quality is affected by how quickly the water is removed from the treatment unit, thereby affecting sedimentation time and possibly causing resuspension of particles. The depth from which the water is drawn also affects water quality, since the water is typically cleaner the higher it is in the water column. Finally, the design of the outlet is also the main means of controlling peak flow volumes and rates. Outlet designs are specific for each BMP depending on the goals to be achieved. The following sections will discuss many of the most common outlet designs. Hydraulic calculations for outlets types as well as storage and drawdowns are provided in Section 3.0 Stormwater Management and Calculations.

It should be noted that floatation issues should be considered with any structure (outlet box, riser, etc.) placed within a BMP.

### 5.8.1 Outlet Boxes

Outlet boxes typically consist of a cast in place or precast concrete structure, with a free-flowing weir providing the water control mechanism. They are typically employed on smaller BMPs with lower flow volumes. The weirs can be made of various materials (wood, metal, concrete, etc.), and there are several standard weir shapes, with rectangular and v-notch being the most common. Each weir has a formula for calculating the flow over the weir based on the height of the water column and shape of the weir. A rectangular weir releases a relatively linearly increasing flow volume as the level of water in the BMP rises. A v-notch weir releases a relatively exponentially increasing flow volume as the level of water in the BMP rises. V-notch weirs allow more accurate flow measurement and control at lower flows, but sometimes cannot handle peak storm events. There are also "compound" weir designs, which incorporate aspects of different weir designs to achieve specific results. For instance, a compound weir might have a small v-notch in the lowest portion to provide lower release rates for smaller storm events, and a large rectangular weir at the top to provide larger release rates for the larger storm events.

### 5.8.2 Drop Inlets

Drop inlets are common outlet devices for wet and dry extended detention basins, as well as stormwater wetlands and bioretention facilities. The purpose of drop inlets is to allow the rapid release of water once the lip of the outlet is attained. Drop inlets are not as effective at providing runoff peak attenuation. In general, BMPs with drop inlets also incorporate a lower level outlet or an outlet designed to achieve specific attenuation objectives (see Section 5.6.4 Multiple Outlets below).

Drop inlets usually consist of a riser structure in the reservoir area connected to a pipe or box culvert (outlet conduit) that extends through the dam embankment. Drop inlets should be designed to operate as weirs. To maintain weir type conditions, the head over the inlet should not exceed 33% of the inlet riser diameter. At greater heads, the flow may become unstable as it approaches the transition to orifice flow, leading to surging, noise, vibration, or vortex action. In addition, downstream conditions, full flow conditions in the pipe, or other factors can result in complicated hydraulics that may cause excessive surging, noise, or vibration during operation. A full hydraulic analysis of the entire drop inlet system showing the controlling factors at all flow regimes is recommended to ensure proper operation.

### 5.8.3 Perforated Riser

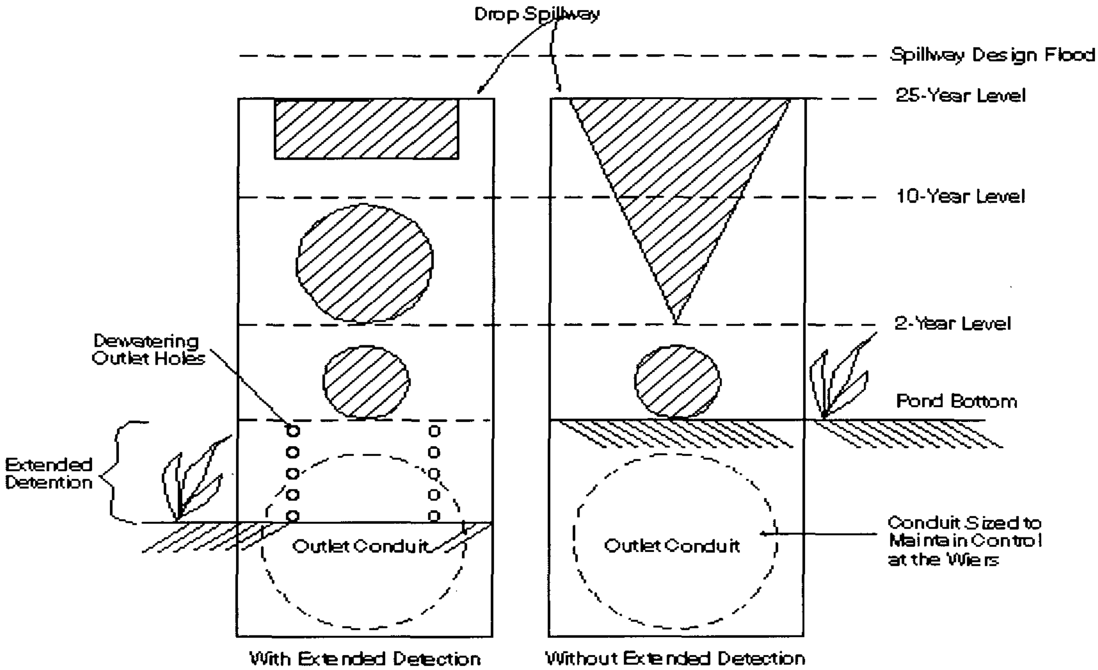
Another common outlet type for relatively small BMPs is a vertical riser with one or more columns of perforations. It is typically constructed out of plastic pipe (PVC, HDPE, etc.). The objective of providing an array of small orifices, instead of a single orifice, is to reduce the velocity of currents near the outlet. Perforations larger than 1-inch diameter are not recommended.

Perforated risers have the disadvantage that the outlet rates are greatest early in a storm event when most of the entrained sediment is still suspended. Perforated risers also draw most of the discharged water from the deepest portions of the basins where the highest concentration of suspended sediments occur.

### 5.8.4 Multiple Outlets

Multiple outlets are used to achieve specific runoff peak attenuation goals. In general, runoff peak control is required for several storm magnitudes. Outlets are arranged to provide the required attenuation while minimizing the overall size of the basin. Multiple outlets frequently combine a number of different control devices, including orifices, rectangular and V-notch weirs, and drop inlets (see Figure 5-4). Flow curves for the various outlets at different water elevations are simply superimposed to provide the overall discharge rate.

**Figure 5-4**
Approaches to Multi-Outlet Design

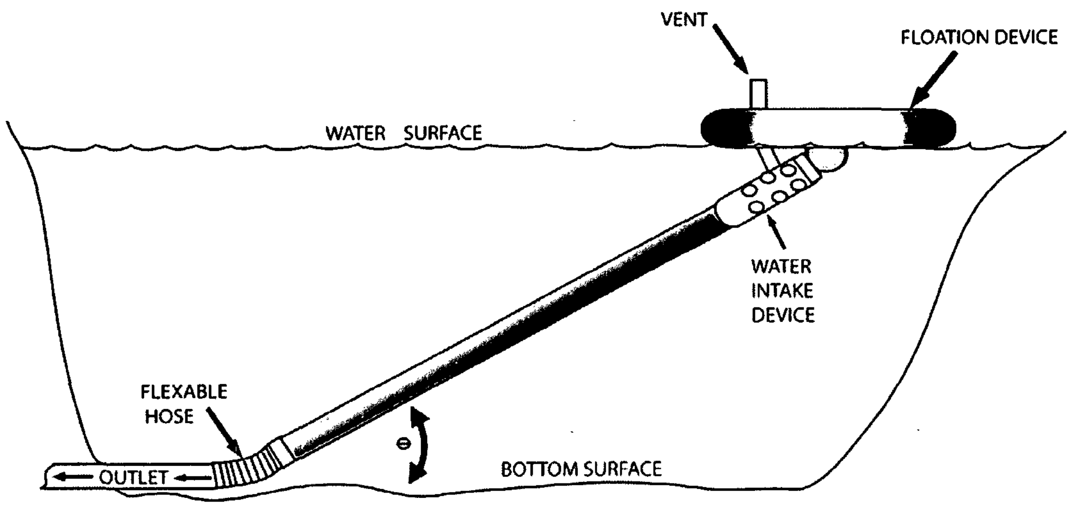



### 5.8.5 Skimmers

Skimmer-type dewatering devices (see Figure 5-5) provide constant volume release rates regardless of water level, and collect water from the surface of a ponded area and therefore do not draw sediment-laden water from the submerged volume of the basin. Water near the surface has the lowest concentration of suspended sediment. Furthermore, for a specified dewatering period, the discharge rate for skimmers compared to perforated risers is significantly lower during the critical time when turbulence is greatest and large quantities of sediment are in suspension.

Tests of skimmers show reductions of up to 45 percent in the mass of sediment discharged from sediment basins with skimmers compared to conventional perforated risers (Millen et al., 1996). However, they are mechanically more complex than most outlet types and require frequent inspection and maintenance to operate as designed.

**Figure 5-5**
Schematic Drawing of a Skimmer




### 5.8.6 Spillways

A spillway is merely a section of the embankment/impoundment that is designed to allow the water exiting a BMP to spill over that portion of the embankment. Spillways can be lined with grass, rip-rap, concrete, or other such materials. Manning's coefficient should be carefully selected to accurately depict the conditions and type of spillway lining. Uniform flow may be assumed in the exit channel when the flow is subcritical; however, the assumption is less accurate when the channel slope approaches or exceeds 10 percent. If the permissible velocity for grass cover will be exceeded, the spillway section can be reinforced using turf-reinforcing geotextiles. Unit tractive force or permissible velocity design criteria for reinforcing systems must be obtained from the geotextile vendor. Riprap emergency spillways may be considered when design velocities exceed those that are acceptable for vegetated emergency spillways. Tractive force analysis should be used when designing Riprap spillways. Riprap spillways are recommended on berms constructed of fill material. Spillways are commonly used as emergency overflow devices.

### 5.8.7 Emergency Overflow

All BMPs that incorporate some sort of water impoundment not only need the primary outlet structure, but also are required to have an emergency overflow for large storm events and/or in case of primary outlet structure failure so that the embankment/impoundment will not be compromised by high water levels. An emergency overflow separate from the principal outlet is advisable, however, in some cases that may be impractical. In these instances, a combined principal-emergency outlet may be considered. A combined principal-emergency outlet is a single outlet structure that conveys both low flows (e.g., stormwater management functions) and extreme flows. A primary design consideration for a combined principal-emergency outlet, particularly when in the form of drop inlet structures, is protection against clogging. Trash racks should be designed as described below. When a combined principal-emergency outlet is proposed, then the emergency outlet portion should be designed as if no additional storage is available and as if all normally operating weirs, ports and/or orifices are inoperative or clogged.

### 5.8.8 Trash Racks

Most outlets are subject to some degree of trash and debris from incoming flows, and certain outlets are more susceptible to clogging than others. Before a debris control structure is designed, the anticipated debris problem should be analyzed. The type and quantity of debris are determined primarily by upstream land use, soil erodibility, watershed size, and the type of stormwater management facility.

Trash racks to serve drop inlets should be designed to provide positive protection against clogging of the outlet under any operating level. The average velocity of flow through a clean trash rack should not exceed 2.5 fps during peak design flow. Velocity can be computed on the basis of the net area of opening through that part of the rack receiving the flow. The same criteria should apply to ports or openings along the side of a riser structure. The clear distance between bars generally should not be less than 2 inches; however, one exception to this may be near the apex of the trash rack. Bar spacing should be no greater than one-half of the minimum conduit dimension in the drop inlet, with an absolute maximum of 5.5 inches to discourage child access.

In some cases, debris-control devices may be required for low-level intakes at the basin bottom. In these situations, debris control structures such as those discussed in the FHWA publication "Debris Control Structures" (HEC 9) (USDOT, 1971) should be considered where appropriate.

### 5.8.9. Anti-Vortex Devices

All closed-conduit outlets designed for pressure flow should have adequate anti-vortex devices. Anti-vortex devices may take the form of a baffle or plate set on top of a riser, or a headwall set on one side of a riser. The SCS two-way covered riser (USDOT, 1971) has very reliable anti-vortex and debris-control provisions inherent in its standard design.

### 5.8.10. Basin Drains

Basins that have permanent pools water must be designed with provisions for draining the permanent pool. This will facilitate maintenance and sediment removal. The draining mechanism usually consists of some type of valve or gate attached to the spillway structure. Basin drains should be designed with sufficient capacity so that maintenance (e.g., sediment removal) can be performed without risk of inundation from relatively common or frequent rainfall events. Therefore, drains should be sized to pass a flood having a 1-year recurrence interval with limited ponding in the reservoir area. In most cases, the drain system should be no smaller than 8 inches in diameter.

In most cases, sluice gates are preferred over "inline" type valves such as those used in water distribution systems (e.g., eccentric plug valves, knife gate valves, and gate valves). Sluice gates generally are more appropriate for passing debris-laden flow, less prone to clogging, and easier to maintain.

The basin drain should be capable of draining the basin in 24 hours. However, an uncontrolled or rapid drawdown could cause problems such as slides or sloughing of the saturated upstream slope of the embankment or shoreline area. In general, drawdown rates should not exceed 6 inches per day. For embankments or shoreline slopes of clay or silt, drawdown rates as low as 1 foot per week may be required to maintain slope stability. The Operation and Maintenance Manual should contain instructions regarding draining the basin.

Instances where basins cannot be drained by gravity are common. In particular, the permanent pool may be constructed by excavating below the adjacent grade, and/or the bottom of the basin extends below the groundwater table. In these cases, it will be necessary to dewater the basin using pumps. The pump discharge may need to be filtered prior to discharge to the receiving downstream watercourse to avoid turbidity and sediment impacts.

September 28, 2007 Changes:

1. 5.7: Changed the minimum slope in the underdrain system from 1.0% to 0.5%.
2. 5.7: Specified that the underdrain pipes shall be designed to carry 2-10 times the maximum flow leaving the BMP system, as opposed to 10 times the flow. This is based on the expected stability of the drainage area.
3. 5.7: Further specified the underdrain requirements; sand, filter fabric or choking stone, #57 stone, and underdrain pipe(s).
4. Figure 5-1: Redrew for clarification.

# 6. Landscape and Soil Composition Specifications

## 6.1. Importance of Plants and Soil Composition in BMPs

The proper design of plants and soil composition specifications is a critical aspect to the function and success of many stormwater BMPs. Plants increase pollutant removal by providing resistance to the flow of stormwater and subsequently reducing runoff velocity. Slower runoff velocities translate into more time for the functioning of pollutant removal pathways such as settling, filtering, infiltration, and adsorption (Schueler, 1996). Additional benefits from BMP plants and soils include:

- Treatment benefits such as organic carbon needed for microbial transformation processes.
- Moderation of environmental factors such as water temperature and oxygen concentrations in sediment.
- Plant roots stabilize the soil, including aggraded sediments, and remove pollutants that adhere to the sediment particles from runoff.
- Increased pollutant removal by up-take, called phytoextraction.
- Amelioration of the heat island effect.

The soil composition of many stormwater BMPs also is vital to their relative success or failure in achieving their intended purpose. Soil specifications can vary according to the design objectives (e.g., nutrient removal), as well as *in situ* topsoil composition. Properly designed soil media aids in infiltration and natural detention as well as plant health. The use of soil amendments can help prevent or minimize adverse stormwater impacts during construction, and are used along with vegetation as a permanent runoff treatment BMP.

In addition, cost savings are realized if the stormwater BMP facility is part of an integrated stormwater landscape. The benefits of this approach include:

- Reduced construction costs.
- Combined maintenance with other landscape portions of the development.
- Aesthetic benefits.
- Greater likelihood of maintaining long-term functionality.

## 6.2. Hydrologic Zones and Plant Selection

The interplay between plants, hydrology, and soil composition are vital to the function of particular stormwater BMPs. Therefore, it is essential that selected plant materials are appropriate for the anticipated conditions. Hydrologic zones describe the degree to which an area is inundated by water. Plant selection should be consistent with anticipated hydrology. These tolerance levels have been divided into four zones:

- Deep Pool: 18"-36" deep
- Shallow Water: 3" -6" deep
- Shallow Land: 1" "-12" above normal pool
- Upland: never inundated

Please note that the gap between 3 feet deep and 18 inches deep is not an error but is intentional as there are few species that thrive within that water depth range

### 6.2.1. Deep Pool

Open water and permanent deep pools range from 18 inches to 3 feet in depth and are best colonized by submergent plants. The deep-water zone at the outlet is not routinely planted to prevent clogging of the outlet structure.

The function of vegetated deep pools areas is to absorb nutrients in the water column, enhance sediment deposition, improve oxidation and create additional aquatic habitat. Plants for the deep pool should be selected based on their ability to:

- Withstand constant inundation of water of one foot or greater in depth.
- Enhance pollutant uptake.
- Provide food and cover for waterfowl, fish, amphibians, desirable insects, and other aquatic life.

### 6.2.2. Shallow Water

Shallow Water includes all areas that are inundated by the normal pool to a depth of 6 inches. This zone does, however, become drier during periods of drought. The shallow water zone coincides with lower portion of the aquatic bench or vegetated shelf within Wet Ponds and Stormwater Wetlands. This zone offers ideal conditions for the growth of wide variety of emergent wetland species. When planted, this area provides important habitat for many aquatic species, which will provide ecological mosquito control , eliminating the need for insecticide applications. In order to create a natural setting, emergent plants are typically planted in groups or clusters. As this zone matures, some species will dominate portions of the site and tend to outgrow less aggressive species. Some species will migrate upslope into saturated soils and others will spread to colonize slightly deeper water. The shallow water zone should be planted to ensure dense cover to protect the shoreline. This zone provides opportunities for a number of herbaceous plants, shrubs and trees, selection of which should consider their ability to:

- Withstand constant inundation of water to depths of up to 6 inches.
- Stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation.
- Enhance pollutant uptake and transformation.
- Provide food and cover for beneficial insects, and other aquatic life.
- Provide shade along the western and southern sides of a BMP facility to help reduce temperature of open waters.

- Reduce human access to potential hazards without blocking maintenance access.
- Require little or no maintenance requirements because they may be difficult or impossible to reach.

### 6.2.3. Shallow Land

The shallow land zone is the temporary storage volume portion of a Wet Pond or Stormwater Wetland. The width of this zone will depend on the design slope. The soil substrate will be periodically saturated. The primary landscaping objectives for this zone are to stabilize the slopes characteristic of this zone and optimize pollutant removal. Plants should be selected that can:

- Minimize mosquito-breeding potential.
- Withstand irregular inundation , as well as significant drought.
- Stabilize the ground from erosion caused by run-off.
- Provide shade along the western and southern sides to help reduce temperature of open waters.
- Provide pollutant uptake.
- Provide habitat for waterfowl, songbirds, and wildlife (plants may also be selected and located to control overpopulation of waterfowl).

### 6.2.4. Upland

This zone extends above the maximum design water surface elevation (never inundated) and often includes the outermost buffer of a pond or wetland. Plant selections should be made based on soil condition, light, and function within the landscape because little or no water inundation will occur. Ground covers should require no mowing. Placement of plants in the upland area is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, serve as a buffer, or provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plants.

## 6.3. Wetland Indicator Status

The wetland indicator status (from Region 1, Reed, 1988) has been included to show "the estimated probability of a species occurring in wetlands versus non-wetlands" (Reed, 1988). Reed defines the indicator categories as follows:

- Obligate wetland (OBL): Plants that nearly always (> 99% of the time) occur in wetlands.
- Facultative Wetland (FACW): Plants that usually occur in wetlands (67 to 99% of the time), but occasionally found in non-wetlands.
- Facultative (FAC): Plants that are equally likely to occur in wetlands and non-wetlands and are found in wetlands 34 to 66% of the time.
- Facultative Upland (FACU): Plants that usually occur in non-wetlands (67 to 99% of the time), but occasionally found in wetlands (from 1 to 33% of the time).

- Upland (UPL): Plants that occur > 99% of the time in non-wetlands.

## 6.4. Landscape Plans

Healthy, thriving vegetation plays a key role in the performance of many stormwater BMP facilities. Facility-specific planting requirements are given in their respective chapters. These requirements are based on the collective experiences of NC DENR and North Carolina State University Biological and Agricultural Engineering faculty and staff as well as standard landscape industry methods for design and construction.

The landscape planting design must include elements that ensure plant survival and overall stormwater BMP facility functional success. Plant selection is a complex task, involving matching the plant's physiological characteristics with a site's particular environmental conditions. The following factors should be considered:

- Site conditions (e.g., wind direction and intensity, street lighting, type and quantity of pollutants contained within stormwater runoff, etc.).
- Soil moisture and drought tolerance.
- *Sediment and organic matter build-up.*
- Potential for outlet structure clogging (e.g., root structure).
- Maintenance.
- Wildlife use (including mosquitoes).
- Aesthetics/ability to meet both landscape and stormwater BMP requirements.

Individual plants often have physiological characteristics difficult to convey in a general list. It is necessary to investigate specific information to ensure successful plant selection. There are many resources available to guide designers in the selection of plant material for stormwater BMP facilities. Knowledgeable landscape architects, wetland scientists, urban foresters, and nursery suppliers provide valuable information for considering specific conditions for successful plant establishment and accounting for the variable nature of stormwater hydrology.

### 6.4.1. Required Items in a Landscape Plan

Landscape plans must be prepared by a qualified design professional. They must include the following items, at a minimum:

1. Landscape plan sheet
   - A scaled construction drawing (typically at 1" = 20') to accurately locate and represent the plant material used within the BMP facility. Representation of plant material should be to scale and depicted at the mature width or spread.
   - A key that identifies all plant material used in the planting plan. The symbols used to identify the plants will correlate with the plant schedule. Plant groupings on the drawing are usually

shown by an identifying symbol and the number of plants in that particular group.
- A list any other necessary information to communicate special construction requirements, materials, or methods such as specific plants that must be field located or approved by the designer and size or form matching of an important plant grouping.

2. Plant list/table
   - This must include scientific name, common name, quantity, nursery container size, quantity, container type (e.g., bare root, b&b, plug, container, etc.), appropriate planting season, and other information in accordance with the BMP facility-specific planting section and landscape industry standards.
   - Source of the plant materials must be indicated in the plant schedule. Plant material should be purchased from a similar provenance[1] or local source to ensure survivability.

3. Soil media specifications. If topsoil is specified, indicate the topsoil stockpile location, including source of the topsoil if imported to the site.

4. Construction notes with sequencing, soil and plant installation instructions, and initial maintenance requirements.

5. A description of the landscape contractor's responsibilities.

6. A minimum two-year warranty period stipulating requirements for plant survival/replacement.

At the end of the first year and again at the end of the two-year warranty period, all plants that do not survive must be replaced. Establishment procedures, such as control of invasive weeds, animal and vandal damage, mulching, re-staking, watering, and

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[1] Provenance means "place of origin." Plant provenance refers to the place where a plant evolved and had its genetic makeup determined. Trees and shrubs may be native to many areas of the country or world, but you can have a case where the seeds or cuttings taken from the same tree or shrub in Illinois or Pennsylvania would have a different genetic makeup than one taken from the same species in North Carolina.

Plants evolve and adapt over the years - these changes are mapped into the genetic material. This mapping can have a profound effect on cold hardiness, resistance to heat, or drought tolerance.

Keep this in mind this spring when you purchase a shrub or tree for your stormwater BMP. Check if it is native to your area, but also find out where that particular tree or shrub was actually grown. A good nursery or greenhouse should have already considered that when they placed the plant for sale - but you should still keep it in mind when you purchase.

mesh or tube protection replacement, shall be implemented to the extent needed to ensure plant survival. Staking must be removed after establishment (approximately 12 months), to prevent girdling (strangling) of all woody plants.

The design for plantings shall minimize the need for herbicides, fertilizers, pesticides, or soil amendments at any time before, during, and after construction and on a long-term basis. Furthermore, plantings shall be designed to minimize the need for mowing, pruning, and irrigation.

Grass or wildflower seed must be applied at the rates specified by the suppliers. If plant establishment cannot be achieved with seeding by the time of substantial completion of the stormwater facility portion of the project, then the contractor shall plant the area with wildflower sod, plugs, container plants, or other means to complete the specified plantings and protect against erosion before water is allowed to enter the stormwater BMP facility.

### 6.4.2. Guidelines for Plant Placement

The guidelines listed below should be followed:

- No trees or shrubs should be planted within 10 feet of inlet or outlet pipes, or manmade drainage structures such as spillways or flow spreaders. Species with roots that seek water (e.g., willow and poplar), should be avoided within 50 feet of pipes or manmade structures.
- Planting should be restricted on berms that impound water either permanently or temporarily during storm events. This restriction does not apply to cut slopes that form pond banks, only to berms.
  - Trees or shrubs must not be planted on portions of water impounding berms taller than 4 feet high; only grasses may be planted. Grasses allow for unobstructed visibility of berm slopes for detecting potential dam safety problems such as animal burrows, slumping, or fractures in the berm.
  - Trees planted on portions of water-impounding berms less than 4 feet high must be small (less than 20 feet mature height) and have a fibrous root system. These trees reduce the likelihood of blow-down, or the possibility of channeling or piping water through the root system, which may contribute to dam failure on berms that retain water.

  *Note: the internal berm within a wet pond is not subject to this planting restriction since the failure of an internal berm would be unlikely to create a safety issue.*

- All landscape material, including grass, should be planted in good topsoil. Native underlying soils may be suitable for planting if amended with 4 inches of well-aged compost tilled into the subgrade. Compost used should meet specifications for Grade A compost quality.

- Soil in which trees or shrubs are planted may need additional enrichment or additional compost top-dressing depending on the results of the soil analysis. Consult a nurseryman, landscape professional, or arborist for site-specific recommendations.

- For a naturalistic effect, as well as ease of maintenance, trees or shrubs should be planted in clumps to form *'landscape islands'* rather than evenly spaced.

- The landscaped islands should be a minimum of six feet apart, and if set back from fences or other barriers, the setback distance should also be a minimum of six feet. Where the tree foliage extends low to the ground, the 6-foot setback should be counted from the outer drip line of the trees (estimated at maturity). This setback allows a 6-foot wide mower to pass around and between clumps.

- Evergreen trees and trees which produce relatively little leaf-fall are preferred in areas draining to a detention device.

- Trees should be set back so that branches do not extend over the permanent pool of a detention device (to prevent leaf-drop into the water and clogging issues).

- Drought-tolerant species are recommended.

## 6.5. Soil Media

Soils are highly complex systems that provide essential environmental benefits including biofiltration of pollutants, nutrients for plant growth, and the storage and slow release of storm flows. The ability of soil to effectively store and slowly release water is dependent on its' properties—texture, structure, organic matter content, and biota—as well as depth. Plant roots, macro fauna, and microbes tunnel, excavate, penetrate, and physically and chemically bond soil particles to form stable aggregates that enhance soil structure and porosity. Soil properties are the principal factor controlling the fate of water in the hydrologic system. Water loss, utilization, contamination, and purification are all affected by the soil (Brady and Weil, 2007).

Organic matter is a critical ingredient in the function of a soil. Mixed into the soil, organic matter absorbs water, physically separates clay and silt particles, and reduces erosion. Microbial populations and vegetation depend on the replenishment of organic matter to retain and slowly release nutrients for growth. Construction activity removes the upper layers of soil, compacts exposed sub-soils low in organic matter, and alters the site's hydrologic characteristics by converting the predominantly subsurface flow regime of the pre-disturbance site to primarily overland flow.

Soil permeability is an important design factor in stormwater BMPs. It is advantageous and sometimes necessary to have high permeability *in-situ* soils for systems where infiltration may be desired (e.g. bioretention, infiltration devices, etc.). It is also advantageous and sometimes necessary to have low permeability *in-situ* soil for systems where permanent ponded water is required (e.g. stormwater wetlands, wet detention basins and liners must be used if *in-situ* permeability is too high). In some BMP systems (e.g. sand filters, bioretention, etc.), high permeability media is required within the BMP, but since relatively small quantities are typically required, suitable soils can be imported to a site if necessary.

The organic content of soils can be an important factor in BMP selection and design for two reasons. First, BMP vegetation thrives best with the proper soil organic content. Organic content requirements for the soil in planted areas can range from 2-10% (Oregon State University Forest Nursery Manual, 1984), but it is a very site and plant specific value, based on an analysis of the topsoil. The organic content of soils can affect pollutant removal rates in BMPs that pass stormwater through soil media. High organic content has been shown to increase removal rates of some metals and some organic compounds.

Finally, another important aspect of soils is their typically high erosivity. Soils need to be quickly stabilized with vegetative cover or they will suffer from wind and water erosion (sometimes severely). Vegetative cover must be properly maintained over the life of the BMP to prevent bare spots from occurring and the subsequent erosion of the exposed soils. Sometimes additional measures (e.g. rock linings, geosynthetics, etc.) must be taken to protect soils from erosion in certain circumstances (i.e., steep slopes, excessive BMP outlet velocities, etc.)

### 6.5.1. Soil Analysis

In order to reduce costs, *in situ* excavated soil, rather than imported soil can be used for stormwater wetlands (*in situ* soils should never be used for bioretention). Using on-site excavated soil for the amended soil in a stormwater BMP, however, may reduce control over gradation, organic content, and final product performance. In turn, this can significantly increase project costs and complicate construction logistics when attempting to blend soil mix components in restricted space or during winter months.

As a result, if it is determined *in situ* soils will be utilized, then a soil analysis must be conducted. The purpose of the analysis is to determine the viability of soils to assure healthy tree and vegetation growth and to provide adequate infiltration rates through the topsoil, or soil media. The analysis will determine whether on-site soils will ultimately be suitable for the particular BMPs being utilized, what types and quantities of amendments will be required, or if an engineered soil media will be necessary. All soil mixes for stormwater BMPs must be designed to maintain long-term viability and pollutant-processing capability. BMP facilities receiving high quantities of heavy metals will need periodic replacement.

The soil analysis work for a BMP system should be performed by a qualified, licensed professional. Soil analyses should include the following:

- Soil pH (whether acid, neutral, or alkaline).

- Soil texture.
- Soil test NCDA & CS (nutrient content).
- Content (percent clay, organic material, etc.).

Soil samples must be analyzed by experienced and qualified individuals, such as the local Cooperative Extension or NRCS office, who will explain in writing the results, what they mean, as well as what soil amendments would be required. Certain soil conditions, such as marine clays, can present serious constraints to the growth of plant materials and may require the guidance of qualified professionals. When poor soils cannot be amended, seed mixes and plant material must be selected to establish ground cover as quickly as possible.

A soils report evaluating the above parameters should be included in a stormwater management plan submittal to verify the treatment capability of the soil mix.

Analyzing soils for hydraulic conductivity and infiltration rate is highly recommended.

### 6.5.2. Soil Amendments

The hydrologic characteristics of disturbed construction site soils can be enhanced with the addition of organic matter. When properly implemented and maintained, incorporating compost into disturbed *in situ* soils provides hydrologic as well as other significant environmental functions including:

- Reduced erosion through soil stabilization.
- Increased sediment filtration.
- Pollutant adsorption and bioinfiltration (including heavy metals, oil, and grease).
- Improved plant growth, disease resistance, and vigor.

Application rates and techniques for incorporating amendments depend upon a soil analysis and requirements of the plants proposed to be used in a BMP.

Organic soil amendments should be a stable, mature compost derived from organic waste materials including yard debris, bio-solids, wood wastes, or other organic materials. Peat moss is not recommended as it decomposes too quickly in North Carolina (about 3-6 months). Compost quality can be determined by examining the material and qualitative tests; it should have the following characteristics:

- Earthy smell (not sour, sweet, or ammonia-like).
- Brown to black color.
- Mixed particle sizes
- Crumbly texture.
- Stable temperature and does not get hot when re-wetted.
- Moisture content between 35 to 50%.
- No viable weed seeds.
- Manufactured inert material should be less than 1% on a dry weight or volume

basis.

The *minimum organic matter content* can be achieved by calculating a custom amendment rate for the existing soil conditions. A quick way to determine the approximate organic matter content of a soil mix would be to use the following rule of thumb:

- Compost is typically 40 to 50% organic matter (use 45% as an average).
- Compost weighs approximately 50% as much as loam.
- A mix that is 40% compost measured by volume is roughly 20% organic matter by volume.
- Compost is only 50% as dense as the soil, so the mix is approximately 10% organic matter by weight.

Soil amendments can be used two ways: 1) placed on top of the soil, or 2) incorporated into it. If applied as a land cover on top of the soil, it should have a minimum depth of 2 to 3 inches, depending on slope and soil types. Slopes steeper than 4:1 should receive 3 inches of compost as a cover.[2] The intent of incorporating compost into the soil is to increase the organic content of the soil, replicating a forested soil condition.

Compost is not recommended for areas of concentrated flow. It can be used in swales or on the sides of ditches above the expected flow line.

### 6.5.3. Soil Specifications

Soils used within a stormwater BMP must adhere to the following requirements:

- The soil mix must be uniform and free of stones, stumps, roots, or other similar material greater than 2 inches.

- Soil texture of the mix used for stormwater wetlands should be loamy sand, with no more than 10% clay (USDA Soil Textural Classification).

- A minimum organic content of 10% by dry weight for areas planted with woody species and 5% for turf areas.

- The pH should be between 5.5 and 7.0. If the pH falls outside of this range, it may be modified with lime to increase the pH or iron sulfate and sulfur to lower the pH. The lime or iron sulfate must be mixed uniformly into the soil prior to use.

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[2] Washington State Department of Transportation has been applying compost to condition soils on slopes ranging up to 33% since 1992. No stability problems have resulted from the increased water holding capacity of the compost. Compost can be applied to the ground surface without incorporation to improve plant growth and prevent erosion on steep slopes that cannot be accessed by equipment (Hinman, 2005).

- Topsoil stockpile location (if using on-site soils) or source of topsoil if imported to the site. Soil analysis for all topsoil to be used within a BMP facility[3].

## 6.6. Site Preparation, Grading, and Installation

Vegetation within the footprint of the stormwater BMP facility area should be removed during site preparation with equipment appropriate for the type of material encountered and site conditions. It is recommended that the maximum amount of pre-existing native vegetation be retained and protected. Vegetation protection areas, including wetlands, with intact native soils and vegetation should not be cleared and harvested for use in BMP facilities.

Areas that recently have been involved in construction are subject to extreme compaction. Soil compaction can lead to BMP failure where infiltration is a key factor in its function. No material storage or heavy equipment should be allowed within the stormwater BMP facility area after site clearing and grading have been completed, except to excavate and grade as needed to construct the BMP.

Excavation should not be allowed during wet or saturated conditions. Excavation should be performed by machinery operating adjacent to the BMP facility area and no heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires should be allowed on the bottom of bioretention or infiltration BMPs. If machinery must operate in a BMP facility for excavation, then use lightweight, low ground-contact pressure equipment and scarify the base at completion to refracture the subsoil to a minimum of 12 inches (Prince George's County, 2002)[4]. In other cases where exfiltration is a concern (e.g., stormwater wetlands), it is desirable to compact the soil to form an impermeable barrier between the bottom of the wetland and the surrounding native soils.

If existing areas surrounding the stormwater BMP facility are disturbed by construction, then the top 6 to 8 inches of soil should be tilled. *No tilling shall occur within the drip line of existing trees.* After tilling is completed, no other construction traffic shall be allowed in the area, except for planting and related work.

All construction and other debris should be removed before topsoil is placed.

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[3] This requirement is due to the fact that nitrogen and phosphorous levels in agricultural soils tend to be very high. The purpose of the stormwater BMP is generally to reduce the nutrient load of the runoff into receiving waters as well as peak flow attenuation.

[4] This will improve seed contact with the soil, increase germination rates, and allow the roots to penetrate the soil. For areas to be sodded, disking is necessary so that the roots can penetrate the soil. Providing good growing conditions can prevent poor vegetative cover. This saves money because vegetation will be less likely to need replacing.

Cap the scarified sub-soil with topsoil or the specified soil mix. On-site soil mixing or placement should not be performed if the soil is saturated. The soil mixture should be placed and graded by excavators and/or backhoes operating *adjacent* to the BMP facility. The soil mixture should be placed in horizontal layers not to exceed 12 inches per lift for the entire area of the BMP facility.

Note that if topsoil has been stockpiled in deep mounds for a long period of time, it may be necessary to test the soil for pH as well as microbial activity. If the microbial activity has been destroyed, it is necessary to inoculate the soil after application.

### 6.6.1 Determining the Final Grade

The soil mixture will settle and proper compaction will be achieved by allowing time for nature compaction and settlement. However, to speed the process, each lift can be watered until just saturated. The water should be applied by spraying or sprinkling.

To achieve the appropriate grade, changes in soil depth from tilling and incorporating soil amendments need to be estimated. The difference in volume of the dense versus the loose soil condition is determined by the 'fluff factor' of the soil. The fluff factor of compacted sub-soils tends to be around 1.3 to 1.4. Tilling typically penetrates the upper 6 to 8 inches. Assuming a 6-inch depth, the depth adjusted for the fluff factor will correspond to 7.8 to 8.4-inch depth of loose soil. If amended at a 2:1 ratio of loose soil to compost, or 4 inches, the final amended soil elevation must account for compost settling into the void spaces of the loose soil and compaction. If the soil and compost are rototilled to mix and then the soil tamped lightly to compress, the resulting increase in elevation for soils amended to a 6-inch depth would be approximately 3 inches.

### 6.6.2 Planting and After-Care

Soil amendments should be incorporated at the end of the site development process to prevent sediment from entering the BMP facility. The BMP should be planted and mulched immediately after amending the soil to stabilize the site as soon as possible.

Newly installed plant material requires water in order to recover from the shock of being transplanted. Be sure that some source of water is provided, especially during dry periods. This will reduce plant loss and provide the new plant materials with a chance to establish root growth.

In general, fall and winter are optimal for planting in North Carolina. There are some exceptions. Shallow water plants should be installed between April 1 and July 15 in North Carolina. Winter planting is difficult with shallow water plants.

Minimize or eliminate the use of pesticides and fertilizers. A one-time application of fertilized is allowable to help establishment. Landscape management personnel should be trained to adjust chemical inputs accordingly and manage to recognize plant health problems.

September 28, 2007 Changes:

1. 6.2: Corrected the topographic zone depths.

# 7. BMP Inspection and Maintenance

## 7.1. The Importance of Maintaining BMPs

Most of this manual is devoted to proper design of stormwater BMPs, a task that requires a significant investment of effort and expense. Once they are constructed, BMPs are crucial in protecting water quality from the impacts of development projects. If designed correctly, BMPs can also be an aesthetic asset to the development. However, no matter how well they are designed and constructed, BMPs will not function correctly nor look attractive unless they are properly maintained. Most maintenance problems with BMPs are less costly to correct when they are caught early – as the old adage goes, "an ounce of prevention is worth a pound of cure."

Regular inspection and maintenance is an ongoing legal requirement after the BMP is constructed – inspections must be completed at appropriate times throughout the year and inspection records must be available upon request. An appropriate professional should conduct BMP inspections. NC State University offers a BMP Inspection and Maintenance Certification Program; more information is available at their web site: http://www.bae.ncsu.edu/people/faculty/hunt/.

This chapter will discuss the logistical issues associated with BMP inspection and maintenance as well as provide an overview of some of the tasks associated with maintaining BMPs. Each of the BMP chapters in this manual includes a table explaining the specific inspection and maintenance activities required to ensure the proper functioning of the BMP.

## 7.2. Legal and Financial Issues

### 7.2.1. Access and Maintenance Easements

BMPs must have access and maintenance easements to provide the legal authority for inspections, maintenance personnel and equipment. The location and configuration of easements must be established during the design phase and should be clearly shown on the design drawings. The entire footprint of the BMP system must be included in the access and maintenance easement, plus an additional ten or more feet around the BMP to provide enough room to complete maintenance tasks. This BMP system includes the side slopes, forebay, riser structure, BMP device, and basin outlet, dam embankment, outlet, and emergency spillway.

Access and maintenance easements must be designed and built with a concept of the maintenance tasks that may be needed. If heavy equipment will be necessary to perform maintenance tasks (such as for devices with a forebay that will require sediment clean-out), typically a roadway with a minimum width of ten feet to the BMP must be available. Easements are usually owned and maintained by the owner of the BMP facility, whether an individual, a corporation, or a government. Easements for BMPs that are not publicly maintained should include provisions to permit public inspection and maintenance. An example of an Access and Maintenance Easement Agreement is provided in Appendix C.

### 7.2.2. Inspection and Maintenance Agreements

BMP facilities are typically built, owned and maintained by non-governmental entities. To insure proper long-term maintenance, a signed and notarized Inspection and Maintenance Agreement must accompany the design plans for any BMP. An Inspection and Maintenance Agreement will include the following:

- The frequency of inspections that are needed (based on the type of BMP proposed).
- The components of the BMP that need to be inspected.
- The types of problems that may be observed with each BMP component.
- The appropriate remedy for any problems that may occur.

Sample Inspection and Maintenance Agreement provisions are included at the end of each BMP chapter. The most effective Inspection and Maintenance Agreements are site-specific for the particular BMP components that are used on the site as well as any conditions that are unique to the site (for example, the presence of steep slopes that should be inspected for soil stability).

**Table 7-1**
Required Inspection Frequency for BMPs

| Inspection Frequency | BMPs |
|---|---|
| Monthly and within 24 hours after every water quality storm (greater than 1.5 inches in Coastal Counties and greater than 1.0 inch elsewhere) | Stormwater wetlands<br>Wet detention basins<br>Bioretention cells |
| Quarterly and within 24 hours after every water quality storm (greater than 1.5 inches in Coastal Counties and greater than 1.0 inch elsewhere) | Level spreaders<br>Infiltration devices<br>Sand filters<br>Extended dry detention basins<br>Permeable pavement<br>Rooftop runoff management<br>Filter strips *<br>Grassed swales *<br>Restored riparian buffers * |

* Although these devices require quarterly inspection, mowing will usually be done at more *frequent intervals during the growing season.*

To summarize Table 7-1, devices that include vegetation in a highly engineered system require inspection monthly and after large storm events to catch any problems with flow conveyance or vegetative health before they become serious. All other BMPs should be inspected quarterly and after large storm events.

The signed and notarized Inspection and Maintenance Agreement should be filed with the appropriate Register of Deeds. The responsible party should keep a copy of the Inspection and Maintenance Agreement along with a current set of BMP plans at a known set location.

### 7.2.3. Inspection and Maintenance Record-Keeping

All inspection and maintenance activities should be recorded. One easy way to do this is to create an Inspection and Maintenance checklist based on the Inspection and Maintenance Agreement. The checklist, at a minimum, should include the following:

- Date of inspection.
- Condition of each of the BMP elements.
- Any maintenance work that was performed (as well as who performed the work).
- Any issues noted for future maintenance (sediment accumulating, vegetation needing pruning or replacement, etc.).

Each project should have a maintenance record. Records should be kept in a log in a known set location. Any deficient BMP elements noted in the inspection should be corrected, repaired or replaced immediately. These deficiencies can affect the integrity of structures, safety of the public, and the removal efficiency of the BMP.

Major repairs or maintenance work should include the same level of inspection and documentation as original installations. Inspection checklists and record logs should be kept in a known set location.

### 7.2.4. Maintenance Responsibilities

As stated in the section above, maintenance is usually the responsibility of the owner, which in most cases is a private individual, corporation, or homeowners association. Simple maintenance items such as minor landscaping tasks, litter removal, and mowing can be done by the owner, or can be incorporated in conventional grounds maintenance contracts for the overall property.

Although a nonprofessional can undertake many maintenance tasks effectively, a professional should be consulted periodically to ensure that all needs of the BMP facility are met. Some elements that can need professional judgment include structures, outlets, and embankments/dams by a professional engineer, as well as plant system health by an appropriate plant professional. Some developing problems may not be obvious to the untrained eye.

In addition, it is advisable to have professionals do the more difficult or specialized work. Filling eroded areas and soil-disturbing activities, such as re-sodding or replanting vegetation, are tasks that are best assigned to a professional landscaping firm. If the work is not done properly the first time, not only will the effort have been wasted, but also the facility may have been damaged by excessive erosion. Grading and sediment removal are best left to professional contractors. Appropriate professionals (e.g. BMP maintenance specialists, professional engineers, aquatic plant specialists, etc.) should be hired for specialized tasks such as inspections of vegetation and structures.

### 7.2.5. Providing for Maintenance Expenses

The expenses associated with maintaining a BMP are highly dependent on the BMP type and design. However, the most important factor that determines the cost of BMP maintenance is the condition of the drainage area upstream of the BMP. If a drainage area conveys a high load of sediment and other pollutants to a BMP, the cost of maintaining the BMP will increase dramatically. Preventing pollution in the drainage area as much as possible will reduce the cost of BMP maintenance.

A funding mechanism should be created and regularly funded with an amount that provides enough money to pay for the maintenance expenses over the lifetime of the BMP. One option is to establish an escrow account, which can be spent solely for sediment removal, structural, biological or vegetative replacement, major repair, or reconstruction of the BMPs. In the case of a residential subdivision, the escrow account could be funded by a combination of an initial payment by the developer and regular contributions by the homeowners' association. For an example of how to legally structure such an account, please see the Phase II model stormwater ordinance at the Division of Water Quality's web site:
http://h2o.enr.state.nc.us/su/phase_2_mod_ord.htm.

Routine maintenance costs are relatively easy to estimate, and include the expenses associated with the following activities:

- Conducting BMP inspections at the intervals shown in Table 7-1.
- Maintaining site safety, including any perimeter fences and other access inhibitors (trash racks or pipe grates).
- Removing trash.
- Removing sediment that has accumulated in any components of the BMP.
- For infiltration-type systems, maintaining the filtering media and cleaning or replacing it when necessary.
- Restoring soils to assure performance.
- Pruning woody vegetation pruning.
- Replacing dead vegetation.
- Stabilizing any eroding side slopes.
- Repairing damaged or eroded outlet devices and conveyance systems.
- Repairing embankments, dams, and channels due to erosion or rodents.

Emergency maintenance costs are more difficult to estimate. They depend on the frequency of occurrence and the nature of the problem, which could vary from storm erosion repairs to complete failure of a structure.

## 7.3. Summary of BMP Maintenance Tasks

### 7.3.1. Emergency Maintenance

Maintenance after floods and other emergencies requires immediate mobilization. It can include replanting and repairs to structures. Living systems are likely to need at least minor repairs after emergencies. Following an emergency such as a flood, standing water may pose health risks because of mosquitoes. Mosquito control should be considered if this becomes a problem.

For all installations obstructions and debris deposited during storm events should be removed immediately. Exceptions include debris that provides habitat and does not damage vegetation or divert currents to, from, or in the BMP. In fact, because of the high quality habitat that can be found in woody debris, careful re-positioning rather than complete removal may be desirable. There may be instances where debris is even added. Such locations should be noted so that this debris is not accidentally removed. Educating adjacent property owners about the habitat benefits of debris and vegetation can decrease requests for removal.

### 7.3.2. Debris and Litter Removal

Regularly removing debris and litter is well worth the effort and can be expected to help in the following ways:

- Reduce the chance of clogging in outlet structures, trash racks, and other facility components.
- Prevent damage to vegetated areas.
- Reduce mosquito breeding habitats.
- Maintain facility appearance.
- Reduce conditions for excessive surface algae.
- Reduce the likelihood of stagnant pool formation.

Special attention should be given to removing floating debris, which can clog the outlet device or riser.

### 7.3.3. Sediment Removal and Disposal

Sediment gradually accumulates in many BMPs. For most BMPs, accumulated sediment must eventually be removed. However, removal intervals vary so dramatically among facilities that no "rules of thumb" are applicable. The specific setting of a BMP is important in determining how often sediment must be removed. Important factors that determine rates of sedimentation include the current and future land uses upstream and the presence of other sediment-trapping BMPs upstream.

Before installing a BMP, designers should estimate the lifetime sediment accumulation that the BMP will have to handle. Several time periods may be considered, representing expected changes in land use in the watershed. To estimate sediment accumulation, first, an estimate of the long term sediment load from upstream is needed, then an estimate of BMP sediment removal efficiency (see Sections 3.0 and 4.0). The analysis of watershed sediment loss and BMP efficiency can be expedited by using a sediment delivery computer model.

The frequency of sediment removal is then based on the sediment accumulation rate described above versus the amount of sediment storage volume that is inherently provided in the BMP without affecting treatment efficiency or stormwater storage volume. Again, the frequency of sediment removal is BMP and site specific, and could be as frequent as every couple years, or as long as 15-25 years. The volume of sediment needing to be removed and disposed of per dredging cycle is the volume calculated above multiplied by any density or dewatering factors, as appropriate.

Wet sediment is more difficult and expensive to remove than dry sediment. Ideally, the entire facility can be drained and allowed to dry sufficiently so that heavy equipment can operate on the bottom. Provisions for draining permanent pools should be incorporated in the design of water impoundments where feasible. Also, low flow channels and outlets should be included in all BMPs to bypass stormwater flow during maintenance. However, in many impoundments periodic rainfall keeps the sediment soft, preventing access by heavy equipment. In these cases, sediment may have to be removed from the shoreline by using backhoes, grade-alls, or similar equipment.

Proper disposal of the sediment removed from a BMP is required. It is least expensive if an onsite area or a nearby site has been set aside for the sediment. This area must be located outside of the floodplain. If such a disposal area is not set aside, transportation and landfill tipping fees can greatly increase the cost of the BMP, especially where disposal of wet sediment is not allowed in the local landfill., Often, the material must be dewatered before disposal, which again adds more cost and requires land area where wet material can be temporarily placed to dry.

Sediment removal is usually the largest single cost of maintaining a BMP facility, so the necessary funds should be allocated in advance. Since sediment removal costs are so site specific and dependent on disposal plans, it is difficult to provide good estimates. Actual estimates should be obtained during the design phase of the BMP from sediment removal contractors based on the planned situation. The estimates should include: mobilization expenses, sediment removal expenses, material transport expenses (if applicable), and disposal expenses (if applicable).

### 7.3.4. Stability and Erosion Control

The best way to promote soil stability and erosion control is to maintain a healthy ground cover in and around BMPs. Areas of bare soil quickly erode, potentially clogging the facility with soil and threatening its integrity. Therefore, bare areas must be re-stabilized as quickly as possible. Newly seeded areas should be protected with mulch and/or an erosion mat that is securely staked. For BMP's that rely on filtration, such as bioretention facilities, it is critical that adjacent soils do not contaminate the selected media during or after construction. If the site is not permanently stabilized with vegetation when the filter media is installed, the best design practice is to specify sod or other robust erosion control practices for all slopes in and immediately around the BMP.

Erosion is quite common in or around the inlet and outlet of the BMP facility and should be repaired as soon as possible. Erosion control activities should also extend to areas immediately downstream of the BMP.

The roots of woody growth such as young trees and bushes in embankments are destabilizing. Consistent mowing of the embankment controls stray seedlings that take root. Woody growth, such as trees and bushes, further away from the embankment should not pose a threat to the stability of the embankment and can provide important runoff filtering benefits. Trees and bushes should be planted outside maintenance and access areas.

Animal burrows also diminish the structural integrity of an embankment. Muskrats, in particular, burrow tunnels up to 6 inches in diameter. Efforts should be made to control animal burrowing. Burrows should be filled as soon as possible.

### 7.3.5. Maintenance of Mechanical Components

Each type of BMP may have mechanical components that need periodic attention. For example, valves, sluice gates, fence gates, locks, and access hatches should be functional at all times. The routine inspection, exercising, and preventive maintenance on such mechanical components should be included on a routine inspection/maintenance checklist.

### 7.3.6. Vegetation Maintenance

Vegetation maintenance is an important component of any maintenance program. The grasses and plants in all BMPs, but particularly in vegetative BMPs such as filter strips, grass swales, restored riparian buffers, bioretention facilities, and stormwater wetlands, require regular attention. The development of distressed vegetation, bare spots, and rills indicates that a BMP is not functioning properly. Problems can have many sources, such as:

- Excessive sediment accumulation, which clogs the soil pores and produces anaerobic conditions.
- Nutrient deficiencies or imbalances, including pH and potassium.
- Water-logged conditions caused by reduced soil drainage or high seasonal water table.
- Invasive weeds.

The soil in vegetated areas should be tested every other year and adjustments made to sustain vigorous plant growth with deep, well-developed root systems. Aeration of soils is recommended for filter strips and grassed swales where sediment accumulation rates are high. Ideally, vegetative covers should be mown infrequently, allowing them to develop thick stands of tall grass and other plant vegetation. Also, trampling from pedestrian traffic should be prevented.

Areas immediately up- and downstream of some BMP plant installations often experience increased erosion. Although properly designed, located, and transitioned installations experience this effect to only a minor degree, all erosion should be repaired immediately to prevent spreading. Live stakes, live fascines, and other soil bioengineering techniques, possibly in combination with 3-D geotextiles, can be applied to erosion in natural drainage ways with minor grading.

Table 7-2 below describes some specific vegetation maintenance activities at various types of BMPs. It is important to note that DWQ has some specific requirements related to some management practices, such as those performed within buffers, that must be followed. In addition, any vegetation that poses threats to human safety, buildings, fences, and other important structures should be removed. Finally, vegetation maintenance activities naturally change as the project ages from construction, when the vegetation is still getting established, to a mature state.

### 7.3.7. Maintenance of the Aquatic Environment

An important yet often overlooked aspect of non-routine maintenance of BMPs that maintain a permanent pool of water is the need to regularly monitor and manage conditions to promote a healthy aquatic environment. An indicator of excess nutrients (a common problem) is excessive algae growth in the permanent pool of water. In most cases, these problems can be addressed by encouraging the growth of more desirable aquatic and semi-aquatic vegetation in and around the permanent pool. The plants selected should be tolerant of varying water levels and have a high capacity to incorporate the specific nutrients associated with the problem. If algae proliferation is not addressed, algae-laden water will be washed downstream during rain events and may contribute to nuisance odors and stresses in downstream aquatic habitat.

### 7.3.8. Insect Control

Ponded water can function as breeding grounds for mosquitoes and other insects. Mosquito problems can be minimized through proper design and maintenance. The best control technique for BMPs that maintain a permanent pool of water is to ensure that it does not develop stagnant areas. BMPs with permanent pools should include a source of steady dry-weather flow. Promptly removing floatable debris helps eliminate areas where water can collect and then stagnate. In larger basins, fish, which feed on mosquito larvae, can be stocked. Additionally, splash aerators can be employed to prevent stagnant water, however, this requires electricity at the site, increases maintenance costs, and must be properly designed so as to not decrease the settling efficiency of the BMP.

**Table 7-2**
Vegetation Maintenance for BMPs

| Maintenance Activity | Instructions |
|---|---|
| **Replacement of Dead Plants** | All dead plants should be removed and disposed of. Before vegetation that has failed on a large scale is replaced, the cause of such failure should be investigated. If the cause can be determined, it should be eliminated before any reinstallation. |
| **Fertilization** | The objective of fertilizing at a BMP is to secure optimum vegetative growth rather than yield (often the objective with other activities such as farming). Infertile soils should be amended before installation and then fertilized periodically thereafter. Fertilizer can be composed of minerals, organic matter (manure), compost, green crops, or other materials. |
| **Irrigation/ Watering** | Watering of the vegetation can often be required during the germination and establishment of the vegetation, as well as occasionally to preserve the vegetation through drought conditions. This can typically be accomplished by pumping water retained in the BMP or from the stream, installing a permanent irrigation system or frost-proof hose bib, or using portable water trucks. |
| **Mulching** | Mulching should be used to maintain soil temperature and moisture, as well as site aesthetics. A half-inch layer is typically adequate. Ideally, mulch should be removed before winter to prevent an infestation of rodents. |
| **Weeding** | Weeding is often necessary in the first growing season, particularly if herbaceous grasses are out-competing the young woody vegetation growth. The need for weeding may be largely eliminated by minimizing the amount of seed used for temporary erosion control. Weeding may also be required if, over time, invasive or undesirable species are entering the site and out-competing plants that are specifically involved in the treatment of the stormwater. |
| **Cultivating/ Hoeing** | Hoeing is often required to loosen overly compacted soil and eliminate weeds that compete with the desirable vegetation. |
| **Pruning** | Pruning is used to trim to shape and remove dead wood. It can force single-shoot shrubs and trees to assume a bushier configuration. |
| **Thinning** | Thinning dense brush may be necessary for particular species to thrive, increase the vigor of individual specimens, to reduce flow obstructions, and to increase the ability of maintenance staff to access the entire BMP. Tall maturing trees, for the most part, have no place in a BMP (except for buffers) and should be removed as soon as possible. |
| **Staking** | Saplings of tall trees planted in or near the BMP may require staking. Care should be taken not to damage the tree's roots with stakes. Stakes should be kept in place for 6 to 18 months, and the condition of stakes and ties should be checked periodically. |
| **Wound Dressing** | The wounds on any trees found broken off or damaged should be dressed following recommendations from a trained arborist. |

**Table 7-2, continued**
Vegetation Maintenance for BMPs

| Maintenance Activity | Instructions |
|---|---|
| **Disease Control** | Based on monitoring observations, either insecticides or (preferably) organic means of pest and fungal control should be used. |
| **Protection from Animals and Human Foot Traffic** | Fencing and signage should be installed to warn pedestrians and to prevent damage due to trampling. These measures are often most necessary during the early phases of installation but may be required at any time. Measures for controlling human foot traffic include signs, fencing, floating log barriers, impenetrable bushes, ditches, paths, and piled brush. Wildlife damage is caused by the animals browsing, grazing, and rubbing the plants. The use of chemical wildlife repellents should be avoided. Fences and meshes can be used to deter entry to the BMP. Tree tubes can be used to prevent damage to individual specimens. |
| **Mowing** | Mowing of perennial herbaceous grasses and wildflowers, especially once seed heads have set, promotes redistribution of seed for this self-sustaining system. Mowing should be carefully controlled, however, especially when performed for aesthetics. As adjacent property owners and customers in general learn more about BMPs, their vision of what is aesthetically pleasing can change. Grasses, in healthy herbaceous stands, should never be mown more than once per year. |

### 7.3.9. Maintenance of Other Project Features

All other devices and features associated with the BMP should be monitored and maintained appropriately. These additional items could affect the safety or aesthetics of the facility, which can be as important if not more important than the operational efficiency of the facility. Such items could include:

- Fences
- Access roads
- Trails
- Lighting
- Signage (e.g. no trespassing, emergency notification contact information, etc.)
- Nest boxes
- Platforms
- Watering systems

September 28, 2007 Changes:

1. Footer: Corrected from October 2006 to July 2007.

# 8. Level Spreaders

Level spreaders do not remove pollutants by themselves, but they are so crucial in assuring the effectiveness of certain BMPs and in protecting the function of riparian buffers that an entire chapter is devoted to them in this manual. Potential locations for a level spreader include, but are not limited to, the following:

- The inlet of a bioretention cell or an infiltration basin, where a level spreader can reduce inlet velocities and diffuse flow for proper stormwater treatment.
- Prior to a restored riparian buffer or a filter strip, where a level spreader can diffuse the flow to allow the vegetation to effectively remove pollutants.
- Prior to a stormwater discharge to a riparian buffer or a wetland, where a level spreader can diffuse the flow into the vegetated area to prevent erosion and allow for pollutant removal.

## 8.1. General Characteristics

A level spreader consists of a concrete linear structure constructed at virtually zero percent grade. Depending on the use of the level spreader, other elements may include a high flow bypass system, a forebay and a filter strip. If the level spreader is not outleting to a bioretention cell or another infiltration system, it will outlet to a filter strip. The filter strip is defined as the land between the outlet of the level spreader continuing downslope to the top of the stream bank or other surface water. Often, the filter strip consists of the 50-foot wide area beside a stream or other surface water that is protected by one of the Riparian Area Protection Rules. Outside of areas covered by Riparian Area Protection Rules, the filter strip must be a minimum of 30 feet in width. A filter strip is not required if the purpose of the level spreader is to outlet to wetlands.

One of the main purposes of a level spreader is to disperse concentrated stormwater flows over a wide enough area to prevent erosion of the BMP or filter strip where it outlets. Erosion can undermine a BMP, and an eroded filter strip can be a significant source of sediment pollution to the streams and other natural water bodies. The other main purpose of a level spreader is to increase the interaction between the stormwater and the vegetation and soils in the BMP or filter strip. The vegetation and soils bring about pollutant removal via filtration, infiltration, absorption, adsorption, and volatilization.

A level spreader may be used as a stand-alone device or as part of a larger BMP system. For example, a level spreader may also be used to diffuse the outflow of a BMP through a filter strip. If the flow from a drainage area exceeds the capacity of a level spreader, another BMP such as a dry extended detention basin or a wet detention pond may be used before the level spreader to attenuate the flow to an appropriate rate.

**Figure 8-1:**
Plan View of a Level Spreader (adapted from Hathaway 2006)

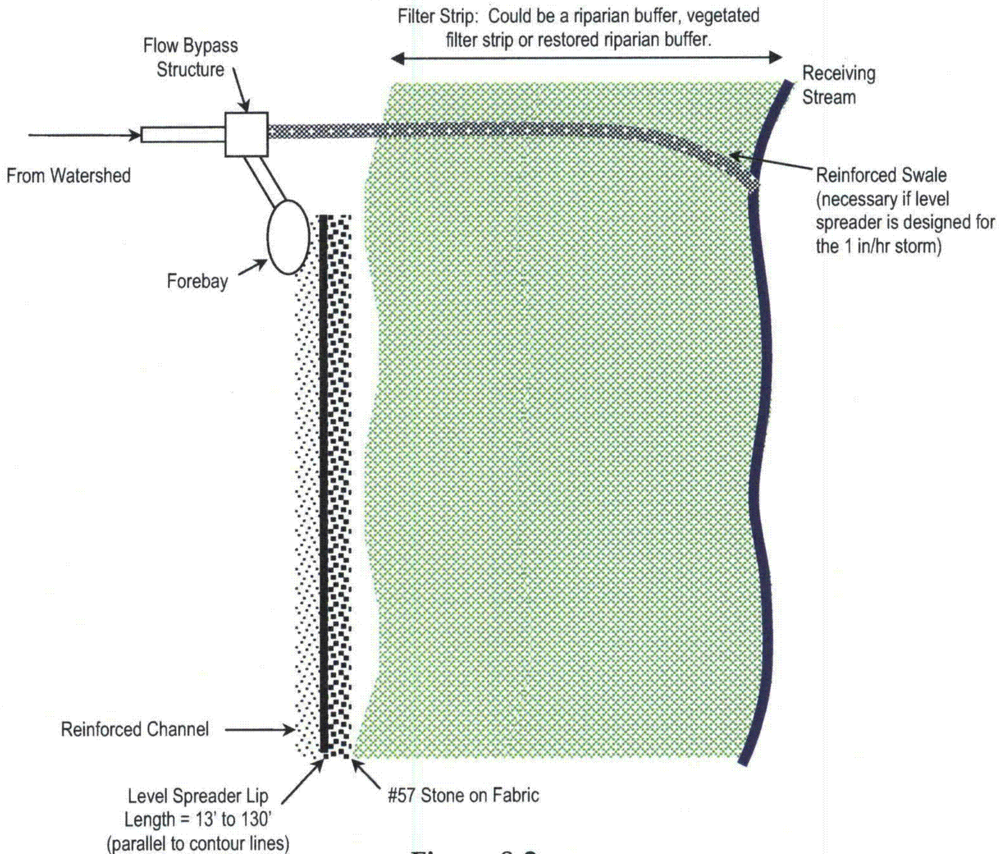
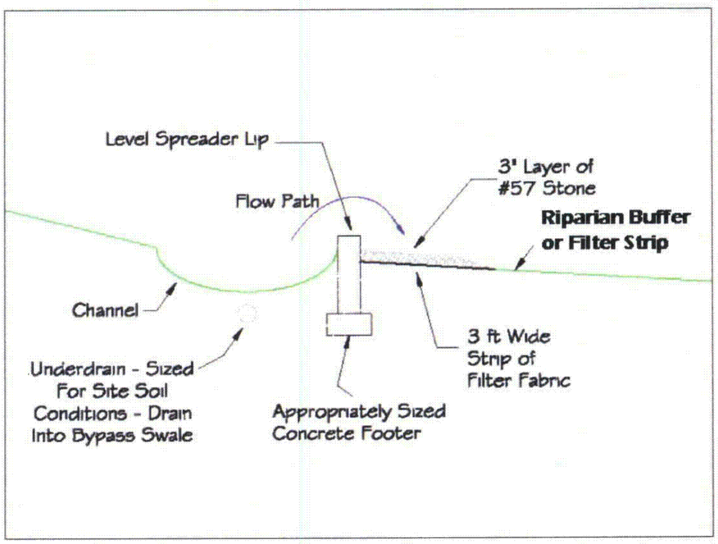



**Figure 8-2:**
Profile View of a Level Spreader (adapted from, Hathaway 2006)



## 8.2 Siting for Level Spreaders Used With Filter Strips

A filter strip, as stated previously, is simply the land between the level spreader and the receiving stream. This land could consist of a protected riparian area, a vegetated buffer required by another stormwater program, a restored riparian buffer, or a filter strip used as a BMP (see Chapter 13 for appropriate design). Regardless of the reason for constructing or protecting the filter strip, it is important to determine whether the site is appropriate for a level spreader. In order to do this, the designer will need to gather the following information:

- The peak flows during the one inch per hour intensity storm and the ten-year storm,
- The topography of the proposed filter strip (obtained during a field visit), and
- A characterization of the vegetation in the proposed filter strip (obtained and photographed during a field visit).

After the field visit, the filter strip vegetation should be characterized as one of the following:

- *Grass:* an area that is densely covered with grass.
- *Thick ground cover:* a natural or naturalized area containing that is densely covered with a mixture of grasses, shrubs and herbs. Some trees may be present, but they are not the predominant species. The vegetation must be allowed to grow and not be cut back.
- *Forest:* an area that is densely wooded with a ground cover of mulch or leaves.

One required characteristic of all three types of filter strip vegetation is that it be dense, with no areas of bare soil. If existing vegetation is not dense, then the filter strip should be enhanced with additional plants so that it will not erode as stormwater flow is diffused across it.

Once the above information is obtained, the designer has enough information to determine whether the site is appropriate for a level spreader. The following criteria must be met depending on the vegetation in the filter strip:

- *Filter strips with grass or thick ground cover:* Slopes must be less than or equal to 8% for filter strips and the flow resulting from the 1 inch per hour intensity storm may not exceed 10 cfs.
- *Filter strips with forest vegetation:* Slopes must be less than or equal to 6% and the flow resulting from the 1 inch per hour intensity storm may not exceed 2 cfs.
- *Filter strips with a combination of either grass or thick ground cover AND forest vegetation:* Slopes must be less than or equal to 6% and flow requirements are met (see Design and Construction section for computing flow limits for a combined vegetation filter strip).

In addition, for all vegetation types, uniform, diffuse flow must be possible (i.e., no draws may be present in the filter strip).

Level spreaders are *not* appropriate when one or more of the following conditions exist:

- There is a draw located within the filter strip downslope of the proposed level spreader.
- The stormwater flows exceed the above guidelines unless another BMP is installed to attenuate the flow before it is discharged to the level spreader.
- The slope in the filter strip exceeds the above guidelines unless DWQ approves level spreaders to be placed in series (explained in the paragraph below).

Level spreaders must be placed outside of protected riparian areas unless the designer obtains a variance from the Environmental Management Commission. In addition, they may only be installed where the existing filter strip topography is appropriate and the stormwater flow will not exceed the capacity of the level spreader. If diffuse flow is not achievable based on site topography and stormwater flow rate, level spreaders may not be used. Other BMP choices for areas where level spreaders are not appropriate will be discussed in the Design and Construction section.

If a filter strip exceeds the allowable slopes given above and up to a 15% maximum slope, installing level spreaders in series is a possibility if it can be shown that no other solution is practicable. Level spreaders in series *may* be approved by DWQ on a case-by-case basis following a site visit. Placing level spreaders in series will require siting a level spreader within a protected riparian area; therefore, a variance will be required from the Environmental Management Commission. See the Design and Construction section for appropriate placement of level spreaders in series.

It is important to site the level spreader in a location where safe and legal access is available for construction and maintenance.

## 8.3 Design and Construction

A level spreader system the drainage area consists of up to separate four parts (see Figures 8-1 and 8-2 above):

1. *Flow Bypass System:* A diverter box (or other type of flow splitter) that passes all flow above the one inch per hour intensity to a swale capable of safely passing the ten-year storm without eroding. A flow bypass system is not needed if the level spreader lip is constructed to be long enough to handle the flow from the ten-year storm. Also, if the level spreader is receiving flow from another BMP such as a wet detention basin, then a forebay is not needed.
2. *Forebay:* A bowl-shaped feature that slows the stormwater runoff and settles out some sediment and debris. If the level spreader is receiving flow from another BMP such as a wet detention basin, then a forebay is not needed.
3. *Level Spreader Lip:* The main body of the level spreader that receives water from the forebay (or directly from a BMP). The concrete lip is constructed so that it is level along its entire length. A swale is constructed immediately upslope of the level spreader lip, which allows stormwater to rise and fall evenly over the lip.

4. *Filter Strip:* The densely vegetated area that receives flow from the level spreader.

### 8.3.1 High Flow Bypass System

The flow bypass system must be constructed so that all flows above the one-inch per hour intensity are diverted to a bypass channel. If the level spreader is receiving flow from another BMP such as a wet detention pond, then a flow bypass system is not necessary. Additionally, a flow bypass system is not necessary if the level spreader is designed to handle the peak flow from the ten-year storm event.

For a stand-alone level spreader, high flows will be bypassed through the use of a diverter box or other flow splitting device. Please see Section 5.3 for more information on flow splitters.

This bypass channel must be designed to safely pass the ten-year design storm without erosion. If there is enough sunlight in the filter strip to support it, it is preferable to use turf reinforcement in place of riprap. This will reduce the cost of constructing the bypass channel while increasing pollutant removal and flow capacity of the bypass channel.

The outlet of the bypass channel must be designed to reduce the impacts to the receiving stream. The bypass channel should be designed to enter the stream at an angle rather than a directly perpendicular manner, which may create erosion on the opposite stream bank. The bypass channel should discharge into a pool (deep section) of the stream. At the point of entry, stream banks may need to be protected with riprap or other engineered solution. Another option is to direct the bypass channel to a velocity dissipater or to use a bypass pipe that discharges to a culvert.

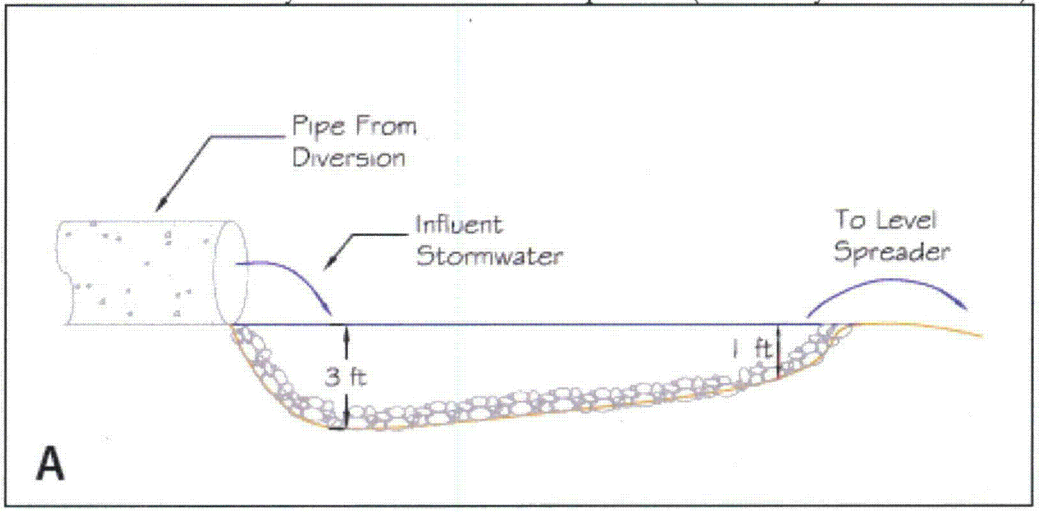
Bypass channels are considered an "allowable" use within a protected riparian buffer. Tree removal and disturbance must be minimized and a buffer authorization must be obtained from the DWQ 401 Oversight/Express Permitting Unit or the local delegated buffer permitting authority.

### 8.3.2 Forebay

After passing through the flow bypass system, stormwater should be directed to a forebay (unless the level spreader is receiving flow from another BMP, in which case a forebay is not necessary). The forebay is an excavated, bowl-shaped feature that slows the stormwater and allows sediment and debris to settle out. Horizontal angle of entry pipe is 30° [recommended]; armor may be needed to prevent scour. Figure 8-3 shows a schematic of a forebay specifically designed for use with a level spreader.

It is recommended that the forebay be designed so that its surface area is 0.2% of the contributing area's impervious surface. The recommended depth is one foot at the back end, sloping to three feet on the front side (portion closest to the inlet). A forebay is required unless no practical alternative is demonstrated and the level spreader is maintained by a municipal stormwater utility or NCDOT. The forebay can be lined with Class B riprap to dissipate energy. Design guidelines for the forebay provided are recommendations based on field research. Best professional judgment should be used with regard to forebay surface area and depth.

**Figure 8-3:**
Schematic of a Forebay for Use With a Level Spreader (Hathaway and Hunt 2006)




### 8.3.3 Level Spreader Lip

The level spreader lip consists of a grassed swale to distribute the water along the length of a level concrete weir. Water rises and falls evenly over the lip of the level spreader, which therefore distributes the flow evenly over its length. The lip of the level spreader should constructed out of concrete and should be 3 to 6 inches higher than the existing ground (downslope side) and anchored into the soil with an appropriately-sized concrete footer. The lip shall be installed at a 0-0.05% grade (level). An under drain is recommended to reduce ponding in the swale.

One of the most important design criteria for the level spreader lip is that it must be constructed parallel to contour lines. Often, this will result in a level spreader that is curved, which is perfectly acceptable.

The level spreader must be a minimum of 13 feet and a maximum of 130 feet in length (see Table 8-1 for determining required length). The appropriate length for the level spreader is determined based on two criteria: The type of vegetation in the filter strip and the design flow. Significantly longer level spreaders are needed when the filter strip is composed of forest vegetation. This is due to the fact that the forest flow is much more susceptible to erosion than an area with grass or thick ground cover. If the level spreader is outleting to a bioretention area or another filtration BMP, then the lengths appropriate for a forested filter strip should be used to prevent erosion within the BMP.

The design flow will be based upon one of the following:

- The peak flow resulting from the one inch per hour intensity flow (in which case a high flow bypass system and a forebay will be required).
- The peak flow resulting from the ten-year storm (in which case a forebay will be required).
- The drawdown rate from the upslope BMP if one is present (in which case neither a high flow bypass system or a forebay will be required).

**Table 8-1: Level spreader lengths**

| Grass or thick ground cover filter strip | Forest filter strip |
|---|---|
| 13 feet of level spreader lip per 1 cfs of flow for slopes from 0 to 8 percent | 65 feet of level spreader lip per 1 cfs of flow for slopes from 0 to 6 percent |

If the filter strip is composed of a mixture of grass or thick ground cover and forest vegetation, then the level spreader length should be determined by calculating the weighted average of the lengths required for each vegetation type. For example, if a level spreader is constructed adjacent to a 50-foot Neuse Riparian Buffer where Zone 2 (the outer 20 feet) will be maintained as grass and Zone 1 (the inner 30 feet) has existing forested vegetation, the appropriate level spreader length will be:

$$(20/50) \times (13\ \text{ft}/1\text{cfs}) + (30/50) \times (65\ \text{ft}/1\ \text{cfs}) = 44.2 \text{ or } 44 \text{ feet per cfs of flow}$$

The downstream side of the level spreader should be designed to further encourage diffuse flow of water and minimize erosion. The first 3 feet from the level spreader lip should use geotextile fabric with a 3-4 inch deep layer of #57 stone placed on top, or permanent erosion control matting. If geotextile fabric is used, it should be selected based on the soil type (sand, silt or clay). The fabric should be extended 3 feet from the level spreader lip to the downslope area in order to reduce erosion and located outside of Zone 2 of riparian buffer.

### 8.3.4 Filter Strip

If the filter strip does not contain dense vegetation, it should be enhanced with additional plantings to reduce the chance of erosion. The first 10 feet of the filter strip downslope of the level spreader is not recommended to exceed 4 percent slope.

### 8.3.5 Level Spreaders in Series

If a filter strip slope exceeds 6 percent for filter strips that contain forest vegetation or 8 percent for filter strips with grass or thick ground cover up to a maximum of 15 percent slope, installing level spreaders is a possibility if it can be shown that no other solution is practicable. Level spreaders in series may be approved by DWQ on a case-by-case basis following a site visit.

At the higher slopes of 6 or 8 to 15 percent, level spreaders will need to be placed every 25 feet in order to maintain diffuse flow. In an area covered by a Riparian Area Protection Rule, this will necessitate placing one level spreader just outside the buffer (50 feet from the stream bank) and a second level spreader in Zone 1 of the buffer (25 feet from the stream bank). Constructing a level spreader in Zone 1 will require a major variance from the Environmental Management Commission.

### 8.3.6 Options where Level Spreaders are not Appropriate

Level spreaders may not be installed on sites where flows are too high to be conveyed by a 130-foot level spreader or the topography of the filter strip (if applicable) is too steep. The option that is selected in these cases will depend if the problem results from high flows from the drainage area or steep slopes in the filter strip.

If the flows are too high, but slopes within the filter strip are within the allowable range, then a BMP that captures the stormwater runoff and releases it to the level spreader at a slower rate may be installed upslope. BMPs that attenuate flow include:

- *Dry extended detention basin*: This BMP will eliminate the need for a high flow bypass system and a forebay.
- *Wet detention basin*: This BMP will also eliminate the need for a high flow bypass system and a forebay. One option is to use 2-1/2" floating [Faircloth] skimmer in the pond to achieve a stable flow to the level spreader.

If the topography of the filter strip is too steep for a level spreader, a different type of BMP will be needed. If the intended filter strip is an area protected by the Riparian Buffer Rules, then the stormwater will have to be treated by a BMP that removes 30 or more percent of the nutrients rather than using a level spreader. The outfall of this BMP can then be routed directly through the buffer with written approval from the DWQ.

### 8.3.7 Preformed Scour Holes

Preformed scour holes are preshaped, riprap-lined basins located directly downgrade of an outfall. The purpose of a preformed scour hole is to dissipate energy and diffuse flow. They may be used to provide diffuse flow only when all of the following requirements are met:

- The outfall area must be flat (less than 2 percent slope).
- The scour hole must be located outside of protected riparian areas.
- The maximum allowable discharge to a scour hole from a 15-inch pipe is 6 cfs based on the ten-year storm discharge.
- The maximum allowable discharge to a scour hole from an 18-inch pipe is 10 cfs based on the ten-year storm discharge.
- Pipes larger than 18 inches may not be discharged to a scour hole.

Once flow has filled the shallow basin, it overtops the preformed scour hole and is redistributed as diffuse flow to the surrounding area. A typical example of a preformed scour hole layout and its components is shown in Figure 8-4. Figure 8-5 is a cross section of a typical preformed scour hole.

**Figure 8-4**
Typical preformed scour hole layout and components (NCDOT 2006)

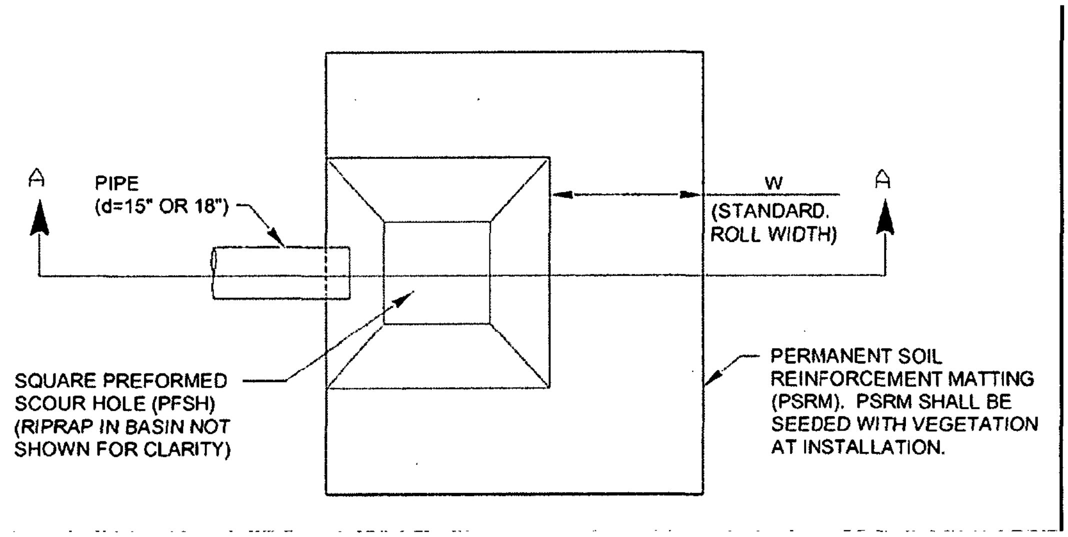
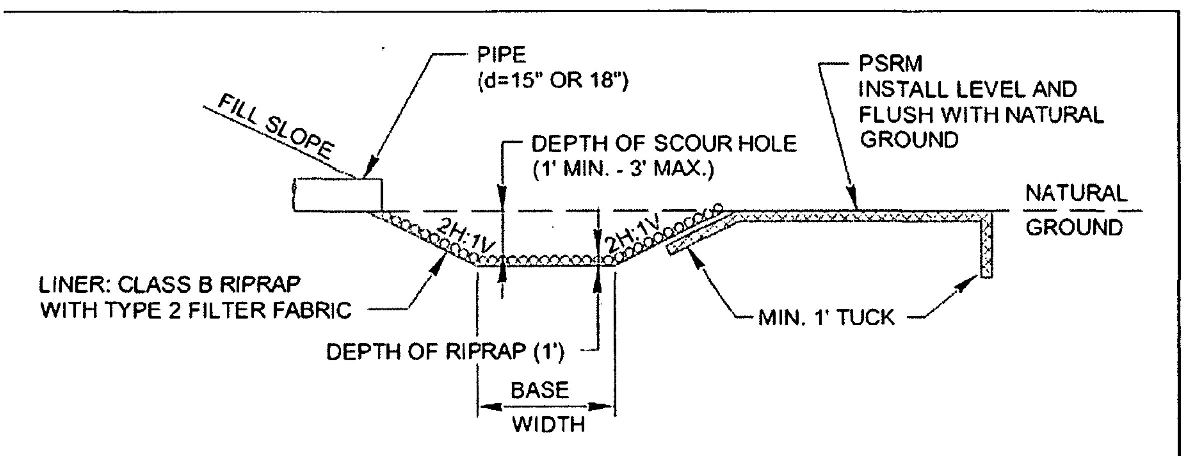



**Figure 8-5**
Preformed scour hole cross section (NCDOT 2006)




Once these site constraints are met, the size of the preformed scour hole is calculated based on the class of riprap used to line the hole and the diameter of the discharge pipe. For optimum energy dissipation, the ratio of the scour hole depth should be between 16 and 32 inches deep. The basin should be stabilized with filter fabric and riprap to absorb the impact of the discharge and to prevent additional erosion. Class B riprap (d50 = 8 inches) should be used on top of the filter fabric to line the preformed scour hole. The minimum and maximum stone sizes for Class B riprap are 5 inches and 12 inches, respectively.

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

Design requirements for scour holes:

- The base of the scour hole is square. The width is calculated as follows: Base width = 3 × Discharge pipe size.
- Riprap must be Class B (d50 = 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.
- Side slope for all four sides of the scour hole is 2H:1V.
- Riprap thickness is equal to 1.5 times the midrange riprap stone size (d50), or 1 foot for Class B riprap.
- Minimum depth of the scour hole is 1 foot.
- Maximum depth of the scour hole is 3 feet.

Construction requirements for scour holes:

- To avoid shifting of the scour hole after installation, the BMP should be installed in undisturbed soil instead of in fill material.
- Install preformed scour holes after site stabilization.
- Ensure that the apron is flush with natural ground. The elevation of the top of the preformed scour hole should be the same as the elevation of the PSRM.
- Ensure 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 BMP.
- 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.

Note: This entire Scour Hole section was condensed from the 2006 NC Department of Transportation BMP Manual. DWQ appreciates their willingness to share their expertise on scour hole design.

## 8.4. Construction

Immediately before the level spreader is constructed, verify that ground contours are parallel to the level spreader location called for in the plans, slopes are less than 6 to 8 percent, and that no draws are located in the filter strip adjacent to the level spreader. If this is the case, the level spreader may need to be relocated to a more appropriate area. Also verify in the field that the level spreader is fully 50 feet away from the stream if it is being installed in an area covered by a Riparian Area Protection Rule.

Before construction, reassess the vegetation in the filter strip. The filter strip should be densely vegetated prior to the construction of the level spreader. If not, additional plantings will need to be added prior to the construction of the level spreader. If grass cover needs to be re-established in the filter strip (only allowed within Zone 2 of a protected riparian buffer), construction may be limited to the growing season.

The most important construction task is to insure that the level spreader is actually level. A correctly installed level spreader will have no greater than 0.05% grade on the spreader lip to ensure a uniform distribution of flow; otherwise water will channelize below the structure and become a source of erosion. Level spreaders should be constructed on undisturbed soil whenever possible. If the use of fill is unavoidable, it shall be constructed on material compacted to 95% of standard proctor test levels prior to seeding for that area not considered the seedbed.

The level spreader and filter strip must be protected from harm (e.g., sediment and stormwater flows) during construction. A temporary stormwater diversion will likely be necessary until the level spreader has fully stabilized. If the disturbed areas are minor, they often can be stabilized with vegetative measures.

## 8.5. Maintenance

### 8.5.1. Common Maintenance Issues

During the first one or two years after construction, filter strips and level spreaders should be inspected for proper distribution of flows and signs of erosion during and after major storm events. After the first one or two years, the strip may be inspected annually or biannually. If evidence of erosion exists, the eroded areas should be filled in and reseeded. The cause of the erosion should then be determined and, if possible, eliminated.

Filter strips that are not maintained properly may quickly become nonfunctional (Schueler et al., 1992). Maintenance involves routine activities such as mowing, trimming, and replanting when necessary. Strips that receive excessive sediment may require periodic regrading and reseeding of their upslope edge because deposited sediment can kill grass and change the elevation of the edge such that the stormwater no longer flows through the strip in thin sheets. Maintenance requirements are as follows:

### 8.5.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- Immediately after the filter strip is established, any newly planted vegetation will be watered twice weekly if needed until the plants become established (commonly six weeks).
- Once a year, the filter strip will be reseeded to maintain a dense growth of vegetation
- Stable groundcover will be maintained in the drainage area to reduce the sediment load to the vegetation.
- Two to three times a year, grass filter strips will be mowed and the clippings harvested to promote the growth of thick vegetation with optimum pollutant removal efficiency. Turf grass should not be cut shorter than 3 to 5 inches and may be allowed to grow as tall as 12 inches depending on aesthetic requirements (NIPC, 1993). Forested filter strips do not require this type of maintenance.
- Once a year, the soil will be aerated if necessary.
- Once a year, soil pH will be tested and lime will be added if necessary.

After the filter strip is established, it will be inspected **quarterly and within 24 hours after every storm event greater than 1.0 inch (or 1.5 inches if in a Coastal County)**. Records of inspection and maintenance will be kept in a known set location and will be available upon request.

*Inspection activities shall be performed as follows. Any problems that are found shall be repaired immediately.*

**Table 8-2**

Sample Inspection and Maintenance Provisions for Level Spreaders, Filter Strips and Restored Riparian Buffers

| **BMP element:** | **Potential problem:** | **How to remediate the problem:** |
|---|---|---|
| **The entire filter strip system** | Trash/debris is present. | Remove the trash/debris. |
| **The flow splitter device (if applicable)** | The flow splitter device is clogged. | Unclog the conveyance and dispose of any sediment off-site. |
| | The flow splitter device is damaged. | Make any necessary repairs or replace if damage is too large for repair. |
| **The swale and the level lip** | The swale is clogged with sediment. | Remove the sediment and dispose of it off-site. |
| | The level lip is cracked, settled, undercut, eroded or otherwise damaged. | Repair or replace lip. |
| | There is erosion around the end of the level spreader that shows stormwater has bypassed it. | Regrade the soil to create a berm that is higher than the level lip, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer |

| | | |
|---|---|---|
| | | application. |
| | Trees or shrubs have begun to grow on the swale or just downslope of the level lip. | Remove them. |
| **The bypass channel** | Areas of bare soil and/or erosive gullies have formed. | Regrade the soil if necessary to remove the gully, and then reestablish proper erosion control. |
| | Turf reinforcement is damaged or riprap is rolling downhill. | Study the site to see if a larger bypass channel is needed (enlarge if necessary). After this, reestablish the erosion control material. |

| | | |
|---|---|---|
| **The filter strip** | Grass is too short or too long (if applicable). | Maintain grass at a height of approximately three to six inches. |
| | Areas of bare soil and/or erosive gullies have formed. | Regrade the soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application. |
| | Sediment is building up on the filter strip. | Remove the sediment and restabilize the soil with vegetation if necessary. Provide lime and a one-time fertilizer application. |
| | Plants are desiccated. | Provide additional irrigation and fertilizer as needed. |
| | Plants are dead, diseased or dying. | Determine the source of the problem: soils, hydrology, disease, etc. Remedy the problem and replace plants. Provide a one-time fertilizer application. |
| | Nuisance vegetation is choking out desirable species. | Remove vegetation by hand if possible. If pesticide is used, do not allow it to get into the receiving water. |
| **The receiving water** | Erosion or other signs of damage have occurred at the outlet. | Contact the NC Division of Water Quality local Regional Office, or the 401 Oversight Unit at 919-733-1786. |

[1] NOTE: Contact NC Division of Water Quality, 401/Wetlands Unit at 919-733-1786 BEFORE any work in Protected Riparian Buffers.

September 28, 2007 Changes:

1. 8.0: Removed the reference to "sand infiltration basin" and replaced it with "infiltration basin."
2. 8.3.6: Clarified the requirements for areas where the terrain is too steep for level spreader use.
3. 8.5: Updated the maintenance section.
4. Figure 8-1: Altered for clarification.
5. Figure 8-2: Corrected to indicate that level spreaders can drain to either riparian buffers or filter strips, not just buffers.
6. Table 8-1: Deleted, "If the forest vegetation is 100-150 feet wide, then the length can be reduced to 50 feet of level spreader per 1 cfs of flow. If the forest vegetation is more than 150 feet wide, then the length can be reduced to 40 feet of level spreader per 1 cfs of flow."

# 9. Stormwater Wetlands

**Description**

Stormwater wetlands are constructed systems that mimic the functions of natural wetlands and use physical, chemical, and biological processes to treat stormwater pollution.

## Stormwater Wetlands

| Regulatory Credits* | | Feasibility Considerations | |
|---|---|---|---|
| *Pollutant Removal* | | | |
| 85% | Total Suspended Solids | High | Land Requirement |
| 40% | Total Nitrogen | Med | Cost of Construction |
| 35% | Total Phosphorus | Med | Maintenance Burden |
| *Water Quantity* | | Med-High | Treatable Basin Size |
| yes | Peak Runoff Attenuation | Med | Possible Site Constraints |
| yes | Runoff Volume Reduction | Med | Community Acceptance |

* Stormwater wetlands that are designed as part of a pond/wetland system will receive variable credit. See Section 9.1.

**Advantages**

- Creates a shallow matrix of sediment, plants, water, and detritus that collectively removes multiple pollutants through a series of complementary physical, chemical, and biological processes.
- One of the best BMP designs for maximum TSS, nitrogen, and phosphorus removal while also providing stormwater volume control.
- Aesthetically pleasing when properly landscaped and maintained.
- Can provide an excellent habitat for wildlife and waterfowl.

**Disadvantages**

- Occupies more land than other stormwater BMPs such as detention basins.
- Needs to meet critical water balance requirements to stay healthy and properly functioning.
- Poorly maintained stormwater wetlands can be colonized by invasive species that out-compete native wetlands plants. Removal of invasive plants is difficult and labor intensive and may need to be done repeatedly.

## Major Design Elements

| | |
|---|---|
| **Required by the NC Administrative Rules of the Environmental Management Commission.** Other specifications may be necessary to meet the stated pollutant removal requirements. | |
| 1 | Sizing shall take into account all runoff at ultimate build-out including off-site drainage. |
| 2 | Side slopes stabilized with vegetation shall be no steeper than 3:1. |
| 3 | Wetland shall be located in a recorded drainage easement with a recorded access easement to a public ROW. |
| 4 | The wetland must drawdown in 2-5 days. |
| 5 | Flow through the wetland shall not be short-circuited. It shall be made as lengthy as possible. |
| 6 | A forebay is required. |
| 7 | Overflows shall pass through a minimum 30 feet long vegetative filter, 50-foot filter is required for some projects. |
| **Required by DWQ policy.** These are based on available research, and represent what DWQ considers necessary to achieve the stated removal efficiencies. | |
| 8 | Wetlands require pretreatment. |
| 9 | Sizing of wetland is based on storage volume requirements and shall be as described in this section. |
| 10 | The minimum treatment volume for a stormwater wetland shall be 3,630 $ft^3$. Lesser volumes will be approved on a case-by-case basis. |
| 11 | Maximum shallow land depth shall be 1 foot. |
| 12 | Minimum length to width ratio shall be 1.5:1. |
| 13 | The wetland must be stabilized within 14 days of construction. |
| 14 | One of the following two criteria must be met, 1.) The deep pools shall be at least six inches below the seasonably low water table, or 2.) A clay liner shall be installed such that the minimum infiltration rate is 0.01 in/hr. Appropriate topsoil will be added to the clay liner to support plant growth. |
| 15 | Cattails are not to be planted. |

## 9.1. General Characteristics and Purpose

Stormwater wetlands provide an efficient biological method for removing a wide variety of pollutants, (e.g. suspended solids, nutrients (nitrogen and phosphorus), heavy metals, toxic organic pollutants, and petroleum compounds) in a managed environment so that they will not reach natural wetlands or other ecologically important aquatic resources. Properly designed wetlands can also be used to reduce pollution associated with high levels of fecal coliform and other pathogen contamination. These wetlands temporarily store stormwater runoff in shallow pools that support emergent and riparian vegetation.

The storage, complex microtopography, and vegetative community in stormwater wetlands combine to form an ideal matrix for the removal of many pollutants. Stormwater wetlands can also effectively reduce peak runoff rates and stabilize flow to adjacent natural wetlands and streams. An example stormwater wetland is shown in Figure 9-1.

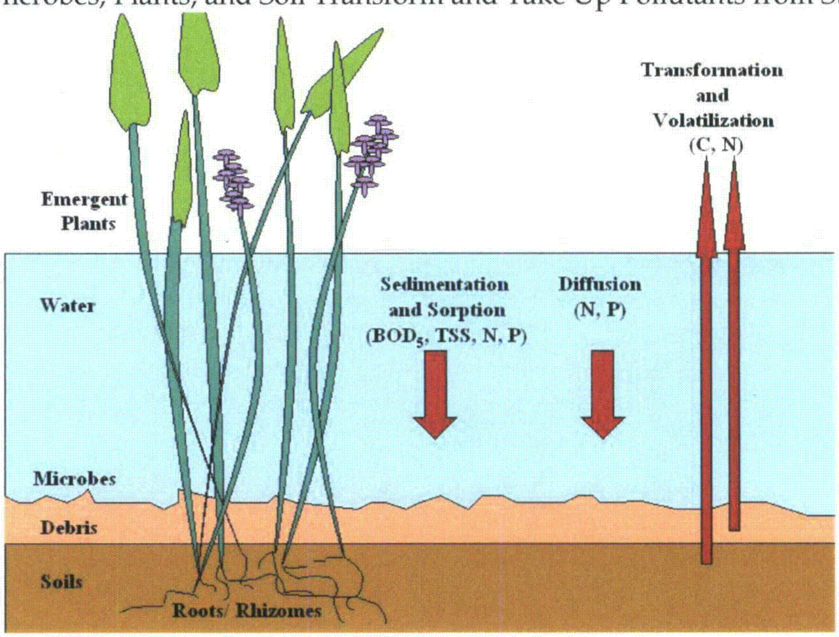
Wetlands are effective sedimentation devices and provide conditions that facilitate the chemical and biological processes that cleanse water. Pollutants are taken up and transformed by plants and microbes, immobilized in sediment, and released in reduced concentrations in the wetland's outflow as shown in Figure 9-2.

**Figure 9-1**

Stormwater Wetland, National Museum of the American Indian in Washington, DC (Courtesy D. Medina)

**Figure 9-2**

Wetland Microbes, Plants, and Soil Transform and Take Up Pollutants from Stormwater



Plants improve water quality by slowing water flow and settling solids, transforming or immobilizing pollutants, and supplying reduced carbon and attachment area for microbes (bacteria and fungi). Dense strands of vegetation create the quiescent conditions that facilitate the physical, chemical, and biological processes that cleanse the stormwater. Many herbaceous wetland plants die annually. Because the dead plant material requires months or years to decompose, a dense layer of plant litter accumulates in the wetland. Like the living vegetation, the litter creates a substrate that supports bacterial growth and physically traps solids.

Microorganisms, adhering to vegetation, roots, and sediment in the wetland, can decompose organic compounds and convert significant quantities of nitrate directly to nitrogen gas. Large amounts of nitrogen and phosphorus also can be incorporated in new soil and in the extra biomass of the wetland vegetation. Transformations can take place through both aerobic and anaerobic processes. For these reasons, maintaining the health of the vegetative community is critical for effective pollutant removal.

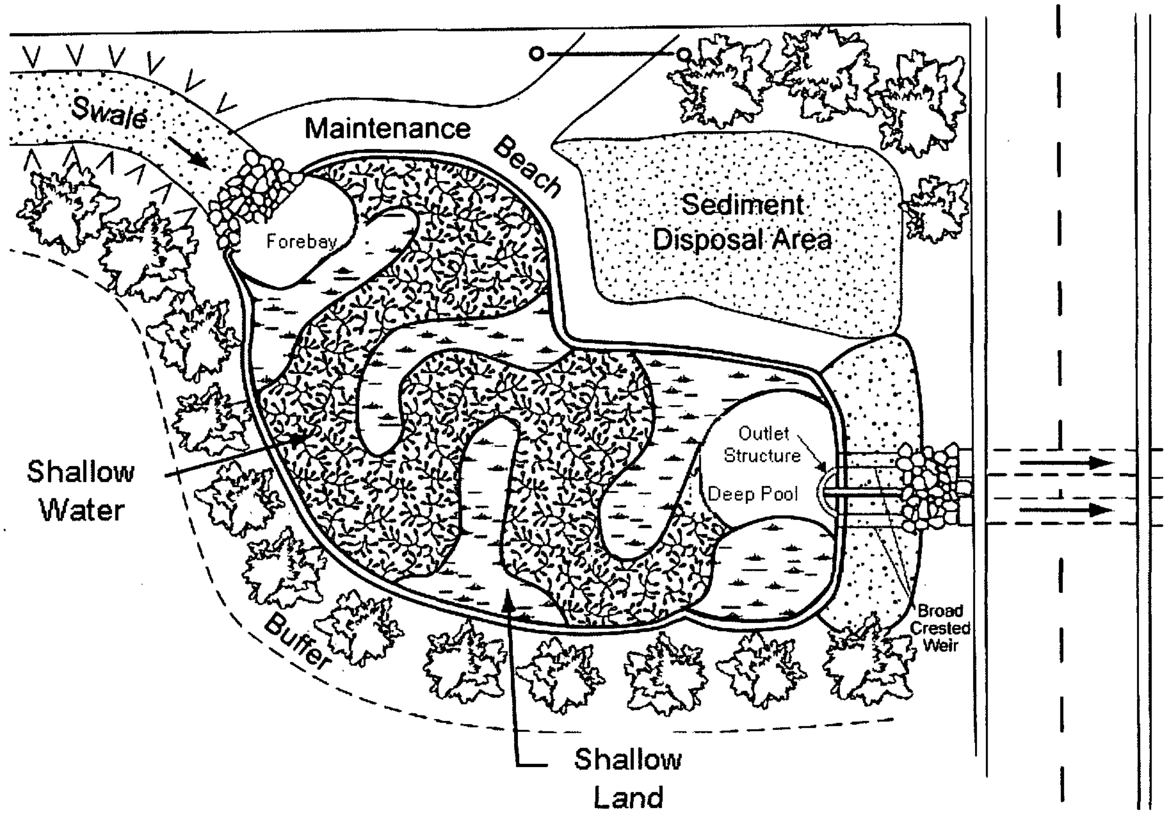
The ability of the emergent plants to settle and stabilize suspended solids in sediments and reduce resuspension is important. The settling characteristic allows the wetland to remove pollutants such as phosphorus, trace metals, and hydrocarbons that are typically adsorbed to the surfaces of suspended particles.

Long-term data from stormwater wetlands indicate that treatment performance for parameters such as 5-day biochemical oxygen demand ($BOD_5$), total suspended solids (TSS), and total nitrogen (TN) typically does not deteriorate over the life of a stormwater wetland. The dissolved oxygen (DO) concentration in wetland outflows may be below 1.0 mg/L. Higher DO concentrations can be achieved by incorporating aeration techniques such as turbulent or cascading discharge zones, or mechanical mixing.

Stormwater wetlands occupy somewhat more surface area than a wet detention pond, but has the potential to be better integrated aesthetically into a site design because of the abundance of aquatic vegetation. Stormwater wetlands require a drainage area sufficiently large, or adequate groundwater or surface water supplies, to provide year-round hydration. In sloping terrain, wetland cells can be arranged in series on terraces. Stormwater wetlands are appropriately located at the lower parts of the development site. Careful planning is needed to be sure that sufficient water will be retained to sustain good wetland plant growth. Since water depths are shallower than in wet detention ponds, water loss by evaporation is an important concern.

Stormwater wetlands are designed in such a way that the distance that the water flows from the entrance to the exit is maximized. This allows for sufficient contact time for pollutant removal. Figure 9-3 shows an example of how a wetland can be configured to maximize the distance that the water flows.

**Figure 9-3**
Stormwater Wetland*
From Design of Stormwater Wetland Systems, Adapted from Schueler, 1992




* *Additional deep pools are encouraged throughout the wetland.*

## 9.2. Meeting Regulatory Requirements

To obtain a permit to construct a stormwater wetland in North Carolina, the stormwater wetland must meet all of the Major Design Elements that are listed at the beginning of this section. In-stream impoundments are not allowed for creating BMPs.

Some wetlands can be constructed as a pond/wetland system. In these cases, part of the BMP is a pond and part of it is a wetland. The nitrogen removal rate for a pond/wetland system can range from 25-40%. The removal rate for a specific pond/wetland system design is prorated, depending on the ratio of permanent treatment volume that is allocated between the pond and the wetland. If 100% of the volume is allocated to the pond, the removal rate is 25% (as in a wet detention basin design). If 100% of the volume is allocated to the wetland, the removal rate is 40% (as in a wetland design). The removal rate is linearly interpolated between these two values. For instance, if the permanent treatment volume were allocated to be 33% a pond and 67% a wetland, the resulting removal rate would be 35%.

*Pollutant Removal Calculations*
The pollutant removal calculations for Stormwater Wetlands are as described in Section 3.4, and use the pollutant removal rates provided in Table 4-2 in Section 4.0. Construction of a stormwater wetland also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading. Further enhancing the passive reduction of nutrient loading is the fact that the surface area of any permanent water surface contributes no pollutant runoff (an export coefficient of 0.0 lb/ac/yr).

*Volume Control Calculations*
Stormwater wetlands can typically be designed with enough storage to provide active storage control, calculations for which are provided in Section 3.4. They will also provide some passive volume control capabilities by providing pervious surface, and therefore reducing the total runoff volume to be controlled.

## 9.3 Design

Design is a six-step process:
1.) Understand basic layout concepts
2.) Determine the volume of water to treat
3.) Determine the surface area and depth of each wetland zone
4.) Select the soil media type
5.) Select the appropriate overflow bypass
6.) Select plants

### 9.3.1 Step 1: Understand Basic Layout Concepts

*Stormwater Wetland Components*
Each of these wetland types consists of six components:

1. Inlet: This is where water enters the wetland. It can be a swale, a pipe, a diverter box, sheet flow, or other method of transporting water to the wetland. Some examples are provided in Figure 9-4.

2. Zone 1, Deep Pools: One of the following two requirements must be met for deep pool construction, 1.) The deep pools are at least 6 inches below the seasonably low water table, or 2.) A clay liner is installed such that the infiltration rate is at least 0.01 in/hr. The clay liner will be installed in the deep pool and shallow water zones if this option is chosen. Also, appropriate topsoil must be added to the top of the clay liner in order to support plant growth in these areas (see Chapter 6 for soil specifications). These requirements address an important design element. Failure to adhere to these requirements may result in a wetland that does not hold water as shown in Figure 9-5. The design in this photograph is actually a wet pond, but wetlands operate on the same principal. Large non-vegetated open water areas near the wetland outlet (other than the deep pool) should be avoided to reduce the potential for planktonic algal growth, as shown in Figure 9-6; however, small open water/pool areas are excellent for mosquito control.

a. Forebay: The forebay is a deep pool that directly follows the inlet and collects sediment and other materials in order to ease maintenance of the BMP. The water flows out of the forebay and into the wetland. The entrance to the forebay is deeper than the exit of the forebay. This design will dissipate the energy of the water entering the system, and will also ensure that large solids settle out.
b. Non-Forebay Deep Pools: The deep pools are always full of water and are areas where rooted plants do not live. Water lilies and other floating plants are used in this area, except for the deep pool next to the wetland overflow device. This deep pool should be non-vegetated in this area so that the overflow device does not clog. Deep pools provide habitat for wildlife, such as the mosquito-eating fish, *Gambousia*. Include a deep pool next to the outlet structure in order to allow for proper drawdown.

3. Zone 2, Shallow water, also referred to as "low marsh": The shallow water is also always full of water, but some rooted plants are able to live in this zone. See Table 9-1 at the end of this Section. The shallow water zone provides a constant hydraulic connection between the inlet and outlet structure of the wetland. The top of the shallow water zone represents the top of the permanent pool. The deep pool is also considered part of the permanent pool, where applicable.

4. Zone 3, Shallow land, also referred to as "high marsh": The shallow land is wet only after a rain event, and rooted plants are able to live in this zone. See Table 9-1 at the end of this Section. If pathogens are the target pollutant, design the shallow land to be a large section of the wetland. Pathogens will settle on the shallow land areas as the water draws down, and will be killed by sunlight. Zone 3 contains the entire treatment volume, as indicated in Figures 9-7a and 9-7b. The top of the shallow land zone represents the top of the temporary pool.

5. Zone 4, Upland (not labeled in the figures above): Upland areas are never wet, are not a required element of wetland design, and can be eliminated if space is of concern. They serve mainly as an amenity. Many wetlands have upland areas as an island in the center of the wetland. If the design is an educational wetland, or if the wetland is to be used as an amenity, designers will often install a viewing platform over the wetland that is supported on one end by the upland area.

6. Outlet structure: The outlet structure consists of a drawdown orifice placed at the top of the shallow water elevation so that stormwater accumulating in the shallow land area will be able to slowly drawdown from the wetland. The outlet structure may also be designed to pass larger storm events, which will have a higher flow outlet at the proper elevation.

**Figure 9-4**
Wetland Inlet Device Examples: Culvert and Rip-Rap Channel
(Courtesy of Sharon Schulze, NC State Science House)

**Figure 9-5**
A Wetland Design Should Not Be Located Above the Water Table

**Figure 9-6**
Algal Growth in Large Open Water Areas

*Slopes and Velocities*
Head loss is an important consideration for stormwater wetlands where a large range in flow rates is encountered. Mathematical equations describing head loss effects are discussed in detail in a number of texts (for example, French, 1985), and empirical relationships to describe treatment performance are available in Kadlec and Knight (1996). The general approach uses equations for mass, energy, and momentum conservation coupled with an equation for frictional resistance.

*Sediment Accumulation*
The embankment height of stormwater wetlands should be designed to accommodate the gradual accumulation of sediment over the lifetime of the facility. Likewise, outlets should be designed to compensate for sediment accumulation by allowing the normal pool elevation to be adjusted to higher levels to maintain the same treatment volume as sediment accumulates over time.

*Converting Sediment and Erosion Control Devices*
Often, the same basin can be used during construction as a sediment and erosion control device and later converted to a stormwater wetland. Before conversion, all accumulated sediment must be removed and properly disposed of, then the appropriate modifications to the basin depth, geometry, and hydrology, as well as inlet and outlet structures, etc., must be made.

*Maintenance Considerations*
When performing the remaining steps of designing a stormwater wetland, consider how landscape professionals will later access the site for maintenance. Is the outlet located near enough to the side of the wetland so that the drainage orifice can be unclogged

regularly? If a flashboard riser is used, is it accessible? Can heavy equipment access the forebay to remove sediment? All aspects of design should consider future maintenance.

*Safety Considerations*
The permanent pool of water presents an attractive play area to children and thus may create safety problems. Design features that discourage child access are recommended. Trash racks and other debris-control structures should be sized to prevent entry by children. Other safety considerations include using fences around the spillway structure, embankment, and stormwater wetland slopes; using shallow safety benches around the stormwater wetland; and posting warning signs.

Fencing of stormwater wetlands is not generally aesthetically pleasing but may be required by the local review authority. A preferred method is to manage the contours of the stormwater wetland to eliminate dropoffs and other safety hazards as discussed above. Riser openings must restrict unauthorized access. Endwalls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent falls.

### 9.3.2 Step 2: Determine the Volume of Water to Treat

*Water Treatment Volume*
A wetland is intended to treat the first flush. Section 3, Stormwater Calculations, details the volumetric calculation.

*Siting Issues*
Stormwater wetlands should not be located within existing jurisdictional wetlands or constructed as in-stream impoundments.

If there are industrial or commercial land uses in the drainage area, accumulated pollutants may eventually increase environmental risk to wildlife. Typical pollutant loads found in residential settings are unlikely to cause this problem.

*Contributing Drainage*
There is no minimum or maximum for the drainage area. Instead, any drainage area that will contribute the minimum volume, 3,630ft$^3$, is allowed. Smaller volumes will be allowed on a case-by-case basis, though supporting calculations such as a water balance or other justification will be required.

*Pretreatment Options*
Wetlands and pond/wetland systems require the use of a forebay (see Section 5.4 for forebay design).

### 9.3.3 Step 3: Determine the Surface Area and Depth of Each Wetland Zone

Flow paths from inlet to outlet points within stormwater wetlands should be maximized. Internal berms and irregular shapes are often used to achieve recommended flow paths. The minimum length to width ratio shall be 1.5:1, however, 3:1 is recommended. Narrow, deep-water zones should be constructed at the wetland inlet and outlet to evenly distribute flow. Inlets also may incorporate pipe manifolds to enhance flow distribution. Deep-water zones perpendicular to the flow direction, and internal berms parallel to the flow, can also be used to reduce the potential for short-circuiting.

The total surface area of the deep pool topographic zone should be broken into several micropools that are well dispersed throughout the wetland so that the distances for fish to travel within the Shallow Water zones to reach the entire wetland is minimized. One deep pool should be located at the entrance of the wetland and one should be located at the exit. Other deep pools can be dispersed throughout the wetland.

*The geometric calculations for wetlands are provided below. As opposed to many other types of BMP designs, the permanent volume of water contained in the stormwater wetland is not part of the design calculations, but is merely a result of the breakdown of hydrologic zones and their respective depths.*

a. <u>Step 3a, Determine the Surface Area of the Entire Wetland and Each Wetland Zone</u>: Two factors determine the surface area, 1.) The watershed volume that is to be contained ($Q_{Volume}$), and 2.) The depth of water that plants can sustain for several days in the shallow land area ($D_{Plants}$) (the depth of the temporary pool), which is up to 12 inches. (Hunt, Doll, 2000). The total surface area of the wetland is determined by the quotient of these variables. Then, determine the surface area of each wetland zone. The surface area of each wetland zone is a percentage of the total required surface area. Calculations for determining the surface areas of the various wetland zones are provided below.
   - *Surface Area*: The total surface area of the wetland is $\dfrac{Q_{Volume}(ft^3)}{D_{Plants}(ft)}$ ($ft^2$).

     (Note: $D_{Plants}$ can be up to 12 inches.) This surface area is distributed to the various wetland zones as outlined below:
     - Deep Pools: Ideally, these should be several areas should be a minimum of 5 $ft^2$ in order to provide a proper habitat for wildlife.
       - Non-Forebay: 5-10% of wetland surface
       - Forebay: 10% of wetland surface (Note: If alternate pre-treatment is used, the surface area dedicated for the forebay may be dispersed among the other topographic regions as necessary.)
     - Shallow Water (low marsh): 40% of wetland surface
     - Shallow Land (high marsh): 30-40% of wetland surface (maximize this percentage if pathogens are the target pollutant)

- Upland: This is an optional design element. If upland is included it will not take up any of the required calculated surface area. It will be in addition to the required area.

b. Step 3b, Determine the Depth: Determine the appropriate depth for each wetland zone. Each level of the wetland has a recommended depth. If a clay liner is used in lieu of installing the deep pools at least six inches below the seasonably high water table, then four inches or more of topsoil shall be added on top of the clay liner. Soil amendments may be necessary depending on results of a soil analysis (see Chapter 6). This will ensure that the plants have adequate soil for growth. If a clay liner is used, it must be installed along the entire bottom of the deep pools and the shallow water areas. This will ensure that water is maintained in these two areas, as they are intended to be underwater at all times. The shallow land area does not need a clay liner. It is intended only to be wet only following rain events. The depths of each wetland topographic zone for each of the two options are shown in Figures 9-7a and 9-7b.
   - Deep Pools:
     - Non-Forebay: This depth is 18-36" (include one at the outlet structure for proper drawdown). The deep pools should be approximately 5 feet in diameter.
     - Forebay: This depth is 18-36" (deepest near the inlet to dissipate hydraulic energy, more shallow near the exit)
   - Shallow Water (low marsh): This depth is 3-6". This is an important requirement. The primary cause of wetland failure is designing this layer to be too deep.
   - Shallow Land (high marsh): This depth is 12". This is the depth, $D_{Plants}$, used in the surface area calculation, and is also the "depth" of the temporary pool.
   - Upland: This area can extend up to approximately 4 feet above the shallow land zone.

c. Step 3c, Check the Volume: Ensure that the volume of the shallow land section can accommodate the treatment volume necessary for the wetland (as was calculated in Step 2). The shallow land zone contains the treatment volume after a rain event. The treatment volume becomes the temporary pool, as shown in Figures 9-7a and 9-7b.

**Figure 9-7a**

Wetland Conceptual Diagram, Option 1: Most Shallow Deep Pools 6+" below the SLWT

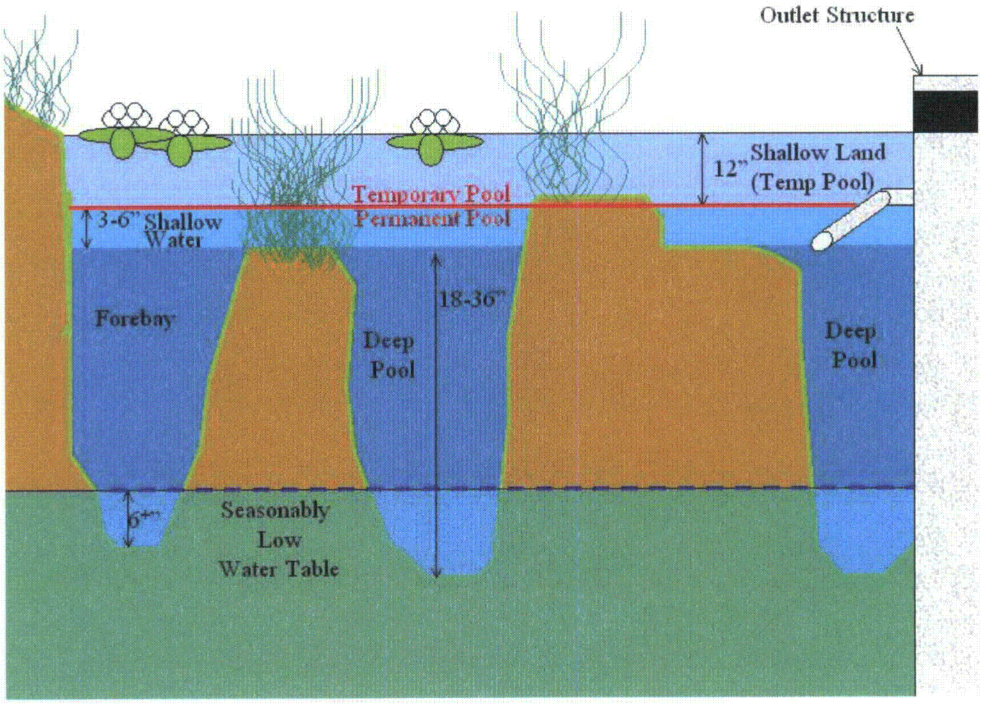
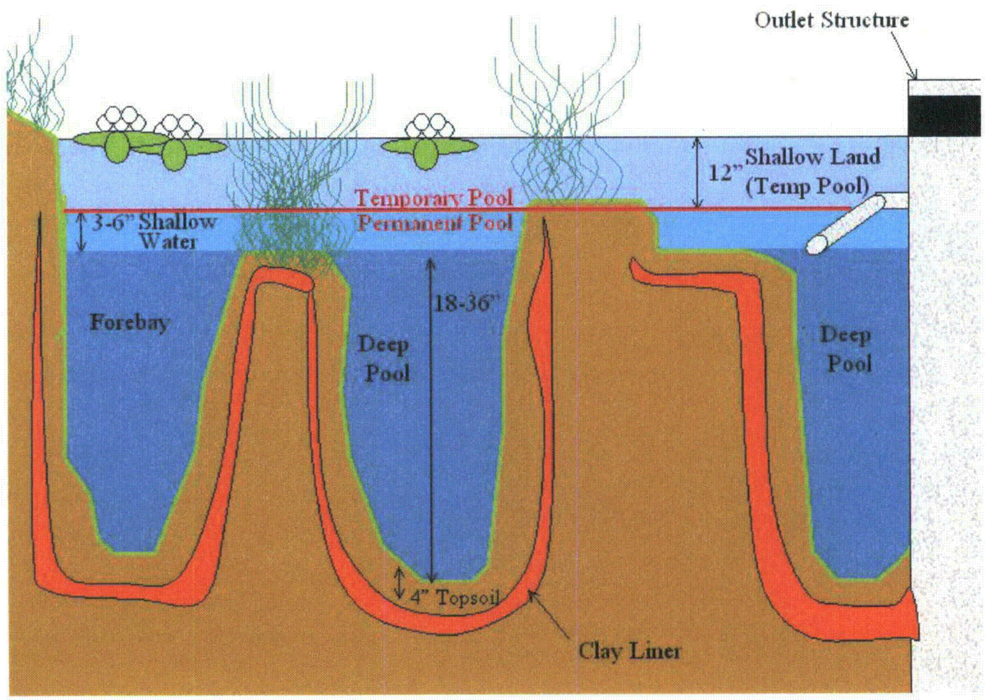



**Figure 9-7b**

Wetland Conceptual Diagram, Option 2: Clay Liner Installed



### 9.3.4 Step 4: Select the Soil Media Type

Stormwater wetlands are appropriate for NRCS type C and D soils. A soil analysis should be conducted within the stormwater facility area to determine the viability of soils to assure healthy vegetation growth and to provide adequate infiltration rates through the topsoil. For wetlands that are designed so that the deep pools are at least six inches below the seasonably low water table, topsoil should make up the top 12 inches of the stormwater wetland except in areas having a permanent pool depth of 6" or more. For wetlands that are designed to have a clay liner, 4" of topsoil shall be added to the top of the clay liner, as shown in Figure 9.7b. In either case, the soil may be amended with organic material (depending on soil analysis results).

If a geosynthetic liner is used to reduce exfiltration from the wetland, a minimum of 1 foot of soil must separate the geosynthetic liner from the planting surface.

### 9.3.5 Step 5: Select the Appropriate Overflow Bypass

The outlet design must be accessible to operators, easy to maintain, and resistant to fouling by floating or submerged plant material or debris. Wetlands should have both low- and high-capacity outlets. High-capacity outlets, such as weir boxes or broad-crested spillways, should be provided unless bypasses are provided for storms in excess of the first flush volume. The low-capacity outlet is typically a drawdown orifice and should be able to draw down the temporary pool within 2-5 days. Multiple-outlet structures are often used to balance the volume control requirements and maintenance needs. Additionally, designers can choose to install manual drawdown valves or flashboard risers (also called sliding weir plates) so that maintenance personnel can drain the wetland for maintenance purposes. If they are installed, they should be secured so that only intended personnel can access them.

The outlet control structure should contain the following:

- High-capacity weir box overflow.
- Low-capacity drawdown sized to drawdown the temporary pool (shallow land zone) in 2-5 days.
- Easy accessibility for inspection and maintenance.

*Overflow structure Maintenance Considerations*

Maintenance should also be considered when designing outlet structures. Often, a wetland will need to be drawn down, such as shown in Figure 9-8. This figure shows the low-capacity drawdown orifice, the high-capacity overflow, and a manually operated valve for maintenance purposes. Alternatively, a flashboard riser can be used to drawdown the water for maintenance, as shown in Figure 9-9.

**Figure 9-8**
Outlet Structure With Manual Drawdown Valve for Maintenance

**Figure 9-9**
Outlet Structure With Flashboard Riser for Maintenance (Wetland Partially Drained)
(Courtesy of Sharon Schulze, NC State Science House)

One method to help ensure that the drawdown orifice does not clog is to turn the orifice downward below the normal pool as shown in Figure 9-10. This will prevent debris floating on the surface from clogging the orifice. If the wetland is located in trout-sensitive waters, consider extending the orifice to close to the bottom of the drawdown structure among a pile of riprap. This will ensure that cooler water enters the stream in an effort to protect trout, which thrive in cold water. The site in Figure 9-10 has been drained.

**Figure 9-10**
Outlet Structure With Down-Turned Drawdown Orifice

The overflow structure should be located near the edge of the wetland so that it can be accessed easily for maintenance, as shown in Figure 9-11. Overflow structures that are several feet into the wetland, as shown in Figure 9-12, will be difficult to reach, and will likely not be well maintained.

**Figure 9-11**
Outlet Structure: Near Wetland Edge, Orifice Easily Accessible for Maintenance

**Figure 9-12**

Outlet Structure: Not Near Wetland Edge, Orifice *Not* Easily Accessible for Maintenance

### 9.3.6 Step 6: Select Plants

High pollutant removal efficiencies in a stormwater wetland depend on a dense cover of emergent plant vegetation. Although various plant types differ in their abilities to remove pollutants from the water column, in general the specific plant species do not appear to be as important for stormwater wetland functioning as plant growth survival and plant densities (Kadlec and Knight 1996). In particular, species should be used that have high colonization and growth rates, can establish large areas that continue through the winter dormant season, have a high potential for pollutant removal, and are very robust in continuously or periodically flooded environments. Non-invasive species should be used. Native species are preferred.

Shrubs and wetland plants should be designed to minimize solar exposure of open water areas (particular critical in mountain settings to prevent thermal pollution of trout waters). A landscape plan prepared by a qualified design professional licensed in North Carolina must be provided to document the methods to be used for establishing and maintaining wetland coverage.

A stormwater wetland facility consists of the area of the wetland, including bottom and side slopes, plus a 10-foot grass buffer around the wetland. Minimum elements of a plan are:

- Delineation of planting ("pondscaping") zones.
- Selection of corresponding plant species.
- A minimum of ten (10) different species, with no more than 30% of a single species.
- 10-foot grass buffer is recommended as Centipede.

- Minimum plant material quantities and plant sizes per 200 square feet:
  - 6 herbaceous plants of at least 4-inch container;
  - 4 shrubs/small trees of at least 1-gallon container;
  - 1 tree of at least 2.5" dbh bare-root or balled and burlapped (B&B) material.
- Source of plant materials.
- Planting layout.
- Sequence and timing for preparing wetland bed (including soil amendments, initial fertilization, and watering, as needed).
- Growing medium specifications (soil specifications).
- Supplementary plantings to replenish losses.

Soil bioengineering techniques, such as the use of fascines and coconut fiber rolls, can be used to create shallow land cells in areas of the stormwater wetland that may be subject to high flow velocities.

In addition, the landscape plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers, as well as aesthetic considerations.

Emergent vegetation (i.e., plants which grow in water but which pierces the surface so that they are partially in air), are an integral component of the water treatment process. Five (5) or more species of emergent wetland plants should be selected in order to optimize treatment processes as well as to promote ecological mosquito control (i.e., attract a variety of predator insects for natural mosquito control).

Cattails *shall not* be planted. Cattails will quickly take over, and choke out other plants in the wetland. This will limit the biodiversity, and ultimately will lead to mosquito infestation.

Plant recommendations are listed in Table 9-1. These lists are not exhaustive. There are many excellent plant references in publication as well as recommendations from wetland scientists and landscape architects. For instructions regarding landscape plan requirements, please refer to Chapter 6 Landscape and Soil Specifications.

**Table 9-1**
Wetland Plant Recommendations

| DEEP POOL | Botanical Name | Common Name |
|---|---|---|
| Floating Aquatic Plants | *Lemna spp.* | Duckweed |
| | *Nuphar polysepalum* | Spatterdock |
| | *Potamogeton spp.* | Pondweed |
| | *Spirodela polyrhiza* | Duckmeat |
| | *Wolffiella lingulata* | Bog mat |
| Submerged Aquatic Plants | *Eleocharis acicularis* | Spikerush |
| | *Elodea spp.* | Waterweed |
| | *Isoetes spp.* | Quillwort |
| | *Lilaeopsis occidentalis* | Lilaeopsis |
| | *Najas spp.* | Naiad |
| | *Zannichellia palustris* | Horned pondweed |

| SHALLOW WATER | Botanical Name | Common Name |
|---|---|---|
| Emergent Plants | *Alisma spp.* | Water plantain |
| | *Acorus spp.* | Sweet flag |
| | *Alopercurus howellii* | Foxtail |
| | *Canna lily* | 'Bengal Tiger' canna |
| | *Cladium jamaicense* | Sawgrass |
| | *Cyperus aristatus* | Flat sedge |
| | *Iris hexagona* | Hexagonal iris |
| | *Iris nelsonii* | Nelson's Iris |
| | *Iris prismatica* | Slender Blue Iris |
| | *Iris virginica* | Blue Flag Iris |
| | *Iris versicolor* | Blue Flag Iris |
| | *Iris fulva* | Copper Iris |
| | *Juncus effusus* | Softrush |
| | *Leptochloa fasicularis* | Salt-meadow grass |
| | *Ludwigia spp.* | Primrose willow |
| | *Oryza sativa* | Rice |
| | *Peltandra virginica* | Arrow Arum |
| | *Plantago major* | Common Plantain |
| | *Pontederia cordata* | Pickerelweed |
| | *Sagittaria latifolia* | Duck Potato |
| | *Sagittaria lancifolia* | Bulltongue |
| | *Sagittaria longiloba* | Arrowhead |
| | *Saururus cernuus* | Lizard Tail |
| | *Schoenoplectus tabernaemontani* | |
| | *Scirpus americanus* | Three-square bulrush |
| | *Zizania aquatica* | Wild rice |
| | *Zizaneopsis miliacea* | Water millet |

| SHALLOW LAND | Botanical Name | Common Name |
|---|---|---|
| Herbaceous Plants | *Asclepias incarnate* | Swamp Milkweed |
| | *Carex spp.* | Sedges |
| | *Chelone glabra* | White Turtlehead |
| | *Crinum americanum* | American crinum lily |
| | *Crinum erubescens* | Swamp lily |
| | *Dichromena latifolia* | White Star Grass |
| | *Eupatorium coelestinum* | Wild Ageratum |
| | *Eupatorium dubium* | Dwarf Joe Pye Weed |
| | *Eupatorium fistulosum* | Joe Pye Weed |
| | *Eupatorium maculatum* | |
| | *Eupatorium purpureum* | |
| | *Helianthus angustifolius* | Swamp sunflower |
| | *Helianthus verticillatus* | |
| | *Hibiscus aculeatus* | Pinelands mallow |
| | *Hibiscus coccinea* | Scarlet rose mallow |
| | *Hibiscus dasycalyx* | Neches River mallow |
| | *Hibiscus grandiflorus* | Velvet mallow |
| | *Hibiscus moscheutus* | Rose mallow |
| | *Hymenocallis eulae* | Spider lily |
| | *Hymenocallis liriosme* | Spring marsh spider lily |
| | *Hymenocallis pygmaea* | Dwarf Spider Lily |
| | *Hymenocallis traubii* | Traub's Spider Lily |
| | *Kosteletskya virginica* | Seashore Mallow |
| | *Lobelia cardinalis* | Cardinal flower |
| | *Lobelia siphilitica, elongata, and allies* (Blue Lobelia) | |
| | *Saccharum giganteum and allies* (Plumegrasses) | |
| | *Zephyranthes atamasco* | Atamasco Lily |
| Shrubs | *Alnus serulata* | Hazel alder |
| | *Aronia arbutifolia* | Red Chokeberry |
| | *Cephalanthus occidentalis* | Common Buttonbush |
| | *Clethra alnifolia* | Summersweet |
| | *Cornus amomum* | Silky Dogwood |
| | *Cyrilla racemiflora* | American Cyrilla |
| | *Gordonia lasianthus* | Loblolly Bay |
| | *Hypericum densiflorum* | Dense Hypericum |
| | *Hypericum prolificum* | Shrubby St.Johnswort |
| | *Ilex decidua* | Possumhaw |
| | *Ilex glabra* | Inkberry |
| | *Ilex verticillata* | Winterberry |
| | *Itea virginica* | Sweetspire |
| | *Kalmia angustifolia* | Lambkill Kalmia |
| | *Magnolia virginica* | Sweetbay Magnolia |
| | *Rosa palustris* | Swamp Rose |
| | *Sambucus canadensis* | Elderberry |
| | *Vaccinium crassifolium* | Creeping Blueberry |
| | *Viburnum nudum* | Possumhaw |

| SHALLOW LAND | Botanical Name | Common Name |
|---|---|---|
| Trees | *Asimina triloba* | Common Pawpaw |
| | *Betula nigra* | River birch |
| | *Carpinus caroliniana* | Ironwood |
| | *Diospyros virginica* | Common persimmon |
| | *Franklinia alatamaha* | Franklinia |
| | *Nyssa biflora* | Swamp blackgum |
| | *Nyssa aquatica* | Water tupelo |
| | *Taxodium distichum* | Bald cypress |

## 9.4 Construction

The wetland must be stabilized within 14 days of construction. Consider construction sequencing so that plants can be planted and the wetland can be brought online within 14 days. Plants may need to be watered during this time if the device is not brought online the same day. Stabilization may be in the form of final vegetation plantings or a temporary means until the vegetation becomes established. A good temporary means of stabilization is a wet hydroseed mix. For rapid germination, scarify the soil to a half-inch prior to hydroseeding.

Inlet and outlet channels should be protected from scour that may occur during periods of high flow. Standard erosion control measures should be used. The Land Quality Section of the North Carolina Department of Environment and Natural Resources and the U.S. Department of Agriculture Natural Resource Conservation Service (NRCS) can provide information on erosion and sediment control techniques.

The stormwater wetland should be staked at the onset of the planting season. Water depths in the wetland should be measured to confirm the original planting zones. At this time, it may be necessary to modify the planting plan to reflect altered depths or the availability of wetland plant stock. Surveyed planting zones should be marked on an "as-built" or record design plan and located in the field using stakes or flags.

The wetland drain should be fully opened for no more than 3 days prior to the planting date (which should coincide with the delivery date for the wetland plant stock) to preserve soil moisture and workability.

The most common and reliable technique for establishing an emergent wetland community in a stormwater wetland is to transplant nursery stock obtained from local aquatic plant nurseries. The optimal period for transplanting extends from early April to mid-June so that the wetland plants will have a full growing season to build the root reserves needed to survive the winter. However, some species may be planted successfully in early fall. Contact your nursery well in advance of construction to ensure that they will have the desired species available.

Post-nursery care of wetland plants is very important in the interval between delivery of the plants and their subsequent installation because they are prone to desiccation. Stock should be frequently watered, fertilized, and shaded.

## 9.5. Maintenance

### 9.5.1 Common Maintenance Issues

Please refer to Section 7.0, General BMP Maintenance, for information on types of maintenance, typical frequency, and specific maintenance tasks that are common to all BMPs. The following information is maintenance that is specific to stormwater wetlands.

The landscape professional managing the wetland should understand the biological requirements of the plants and manage water levels to provide for their needs. Optimum conditions are not always required. The plants' environment is most critical during seed germination and early establishment.

Although wetland plants require water for growth and reproduction, they can be killed due to drowning in excessively deep water. Usually, initial growth is best with transplanted plants in wet, well-aerated soil. Occasional inundation followed by exposure to air of the majority of the vegetation enables the plants to obtain oxygen and grow optimally. Conversely, frequent soil saturation is important for wetland plant survival.

If a minimum coverage of 70 percent is not achieved in the planted wetland zones after the second growing season, supplemental planting should be completed. Coverage of 90 to 95 percent is desirable.

Dramatic shifts can occur as plant succession proceeds. The plant community reflects management and can indicate improvements or problems. For example, a requirement of submergent aquatic plants, such as pondweed (*Potamogeton pectinatos*), is for light to penetrate the water column. The disappearance of these plants may indicate inadequate water clarity. The appearance of invasive species or development of a monoculture is also a sign that there is a problem with the aquatic/soil/vegetative requirements. Additionally, cattails will quickly take over a pond. If cattails become invasive, they can be removed by a licensed aquatic pesticide applicator by wiping aquatic glyphosate, a systemic herbicide, on the cattails.

Unlike maintenance requirements for wet or dry stormwater ponds, sediment should only be selectively removed from stormwater wetlands. Sediment removal disturbs stable vegetation cover and disrupts flowpaths through the wetland. The top few inches of sediment should be stockpiled so that it can be replaced over the surface of the wetland after the completion of sediment removal to re-establish the vegetative cover using its own seed bank. Accumulated sediment should be removed from around inlet and outlet structures.

### 9.5.2 Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- Immediately after the stormwater wetland is established, the wetland plants will be watered twice weekly if needed until the plants become established (commonly six weeks).
- No portion of the stormwater wetland will be fertilized after the first initial fertilization that is required to establish the wetland plants.
- Stable groundcover will be maintained in the drainage area to reduce the sediment load to the wet detention basin.
- Once a year, a dam safety expert will inspect the embankment.

After the wet detention pond is established, I will inspect it **once a month and within 24 hours after every storm event greater than 1.0 inches (or 1.5 inches if in a Coastal County)**. Records of inspection and maintenance will be kept in a known set location and will be available upon request.

Inspection activities shall be performed as follows. Any problems that are found shall be repaired immediately.

**Table 9-2**
Sample Inspection and Maintenance Agreement for Stormwater Wetlands

| **BMP element:** | **Potential problem:** | **How to remediate the problem:** |
|---|---|---|
| **The entire BMP** | Trash/debris is present. | Remove the trash/debris. |
| **The perimeter of the wetland** | Areas of bare soil and/or erosive gullies have formed. | Regrade the soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application. |
| | Vegetation is too short or too long. | Maintain vegetation at a height of approximately six inches. |
| **The inlet device: pipe or swale** | The pipe is clogged (if applicable). | Unclog the pipe. Dispose of the sediment off-site. |
| | The pipe is cracked or otherwise damaged (if applicable). | Replace the pipe. |
| | Erosion is occurring in the swale (if applicable). | Regrade the swale if necessary to smooth it over and provide erosion control devices such as reinforced turf matting or riprap to avoid future problems with erosion. |

**Table 9-2, continued**
Sample Inspection and Maintenance Agreement for Stormwater Wetlands

| BMP element: | Potential problem: | How to remediate the problem: |
|---|---|---|
| **The forebay** | Sediment has accumulated in the forebay to a depth that inhibits the forebay from functioning well. | Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the BMP. |
| | Erosion has occurred. | Provide additional erosion protection such as reinforced turf matting or riprap if needed to prevent future erosion problems. |
| | Weeds are present. | Remove the weeds, preferably by hand. If a pesticide is used, wipe it on the plants rather than spraying. |
| **The deep pool, shallow water and shallow land areas** | Algal growth covers over 50% of the deep pool and shallow water areas. | Consult a professional to remove and control the algal growth. |
| | Cattails, phragmites or other invasive plants cover 50% of the deep pool and shallow water areas. | Remove the plants by wiping them with pesticide (do not spray) - consult a professional. |
| | Shallow land remains flooded more than 5 days after a storm event. | Unclog the outlet device immediately. |
| | Plants are dead, diseased or dying. | Determine the source of the problem: soils, hydrology, disease, etc. Remedy the problem and replace plants. Provide a one-time fertilizer application to establish the ground cover if a soil test indicates it is necessary. |
| | Best professional practices show that pruning is needed to maintain optimal plant health. | Prune according to best professional practices. |
| | Sediment has accumulated and reduced the depth to 75% of the original design depth of the deep pools (see diagram below). | Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the BMP. |

**Table 9-2, continued**

Sample Inspection and Maintenance Agreement for Stormwater Wetlands

| BMP element: | Potential problem: | How to remediate the problem: |
|---|---|---|
| **The embankment** | A tree has started to grow on the embankment. | Consult a dam safety specialist to remove the tree. |
| | An annual inspection by an appropriate professional shows that the embankment needs repair. | Make all needed repairs. |
| | Evidence of muskrat or beaver activity is present. | Use traps to remove muskrats and consult a professional to remove beavers. |
| **The micropool** | Sediment has accumulated and reduced the depth to 75% of the original design depth (see diagram below). | Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the BMP. |
| | Plants are growing in the micropool. | Remove the plants, preferably by hand. If a pesticide is used, wipe it on the plants rather than spraying. |
| **The outlet device** | Clogging has occurred. | Clean out the outlet device. Dispose of the sediment off-site. |
| | The outlet device is damaged | Repair or replace the outlet device. |
| **The receiving water** | Erosion or other signs of damage have occurred at the outlet. | Contact the NC Division of Water Quality 401 Oversight Unit at 919-733-1786. |

<u>September 28, 2007 Changes:</u>

1. Major Design Elements:
    a. Reformatted to include numbered requirements.
    b. Specified that the requirement to drain down within 2 and 5 days is required by the Administrative Code. The Code makes this requirement for wet ponds, and it has been applied to wetlands in this case because this design element is parallel between wet ponds and wetlands.
    c. For clarification, "of drainage" was removed from, "The minimum treatment volume for a stormwater wetland shall be 3,630 $ft^3$ of drainage. Lesser volumes will be approved on a case-by-case basis."
    d. For clarification, "ponding depth" was replaced with "shallow land depth" in the phrase, "Maximum ponding depth shall be 1 foot."
    e. Specified that cattails are not to be planted.
    f. Added, "A forebay is required," per 15A NCAC 02H .1008(e)(6).
    g. Added, "Overflows shall pass through a minimum 30 feet long vegetative filter, 50-foot filter is required for some projects," per 15A NCAC 02H .1008(c)(4) and 15A NCAC 02H .1005(b)(iii).
2. 9.3.1: Clarified that the shallow land topographic zone (zone 3) shall contain the entire treatment volume. Directed readers to Figures 9-7a and 9-7b for further clarification.
3. 9.3.3: Clarified the surface area calculation section to specify that the temporary pool can be up to 12 inches deep, and is contained in the shallow land topographic zone.
4. 9.3.3: Clarified that more than four inches of topsoil above the clay liner is acceptable.
5. Figure 9-7a and 9-7b: Added clarification of the division between the temporary and permanent pools.
6. Figure 9-14: Deleted for clarification.
7. Table 9-2: Deleted the requirement to remove sediment from the forebay when it fills 25% of the forebay.

# 10. Wet Detention Basin

## Description

A wet detention basin is a stormwater management facility that includes a permanent pool of water for removing pollutants and additional capacity above the permanent pool for detaining stormwater runoff.

## Regulatory Credits

*Pollutant Removal*

| | |
|---|---|
| 85% | Total Suspended Solids |
| 25% | Total Nitrogen |
| 40% | Total Phosphorus |

*Water Quantity*

| | |
|---|---|
| yes | Peak Runoff Attenuation |
| no | Runoff Volume Reduction |

## Feasibility Considerations

| | |
|---|---|
| Med-Large | Land Requirement |
| Med | Cost of Construction |
| Med | Maintenance Burden |
| Med-Large | Treatable Drainage Basin Size |
| Med | Possible Site Constraints |
| Med | Community Acceptance |

## Advantages

- Can be aesthetically pleasing and can be sited in both low- and high-visibility areas.
- Can provide wildlife habitat and a focal point for recreation.
- Provides good water quantity control for reducing the frequency of flooding events that cause bank erosion.

## Disadvantages

- Sometimes create problems such as nuisance odors, algae blooms, and rotting debris when not properly maintained.
- Local regulations may impose unappealing features such as fencing around basins to reduce safety hazards.
- May attract excessive waterfowl, which can be a nuisance and can increase fecal coliform levels.
- May contribute to thermal pollution so may not be appropriate in areas where sensitive aquatic species live.

## Major Design Elements

| | |
|---|---|
| **Required by the NC Administrative Rules of the Environmental Management Commission.** Other specifications may be necessary to meet the stated pollutant removal requirements. | |
| 1 | Sizing shall take into account all runoff at ultimate build-out, including off-site drainage. |
| 2 | Vegetated slopes shall be no steeper than 3:1. |
| 3 | BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW. |
| 4 | Basin discharge shall be evenly distributed across a minimum 30 feet long vegetative filter strip unless it is designed to remove 90% TSS. (A 50-ft filter is required in some locations.) |
| 5 | If any portion is used for S&EC during construction must be cleaned out and returned to design state. |
| 6 | The design storage shall be above the permanent pool. |
| 7 | Discharge rate following a 1-inch rainfall shall completely draw down the temporary storage volume between 2 and 5 days. |
| 8 | The average depth of the permanent pool shall be a minimum of 3 feet. |
| 9 | Permanent pool surface area shall be determined using Tables 10-1, 10-2, 10-3, and 10-4. |
| 10 | The flow within the pond shall not short-circuit the pond. |
| 11 | BMP shall be designed with a forebay. |
| 12 | Basin side slopes shall be stabilized with vegetation above the permanent pool level. |
| 13 | The pond shall be designed with side slopes no steeper than 3:1. |
| 14 | The basin shall be designed with sufficient sediment storage to allow for proper operation between scheduled cleanouts. |
| **Required by DWQ policy.** These are based on available research, and represent what DWQ considers necessary to achieve the stated removal efficiencies. | |
| 15 | BMP shall not be located to produce adverse impacts on water levels in adjacent wetlands. |
| 16 | A minimum 10-foot wide vegetated shelf shall be installed around the perimeter. The inside edge of the shelf shall be 6" below the permanent pool elevation; the outside edge of the shelf shall be 6" above the permanent pool elevation. |
| 17 | The forebay volume should be about 20% of the total permanent pool volume, leaving about 80% of the design volume in the main pool. |
| 18 | Freeboard shall be a minimum of 1 foot above the maximum stage of the basin. |

## 10.1. General Characteristics and Purpose

In wet detention basins, a permanent pool of standing water is maintained by the riser—the elevated outlet of the wet detention basin (see Figure 10-1). Water in the permanent pool mixes with and dilutes the initial runoff from storm events. Wet detention basins fill with stormwater and release most of the mixed flow over a period of a few days, slowly returning the basin to its normal depth.

Runoff generated during the early phases of a storm usually has the highest concentrations of sediment and dissolved pollutants. Because a wet detention basin dilutes and settles pollutants in the initial runoff, the concentration of pollutants in the runoff released downstream is reduced. Following storm events, pollutants are removed from water retained in the wet detention basin. Two mechanisms that remove pollutants in wet detention basins include settling of suspended particulates and biological uptake, or consumption of pollutants by plants, algae, and bacteria in the water. However, if the basin is not adequately maintained (e.g., by periodic excavation of the captured sediment), storm flows may re-suspend sediments and deliver them to the stream.

**Figure 10-1**
Permanent Pool of Water in Wet Detention Basin

Wet detention basins are applicable in residential, industrial, and commercial developments where enough space is available. Figures 10-2a and 10-2b are schematic plan views showing the basic elements of a wet detention basin. Wet detention basins are sized and configured to provide significant removal of pollutants from the incoming stormwater runoff. The permanent pool of water is designed for a target TSS removal efficiency according to the size and imperviousness of the contributing watershed. Above this permanent pool of water, wet detention basins are also designed to hold the runoff volume required by the stormwater regulations, and to release it over a period of 2 to 5 days. As a result, most of the suspended sediment and pollutants attached to the sediment settle out of the water. In addition, water is slowly released so that downstream erosion from smaller storms is lessened.

**Figure 10-2a**

Basic Wet Detention Basin Elements: Plan View

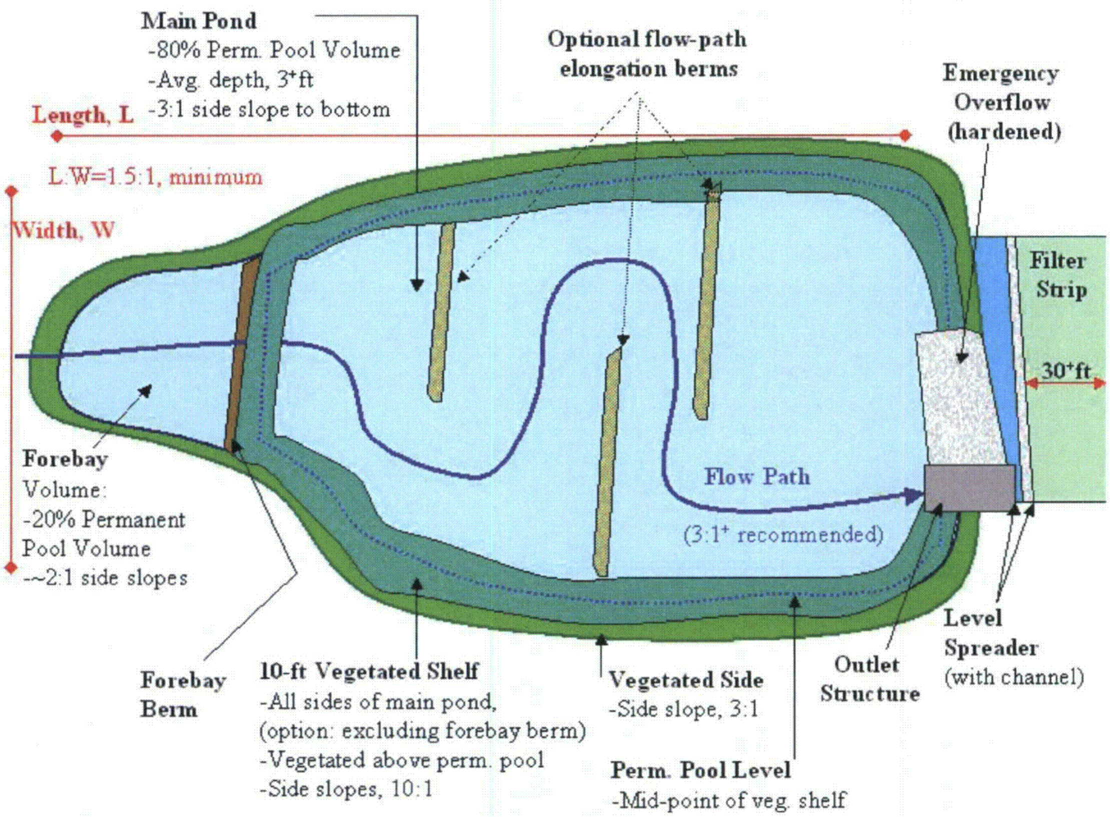
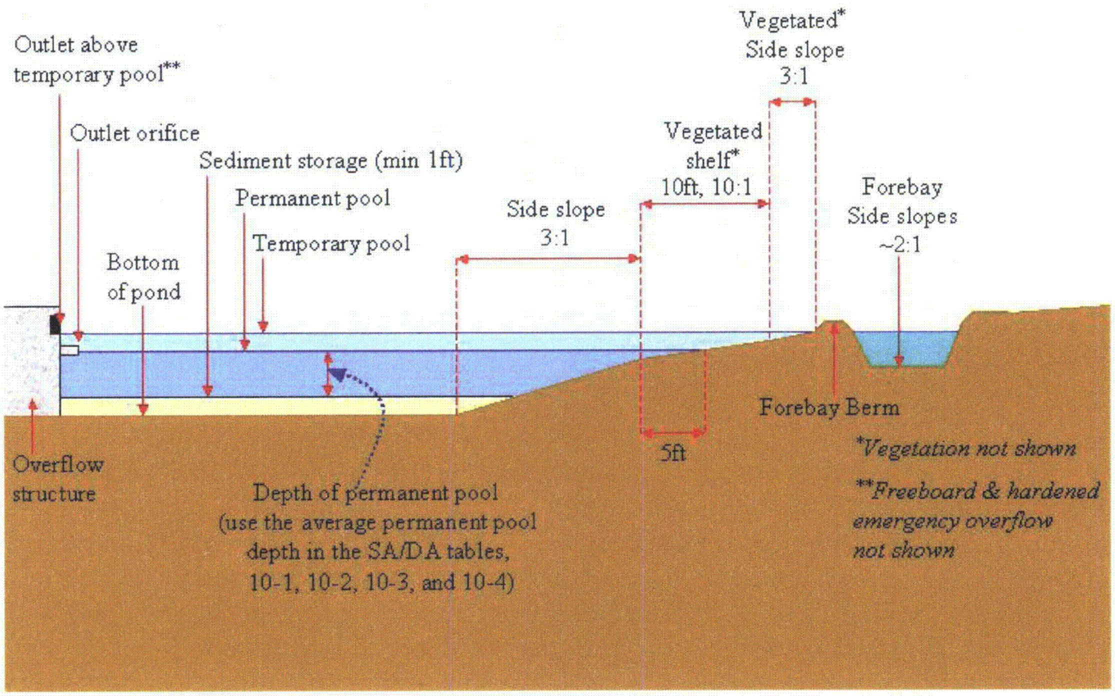


**Figure 10-2b**
Basic Wet Detention Basin Elements: Cross-Section




## 10.2. Meeting Regulatory Requirements

North Carolina rules require that a wet detention basin must be designed by a licensed professional. Further, the designer must subsequently certify that he inspected the facility during construction, that the BMP was built in accordance with the approved plans, and that the system complies with the requirements of the rules.

To obtain a permit to construct a wet detention basin in North Carolina, the wet detention basin must meet all of the regulation-based Major Design Elements listed in the beginning of this section.

To receive the pollutant removal rates listed in the front of this section, the wet detention basin engineering design must, at a minimum, meet all of the Major Design Elements listed in the beginning of this section. Additional regulation-based requirements, and additional good engineering practice requirements, may be required by DWQ.

*Pollutant Removal Rates*

Standard pollutant rates are provided in Table 4-2 in Section 4.0. Construction of a wet detention basin also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading. Further enhancing the passive reduction of nutrient loading is the fact that the surface area of any permanent water surface contributes no nutrient runoff (an export coefficient of 0.0 lb/ac/yr).

*Volume Control Calculations*

Calculations for the temporary pool volume draw-down time are provided in Section 3.4.

If this BMP comes close to meeting your regulatory requirements, but is not exactly what is desired for your site, then these similar types of BMPs might be worth considering: stormwater wetlands, dry extended detention basins.

If this BMP will not meet the regulatory requirements of the site by itself, but is desired to be part of the stormwater treatment solution for the site for other reasons, the following stormwater controls can be used in conjunction to provide enhanced pollution removal rates or volume control capabilities: sand filters, bioretention, infiltration devices, porous pavement, filter strips, grassed swales, and restored riparian buffers.

## 10.3. Design

### 10.3.1. Converting Sediment and Erosion Control Devices

Wet detention basins are typically part of the initial site clearing and grading activities and are often used as sediment basins during construction of the upstream development. The NCDENR *Erosion and Sediment Control Planning and Design Manual* contains design requirements for sediment basins required during construction. A sediment basin typically does not include all the engineering features of a wet detention basin, and the design engineer must insure that the wet detention basin includes all the features identified in this section, including the full sizing as a wet detention basin. If the wet detention basin is used as a sediment trap during construction, all sediment deposited during construction must be removed, erosion features must be repaired, and the vegetated shelf must be restored, before operation as a stormwater BMP begins.

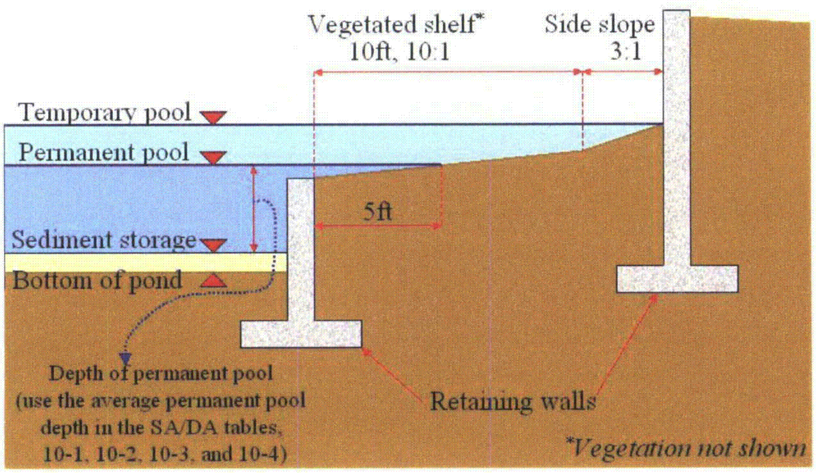
### 10.3.2. Siting Issues

Because large storage volumes are needed to achieve extended detention times, wet detention basins require larger land areas than many other BMPs. Wet detention basins may not be suitable for projects with very limited available land. Permanent retaining walls may be used to obtain the required design volumes while reducing the footprint that would otherwise be required for earthen construction. Retaining walls utilized to contain the permanent pool must not reduce the required 10′ width of the vegetated shelf, and must not extend to a top elevation above the lowest point of the vegetated shelf. Retaining walls utilized to contain the temporary pool must not reduce the required 10′ width of the vegetated shelf, and must not be in contact with the stormwater stored up to the temporary pool elevation. Two retaining walls may be used, as shown in Figure 10-3. Or, the design may be altered to contain only one of the two shown.
Wet detention basins may not be constructed on intermittent streams, on perennial streams, or in jurisdictional wetlands. Large wet detention basins that include a wetland fringe and are abandoned in place without first being drained and regraded may be regulated as wetlands under the provisions of Sections 401 and 404 of the Clean Water Act.

Further, DWQ will require an engineering demonstration that the installation of a wet detention basin adjacent to wetlands will not produce adverse affects on the wetlands water level.

The use of stormwater wet detention basins discharging to cold-water streams capable of supporting trout may be prohibited. Stormwater wet detention basins located in such watersheds should be augmented with engineering measures to significantly reduce or eliminate thermal impacts.

**Figure 10-3**
Alternative Wet Pond Design: Retaining Wall Option



### 10.3.3. Pretreatment and Inflow

Forebays are required on all inlets to a wet detention basin. Chapter 5 Common BMP Design Elements addresses the engineering design requirements for forebays. A properly engineered forebay can concentrate large particle-size sediment for easier removal, and can dissipate the incoming flow energy prior to the stormwater entering the main part of the BMP. The dissipation of incoming flow energy reduces re-suspension of settled material in the main pool, and it reduces the likelihood of erosion features within the BMP. Also, the forebay itself should be configured for energy dissipation within the forebay to avoid re-suspension of large-particle settled material previously captured in the forebay. One of several engineering means of energy dissipation is to have the inlet pipe submerged below the permanent forebay pool level, provided that the inlet placement does not serve to re-suspend previously captured sediment.

DWQ requires that the design volume for the forebay be approximately 20% of the total calculated permanent pool volume. The main pool of the permanent pool would then account for approximately 80% of the design volume.

### 10.3.4. Length, Width (Area), Depth, Geometry

DWQ uses Driscoll's model (US EPA, 1986) to determine the appropriate surface area of the permanent pool for wet detention basins to achieve the required TSS removal rate. The surface area required can be determined using the permanent pool Surface Area to Drainage Area ratio (SA/DA) for given levels of impervious cover and basin depths as outlined in Tables 10-1, 10-2, and 10-3. The tabulated SA/DA ratios are reported as percentages. Table 10-1 is based upon 85 percent TSS removal efficiency in the Mountain and Piedmont regions of North Carolina, while Table 10-2 is based upon 85 percent removal efficiencies for the Coastal region. Table 10-3 presents the design SA/DA ratio for 90 percent TSS removal efficiencies in the Coastal region.

Depth is an important engineering design criterion because most of the pollutants are removed through settling. Very shallow basins may develop currents that can re-suspend materials; on the other hand, very deep wet detention basins can become thermally stratified and/or anoxic and release pollutants back into the water. North Carolina regulations establish 3 feet as the minimum average depth. Further, DWQ requires that the engineering design incorporate a minimum additional depth of one foot for sediment storage. An average pool depth of 3 feet to 7.5 feet is recommended as optimal. Further, DWQ requires that the engineering design include a minimum freeboard of one foot above the maximum stage of the basin.

The permanent pool average depth is defined as the permanent pool volume divided by the permanent pool surface area.

**Table 10-1**

Surface Area to Drainage Area Ratio for Permanent Pool Sizing to Achieve *85 Percent* TSS Pollutant Removal Efficiency in the *Mountain and Piedmont* Regions, Adapted from Driscoll, 1986

| Percent Impervious Cover | Permanent Pool Average Depth (ft) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 |
| 10% | 0.59 | 0.49 | 0.43 | 0.35 | 0.31 | 0.29 | 0.26 |
| 20% | 0.97 | 0.79 | 0.70 | 0.59 | 0.51 | 0.46 | 0.44 |
| 30% | 1.34 | 1.08 | 0.97 | 0.83 | 0.70 | 0.64 | 0.62 |
| 40% | 1.73 | 1.43 | 1.25 | 1.05 | 0.90 | 0.82 | 0.77 |
| 50% | 2.06 | 1.73 | 1.50 | 1.30 | 1.09 | 1.00 | 0.92 |
| 60% | 2.40 | 2.03 | 1.71 | 1.51 | 1.29 | 1.18 | 1.10 |
| 70% | 2.88 | 2.40 | 2.07 | 1.79 | 1.54 | 1.35 | 1.26 |
| 80% | 3.36 | 2.78 | 2.38 | 2.10 | 1.86 | 1.60 | 1.42 |
| 90% | 3.74 | 3.10 | 2.66 | 2.34 | 2.11 | 1.83 | 1.67 |

**Table 10-2**

Surface Area to Drainage Area Ratio for Permanent Pool Sizing to Achieve *85 Percent* TSS Pollutant Removal Efficiency in the *Coastal* Region, Adapted from Driscoll, 1986

| Percent Impervious Cover | Permanent Pool Average Depth (ft) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5′ |
| 10% | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| 20% | 1.7 | 1.3 | 1.2 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 |
| 30% | 2.5 | 2.2 | 1.9 | 1.8 | 1.6 | 1.5 | 1.3 | 1.2 | 1.0 | 0.9 |
| 40% | 3.4 | 3.0 | 2.6 | 2.4 | 2.1 | 1.9 | 1.6 | 1.4 | 1.1 | 1.0 |
| 50% | 4.2 | 3.7 | 3.3 | 3.0 | 2.7 | 2.4 | 2.1 | 1.8 | 1.5 | 1.3 |
| 60% | 5.0 | 4.5 | 3.8 | 3.5 | 3.2 | 2.9 | 2.6 | 2.3 | 2.0 | 1.6 |
| 70% | 6.0 | 5.2 | 4.5 | 4.1 | 3.7 | 3.3[a] | 2.9 | 2.5 | 2.1 | 1.8 |
| 80% | 6.8 | 6.0 | 5.2 | 4.7 | 4.2 | 3.7 | 3.2 | 2.7 | 2.2 | 2.0 |
| 90% | 7.5 | 6.5 | 5.8 | 5.3 | 4.8 | 4.3 | 3.8 | 3.3 | 2.8 | 1.3 |
| 100% | 8.2 | 7.4 | 6.8 | 6.2 | 5.6 | 5.0 | 4.4 | 3.8 | 3.2 | 2.6 |

**Table 10-3**

Surface Area to Drainage Area Ratio for Permanent Pool Sizing to Achieve *90 Percent* TSS Pollutant Removal Efficiency in the *Mountain and Piedmont* Regions, Adapted from Driscoll, 1986

| Percent Impervious Cover | Permanent Pool Average Depth (ft) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 |
| 10% | 0.9 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 |
| 20% | 1.5 | 1.3 | 1.1 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 |
| 30% | 1.9 | 1.8 | 1.7 | 1.5 | 1.4 | 1.4 | 1.3 | 1.1 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 |
| 40% | 2.5 | 2.3 | 2.0 | 1.9 | 1.8 | 1.7 | 1.6 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 |
| 50% | 3.0 | 2.8 | 2.5 | 2.3 | 2.0 | 1.9 | 1.9 | 1.8 | 1.7 | 1.6 | 1.6 | 1.5 | 1.5 |
| 60% | 3.5 | 3.2 | 2.8 | 2.7 | 2.5 | 2.4 | 2.2 | 2.1 | 1.9 | 1.9 | 1.8 | 1.8 | 1.7 |
| 70% | 4.0 | 3.7 | 3.3 | 3.1 | 2.8 | 2.7 | 2.5 | 2.4 | 2.2 | 2.1 | 2.0 | 2.0 | 1.9 |
| 80% | 4.5 | 4.1 | 3.8 | 3.5 | 3.3 | 3.0 | 2.8 | 2.7 | 2.6 | 2.4 | 2.3 | 2.1 | 2.0 |
| 90% | 5.0 | 4.5 | 4.0 | 3.8 | 3.5 | 3.3 | 3.0 | 2.9 | 2.8 | 2.7 | 2.6 | 2.5 | 2.4 |

**Table 10-4**

Surface Area to Drainage Area Ratio for Permanent Pool Sizing to Achieve *90 Percent* TSS Pollutant Removal Efficiency in the *Coastal Region*, Adapted from Driscoll, 1986

| Percent Impervious Cover | Permanent Pool Average Depth (ft) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5′ |
| 10% | 1.3 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 |
| 20% | 2.4 | 2.0 | 1.8 | 1.7 | 1.5 | 1.4 | 1.2 | 1.0 | 0.9 | 0.6 |
| 30% | 3.5 | 3.0 | 2.7 | 2.5 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.8 |
| 40% | 4.5 | 4.0 | 3.5 | 3.1 | 2.8 | 2.5 | 2.1 | 1.8 | 1.4 | 1.1 |
| 50% | 5.6 | 5.0 | 4.3 | 3.9 | 3.5 | 3.1 | 2.7 | 2.3 | 1.9 | 1.5 |
| 60% | 7.0 | 6.0 | 5.3 | 4.8 | 4.3 | 3.9 | 3.4 | 2.9 | 2.4 | 1.9 |
| 70% | 8.1 | 7.0 | 6.0 | 5.5 | 5.0 | 4.5 | 3.9 | 3.4 | 2.9 | 2.3 |
| 80% | 9.4 | 8.0 | 7.0 | 6.4 | 5.7 | 5.2 | 4.6 | 4.0 | 3.4 | 2.8 |
| 90% | 10.7 | 9.0 | 7.9 | 7.2 | 6.5 | 5.9 | 5.2 | 4.6 | 3.9 | 3.3 |
| 100% | 12 | 10.0 | 8.8 | 8.1 | 7.3 | 6.6 | 5.8 | 5.1 | 4.3 | 3.6 |

The engineering design of a wet detention basin must include a 10-foot-wide (minimum) vegetated shelf around the full perimeter of the basin. The inside edge of the shelf shall be no deeper than 6″ below the permanent pool level, and the outside edge shall be 6″ above the permanent pool level. For a 10′ wide shelf, the resulting slope is 10:1. With half the required shelf below the water (maximum depth of 6 inches), and half the required shelf above the water, the vegetated shelf will provide a location for a diverse population of emergent wetland vegetation that enhances biological pollutant removal, provides a habitat for wildlife, protects the shoreline from erosion, and improves sediment trap efficiency. A 10′ wide shelf also provides a safety feature prior to the deeper permanent pool.

Short-circuiting of the stormwater must be prevented. The most direct way of minimizing short-circuiting is to maximize the length of the flow path between the inlet and the outlet: basins with long and narrow shapes can maximize the length of the flow path. Long and narrow but irregularly shaped wet detention basins may appear more natural and therefore may have increased aesthetic value. If local site conditions prohibit a relatively long, narrow facility, baffles may be placed in the wet detention basin to lengthen the stormwater flow path as much as possible. Baffles must extend to the temporary pool elevation or higher. A minimum length-to-width ratio of 1.5:1 is required, but a flow path of at least 3:1 is recommended. Basin shape should minimize dead storage areas, and where possible the width should expand as it approaches the outlet.

Although larger wet detention basins typically remove more pollutants, a threshold size seems to exist above which further improvement of water quality by sedimentation is negligible. The water treatment volume within a wet detention basin is calculated as the total volume beneath the permanent pool water level, and above the sediment storage volume, including any such volume within the forebay.

### 10.3.5. Temporary Storage Volume

In addition to the permanent pool volume, the basin must also have temporary pool storage to provide volume control during storm events. This temporary pool storage volume is located above the permanent pool, and below the 1-foot minimum freeboard requirement. The required temporary pool volume must be calculated as specified in Section 3.3.1.

### 10.3.6. Sediment Accumulation

North Carolina rules require that the wet detention basin shall be sized with an additional volume to account for sediment deposition between clean-out intervals (typically 5 to 15 years). DWQ requires that engineering designs for wet detention basins include at least one additional foot of depth for sediment storage in addition to the permanent pool volume. It is important that operation and maintenance agreements specify that the forebay and the wet pond be cleaned out as soon as the extra sediment storage depth is exhausted. A benchmark for sediment removal should be established to assure timely maintenance. Calculations for volumes and sediment accumulation are provided in Section 3.0.

### 10.3.7. Plant and Landscape Requirements

The design of a wet detention basin is not complete without a detailed landscaping plan. The planting plan must be prepared by a qualified design professional licensed in North Carolina (see Chapter 6 for landscape plan requirements). The landscaping plan for a stormwater wet detention basin should provide specifications for the selection of vegetation, its installation, and the post-installation care for the vegetated shelf, the 3:1 side slopes, the vegetative filter strip, and the immediately surrounding areas.

Wet detention basins should incorporate several diverse species of shallow water and shallow land [wetland] vegetation on the vegetated shelf. Sections 6.2.2 and 6.2.3 discuss the planting requirements for shallow water and shallow land areas. Table 9-1 contains a list of appropriate plant species. Diversity in species increases the robustness of the vegetated shelf by increasing the chances that some species will survive minor changes in the permanent pool water level. This vegetation enhances pollutant removal, protects the shoreline from erosion, and increases safety by discouraging people from entering the basin. A wide range of potential plant species is available for this purpose.

On the tops of berms and on the exterior slopes of containment berms, maintain turf grass in access areas; *Centipede* grass is recommended. Well-maintained grass stabilizes the embankment, enhances access to the facility, and makes inspection and other maintenance much easier. Because many plants release phosphorus in the winter when they die off, wet detention ponds used for phosphorous control should be planted with broad-leaf evergreen trees and shrubs.

Where trees and shrubs are part of the planting plan, they should be selected to maximize shading, primarily along the south, east, and west sides of the basin. This has two benefits: it reduces thermal heating of the water, and it helps to maintain a healthy and aesthetic pond by reducing algal blooms and the potential for anaerobic conditions. Full size trees and very large woody shrubs should not be planted on embankments since under some circumstances their presence can threaten the structural integrity of the embankment. All trees and shrubs should be set back so that the branches will not extend over the basin.

Wildflowers, native grasses, and ground covers should be selected to minimize mowing; fertilizing will be allowed for initial establishment.

### 10.3.8. Surrounding Soils and Liners

When a wet detention basin is to be located in gravelly sands or fractured bedrock, the designer may incorporate a liner to sustain a permanent pool of water. When wet detention basins are near wetlands or other waters, additional engineering calculations and engineering measures may be necessary to insure that these waters will not be adversely affected by the location of the wet detention basin nor will the wet detention basin be drained into the adjacent waters. The installation of additional engineering features, such as slurry walls, liners, or other barriers may be required.

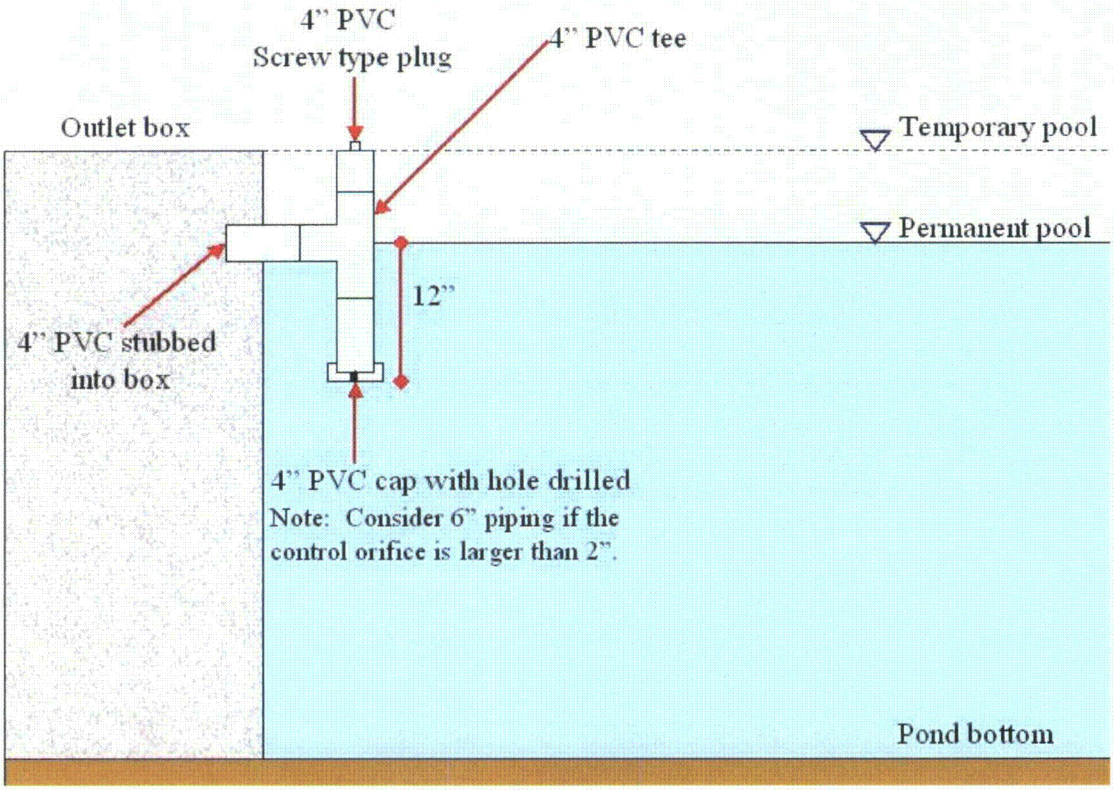
### 10.3.9. Outlet Design

The outlet device shall be designed to release the temporary pool volume over a period of 48 to 120 hours (2 to 5 days). Longer detention times typically do not improve settling efficiency significantly, and the temporary pool volume must be available for the next storm. In addition, prolonged periods of inundation can adversely affect the wetland vegetation growing on the vegetated shelf.

In addition to being designed to achieve the 2 to 5-day drawdown period, outlets also must be functionally simple and easy to maintain. One configuration of the outlet piping that simplifies maintenance and reduces the potential for obstruction is the submerged orifice arrangement shown in Figure 10-4.

**Figure 10-4**

Typical Submerged Orifice Outlet Configuration




Durable materials, such as reinforced concrete, are preferable to corrugated metal in most instances. The riser should be placed in or at the face of the embankment. By placing the riser close to the embankment, maintenance access is facilitated and flotation forces are reduced. The design engineer must present flotation force calculations for any outlet design subject to flotation forces. Outlets are described in greater detail in Section 5.0, Common BMP Design Elements.

Emergency overflow spillways must be designed with hardened materials at the points where extreme conditions might compromise the integrity of the structure.

Under most circumstances North Carolina rules require a vegetative filter strip on the discharge from a wet detention basin, along with a level spreader or other engineered device to ensure even, non-erosive distribution of the flow. Wet detention ponds designed for 85% TSS removal are required to discharge through a 30 foot vegetated filter to minimize erosion and to provide additional pollutant removal. There may be projects where it is difficult to construct a functional vegetated filter, and the outflow must discharge to the watercourse. In these instances, additional storage should be provided to compensate for the lack of a filter and the pond must be designed to remove 90% TSS instead of 85%. Chapter 13 Filter Strip contains information on the design elements of the vegetative filter strip. Chapter 8 Level Spreader contains information on the design elements of a level spreader.

### 10.3.10. Fountains in the Wet Pond

Fountains are optional, decorative wet pond amenities. If they are included they shall be designed as follows:

1. The fountain must draw its water from less than 2' below the permanent pool surface.
2. Separated units (where the nozzle, pump and intake are connected by tubing) may be used only if they draw water from the surface in the deepest part of the pond.
3. The falling water from the fountain must be centered in the pond, away from the shoreline.
4. The maximum horsepower for the fountain's pump is based on the permanent pool volume, as described in Table 10-5. As an example, if the pond's volume is 350,000 cubic feet, the maximum pump horsepower for the fountain is 1. For ponds with less than 30,000 cubic feet, use 1/8 HP.

**Table 10-5**
Fountain Pump Power Requirements

| Minimum Pond Volume ($ft^3$) | Max Pump HP |
|---|---|
| 30,000 | 1/8 |
| 40,000 | 1/6 |
| 60,000 | 1/4 |
| 80,000 | 1/3 |
| 125,000 | 1/2 |
| 175,000 | 3/4 |
| 250,000 | 1 |
| 450,000 | 2 |
| 675,000 | 3 |

### 10.3.11. Safety Considerations

The permanent pool of water presents an attractive play area to children and thus may create safety problems. Engineering design features that discourage child access are recommended. Trash racks and other debris-control structures should be sized to prevent entry by children. Other safety considerations include using fences around the spillway structure, embankment, and wet detention basin slopes; using shallow safety benches around the wet detention basin; and posting warning signs.

Fencing of wet detention basins is not generally aesthetically pleasing but may be required by the local review authority. A preferred method is to engineer the contours of the wet detention basin to eliminate drop offs and other safety hazards as discussed above. Riser openings must not permit unauthorized access. End walls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent falls.

## 10.4 Construction

Even moderate rainfall events during the construction of a wet detention basin can cause extensive damage to it. Protective measures should be employed both in the contributing drainage area, and at the wet detention basin itself. Temporary drainage or erosion control measures should be used to reduce the potential for damage to the wet detention basin before the site is stabilized. The control measures may include stabilizing the surface with erosion mats, sediment traps, and diversions. Vegetative cover and the emergency spillway also should be completed as quickly as possible during construction.

The designer should address the potential for bedding erosion and catastrophic failure of any buried outlet conduit. A filter diaphragm and drain system should be provided along the barrel of the principal spillway to prevent piping. DWQ is aware of an evolution in standard practice, and of accumulated evidence suggesting that in most circumstances filter diaphragms are much superior to anti-seep collars in preventing piping. DWQ strongly prefers filter diaphragms to the older design anti-seep collar.

If reinforced concrete pipe is used for the principal spillway, "O-ring" gaskets (ASTM C361) should be used to create watertight joints and should be inspected during installation.

## 10.5. Maintenance

### 10.5.1 Common Maintenance Issues

Please refer to Section 7.0, General BMP Maintenance, for information on types of maintenance, typical frequency, and specific maintenance tasks that are common to all BMPs. The following information is maintenance that is specific to wet detention basins. Specific items that require careful inspection for a wet detention basin include: evaluation of the aquatic environment, vegetation, and sediment build-up.

A program of monitoring the aquatic environment of a permanent wet detention basin should be established. Items such as water clarity and algal growth should be monitored regularly.

The vegetation located on the vegetated shelf must be properly maintained in order to achieve additional pollutant removal and in order to prevent bank erosion. Bare spots, weeds, and invasive species should be noted and remedied as soon as possible to prevent larger problems. Although a regular grass maintenance program for the upland locations around the BMP will reduce weed intrusion, some weeds invariably will appear. Periodic weeding will therefore be necessary. Chemical application to control weeds should be carefully considered and monitored. Frequent maintenance activities such as removing debris and cutting grass will result in a facility that is both functional and attractive.

Sediment accumulation should be monitored through visual inspection of the basin bottoms and the sediment accumulation depth marker. When the specified depth of sediment has been reached in either the forebay or main basin, the sediment should be removed and disposed of properly, and the forebay or main basin repaired as designed (e.g. proper vegetation replaced).

### 10.5.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- Immediately after the wet detention basin is established, the plants on the vegetated shelf and perimeter of the basin should be watered twice weekly if needed, until the plants become established (commonly six weeks).
- No portion of the wet detention pond should be fertilized after the first initial fertilization that is required to establish the plants on the vegetated shelf.
- Stable groundcover should be maintained in the drainage area to reduce the sediment load to the wet detention basin.
- If the basin must be drained for an emergency or to perform maintenance, the flushing of sediment through the emergency drain should be minimized to the maximum extent practical.
- Once a year, a dam safety expert should inspect the embankment.

After the wet detention pond is established, it should be inspected **once a month and within 24 hours after every storm event greater than 1.0 inches (or 1.5 inches if in a Coastal County)**. Records of inspection and maintenance should be kept in a known set location and must be available upon request.

Inspection activities shall be performed as follows. Any problems that are found shall be repaired immediately.

**Table 10-6**
Sample Inspection and Maintenance Provisions for Wet Detention Basins

| BMP element: | Potential problems: | How to remediate the problem: |
|---|---|---|
| **The entire BMP** | Trash/debris is present. | Remove the trash/debris. |
| **The perimeter of the wet detention basin** | Areas of bare soil and/or erosive gullies have formed. | Regrade the soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application. |
| | Vegetation is too short or too long. | Maintain vegetation at a height of approximately six inches. |
| **The inlet device: pipe or swale** | The pipe is clogged. | Unclog the pipe. Dispose of the sediment off-site. |
| | The pipe is cracked or otherwise damaged. | Replace the pipe. |
| | Erosion is occurring in the swale. | Regrade the swale if necessary to smooth it over and provide erosion control devices such as reinforced turf matting or riprap to avoid future problems with erosion. |
| **The forebay** | Sediment has accumulated to a depth greater than the original design depth for sediment storage. | Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the BMP. |
| | Erosion has occurred. | Provide additional erosion protection such as reinforced turf matting or riprap if needed to prevent future erosion problems. |
| | Weeds are present. | Remove the weeds, preferably by hand. If pesticide is used, wipe it on the plants rather than spraying. |

**Table 10-6, continued**
Sample Inspection and Maintenance Provisions for Wet Detention Basins

| BMP element: | Potential problems: | How to remediate the problem: |
|---|---|---|
| **The vegetated shelf** | Best professional practices show that pruning is needed to maintain optimal plant health. | Prune according to best professional practices |
| | Plants are dead, diseased or dying. | Determine the source of the problem: soils, hydrology, disease, etc. Remedy the problem and replace plants. Provide a one-time fertilizer application to establish the ground cover if a soil test indicates it is necessary. |
| | Weeds are present. | Remove the weeds, preferably by hand. If pesticide is used, wipe it on the plants rather than spraying. |
| **The main treatment area** | Sediment has accumulated to a depth greater than the original design sediment storage depth. | Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the BMP. |
| | Algal growth covers over 50% of the area. | Consult a professional to remove and control the algal growth. |
| | Cattails, phragmites or other invasive plants cover 50% of the basin surface. | Remove the plants by wiping them with pesticide (do not spray). |
| **The embankment** | Shrubs have started to grow on the embankment. | Remove shrubs immediately. |
| | Evidence of muskrat or beaver activity is present. | Use traps to remove muskrats and consult a professional to remove beavers. |
| | A tree has started to grow on the embankment. | Consult a dam safety specialist to remove the tree. |
| | An annual inspection by an appropriate professional shows that the embankment needs repair. | Make all needed repairs. |
| **The outlet device** | Clogging has occurred. | Clean out the outlet device. Dispose of the sediment off-site. |
| | The outlet device is damaged | Repair or replace the outlet device. |
| **The receiving water** | Erosion or other signs of damage have occurred at the outlet. | Contact the local NC Division of Water Quality Regional Office, or the 401 Oversight Unit at 919-733-1786. |

**Figure 10-5: Example Clean Out Diagram**

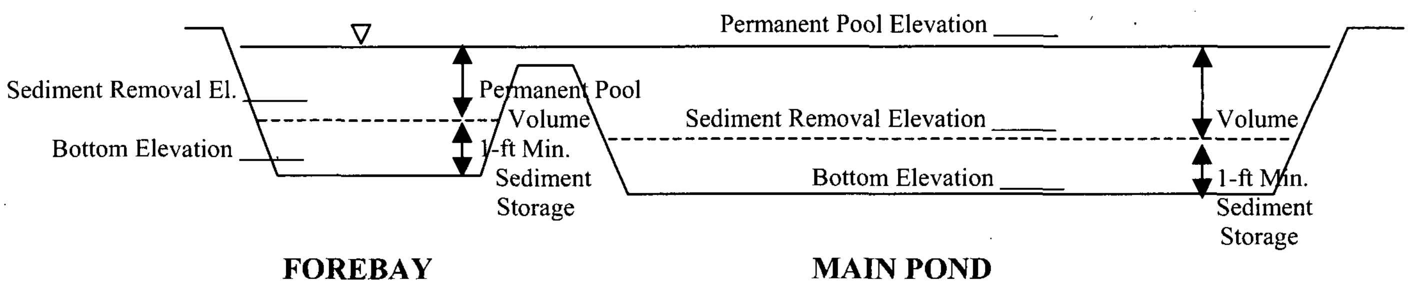
The measuring device used to determine the sediment elevation shall be such that it will give an accurate depth reading and not readily penetrate into accumulated sediments.

When the permanent pool depth reads ______ feet in the main pond, the sediment shall be removed.

When the permanent pool depth reads ______ feet in the forebay, the sediment shall be removed.

## BASIN DIAGRAM

*(fill in the blanks)*



<u>September 28, 2007 Changes:</u>

1. Major Design Elements:
   i. Reformatted to include numbered requirements.
   ii. Clarified the filter strip requirements for ponds designed to remove 90% TSS. The requirement now reads, "Basin discharge shall be evenly distributed across a minimum 30 feet long vegetative filter strip unless it is designed to remove 90% TSS. (A 50-ft filter is required in some locations.)"
   iii. For clarification, the word "full" was removed from, "A minimum 10-foot wide vegetated shelf shall be installed around the full perimeter."
   iv. Added "The pond shall be designed with side slopes no steeper than 3:1." per 15A NCAC 02H .1008(e)(8). The vegetated 3:1 requirement was already included per 15A NCAC 02H .1008(c)(2).
   v. Added, "If any portion is used for S&EC during construction must be cleaned out and returned to design state." per 15A NCAC 02H .1008(c)(7).
   vi. Added, "The design storage shall be above the permanent pool." per 15A NCAC 02H .1008(e)(1).
   vii. Added, "The flow within the pond shall not short-circuit the pond." per 15A NCAC 02H .1008(e)(4).
2. 10.3.2: Added, "Two retaining walls may be used, as shown in Figure 10-3. Or, the design may be altered to contain only one of the two shown," to clarify the wet pond design requirements when retaining wall(s) are used.
3. 10.3.5: Removed a reference to the Simple Method, and specified that the treatment volume shall be calculated as specified in Section 3.
4. 10.3.6: Added "in addition to the permanent pool volume" to, "DWQ requires that engineering designs for wet detention basins include at least one additional foot of depth for sediment storage in addition to the permanent pool volume." This is also shown in Figure 10-2b and 10-3.
5. 10.3.7: Added a reference to the vegetated shelf planting requirements in Chapter 6 and the list of appropriate wetland plantings for the vegetated shelf in Chapter 9.
6. 10.3.9: Clarified the filter strip requirements for ponds designed to remove 90% TSS.
7. 10.3.10: Added guidance for decorative fountains.
8. 10.5.2: Deleted references to "aquatic shelf". Replaced with "vegetated shelf".
9. Figure 10-2a: Renumbered (previously Figure 10-2). Altered previous diagram for clarification. (Plan view wet pond requirements.)
10. Figure 10-2b: Added a figure showing a cross-section of wet pond requirements.
11. Figure 10-3: Added a figure showing the retaining wall option.
12. Figure 10-4: Renumbered. Previously Figure 10-3.
13. Figure 10-5: Added and example clean out diagram for clarification.
14. Table 10-3: Added 90% TSS SA/DA table for the piedmont region.
15. Table 10-4: Renumbered. Previously Table 10-3.
16. Table 10-5: Added decorative fountain pump horsepower requirements.
17. Table 10-6: Renumbered. Previously Table 10-4.

# 11. Sand Filter

## Description

A sand filter is a device that allows stormwater to percolate down through a sand media where pollutants are filtered out.

## Regulatory Credits

*Pollutant Removal*

| | |
|---|---|
| 85% | Total Suspended Solids |
| 35% | Total Nitrogen |
| 45% | Total Phosphorus |

*Water Quantity*

| | |
|---|---|
| possible | Peak Attenuation |
| possible | Volume Capture |

## Feasibility Considerations

| | |
|---|---|
| Med | Land Requirement |
| High | Cost of Construction |
| High | Maintenance Burden |
| Small | Treatable Basin Size |
| Med | Possible Site Constraints |
| Med | Community Acceptance |

## Advantages

- Highly effective at filtering TSS.
- Underground sand filters are useful where space is limited.
- Perimeter sand filters useful for small sites with flat terrain or high water table.

## Disadvantages

- If anoxic conditions develop in the sand filter due to poor drainage, phosphorus levels can increase as water passes through the sand filter.
- May not be effective in controlling peak discharges.
- Large sand filters without vegetation may not be attractive in residential areas.
- Expensive.

## Major Design Elements

| | |
|---|---|
| **Required by the NC Administrative Rules of the Environmental Management Commission.** Other specifications may be necessary to meet the stated pollutant removal requirements. | |
| 1 | Sizing shall take into account all runoff at ultimate build-out including off-site drainage. |
| 2 | Vegetated side slopes shall be no steeper than 3:1. |
| 3 | BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW. |
| 4 | Seasonally high groundwater table must be at least 2 feet below the bottom of the filter for open-bottom designs. |
| 5 | Volume in excess of the design volume, as determined from the design storm, shall bypass the sand filter. |
| 6 | Volume in excess of the design volume, as determined from the design storm, shall be evenly distributed across a minimum 30 feet long vegetated filter strip. (A 50-ft filter is required in some locations.) If this can not be attained, alternate designs will be considered on a case by case basis. |
| 7 | The design shall be located a minimum of 30 feet from surface waters, and 50 feet from Class SA waters. |
| 8 | The design shall be located a minimum of 100 feet from water supply wells. |

| | |
|---|---|
| **Required by DWQ policy.** These are based on available research, and represent what DWQ considers necessary to achieve the stated removal efficiencies. | |
| 9 | Seasonally high groundwater table must be at least 1 foot below the bottom of the filter for closed filter designs in order to prevent draining the water table and floatation. Exceptions will be made if these concerns are mitigated. |
| 10 | Maximum contributing drainage basin is 5 acres. |
| 11 | Minimum width (parallel to flow) of a sedimentation chamber or forebay shall be 1.5 feet. |
| 12 | Sand filter must completely drain within 40 hours. |
| 13 | Sand media shall be as specified below and shall be a minimum of 18" deep (minimum of 12" over the drainage pipes). |
| 14 | For underground sand filters, provide at least 5 feet of clearance between the surface of the sand filter and the bottom of the roof of the underground structure. |

## 11.1. General Characteristics and Purpose

Sand filters can be of open basin design, as shown in Figure 11-1, or of buried trench design (a closed basin), as shown in Figures 11-2a, and 11-2b. Sand filters will typically have underdrain systems to collect the stormwater for discharge from the BMP, but they can also be designed as infiltration type systems if the in-situ soils have appropriate permeability. In contrast to the infiltration devices presented in Section 16, sand filters require that the stormwater pass through a specific depth of specific sand media prior to leaving the device, whereas infiltration devices don't have a media requirement other than sometimes to provide void storage space (such as in an infiltration trench).

Sand filters are designed primarily for water quality enhancement; flow volume control is typically a secondary consideration. They are generally applied to land uses with a large fraction of impervious surfaces. Although an individual sand filter can only handle a small contributing drainage basin, multiple units can be dispersed throughout a large site.

## 11.2. Meeting Regulatory Requirements

A listing of the major design elements is provided on the first page of this section. At a minimum, any sand filter must meet the major design elements indicated as being from the North Carolina Administrative Code. To receive the pollutant removal rates listed in the front of this Section, the sand filter must meet all of the major design elements listed in the beginning of this Section.

*Pollutant Removal Calculations*
The pollutant removal calculations for sand filters are as described in Section 3.4, and use the pollutant removal rates shown at the beginning of this Section. Construction of an open basin sand filter also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading. Buried trench sand filters receive whatever runoff values the surface above them is assigned.

*Volume Control Calculations*
A sand filter can be designed with enough storage to provide active volume capture (calculations for which are provided in Section 3.4), however, special provisions must typically be made to the outlet to provide peak flow attenuation. An open basin sand filter provides some passive volume control capabilities by providing pervious surface and therefore reducing the total runoff volume to be controlled, however, buried trench sand filters may not.

**Figure 11-1**
Site Built Sand Filter (Open Basin)

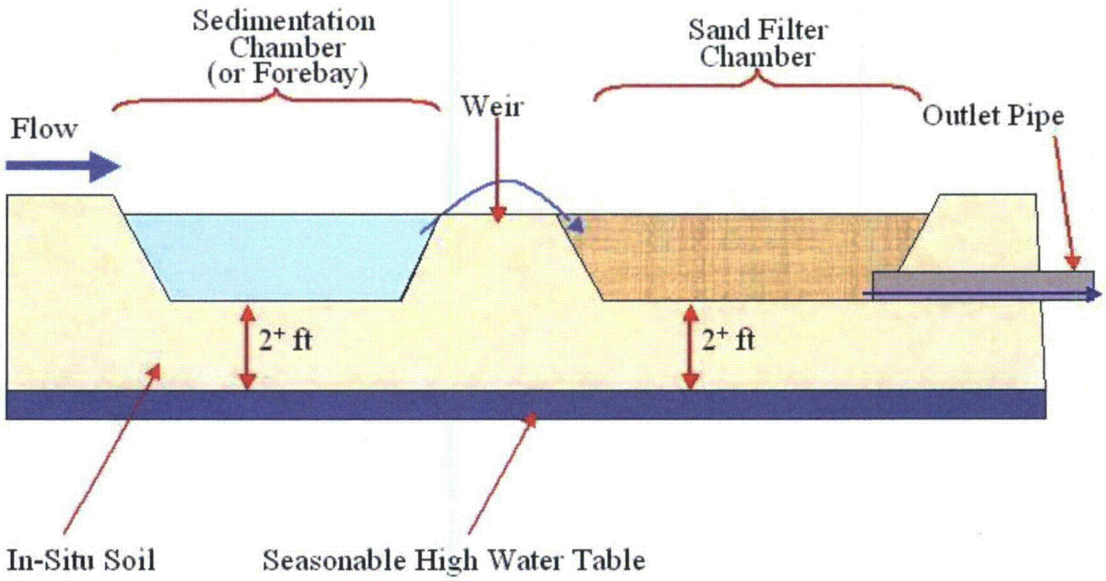
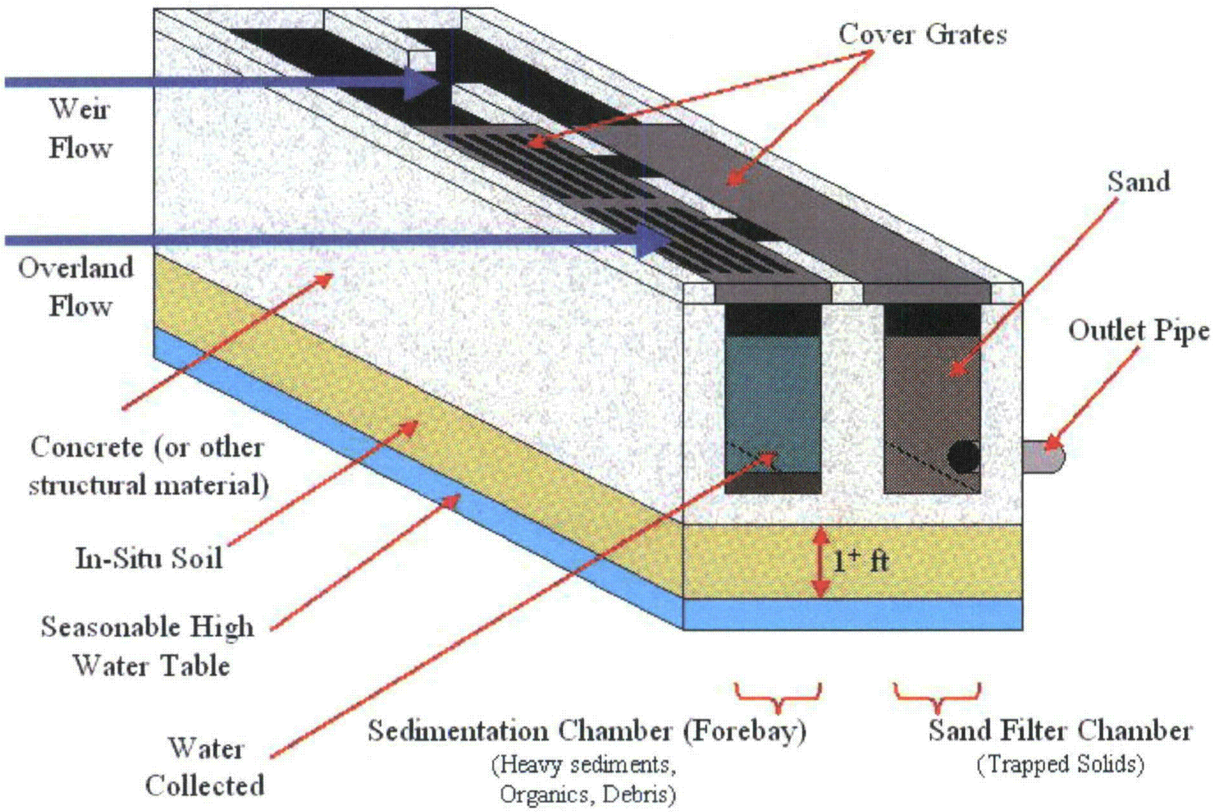
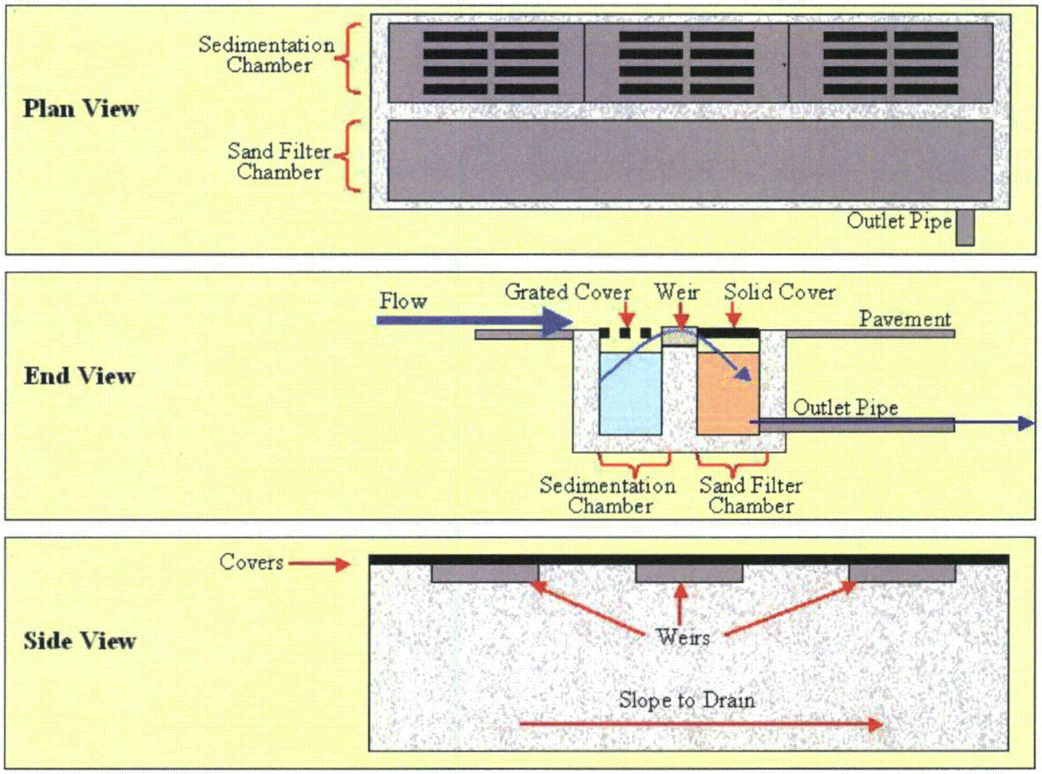


**Figure 11-2a**
Buried Trench (Closed-Basin) Sand Filter, 3-D View*
Derived from Shaver, 1992




*Exceptions to the 1ft SHWT separation will be made if the filter does not drain the water table and does not float. Special care should be used when proposing structures such as concrete because joints may break down over time, causing the water table to leak into the sand filter.

**Figure 11-2b**
Buried Trench (Closed Basin) Sand Filter
Derived from Shaver, 1992




## 11.3. Design

### 11.3.1. Converting Sediment and Erosion Control Devices

A basin used for construction sediment and erosion control can be converted into an open basin type sand filter if all sediment is removed from the basin prior to construction of the sand filter and proper sand filter design is followed. Buried trench type sand filters are typically newly constructed after site construction and not placed in modified site construction sediment and erosion control basins.

### 11.3.2. Siting Issues

Sand filters shall *not* be used in areas with the following characteristics:

- The seasonal high water table is less than 2 feet below the proposed bottom of the facility for an open basin design. If a concrete bottom is used, then the separation can be reduced to a minimum of 1 foot.
- If site restrictions such as bedrock or hydraulics prevent the facility from being constructed to a depth that will allow for the required media thickness, ponding depth, and other appurtenances.

### 11.3.3. Contributing Drainage Basin

The maximum contributing drainage area to an individual sand filter shall be less than 5 acres, however, 1 acre or less is recommended. Multiple sand filters can be used throughout a development to provide treatment for larger sites.

### 11.3.4. Pretreatment and Inflow

Erosive velocities and high sediment loads are a concern with sand filters. Sediment can quickly blind a sand filter and cause premature failure of the BMP. Two devices that can help reduce the impact of these factors on the sand filter are flow splitter devices and forebays.

Flow beyond the design flow can overload the hydraulic capacity of a sand filter (usually resulting in an overflow), cause erosion in open basin sand filters, and deliver more sediment to the sand filter than is necessary. Because of these issues, sand filters are required to be designed "off-line", meaning only the design volume of the stormwater flow is sent from the conveyance system into the treatment unit, and the excess is diverted. Please see Section 5.3 for more information on the design and regulatory compliance issues related to flow splitters and designing systems off-line.

A forebay or sedimentation chamber is required on all sand filters to protect the sand filter from clogging due to sediment, and to reduce the energy of the influent flow. The forebay can be in the form of an open basin (typical with an open basin sand filter design), or a subsurface concrete chamber (typical with a buried trench design). Please see Section 5.5 for design information on forebays. The forebay must contain ponded water (not be drained down with the sand filter). If a subsurface concrete chamber is provided, appropriate means of removing accumulated sediment must be demonstrated. Since individual sand filters treat relatively small volumes of stormwater and the design of the forebay is a percent of the total design volume, the forebay can also be very small. Besides the minimum requirements from Section 5.5, the minimum width (measurement parallel to flow direction) of the sedimentation chamber or forebay shall be 1.5 feet.

After the sedimentation chamber or forebay, the stormwater flow can be distributed over the surface of the sand filter is a variety of ways. For an open sand filter it could flow onto the sand filter as sheet flow via a level spreader, but depending on the geometry of the sand filter, that may not provide even enough flow distribution to prevent overloading and clogging of the leading edge of the sand filter. A common way of distributing flow onto sand filters, both open basin and buried trench type, is through the use of a pipe distribution or weir system. Design of the pipe distribution system could mimic the design of the underdrain system as presented in Section 5.7.

### 11.3.5. Length, Width and Geometry

The area required for a sand filter device is calculated similar to many other BMP types. The applicable regulation will determine whether the Runoff Capture Design Storm or the Runoff Peak Attenuation Design Storm will be used to calculate the design volume of the unit (see Sections 2 and 3). Since a sand filter must be completely drained within 40 hours, the ponding depth is limited by the media's infiltration rate. Once the ponding depth is known, the surface area can be calculated based on the design volume. No credit is given for storage within the media since the influent can come at such a rate that all of the volume would need to be stored above the media since essentially no infiltration will have taken place yet. A sand filter consists of two parts, the sedimentation basin which serves as a sort of forebay and the sand filter itself. These two parts are collectively referred to as the "sand filter". The geometry of these components can vary. An open basin type sand filter can be rectangular, square, circular or irregular. Buried trench systems (closed basin systems) are often very rectangular, approaching linear. The important factor is that the incoming stormwater is distributed relatively evenly over the surface of the sand filter. Use the following series of steps to determine the appropriate sand filter size.

*Step 1*: Compute the water quality volume (WQV) using Schueler's Simple Method, as described in Section 3 and summarized below, and the adjusted water quality volume ($WQV_{Adj}$) as defined below (Center for Watershed Protection, 1996). :

$$WQV(ft^3) = \frac{R_v(unitless)}{1} x \frac{A_D(acres)}{1} x \frac{43{,}560 ft^2}{1 Acre} x \frac{R_D inchRain}{1} x \frac{ft}{12in}$$

$$WQV_{Adj}(ft^3) = (0.75)WQV$$

- WQV: Water Quality Volume ($ft^3$). This is used to size the surface areas of the sedimentation chamber and the sand filter.
- $WQV_{Adj}$: Adjusted Water Quality Volume ($ft^3$). This is used as the volume that must be contained between the sedimentation chamber and the sand filter (above the sand).
- $A_D$: Drainage area to the sand filter (acres)
- $R_v$: Volumetric runoff coefficient (unitless)=0.05+0.009(%Imp)
    - %Imp: Percent of impervious of land draining to the sand filter

*Step 2*: Determine the maximum head on the sand filter and the sedimentation basin, and determine the surface areas of the sand filter and the sedimentation tank.

*Maximum Head on the Sand Filter and the Sedimentation Basin*

$$h_A(ft) = \frac{h_{MaxFilter}(ft)}{2}$$

- $h_A$=Average head (ft). The average head on the sand filter is approximately equal to the average head on the sedimentation basin.

- $h_{MaxFilter}$(ft): Maximum head on the sand filter (ft). This head should be between 2 and 6 feet. Choose the maximum head so that the following equation is true:

$$h_{MaxFilter}(ft) = \frac{WQV_{Adj}(ft^3)}{A_S(ft^2) + A_f(ft^2)}$$

- $A_S$: Surface area of the sedimentation basin ($ft^2$)
- $A_f$: Surface area of the sand filter bed ($ft^2$)

*Sedimentation Basin Surface Area:*
The minimum surface area for the sedimentation basin is determined by the Camp Hazen Equation:

$$A_s(ft^2) = -\frac{Q_o\left(\frac{ft^3}{\sec}\right)}{w\left(\frac{ft}{\sec}\right)} x \ln(1-E)$$

$$A_S(ft^2) = -\frac{\left(\frac{WQV(ft^3)}{24hr}\right)x\left(\frac{1hr}{3600\sec}\right)}{0.0004\left(\frac{ft}{\sec}\right)} x \ln(1-0.9)$$

$$A_S(ft^2) = 0.066WQV(ft^2)$$

$$A_S(ft^2) = 0.066\left[\frac{R_v(unitless)}{1} x \frac{A_D(Acres)}{1} x \frac{43{,}560(ft^2)}{(Acre)} x \frac{R_D(in)}{1} x \frac{1(ft)}{12(in)}\right](ft^2)$$

$$A_S(ft^2) = [240 * R_v(unitless) * A_D(acres)] * R_D(ft^2)$$

- $Q_o$: Average rate of outflow from the sedimentation chamber ($ft^3$/sec). (Center for Watershed Protection, 1996.)
- E: Trap Efficiency of the chamber = 0.9 (unitless)
- w: Settling velocity of particle. Assume that the particles collected by the filter are 20 microns in diameter. For 20 microns, w=0.0004 (ft/sec). This varies depending on the imperviousness of the land draining to the sand filter, but the value presented here is representative of most situations. (Center for Watershed Protection, 1996).

*Sand Filter Bed Surface Area:*
The minimum surface area for the sand filter bed is determined by Darcy's Law:

$$A_f(ft^2) = \frac{(WQV)(d_F)}{(k)(t)(h_A + d_F)}$$

- $d_F$: Depth of the sand filter bed, (ft). This should be a minimum of 1.5 ft.
- k: Coefficient of permeability for the sand filter bed=3.5 (ft/day).
- t: Time required to drain the WQV through the sand filter bed (day). This time should be 40 hours (1.66 days). (Center for Watershed Protection, 1996.)
- $h_A$: Average head (ft)

- Determine the average head of water above the sand filter. The average head above the sand filter is half of the maximum head on the filter (Center for Watershed Protection, 1996).

*Step 3:* Ensure that the Water Quality Volume is Contained:

- Ensure that this combination of variables will contain the required volume ($WQV_{Adj}$ ($ft^3$)):
  - $\left[A_f(ft^2) + A_s(ft^2)\right]x\left[h_{MaxFilter}(ft)\right] \geq WQV_{Adj}(ft^3)$

*Step 4*: Additional Design Requirements:
For underground sand filters, provide at least 5 feet of clearance between the surface of the sand filter and the bottom of the roof of the underground structure to facilitate cleaning and maintenance.

*Example Calculation::* Design a sand filter to treat the first inch of water from a 1 acre site that is 100% impervious. There is 720 ft² of space available for this underground project.

1. Step 1
   - Rv=0.05+0.9(%Imp)=0.05+0.009(100)=0.95
   - $WQV(ft^3) = \frac{0.95(unitless)}{1} x \frac{1(acres)}{1} x \frac{43{,}560 ft^2}{1 Acre} x \frac{1 inchRain}{1} x \frac{ft}{12in} = 3{,}449 ft^3$
   - $WQV_{Adj}(ft^3) = (0.75)(3{,}449) = 2{,}587(ft^3)$
2. Step 2
   - $h_{MaxFilter}(ft) = \frac{2{,}587(ft^3)}{A_S(ft^2) + A_f(ft^2)}$, for maximum heads between 2 and 6 feet, the following combinations of variables will work:

| $h_{MaxFilter}$ (ft) | $WQV_{Adj}$ ($ft^3$) | As+Af ($ft^2$) |
|---|---|---|
| 2.0 | 2,586 | 1,293 |
| 3.0 | 2,586 | 862 |
| 3.6 | 2,586 | 720 |
| 4.0 | 2,586 | 647 |
| 5.0 | 2,586 | 517 |
| 6.0 | 2,586 | 431 |

   - $A_s(ft^2)$=240*0.95*1=228 ($ft^2$), this is the minimum value for the area of the sedimentation basin. Larger basins are acceptable.
   - Choose a combination of $A_f$ and $h_A$ to meet the available space onsite. Typically, the sedimentation chamber and the sand filter bed should be approximately the same size. If there is 720 ft² of space available, then $A_s$ and $A_f$ can both be 360 ft², and the maximum head on the sand filter will be 3.6 ft. The average head is half of the maximum head, 1.8 ft. Check to ensure that the minimum area for the sand filter is attained:

- $A_f(ft^2)= \dfrac{(3{,}449(ft^2))(1.5(ft))}{(3.5(ft/day))(1.66(day))(1.8(ft)+1.5(ft))} = 270\ ft^2.$

  This is the minimum value for the area of the sand filter. Larger sand filters are acceptable, and therefore the chosen combination of variables is acceptable for this design.

  - There are several combinations of surface areas and depths that would be acceptable for this design. In this example:
    - $A_f$=360ft$^2$
    - $A_s$=360ft$^2$
    - $h_{MaxFilter}$=3.6 ft
    - $h_A$=1.8ft

3. Step 3
   - $2{,}592(ft^3) = [360(ft^2)+360(ft^2)]x[3.6(ft)] \geq 2{,}587(ft^3)$
4. Step 4
   - Because this is an underground project, 5 feet of clearance between the surface of the sand filter and the bottom of the underground structure is required to facilitate cleaning.

### 11.3.6. Drainage Considerations

The sand filter chamber shall drain completely within 40 hours. The length of time that it takes to drain the media of a filter is controlled by the infiltration rate of the media (or possibly the infiltration rate of the in-situ soil if the system is designed as an infiltration type system).

### 11.3.7. Media Requirements

The media in the sand filter shall be cleaned, washed, course masonry sand such as ASTM C33. The sand particles shall be less than 2 mm average diameter. The filter bed shall have a minimum depth of 18 inches, with the minimum depth of sand above the drainage pipe being 12 inches.

### 11.3.8. Outlet Design

If the sand filter is designed as an infiltration type system, please refer to the in-situ soil requirements and other applicable design and construction recommendations of Section 16 Infiltration Devices. In general, only sand filters constructed in the coastal areas will have in-situ permeabilities that allow construction of infiltration type sand filters.

In general, sand filter BMPs in the Mountain and Piedmont regions of North Carolina will require underdrains. The underdrain system shall be designed as shown in Section 5.7. The underdrain system will connect to another BMP or to the conveyance system.

Observation wells and/or clean-out pipes must be provided (one minimum per every 1,000 square feet of surface area). The observation wells, as well as the ends of underdrain pipes that do not terminate in an observation well, must be capped.

## 11.4. Maintenance

### 11.4.1 Common Maintenance Issues

Sand filters should be inspected at least once per month, and after any large storm events to check for damage. They must be maintained as needed to remove visible surface sediment accumulation, trash, debris, and leaf litter to prevent the filter from clogging prematurely. Sediment should be cleaned out of the forebay/sedimentation chamber when it accumulates to a depth of more than 6 inches. Any structures (outlets, flow diversions, embankments, etc.) should be checked at least annually for damage or degradation. Figures 11-3a and 11.3b show an example of a sand filter that is overdue for maintenance.

**Figure 11-3a**
Sand Filter Overdue for Maintenance: Sedimentation Chamber

**Figure 11-3b**
Sand Filter Overdue for Maintenance: Sand Filter Chamber

When the filtering capacity diminishes substantially (e.g., when water ponds on the surface for more than 40 hours), remedial actions must be taken. One possible problem is that collector pipe systems can become clogged. Annual flushing through pipe cleanouts is recommended to facilitate unclogging of the pipes without disturbing the filter area. If the water still ponds for more than 40 hours, the top few inches of material should be removed and replaced with fresh material. The removed sediments should be disposed of in an acceptable manner (e.g., landfill). If that does not solve the problem, more extensive rebuilding is required.

### 11.4.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- The drainage area will be carefully managed to reduce the sediment load to the sand filter.
- Once a year, sand media will be skimmed.
- The sand filter media will be replaced whenever it fails to function properly after vacuuming.

The sand filter will be inspected **quarterly and within 24 hours after every storm event greater than 1.0 inches (or 1.5 inches if in a Coastal County)**. Records of inspection and maintenance will be kept in a known set location and will be available upon request.

Inspection activities shall be performed as follows. Any problems that are found shall be repaired immediately.

**Table 11-1**
Sample Inspection and Maintenance Provisions for Sand Filters

| BMP element: | Potential problems: | How to remediate the problem: |
|---|---|---|
| **The entire BMP** | Trash/debris is present. | Remove the trash/debris. |
| **The adjacent pavement (if applicable)** | Sediment is present on the pavement surface. | Sweep or vacuum the sediment as soon as possible. |
| **The perimeter of the sand filter** | Areas of bare soil and/or erosive gullies have formed. | Regrade the soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application. |
| | Vegetation is too short or too long. | Maintain vegetation at a height of approximately six inches. |
| **The flow diversion structure** | The structure is clogged. | Unclog the conveyance and dispose of any sediment off-site. |
| | The structure is damaged. | Make any necessary repairs or replace if damage is too large for repair. |
| **The pretreatment area** | Sediment has accumulated to a depth of greater than six inches. | Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the BMP. |
| | Erosion has occurred. | Provide additional erosion protection such as reinforced turf matting or riprap if needed to prevent future erosion problems. |
| | Weeds are present. | Remove the weeds, preferably by hand. If a pesticide is used, wipe it on the plants rather than spraying. |

**Table 11-1, continued**
Sample Inspection and Maintenance Provisions for Sand Filters

| BMP element: | Potential problems: | How to remediate the problem: |
|---|---|---|
| **The filter bed and underdrain collection system** | Water is ponding on the surface for more than 24 hours after a storm. | Check to see if the collector system is clogged and flush if necessary. If water still ponds, remove the top few inches of filter bed media and replace. If water still ponds, then consult an expert. |
| **The outflow spillway and pipe** | Shrubs or trees have started to grow on the embankment. | Remove shrubs and trees immediately. |
| | The outflow pipe is clogged. | Provide additional erosion protection such as reinforced turf matting or riprap if needed to prevent future erosion problems. |
| | The outflow pipe is damaged. | Repair or replace the pipe. |
| **The receiving water** | Erosion or other signs of damage have occurred at the outlet. | Contact the NC Division of Water Quality 401 Oversight Unit at 919-733-1786. |

September 28, 2007 Changes:

1. Major Design Elements:
   i. Reformatted to include numbered requirements.
   ii. Separated the following requirement into two requirements, "Seasonally high groundwater table must be at least 2 feet below the bottom of the filter for open-bottom designs, and at least 1 foot below the bottom of the filter for pre-cast designs." It now reads,
      1. "Seasonally high groundwater table must be at least 2 feet below the bottom of the filter for open-bottom designs," which is specified as an Administrative Code requirement per 15A NCAC 02H .1008(d)(3),
      2. "Seasonally high groundwater table must be at least 1 foot below the bottom of the filter for closed filter designs in order to prevent draining the water table and floatation. Exceptions will be made if these concerns are mitigated," which is specified as based on NC DWQ policy. The clause regarding the exception has been added.
   iii. Added a requirement that the design shall be located a minimum of 30 feet from surface waters, and 50 feet from Class SA waters per 15A NCAC 02H .1008(d)(1).
   iv. Added a requirement that the design shall be located a minimum of 100 feet from water supply wells per 15A NCAC 02H .1008(d)(2).
   v. Added a requirement that the volume in excess of the design volume, as determined from the design storm, shall bypass the cell per 15A NCAC 02H .1008(d)(4).
   vi. Added a requirement that the volume in excess of the design volume shall be evenly distributed across a minimum 30 feet long vegetative filter strip. (A 50-ft filter is required in some locations.) If this can not be attained, alternate designs will be considered on a case by case basis. This requirement is per 15A NCAC 02H .1008(c)(4) and 15A NCAC 02H .1005(b)(iii).
2. 11.3.5: Three equations referred to a 1.0" depth. Because this depth varies by location, this equation has been updated to reference "$R_D$", the design storm depth used in the Simple Method calculation. *(Note: These changes are not visible in Track Changes.)*
3. 11.3.5: Corrected a typo in one equation, "0.09" has been replaced by "0.9".
4. Figure 11-2a: Altered for clarification.