


North Carolina
Division of Water Quality

Stormwater Best Management Practices Manual

July 2007

NCDENR

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07-02-07

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 it has no more than two dwelling units per acre or 24% built-upon area and meets these requirements:

- 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:

- The stormwater control measures must control and treat the difference between the pre-development and post-development conditions for the 1-year 24-hour storm;
- Runoff volume drawdown time must be a minimum of 24 hours, but not more than 120 hours;
- All structural stormwater treatment systems must be designed to achieve 85% average annual removal of total suspended solids;
- Stormwater management measures must comply with the General Engineering Design Criteria For All Projects requirements listed in 15A NCAC 2H .1008(c);
- 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.

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 practicable.	Control runoff from the first inch of rainfall. New development density not to exceed 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)

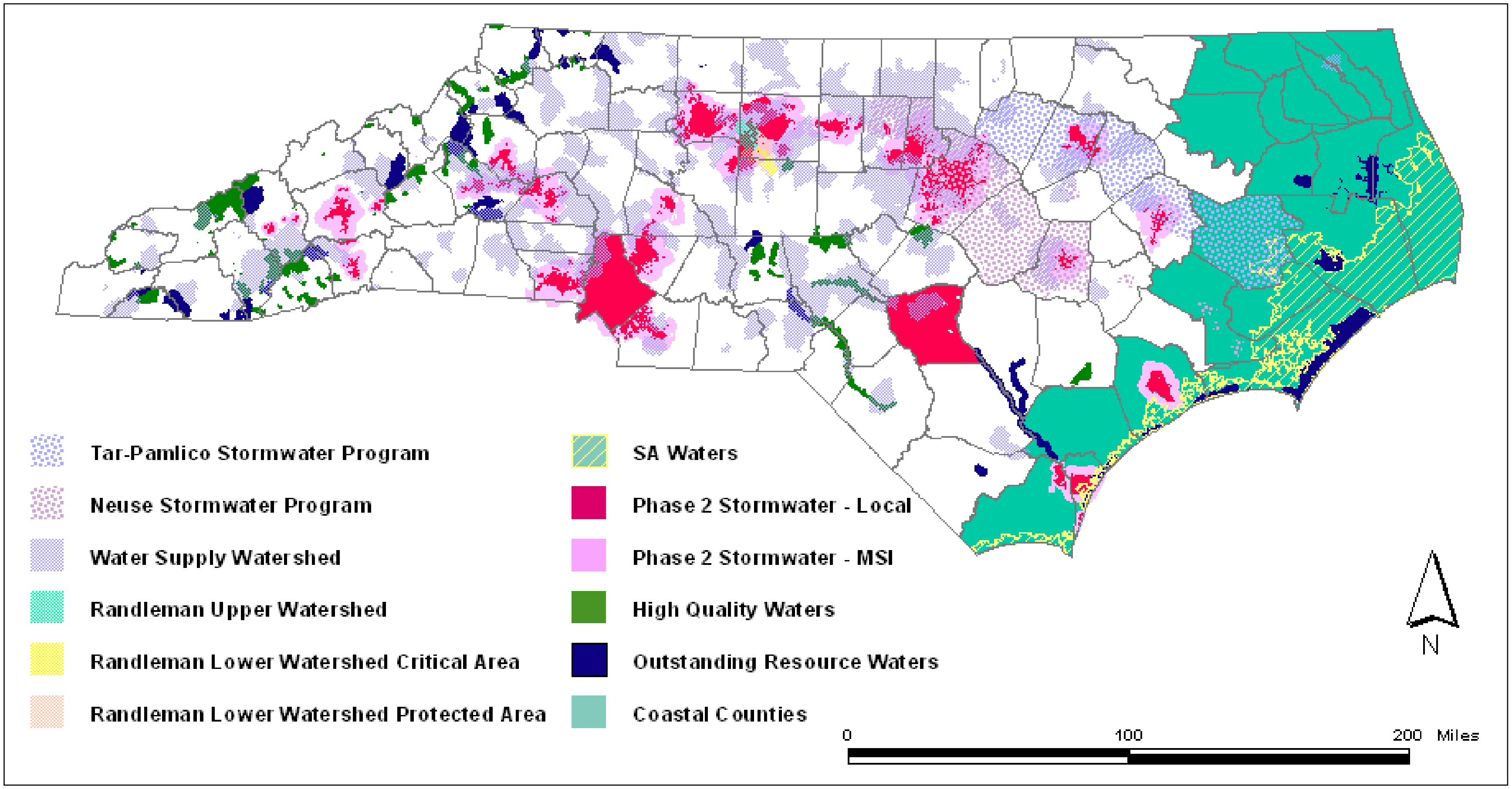
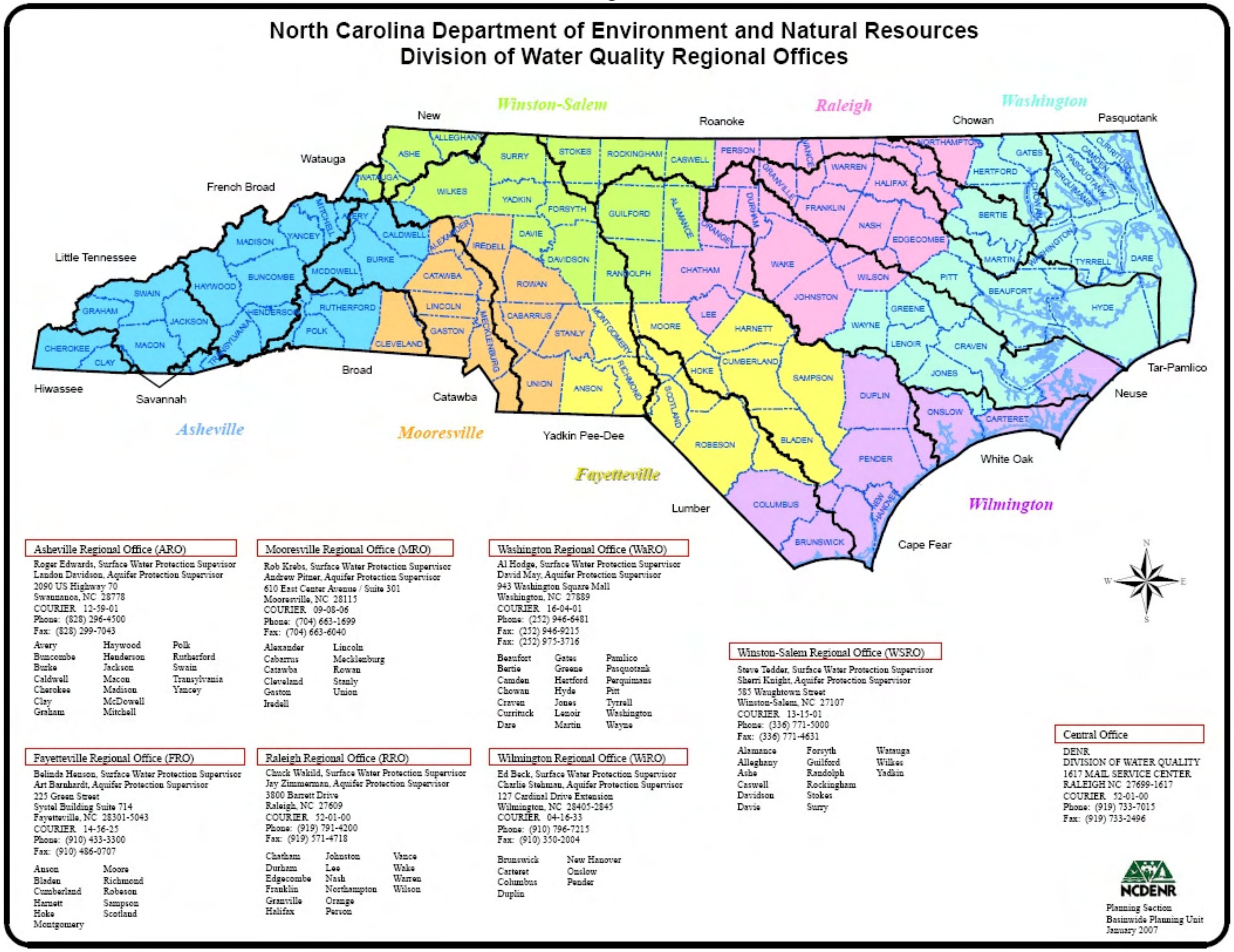


Figure 2-2



North Carolina Department of Environment and Natural Resources
Division of Water Quality Regional Offices
Winston-Salem
Raleigh
Washington
Asheville
Mooresville
Fayetteville
Wilmington
New
Roanoke
Chowan
Pasquotank
Watauga
French Broad
Little Tennessee
Hiwassee
Savannah
Broad
Catawba
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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)	**ORW** (Within 575′ MHW Line)	**Neuse NSW**	**Tar-Pamlico NSW**	**Phase 2**
Permitting Authority	DWQ – RO	DWQ – RO	DWQ – RO	Local Gov't	Local Gov't	Local Gov't
Low Density Maximum BUA **(1)**	30%	25%	25%	N/A	N/A	24%
High Density Maximum BUA **(2)**	None	None	No high density.	N/A	N/A	None
Low Density Setback	30′	30′	30′	50′ RB	50′ RB	30′
High Density Setback	N/A	50′	N/A	50′ RB	50′ RB	30′
S/W Control Req. for High Density **(3)**	1″ R/O	1.5″ R/O	N/A	Peak Reduc.	Peak Reduc.	Note 3
TSS removal Requirement	85%	85%	N/A	N/A	N/A	85%
Stormwater Drawdown Requirement **(4)**	Note 4	Note 4	N/A	Note 4	Note 4	Note 4
Vegetated Conv. For Low Density **(5)**	Yes	Yes	Yes	N/A	N/A	Yes
Deed Restrictions Required **(6)**	Yes	Yes	Yes	N/A	N/A	Yes
Cluster Development Allowed **(7)**	Yes	Yes	No	N/A	N/A	Yes
Infiltration Systems Required for S/W Control **(8)**		Yes				
No New or Expanded Stormwater Discharges **(9)**		Yes				
Neuse Nitogen Loading Limits **(10)**				Yes		
Tar-Pamlico Nitrogen & Phosphorus Loading Limits **(11)**					Yes	

BUA – Built-upon area, **DWQ-RO** – Division of Water Quality – Regional Office **NSW -** Nutrient Sensitive Waters, **ORW** – Outstanding Resource Waters, **RB** – Riparian Buffer, **RO –** Runoff, **SA –** Saltwater "A" Classification (Shellfishing), **S/W –** Stormwater, **TSS** – Total Suspended Solids

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: Stormwater control measures under the Phase 2 requirement must control and treat the difference 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.
(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.

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

Requirement - Based on Classification	**WS-2 CA**	**WS-2 BW**	**WS-3 CA**	**WS-3 BW**	**WS-4 CA**	**WS-4 PA**	**HQW**	**ORW**	**Neuse NSW**	**Tar-Pamlico NSW**	**Randle Upper Portion**	**Randle Lower CA**	**Randle Lower PA**	**Phase 2**	**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	DWQ – RO	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%	12%	N/A	N/A	24%	6%	12%	24%	30%
High Density Max BUA **(2)**	24%	30%	30%	50%	50%	70%	None	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	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	Note 3	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	Yes	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	N/A	N/A	N/A	N/A	Yes	No	Yes	No	N/A
36% BUA w/no Curb & Gutt **(9)**	No	No	No	No	No	Yes	N/A	N/A	N/A	N/A	Yes	No	No	No	N/A
NSW Load Limits **(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

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: Stormwater control measures under the Phase 2 requirement must control and treat the difference between the pre-development and post-development conditions for the 1-year 24-hour storm. 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.

(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.

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.

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 Discrete SCS Curve Number Method
Storage Volume	3.4	Stage-Storage Table
Hydraulic Performance of the Outlet Device	3.5	Weir Equations Orifice Equation
Stage-Storage-Discharge	3.6	Chainsaw Routing Others: HEC-HMS, WinTR-55, SWIMM
Channel Geometry	3.7	Manning Equation
Nutrient Loading	3.8	DWQ Neuse TN Export Worksheet DWQ Tar-Pamlico Nutrient Export Worksheet
Pollutant Removal of BMPs	3.9	Stand-alone BMPs Multiple Drainage Areas BMPs in Parallel 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)

Although there is no conversion factor, the units are resolved because one acre-inch per hour is about the same as one cubic foot per second.

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. DWQ does not approve of the use of the Rational Method for drainage areas that exceed 20 acres.

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.

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)
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.

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.

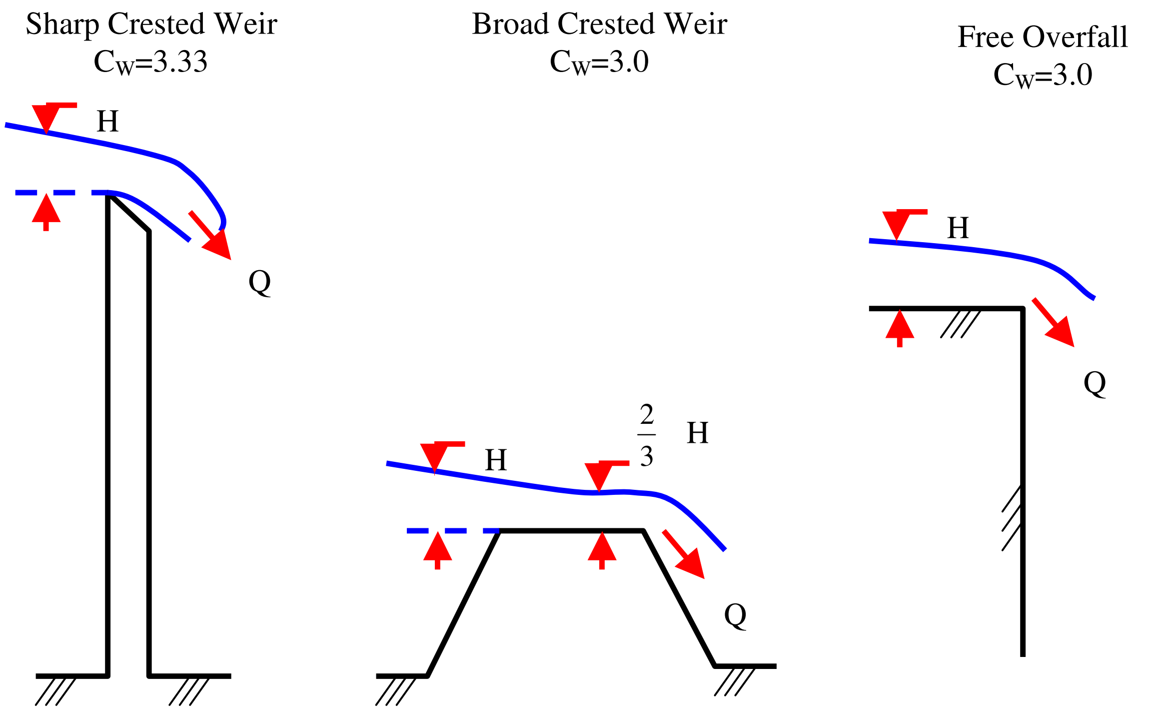
3.5.1. Weir Equations

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

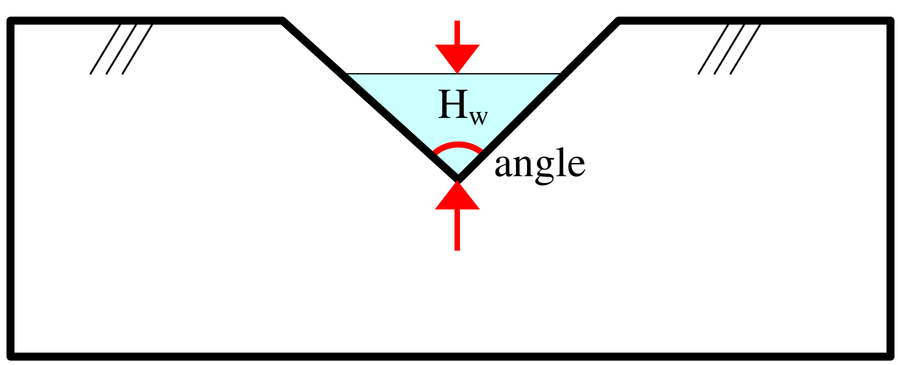
Figure 3-1
Schematic sections through weirs (Malcom 1989)



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:

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

Where:

Q	=	Discharge (cfs)
C_D	=	Coefficient of discharge (dimensionless) – see below
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/2 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

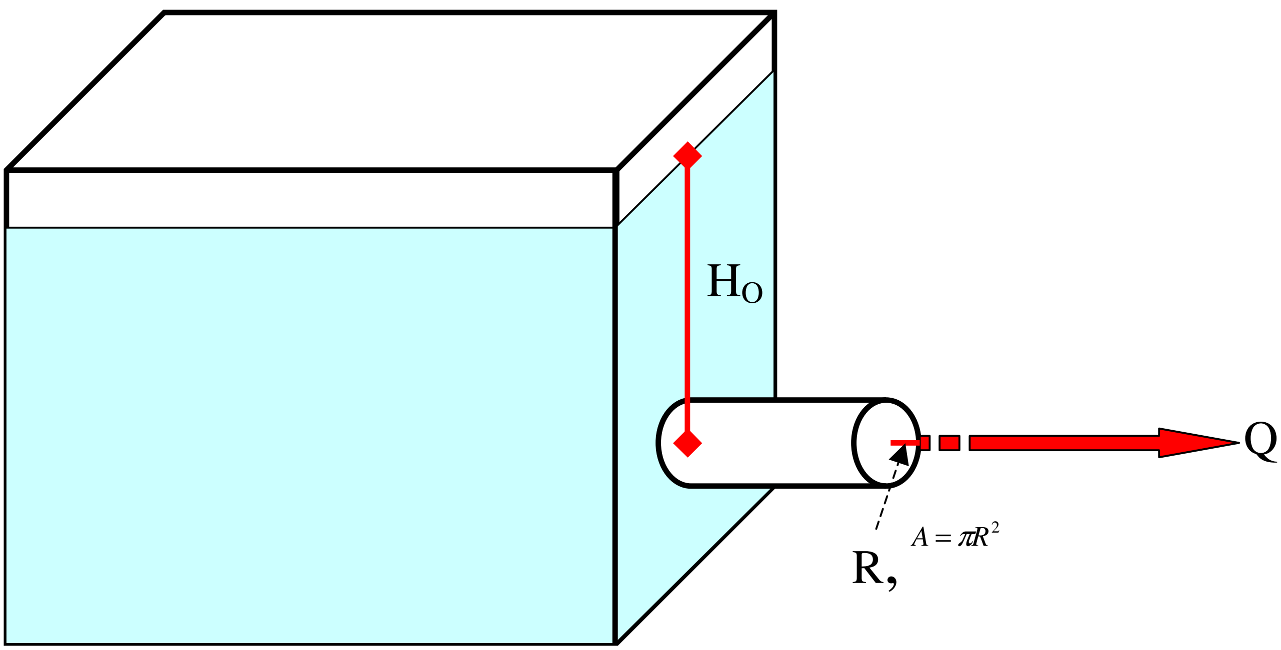


Table 3-8
Values of Coefficient of Discharge, C_D (Malcom, 1989)

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.)

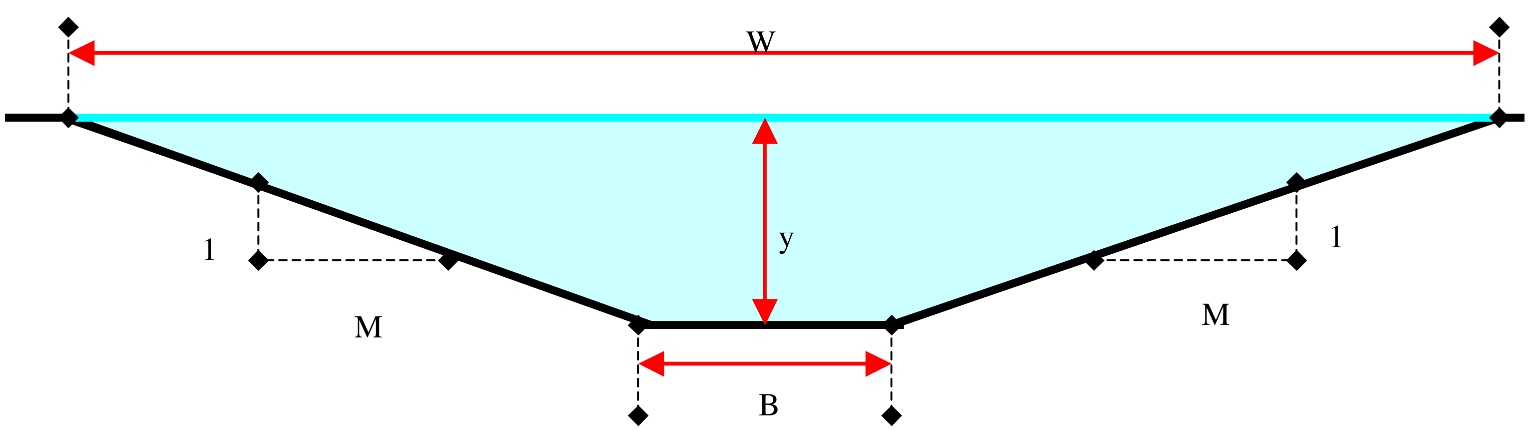
The Manning Equation can be stated as:

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

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 may not be greater than 3; that is, side slopes of a channel may not be steeper than 3:1.

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) *(must be at least 3)*
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 Wet Detention Basin Stormwater Wetlands
Filtration	Sand Filters Bioretention
Infiltration	Infiltration Devices Porous Pavement
Natural Conveyance	Filter Strip Grassed Swale 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.

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%	40%	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, such as wet detention ponds and extended detention wetlands, 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 pocket 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

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
(Minnesota Urban Small Sites BMP Manual, 2001)

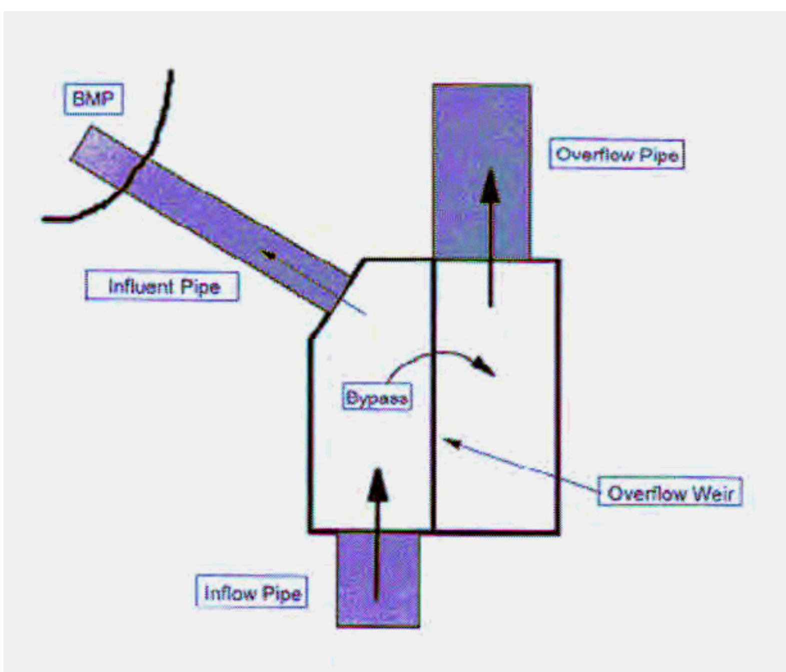
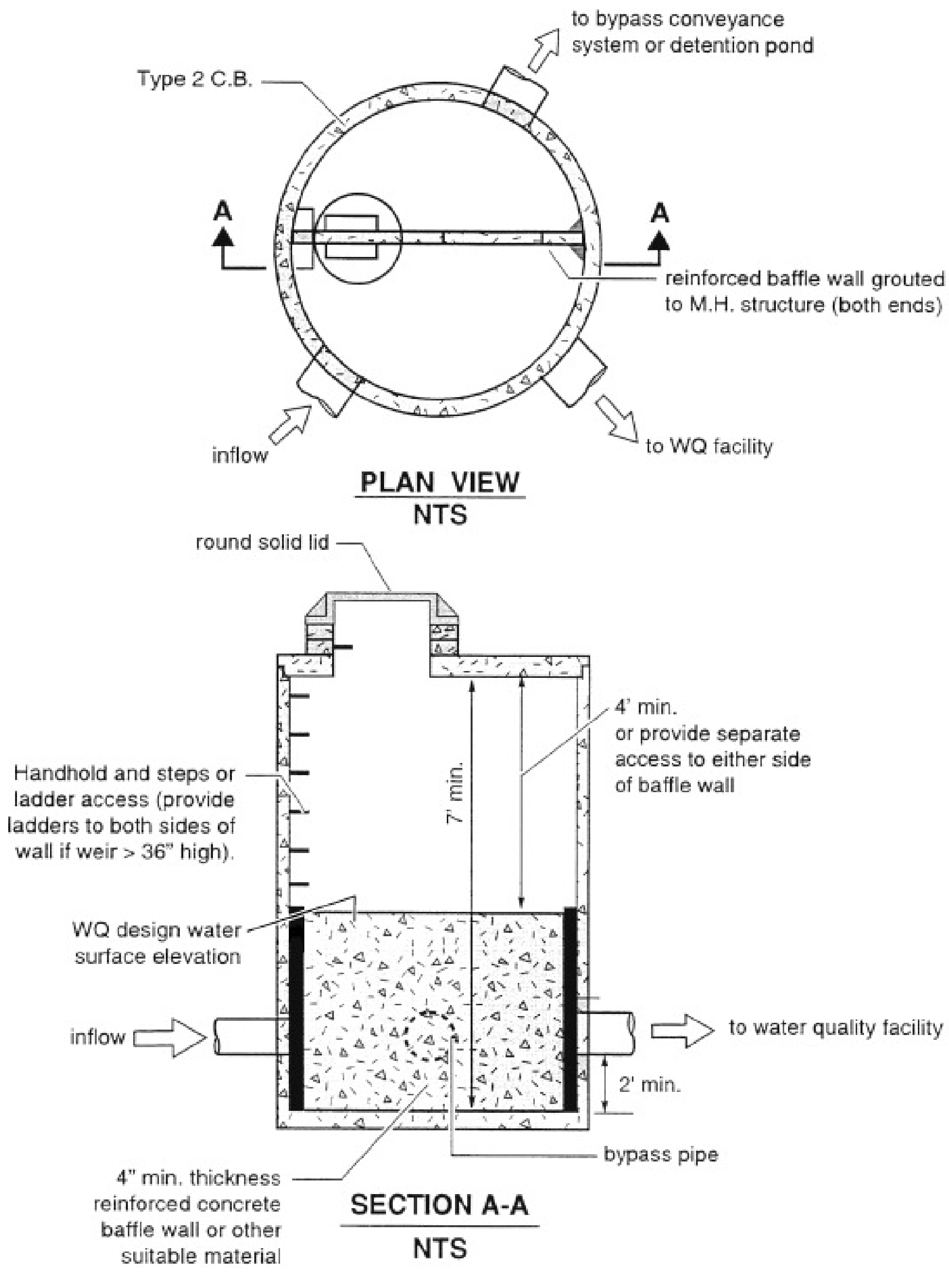
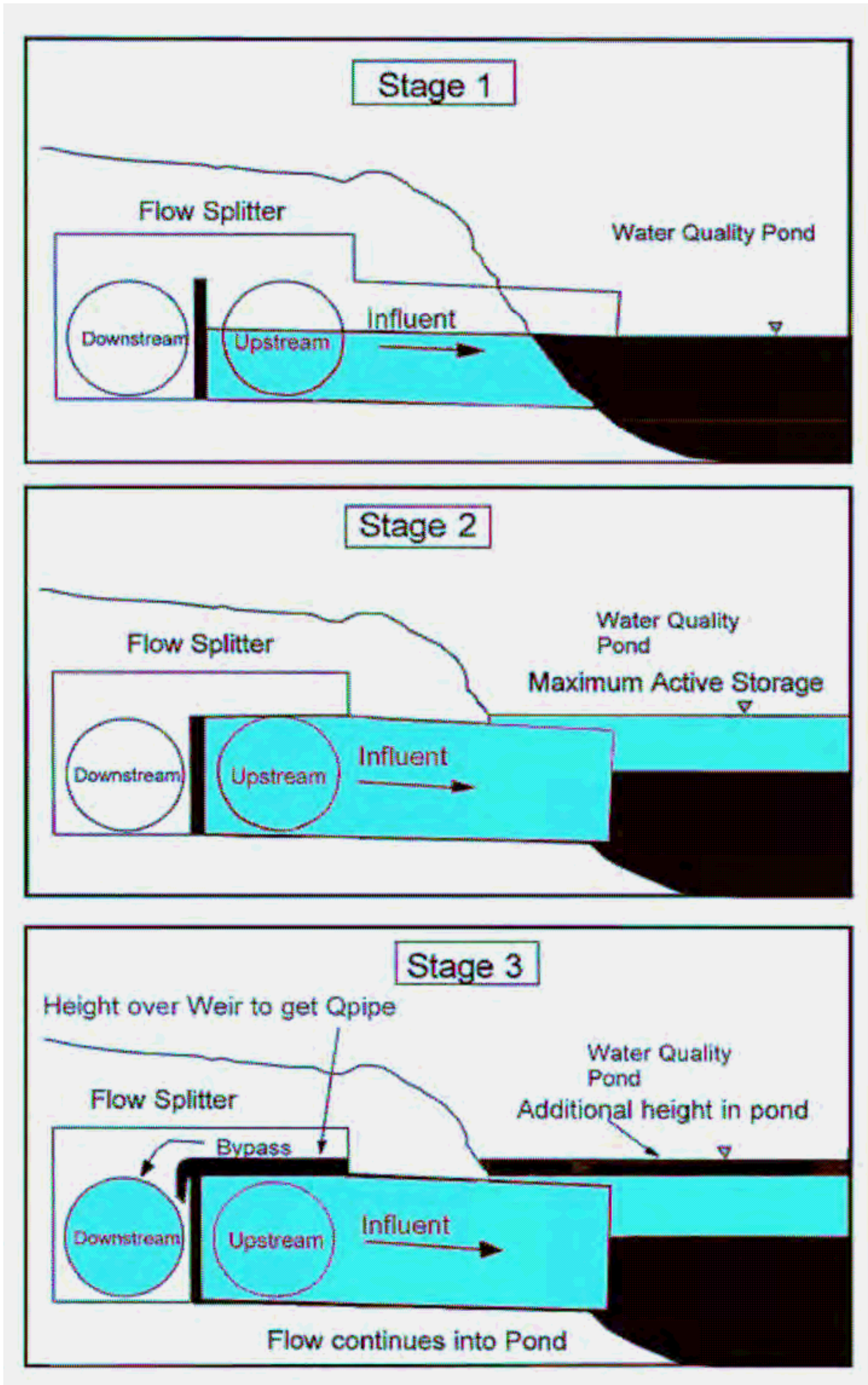


Figure 5-2
Flow splitter in Manhole
(Minnesota Urban Small Sites BMP Manual, 2001)



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 1×10^{-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 1.0 percent and shall be constructed of Schedule 40 or SDR 35 smooth wall PVC pipe. The underdrain pipes shall be designed to carry 10 times the maximum flow exfiltrating from the BMP medium. 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). Some form of filtering device is required to protect the underdrain from blockage. A minimum 3-inch radius of sand around each drainage pipe (including the 3 inches of stone) is recommended for this purpose, but filter fabric can also be used.

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

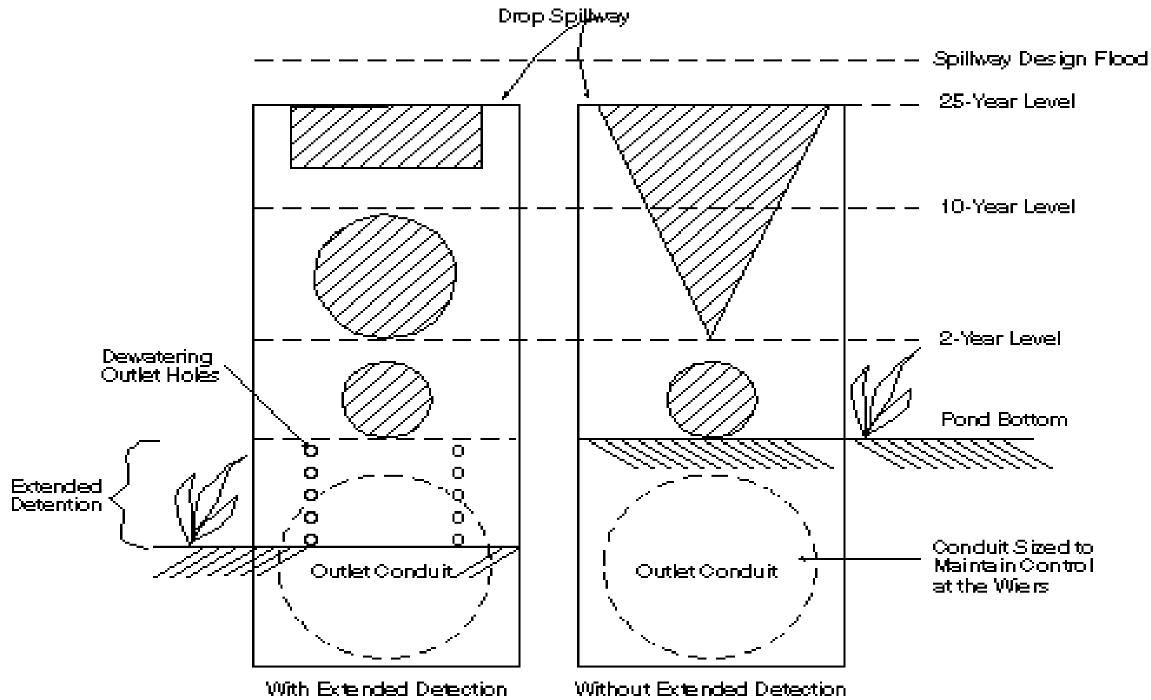
Another common outlet type for relatively small BMPs is a vertical riser with one or more columns of perforations. It is typically constructed out of plastic pipe (PVC, HDPE, etc.). The objective of providing an array of small orifices, instead of a single orifice, is to reduce the velocity of currents 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

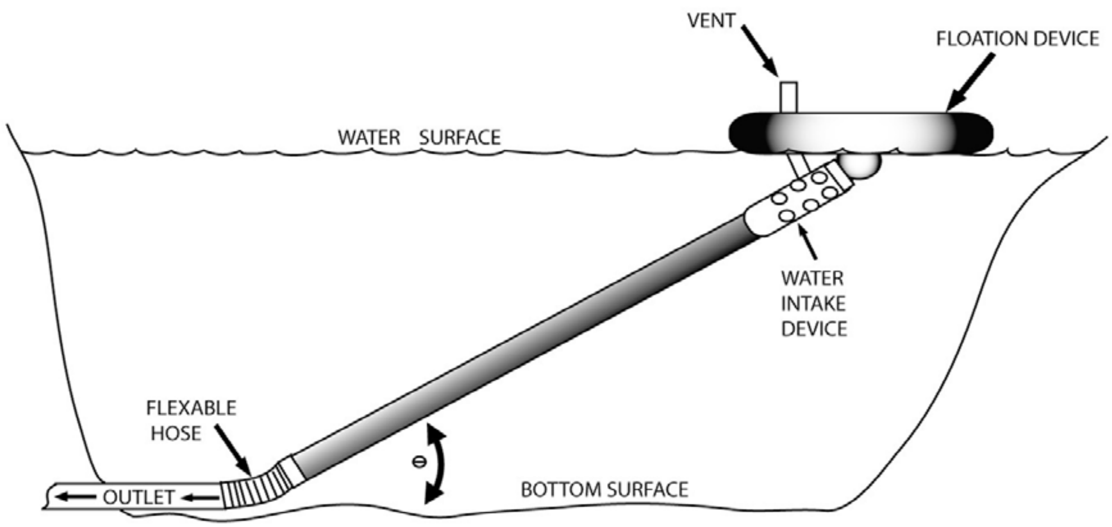


5.8.5 Skimmers

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.

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″-6′ deep
- Shallow Water: 1″ -6″ deep
- Shallow Land: 1″ ″-12″ above normal pool
- Upland: never inundated

Please note that the gap between 6 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 6 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.

[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.

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 Wet detention basins 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 Infiltration devices Sand filters Extended dry detention basins Permeable pavement Rooftop runoff management Filter strips * Grassed swales * 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

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 a sand 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)

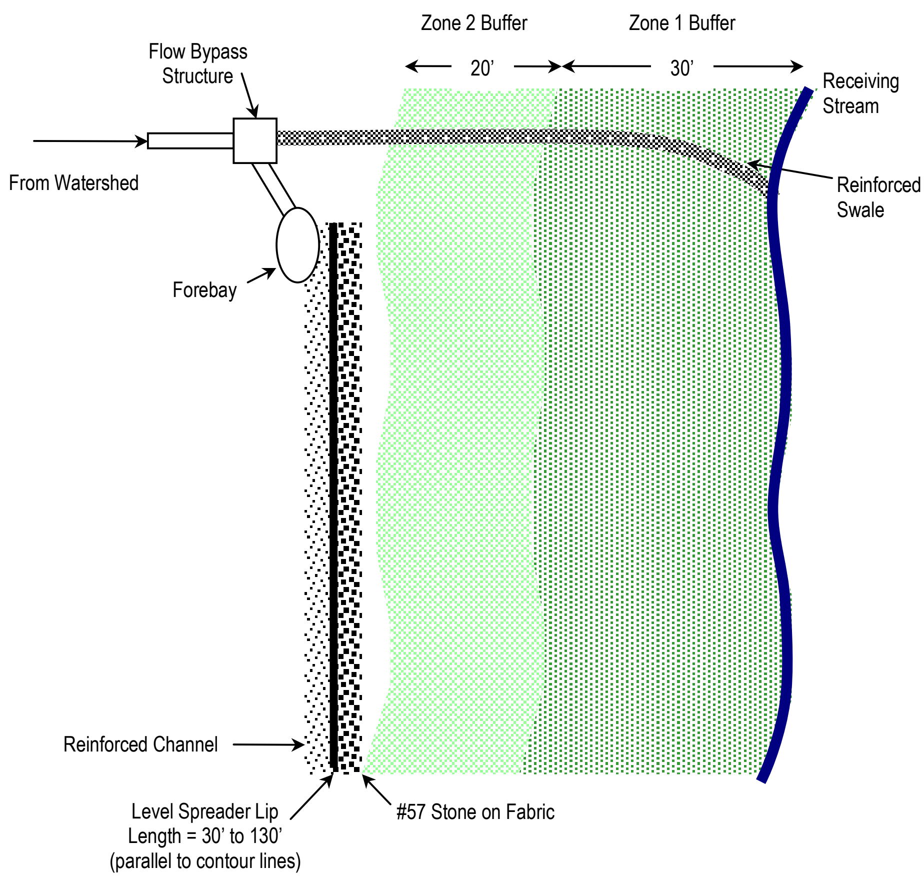
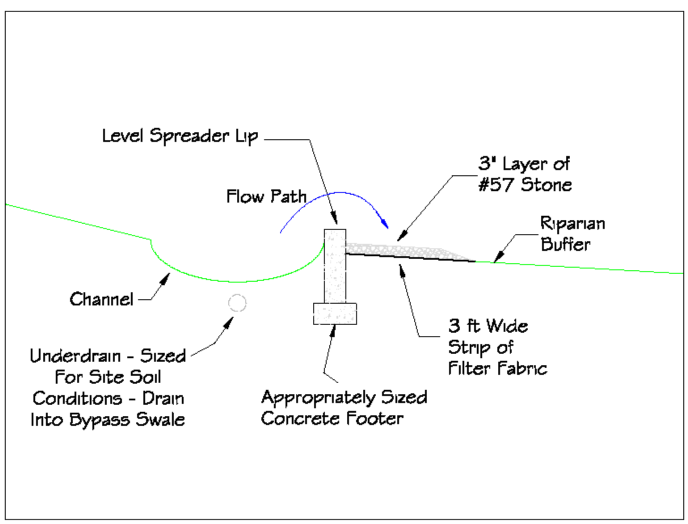


Figure 8-2:
Profile View of a Level Spreader (Hathaway 2006)



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.

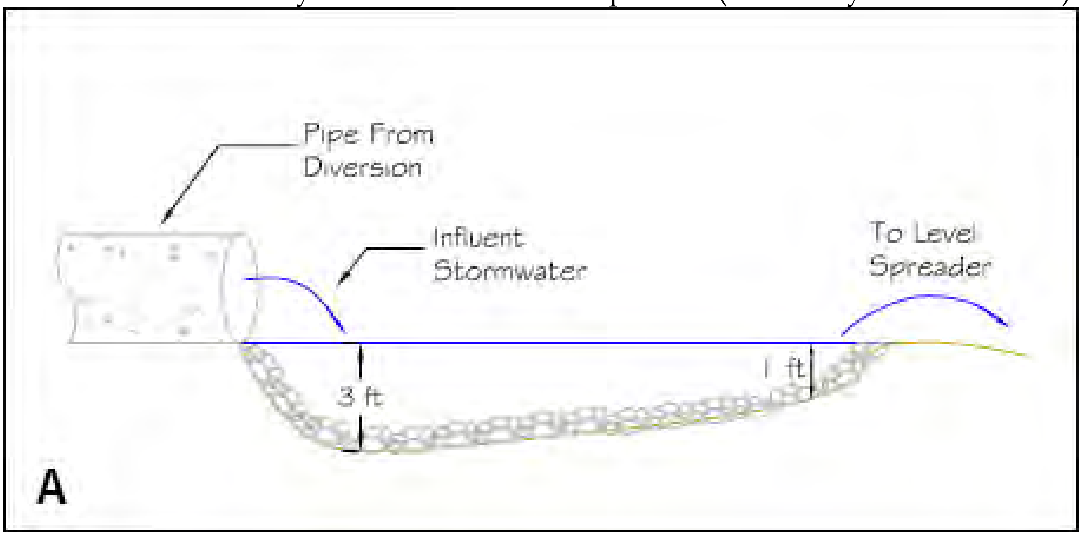
Bypass channels are considered an “allowable” use within a protected riparian buffer. Tree removal and disturbance must be minimized and a buffer authorization must be obtained from the DWQ 401 Oversight/Express Permitting Unit or the local delegated buffer permitting authority.

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 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.

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. The outfall of this BMP can then be routed directly 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)

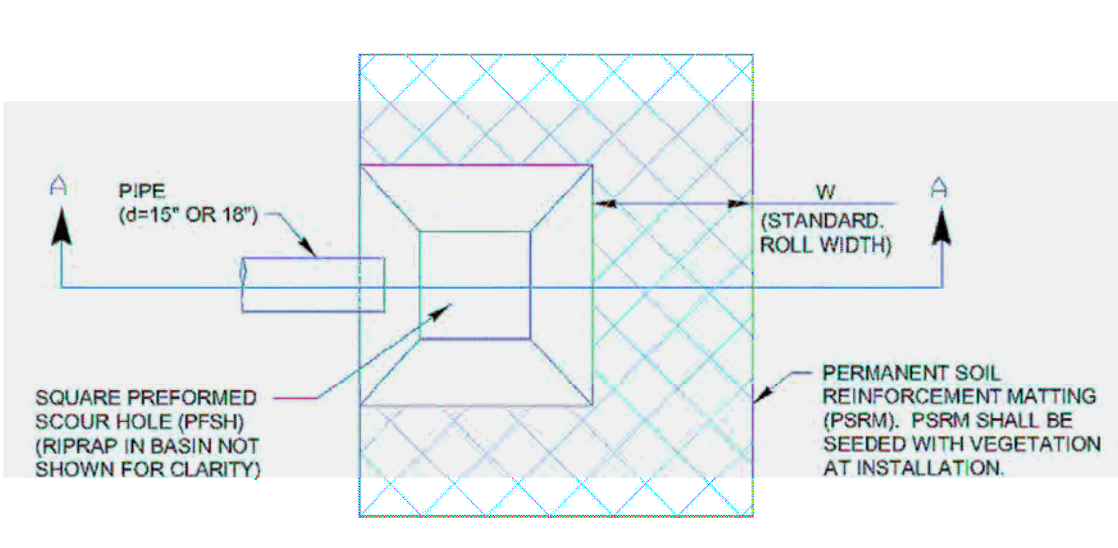
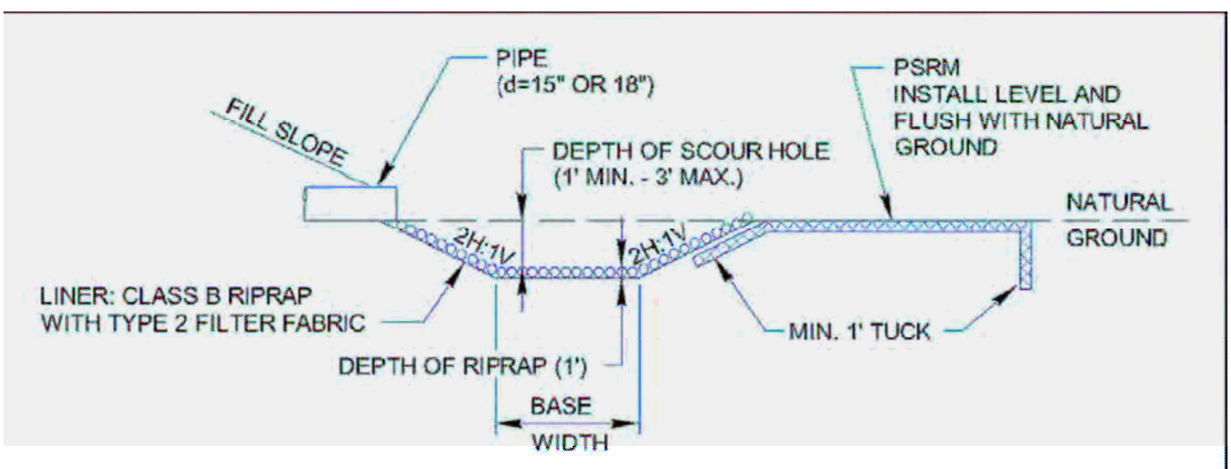


Figure 8-5
Preformed scour hole cross section (NCDOT 2006)



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

All of the components of the level spreader – the flow bypass system, the forebay, the level lip and the filter strip – will require regular inspection and maintenance to insure that they are working correctly and not causing erosive channels through the filter strip. Level spreader inspections will not require a lot of time, but they will need to be done on a regular basis. If repairs are needed, they should be made promptly; otherwise, the problem will grow worse and the cost of the repair will increase.

After every heavy rainfall for first 6 months following construction:

- Check for and repair any channelization or erosion that has occurred in the filter strip. The level spreader will fail if water exits from it as channelized flow.
- Inspect the level lip for settling, erosion, or concentrated flow.

As needed during growing season:
- Mow grass in the filter strip to a 6″ height.

Once a month and after every heavy rainfall (greater than 2 inches).
- Inspect the diverter box and clean and make repairs. Look for clogged inlet or outlet pipes and trash or debris in the box.
- Inspect the forebay and level spreader. Clean and make repairs. Look for:
  - Sediment in forebay and along level spreader lip;
  - Trash and/or leaf buildup.
  - Scour, undercutting of level spreader.
  - Settlement of level spreader structure (no longer level; you see silt downhill below level spreader).
  - Fallen trees on level spreader.
  - #57 stone washing downhill.
- Inspect the filter strip and the bypass swale and make repairs as needed[1]. Look for:
  - Damaged turf reinforcement or riprap rolling downhill.
  - Erosion within the buffer or swale.
  - Concentrated flows downhill of level spreader—look for gullies or sediment flows.

Once a year.
- Remove any weeds or shrubs growing on level spreader or in swale.

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

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.

Major Design Elements

* Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
* Side slopes stabilized with vegetation shall be no steeper than 3:1.
* Wetland shall be located in a recorded drainage easement with a recorded access easement to a public ROW.

** Wetlands require pretreatment.
** Sizing of wetland is based on storage volume requirements and shall be as described in this section.
** 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.
** Maximum ponding depth shall be 1 foot.
** Minimum length to width ratio shall be 1.5:1.
** The wetland must be stabilized within 14 days of construction.
** The wetland must drawdown in 2-5 days.
** 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.

* *This provision is specified in NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

Advantages	Disadvantages
– 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.	– 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.

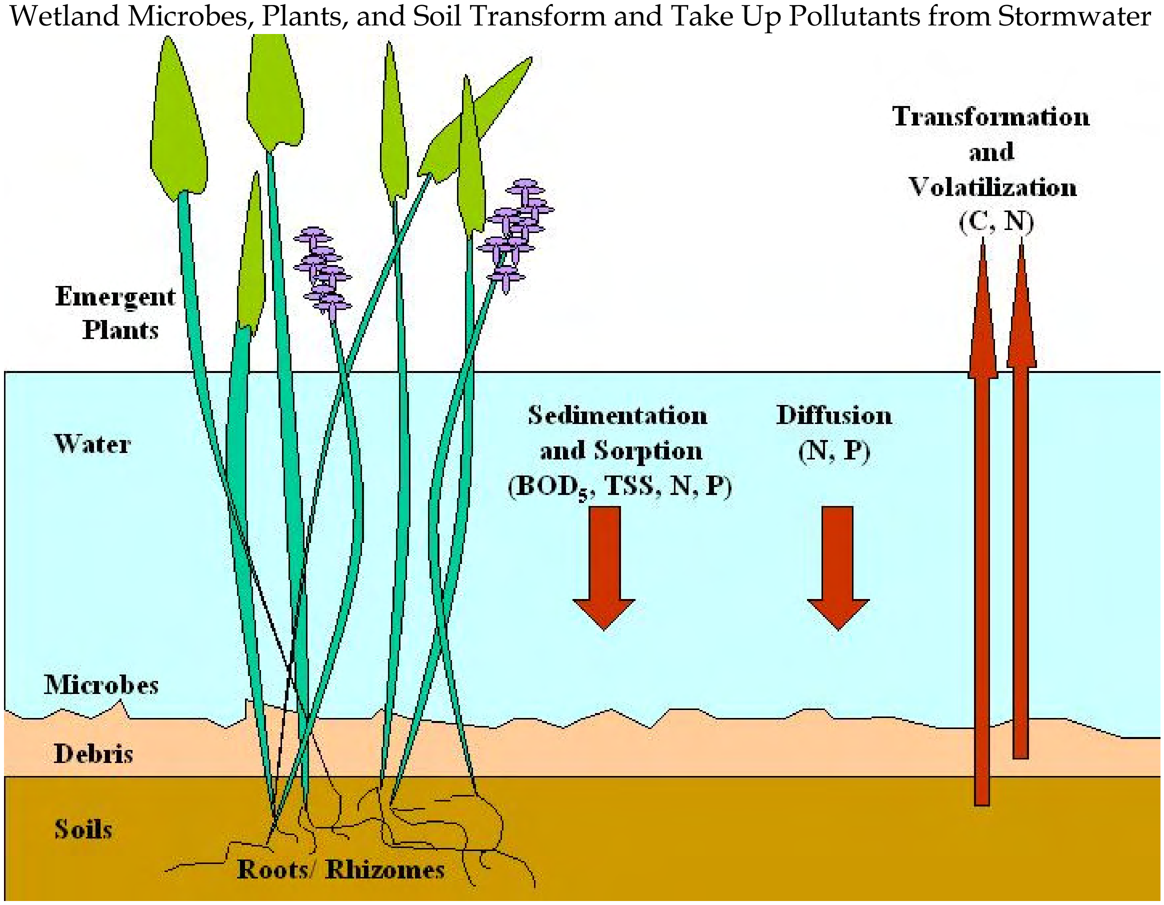
9.1. General Characteristics and Purpose

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.

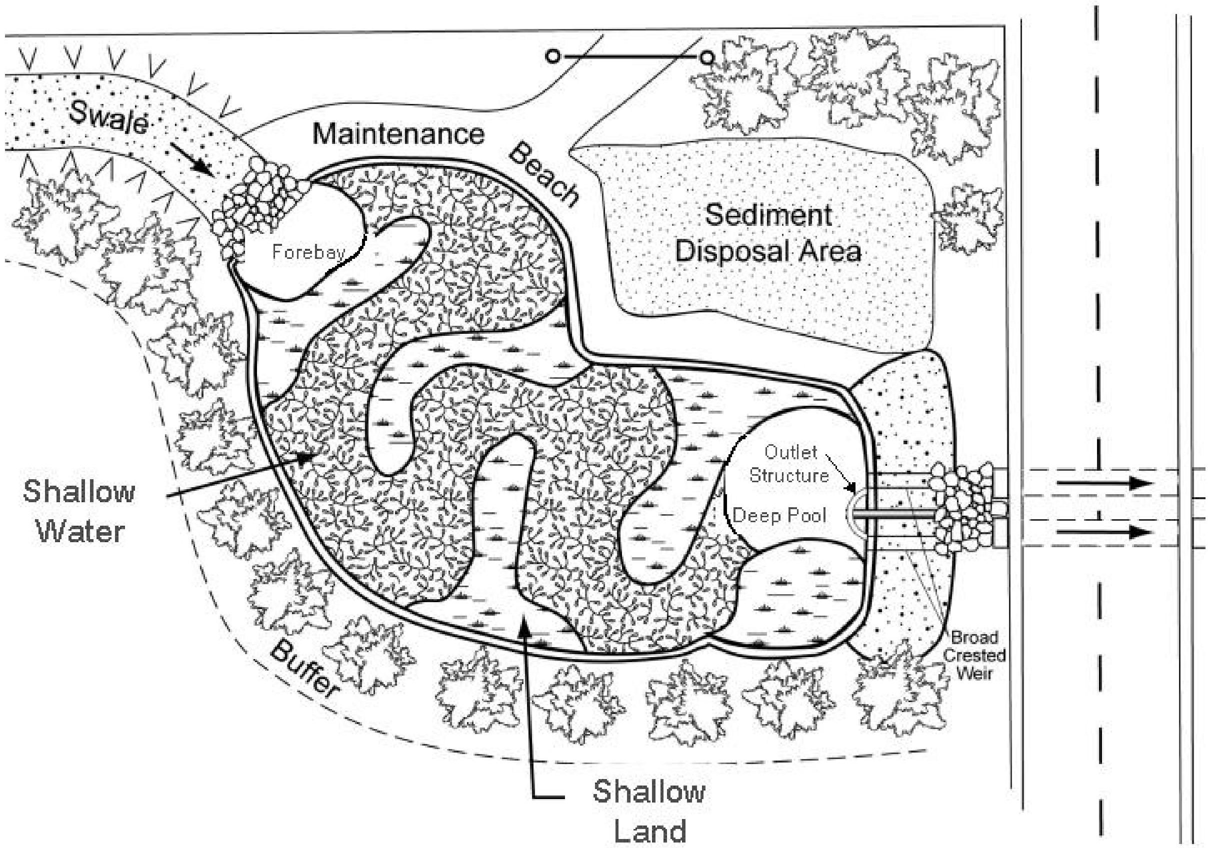
The ability of the emergent plants to settle and stabilize suspended solids in sediments and reduce resuspension is important. The settling characteristic allows the wetland to remove pollutants such as phosphorus, trace metals, and hydrocarbons that are typically adsorbed to the surfaces of suspended 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. The shallow land contains the entire treatment volume. 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</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}), 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 $\frac{Q_{Volume}\,(ft^3)}{D_{Plants}\,(ft)}$ (ft^2). 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)

- o 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 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:
     - o 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.
     - o 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
   - 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: Deep Pools 6+" below the SLWT

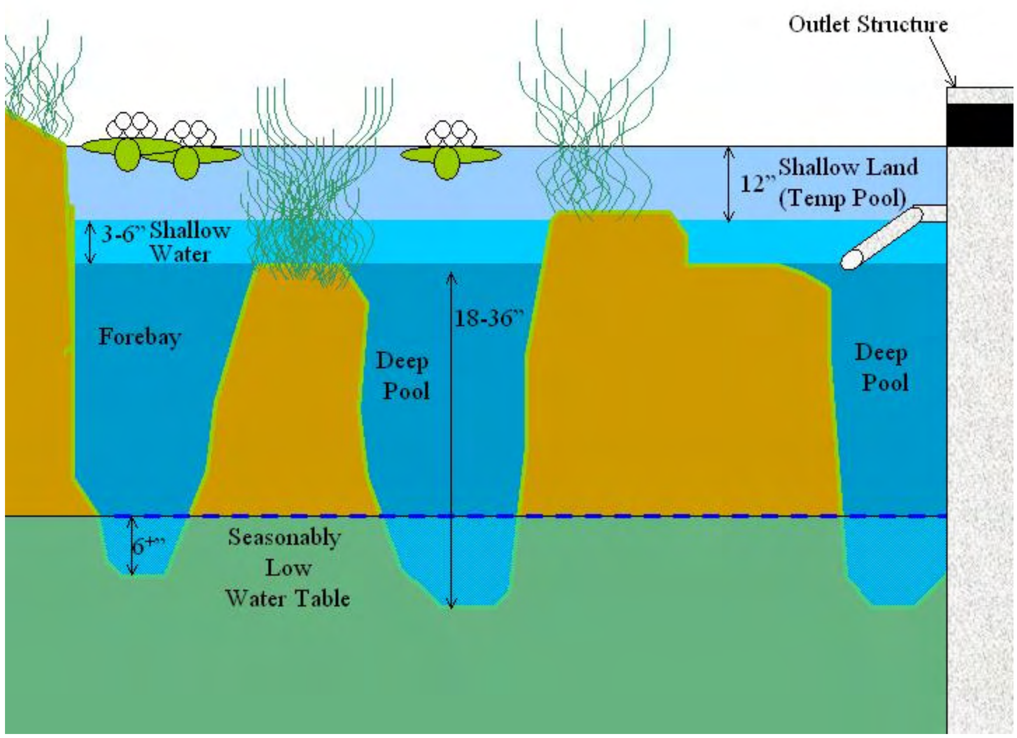
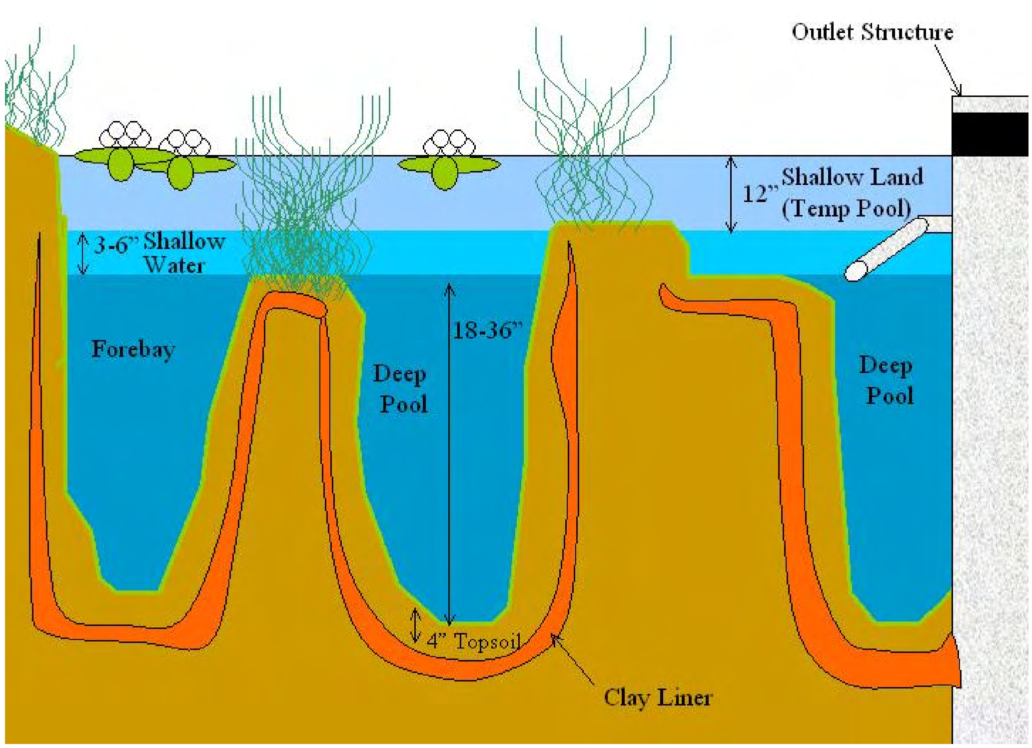


Figure 9-7b
Wetland Conceptual Diagram, Option 2: Clay Liner Installed



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

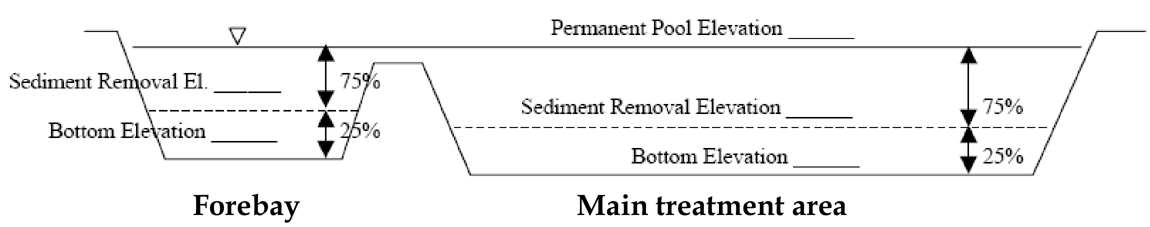
BMP element:	Potential problem:	How to remediate the problem:
The forebay	Sediment has accumulated and reduced the depth to 75% of the original design depth (see diagram below).	Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the BMP.
	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.

Figure 9-14 in intended to aid maintenance personnel in determining when to clean out the wetland. The "main treatment area" in this diagram refers to the deep pools of a wetland.

Figure 9-14
Profile of a Stormwater Wetland



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

Major Design Elements

- * Sizing shall take into account all runoff at ultimate build-out, including off-site drainage.
- * Vegetated slopes shall be no steeper than 3:1.
- * BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
- * BMP shall not be located to produce adverse impacts on water levels in adjacent wetlands.
- * Basin discharge shall be evenly distributed across a minimum 30 feet long vegetative filter strip.
- * Discharge rate following a 1-inch rainfall shall completely draw down the temporary storage volume between 2 and 5 days.
- * The average depth of the permanent pool shall be a minimum of 3 feet.
- * BMP shall be designed with a forebay.
- * Basin side slopes shall be stabilized with vegetation above the permanent pool level.
- * The basin shall be designed with sufficient sediment storage to allow for proper operation between scheduled cleanouts.
- ** The forebay volume should be about 20% of the total permanent pool volume, leaving about 80% of the design volume in the main pool.
- ** Permanent pool surface area shall be determined using Tables 10-1, 10-2, and 10-3.
- ** Freeboard shall be a minimum of 1 foot above the maximum stage of the basin.
- ** A minimum 10-foot wide vegetated shelf shall be installed around the full 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.

* *These provisions are specified in the NC Administrative Code rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *These engineering design provisions are based, in part, on available research studies and are what the Division of Water Quality considers necessary to meet the pollutant removal efficiencies provided in this Manual.*

Major Design Elements, continued

** A minimum basin length to width ratio of 1.5 is required. A minimum flow path ratio of 3:1 is recommended.

** At a minimum, an additional one foot of depth of sediment storage is required in both the forebay and the main pool.

* *These provisions are specified in the NC Administrative Code rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *These engineering design provisions are based, in part, on available research studies and are what the Division of Water Quality considers necessary to meet the pollutant removal efficiencies provided in this Manual.*

Advantages	Disadvantages
– 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. .	– 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.

10.1. General Characteristics and Purpose

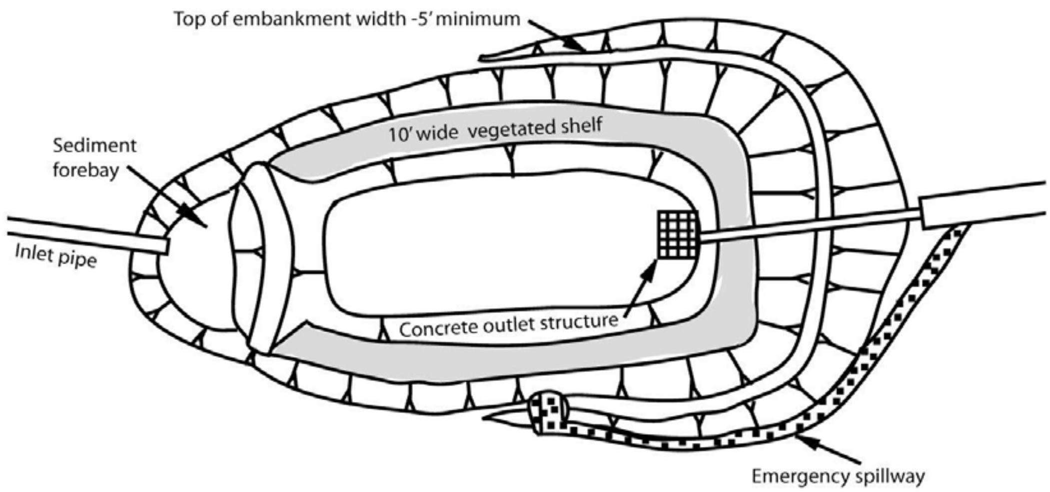
In wet detention basins, a permanent pool of standing water is maintained by the riser—the elevated outlet of the wet detention basin (see Figure 10-1). Water in the permanent pool mixes with and dilutes the initial runoff from storm events. Wet detention basins fill with stormwater and release most 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. Figure 10-2 is a schematic plan view 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 10-2
Basic Wet Detention Basin Elements



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.
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.

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 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 by the Simple Method as presented 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. 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. 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.

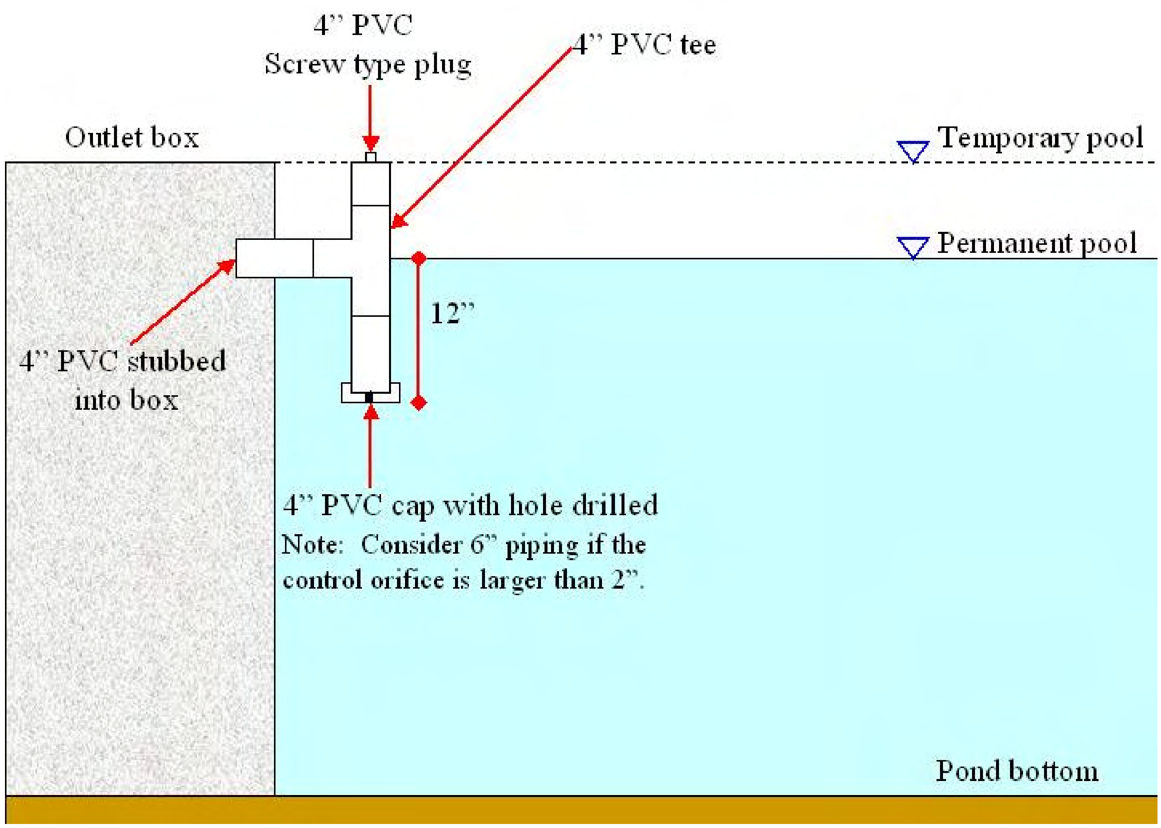
10.3.9. Outlet Design

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 10-3.

Figure 10-3

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. 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. 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 aquatic 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 aquatic 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 shouldbe 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 10-4

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 10-4, 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.

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

Major Design Elements

* Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
* Vegetated side slopes shall be no steeper than 3:1.
* BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
** 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.
** Maximum contributing drainage basin is 5 acres.
** Sand filters must be designed off-line with a flow-splitting device.
** Minimum width (parallel to flow) of a sedimentation chamber or forebay shall be 1.5 feet.
** Sand filter must completely drain within 40 hours.
** Sand media shall be as specified below and shall be a minimum of 18" deep (minimum of 12" over the drainage pipes).
** 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.

* *This provision is specified in the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*
** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

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.

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)

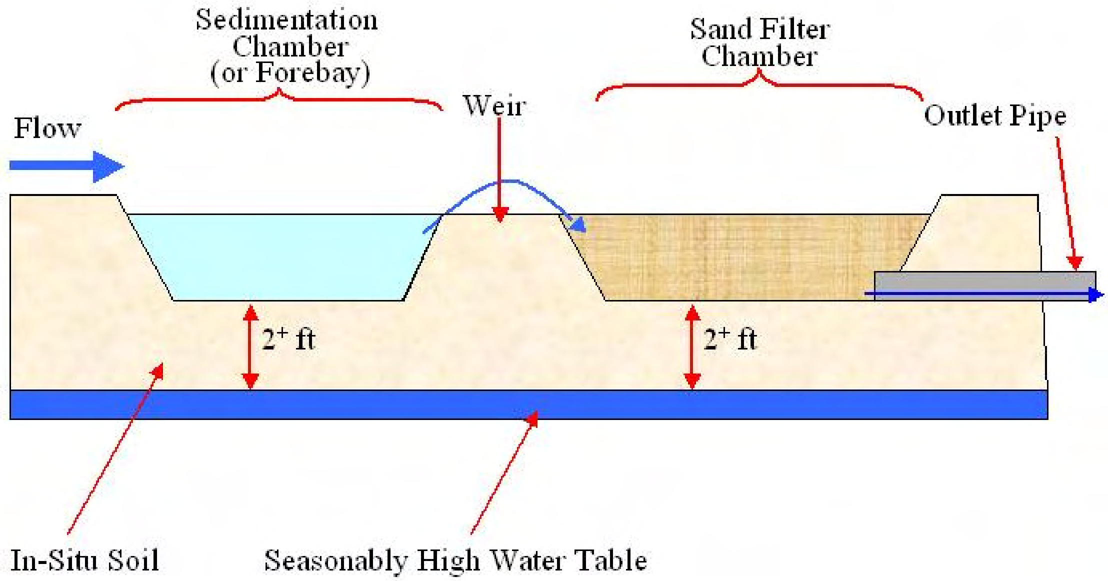


Figure 11-2a
Buried Trench (Closed-Basin) Sand Filter, 3-D View
Derived from Shaver, 1992

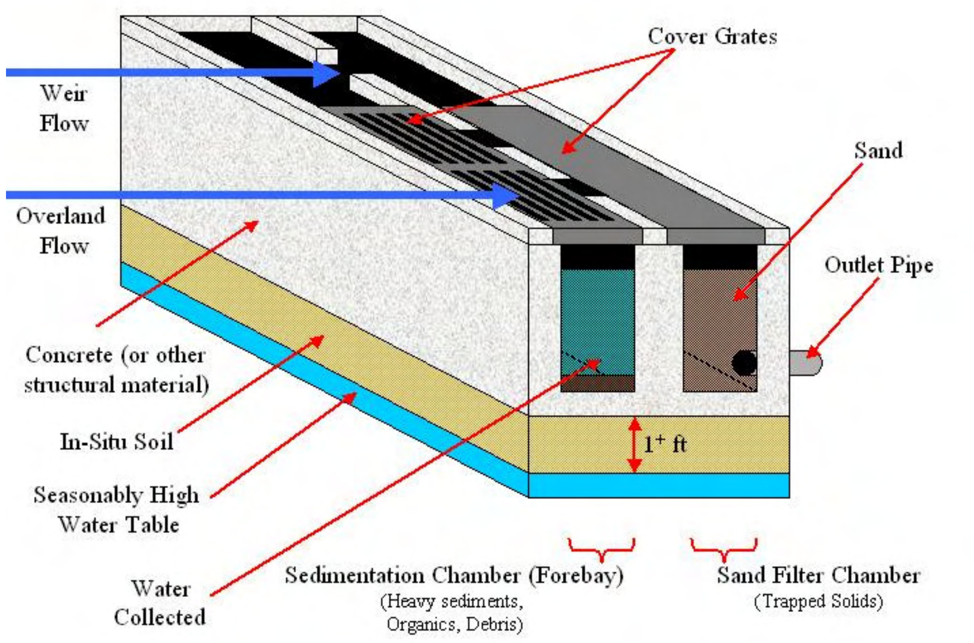
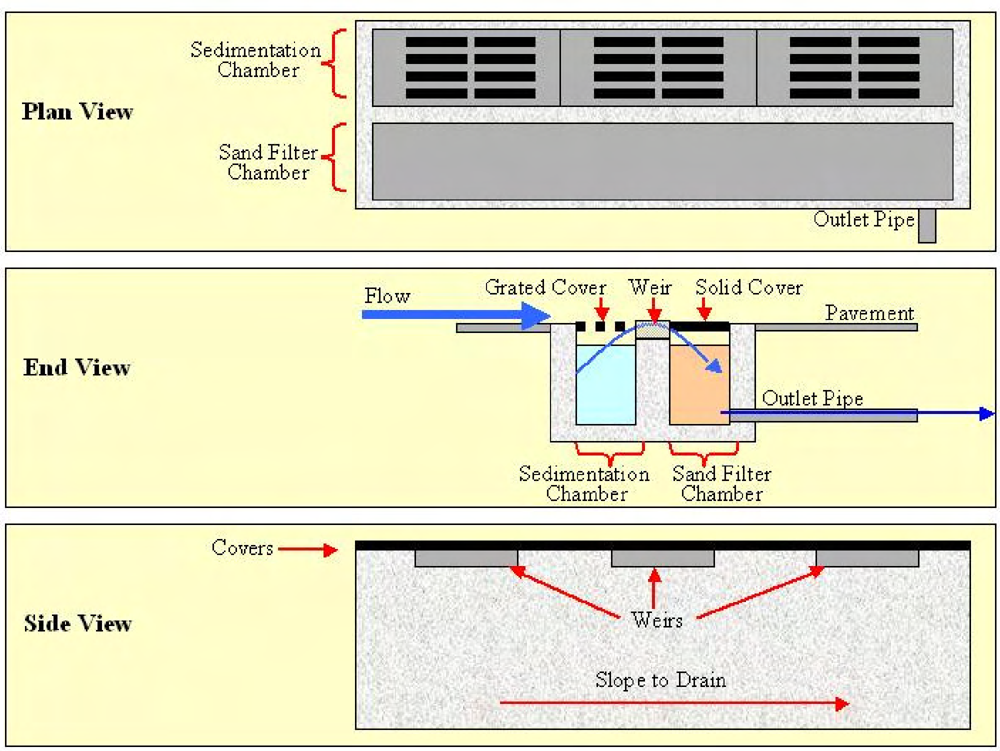


Figure 11-2b
Buried Trench (Closed Basin) Sand Filter
Derived from Shaver, 1992



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 Sections 2 and 3 and summarized below, and the adjusted water quality volume (WQV_{Adj}) as defined below (Center for Watershed Protection, 1996). :

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

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

- 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:

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

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

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

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

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

- 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 ft^2 of space available for this underground project.

1. Step 1
   - Rv=0.05+0.09(%Imp)=0.05+0.009(100)=0.95
   - $WQV\,(ft^3) = \frac{0.95(unitless)}{1} x \frac{1(acres)}{1} x \frac{43{,}560\,ft^2}{1Acre} x \frac{1inchRain}{1} x \frac{ft}{12in} = 3{,}449\,ft^3$
   - $WQV_{Adj}\,(ft^3) = (0.75)(3{,}449) = 2{,}587(ft^3)$
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 ft^2 of space available, then A_s and A_f can both be 360 ft^2, 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.

12 Bioretention

Description

Bioretention is the use of plants and soils for removal of pollutants from stormwater runoff via adsorption, filtration, sedimentation, volatilization, ion exchange, and biological decomposition. In addition, bioretention provides landscaping and habitat enhancement benefits.

Regulatory Credits

Pollutant Removal

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

Water Quantity

yes	Peak Runoff Attenuation
possible	Runoff Volume Reduction

Feasibility Considerations

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

Major Design Elements

- * Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
- * Side slopes stabilized with vegetation shall be no steeper than 3:1.
- * BMP shall be located in a recorded drainage easement with a recorded access easement to a public right of way (ROW).
- ** Bioretention facilities shall not be used where: seasonally high water table less than 2 feet below bottom of BMP, slopes greater than 20%, and non-permanently stabilized drainage areas.
- ** Inflow must be sheet flow or utilize energy dissipating devices.
- ** Ponding depth shall be 12 inches or less. Nine inches is preferred.
- ** Media depth shall be specified for the vegetation used. For grassed cells, use 2 feet minimum. For shrubs or trees use 3 feet minimum.
- ** The geometry of the cell shall be such that no dimension is less than 10 feet (width, length, or radius).
- ** Media should be specified as listed in this section.
- ** The phosphorus index (P-index) for the soil must be low, between 10 and 30. This is enough phosphorus to support plant growth without exporting phosphorus from the cell.
- ** Ponded water shall completely drain into the soil within 12 hours. It shall drain to a level of 24 inches below the soil surface in a minimum of 48 hours. Permeability of 0.5-6"per hour is required, 1-2 in per hour is preferred.
- ** An underdrain shall be typically installed if in-situ soil drainage is less than 2 in/hr or if there is in situ loamy soil (~12% or more of fines). This is usually the case for soil tighter than sandy loam or if there has been significant soil compaction from construction.
- ** Clean-out pipes must be provided if underdrains are required.

* *This provision is specified in NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

Advantages	Disadvantages
– Efficient removal method for suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, pathogens, and temperature. – If providing infiltration in appropriate soil conditions it can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge groundwater. – Flexible adaptation to urban retrofits. – Individual units are well suited for use in small areas, and multiple, distributed units can provide treatment in large drainage areas. – Natural integration into landscaping for urban landscape enhancement.	– Surface soil layer may clog over time (though it can be restored). – Frequent trash removal may be required, especially in high traffic areas. – Vigilance in protecting the bioretention area during construction is essential. – Single unit can only serve a small drainage area. – Requires frequent maintenance of plant material and mulch layer.

12.1. General Characteristics and Purpose

A bioretention cell consists of a depression in the ground filled with a soil media mixture that supports various types of water-tolerant vegetation. The surface of the BMP is depressed in bioretention facilities to allow for ponding of runoff that filters through the BMP media. Water exits the bioretention area via exfiltration into the surrounding soil, flow out an underdrain, and evapotranspiration. The surface of the cell is protected from weeds, mechanical erosion, and desiccation by a layer of mulch. Bioretention is an efficient method for removing a wide variety of pollutants, such as suspended solids, heavy metals, nutrients, pathogens, and temperature (NC Cooperative Extension, 2006). Bioretention areas provide some nutrient uptake in addition to physical filtration. If located at a site with appropriate soil conditions to provide infiltration, bioretention can also be effective in reducing peak runoff rates, reducing runoff volumes, and recharging groundwater.

Many development projects present a challenge to the designer of conventional stormwater BMPs because of physical site constraints. Bioretention areas are intended to address the spatial constraints that can be found in densely developed urban areas where the drainage areas are highly impervious (see Figure 12-1). They can be used on small urban sites that would not normally support the hydrology of a wet detention pond and where the soils would not allow for an infiltration device. Median strips, ramp loops, traffic circles, and parking lot islands are good examples of typical locations for bioretention areas. See Section 12.3.1 for more illustrated examples of the versatility of bioretention facilities.

Bioretention units are ideal for distributing several units throughout a site to provide treatment of larger areas. Developments that incorporate this decentralized approach to stormwater management can achieve savings by: eliminating stormwater management ponds; reducing pipes, inlet structures, curbs and gutters; and having less grading and clearing. Depending on the type of development and site constraints, the costs for using decentralized bioretention stormwater management methods can be reduced by 10 to 25 percent compared to stormwater and site development using other BMPs (Coffman et al., 1998).

Bioretention facilities are generally most effective if they receive runoff as close as possible to the source. Reasons for this include: minimizing the concentration of flow to reduce entry velocity; reducing the need for inlets, pipes, and downstream controls; and allowing for blending of the facilities with the site (e.g., parking median facilities). For sites where infiltration is being utilized, it also avoids excessive groundwater mounding. Where bioretention takes the place of required green space, the landscaping expenses that would be required in the absence of bioretention should be subtracted when determining the actual cost (Low Impact Development Center, 2003). Bioretention cells may also address landscaping/green space requirements of some local governments (Wossink and Hunt, 2003).

Figure 12-1
Bioretention in Parking Lot Island

12.2. Meeting Regulatory Requirements

To obtain a permit to construct a bioretention cell in North Carolina, the bioretention cell must meet all of the Requirements specified in the Major Design Elements located at the beginning of this Section.

Pollutant Removal Calculations
The pollutant removal calculations for bioretention facilities 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 bioretention cell also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading.

Volume Control Calculations
A bioretention cell can sometimes be designed with enough storage to provide active storage control (calculations for which are provided in Section 3.4), however, some may not have enough water storage to meet the volume control requirements of the particular stormwater program (since its storage potential is limited because the ponding depth is limited) so they may need to be used in series with another BMP with volume control capabilities. All bioretention facilities provide some passive volume control capabilities by providing pervious surface and therefore reducing the total runoff volume to be controlled.

12.3. Design

Design is an eight-step process:
1. Understand basic layout concepts.
2. Determine the volume of water to treat.
3. Determine the surface area required.
4. Select the soil media type.
5. Decide the depth of soil media.
6. Size the underdrain pipes (if necessary).
7. Select the appropriate overflow bypass.
8. Select plants and mulch.

12.3.1. Step 1: Understand Basic Layout Concepts

The layout of bioretention areas varies according to individual sites and to specific site constraints such as underlying soils, existing vegetation, drainage, location of utilities, sight distances for traffic, aesthetics, ease of maintenance, etc.

Figure 12-1 illustrates a concept for a bioretention traffic island. These types of bioretention facilities typically take up no more space than what is required by typical zoning rules, and they provide stormwater treatment as well as site aesthetics. The following photographs are examples of existing bioretention cells that have been designed using these techniques. These cells blend into the landscape and appear to be typical flowerbeds or medians. Often, bioretention cells can be designed with flowering plants to enhance the landscape.

Examples of Previously Installed Bioretention Cells
Figure 12-2a shows an 8-inch gravel strip followed by 5 feet of grass for pretreatment along the side that receives water from the jogging trail. This is an example of both gravel strip pre-treatment design as well as when to maintain the gravel strip. This strip has become over-grown with grass and has been clogged with sediment. The mulch has also become thin, and should be replaced.

Figure 12-2a

Bioretention Cell with Pretreatment: Gravel and Grass (Needs Maintenance)

Figure 12-2b shows a bioretention cell with a pretreatment forebay. This is an atypical forebay because it is not earthen. However, it serves the same purpose because it slows down water and allows particles to settle out before entering the cell itself. Notice the sediment that has settled onto the rocks. Without the forebay, this sediment would have collected on the top of the bioretention cell, clogged the soil media, and would have become a maintenance burden.

Figure 12-2b

Bioretention Cell with Pretreatment: Forebay

Figure 12-2c shows an example of a bioretention cell receiving stormwater via a pipe. If water is collected from the roof of a building or other measures have been taken to ensure that there is low sediment in the influent, the risk of sediment contamination is reduced and the pipe method presented in this figure is appropriate. Note that rocks are placed below the entrance pipe in order to dissipate the energy from the flow so that the mulch does not wash away.

Figure 12-2c
Bioretention Cell Without Pretreatment: Low-Sediment Influent

Examples of Additional Design Options
A bioretention area that can be installed along the perimeter of a parking lot is shown in Figure 12-3a. The water is diverted to the bioretention area through the use of a curb diversion structure (see Section 5.0 Common BMP Design Elements for details). A 2-foot buffer between the curb and the bioretention area serves as pretreatment and reduces the possibility of drainage seeping under the pavement section and creating “frost heave” during winter months. Flow diversion by curb diversion structures may not meet the volume attainment requirements.

A bioretention area suitable for installation along a swale is shown in Figure 12-3a. A berm one foot in height separates the swale from the bioretention area. To maintain an off-line system, the bioretention area should be at an elevation such that when the design ponding depth is reached, additional flow continues down the swale and is diverted from the bioretention cell. The flow diversion method shown is for conceptual purposes and may not meet the volume attainment requirements.

Figure 12-3a
Parking Edge and Perimeter with Curb
Prince George's County (2000a)

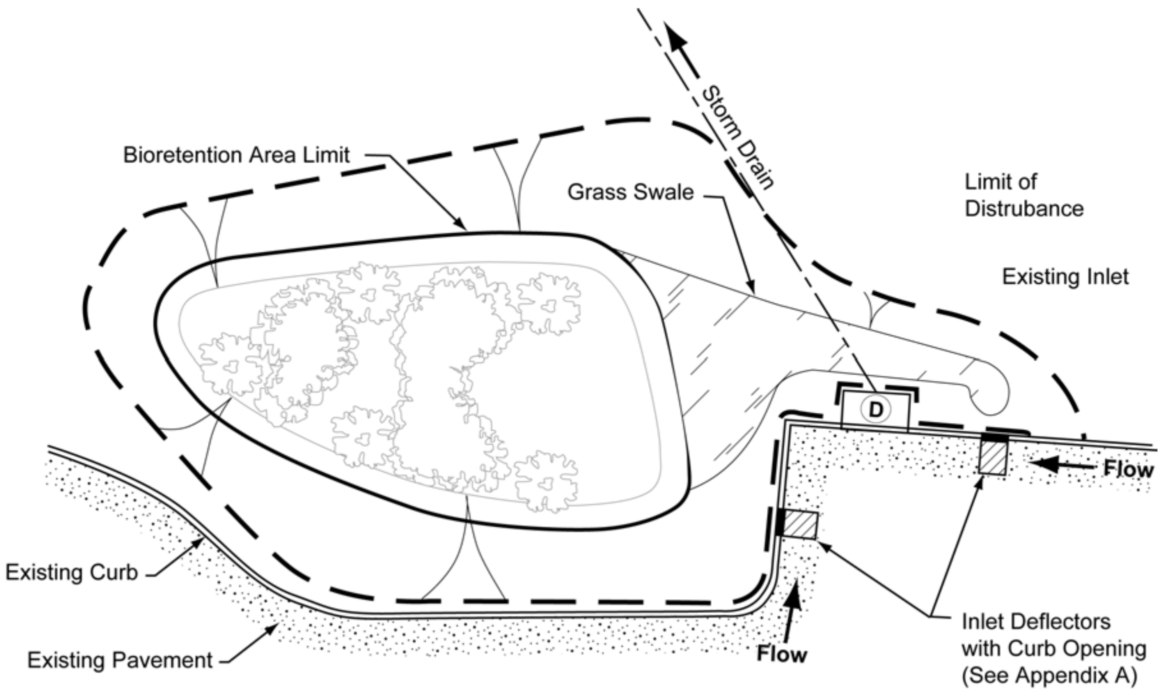
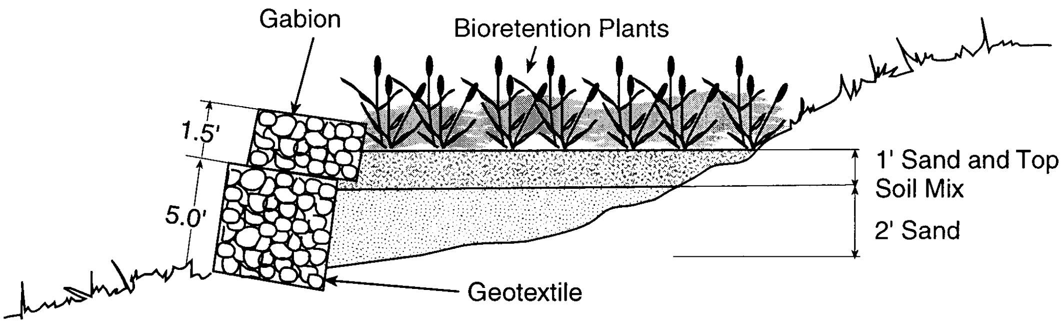


Figure 12-3b depicts a bioretention terrace that can be used in sloping terrain (for 10-20% slopes). An impermeable or very low permeability geomembrane must be used against the gabions or similar retaining structure to prevent flow from leaving the treatment unit through that surface. An underdrain could be placed at the low point of the filter if the native soil that the unit is built against will not provide adequate infiltration capacity.

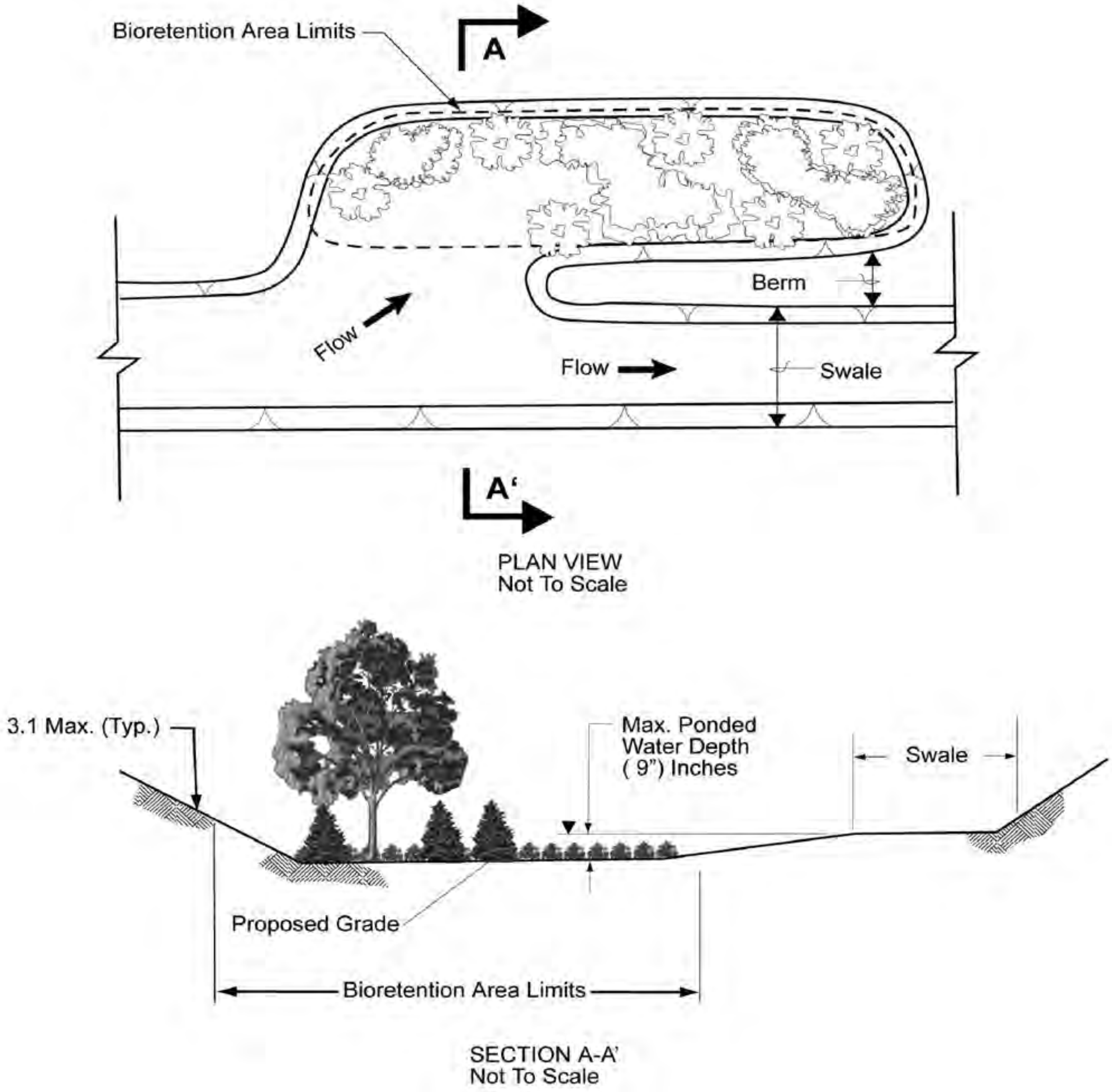
Figure 12-3b
Bioretention Terrace Suitable for Use on Slopes 10-20%



Use of Flow Splitters
Some bioretention units are designed to be "on-line" with respect to the stormwater management system, meaning all of the flow from the specific drainage area flows into the BMP, with the excess beyond the cell design exiting through an overflow device. In these cases, special consideration (sheet flow, rip rap, forebays, etc.) should be taken to reduce the erosion potential within the bioretention unit.

Other bioretention units are designed to be "off-line"; meaning only a portion of the stormwater flow is diverted from the conveyance system into the treatment unit. An example of an offline system is provided in Figure 12-3c. In these cases, a properly designed flow splitter device must be included to receive credit for complying with the regulations. Please see Section 5.0 Common BMP Design Elements for more information on flow splitting devices.

Figure 12-3c
Bioretention Swale: Offline (No Flow Splitter Used)
Prince George's County (2001)



A design of a bioretention cell with a flow splitter is not provided in this guidance document.

Pretreatment Options
Inflow must enter a bioretention cell via sheet flow or alternative energy dissipating devices must be used. Sheet flow provides for the most even distribution of flow and the least energy (minimizing erosion). Sheet flow can be naturally provided as in the

case of a gently sloping parking lot with no curb and gutter or a vegetated buffer/filter strip, or it can be designed into the device by the use of a level spreader. In some instances sheet flow is not attainable and the inflow will enter from concentrated sources such as curb diversion structures, drainage pipes, grassy swales, etc. In these cases a rip rap lined entrance, a forebay, or other energy-dissipating device must be used.

The Simple Method is used to obtain the water treatment volume. Typically, bioretention cells are designed to treat the first flush, which is typically the first inch of rain. The cell must be designed to have a pretreatment area. The most commonly used pretreatment devices are:

1.) A grass and gravel combination: This should consist of 8 inches of gravel followed by 3 to 5 feet of sod. In eastern and central North Carolina, centipede has been used successfully. In the mountains, fescue and bluegrass are appropriate. See Figure 12-2a.
2.) A grassed water quality swale: A water quality swale shall be designed as specified in Chapter 14.
3.) A forebay: This is the option that is used least often. The forebay should be 18-30 inches deep, and used only in areas where standing water is not considered a safety concern. The forebay should be deepest where water enters, and more shallow where water exits in order to dissipate hydraulic energy of the water flowing to the forebay. If there is a risk that water in the forebay could flow into the underdrain without first flowing to the cell, the forebay must be lined. See Figure 12-2b.

The bioretention areas featured in Figures 12-4a, 12-4b, and 12-4c represent examples of bioretention cell designs with various pre-treatment options. These diagrams show design layout options for collecting water from overland flow.

Figure 12-4a
Bioretention Conceptual Layout: Gravel and Grass Pretreatment

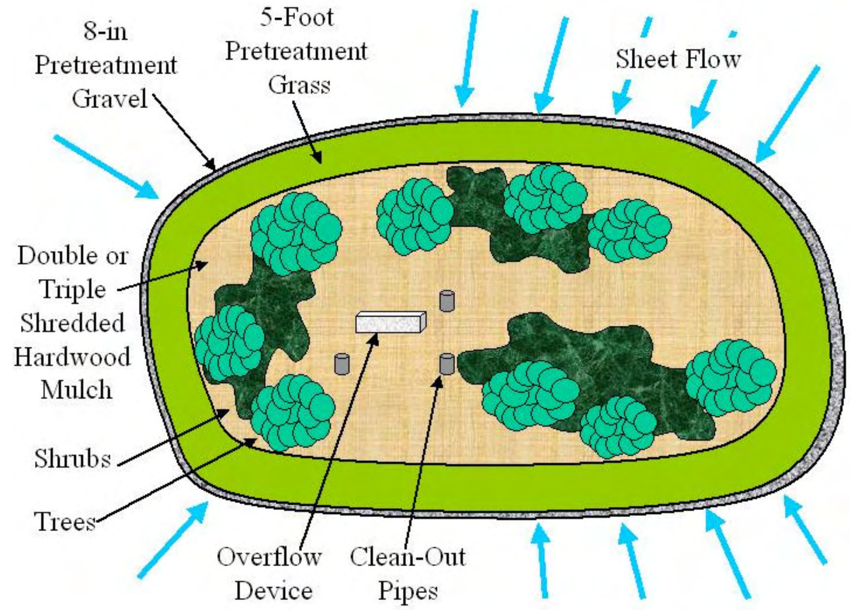


Figure 12-4b
Bioretention Conceptual Layout: Forebay Pretreatment

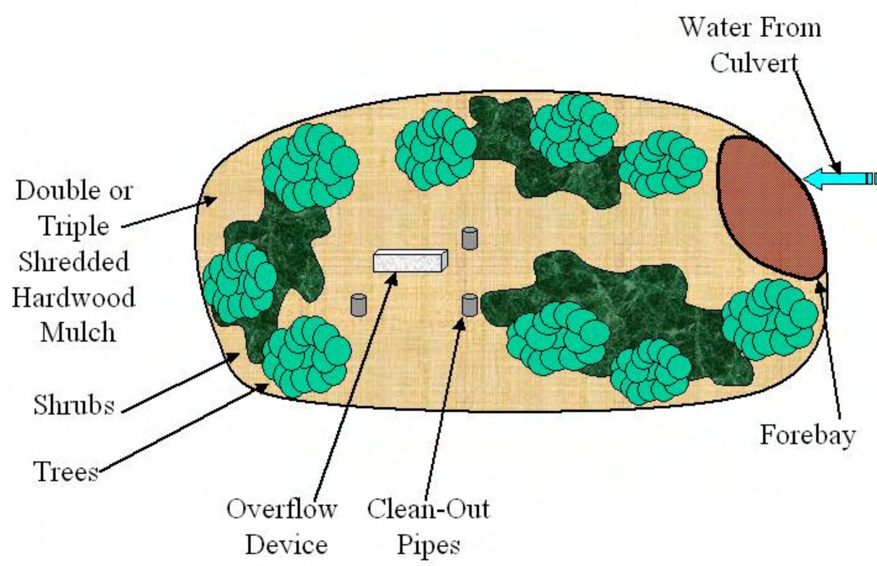
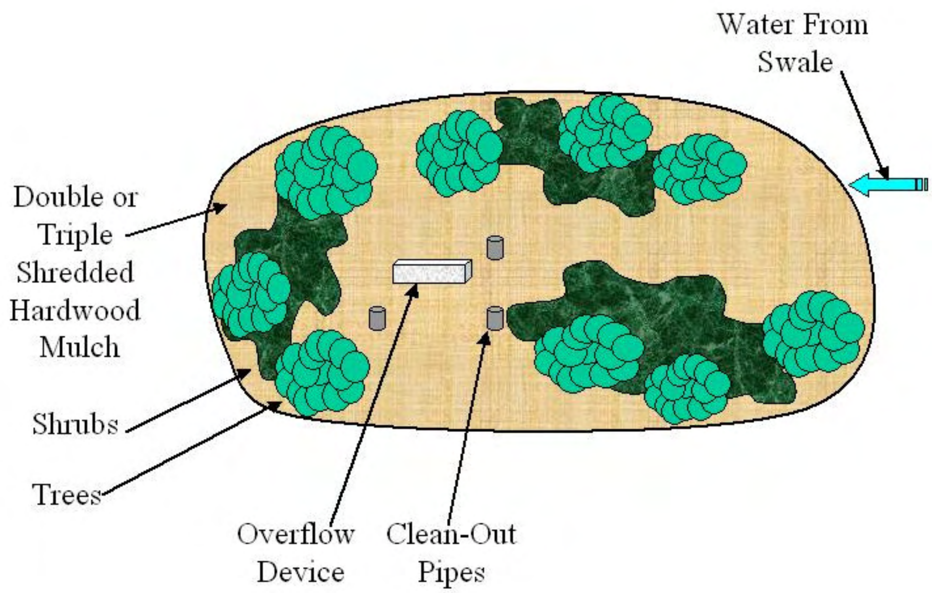


Figure 12-4c
Bioretention Conceptual Layout: Swale Pretreatment



Maintenance Considerations
When performing the following remaining steps of designing a bioretention cell, consider how landscape professionals will later access the site for maintenance. Because the soil must be able to accommodate fast water infiltration, it can not be compacted by heavy equipment. Is the forebay accessible for heavy equipment to remove sediment from it without driving onto the cell? Are the clean-out pipes accessible? All aspects of design should consider future maintenance.

12.3.2. Step 2: Determine the Volume of Water to Treat

Water Volume
An individual bioretention cell is intended to treat the first flush. Section 3, Stormwater Calculations, details the volumetric calculation.

Siting Issues
Bioretention facilities shall *not* be used in areas with the following characteristics:

- The seasonal high water table is less than 2 feet below the bottom of the cell.
- Slopes are 20 percent or greater, unless bioretention terraces are planned.
- Further construction is planned on either the immediately surrounding site or in outparcels that may drain to the bioretention site. (The upstream contributing drainage area must be completely and permanently stabilized (e.g. gravel base course driving surface (preferably paved), or a dense and vigorous vegetative cover). The heavy sediment load from a bare earth construction site will cause premature failure of a bioretention BMP.)
- The cell is inaccessible for maintenance.
- The cell will not comply with local landscape ordinances.

Contributing Drainage Basin
Consider the affect of large storms on potential erosion within the cell as well as potential overflow and downhill erosion upon water leaving the cell. The contributing area to an individual bioretention cell will typically be 5 acres or less because many large watersheds will not have an area that is large enough to serve the treatment volume while also being high enough above the water table.

12.3.3. Step 3: Determine the Surface Area and Depth Required

The cell can be designed to hold the first inch of rainfall from the entire drainage area. The required surface area of the bioretention cell is equal to the required treatment volume divided by the ponding depth. No dimension (width, length, or radius) can be less than 10 feet. This is to provide sufficient space for plants.

12.3.4. Step 4: Select the Soil Media Type.

The soil mix should be uniform and free of stones, stumps, roots or other similar material greater than 2 inches. It should be a homogenous soil mix of 85-88 percent by weight sand (USDA Soil Textural Classification), 8 to 12 percent fines (silt and clay), and 3 to 5 percent organic matter (such as peat moss) shall be used. Higher (12 percent) fines content should be reserved for areas where TN is the target pollutant. In areas where phosphorus is the target pollutant, lower (8 percent) fines should be used. Additionally, the phosphorus content of the soil mix should be low. Soil media should be sent to NC Department of Agriculture [NCDA] labs to be analyzed. The P-Index for bioretention soil media should always range between 10 and 30, regardless of the target pollutant (Hardy et. al., 2003 and Hunt et. al., 2006). The P-Index is an extremely important design element. Cells that are constructed of high P-Index soils can export phosphorus.

The media should be tested to determine an actual drainage rate after placement. The permeability should fall between 0.5 and 6 inches per hour, and 1-2 inches per hour is preferred. As a rule of thumb, using the above-specified media, the infiltration rates should be approximately 2 in/hr and 1 in/hr for 8% and 12% fines, respectively, depending on the target pollutant. An estimated drainage rate for percent fines between 8 and 12 can be approximated during design by linear interpolation. If TSS or pathogens is the target pollutant, the higher permeability can be used because these two pollutants are removed on the surface of the bioretention cell rather than within the cell.

12.3.5. Step 5: Determine the Soil Media Depth

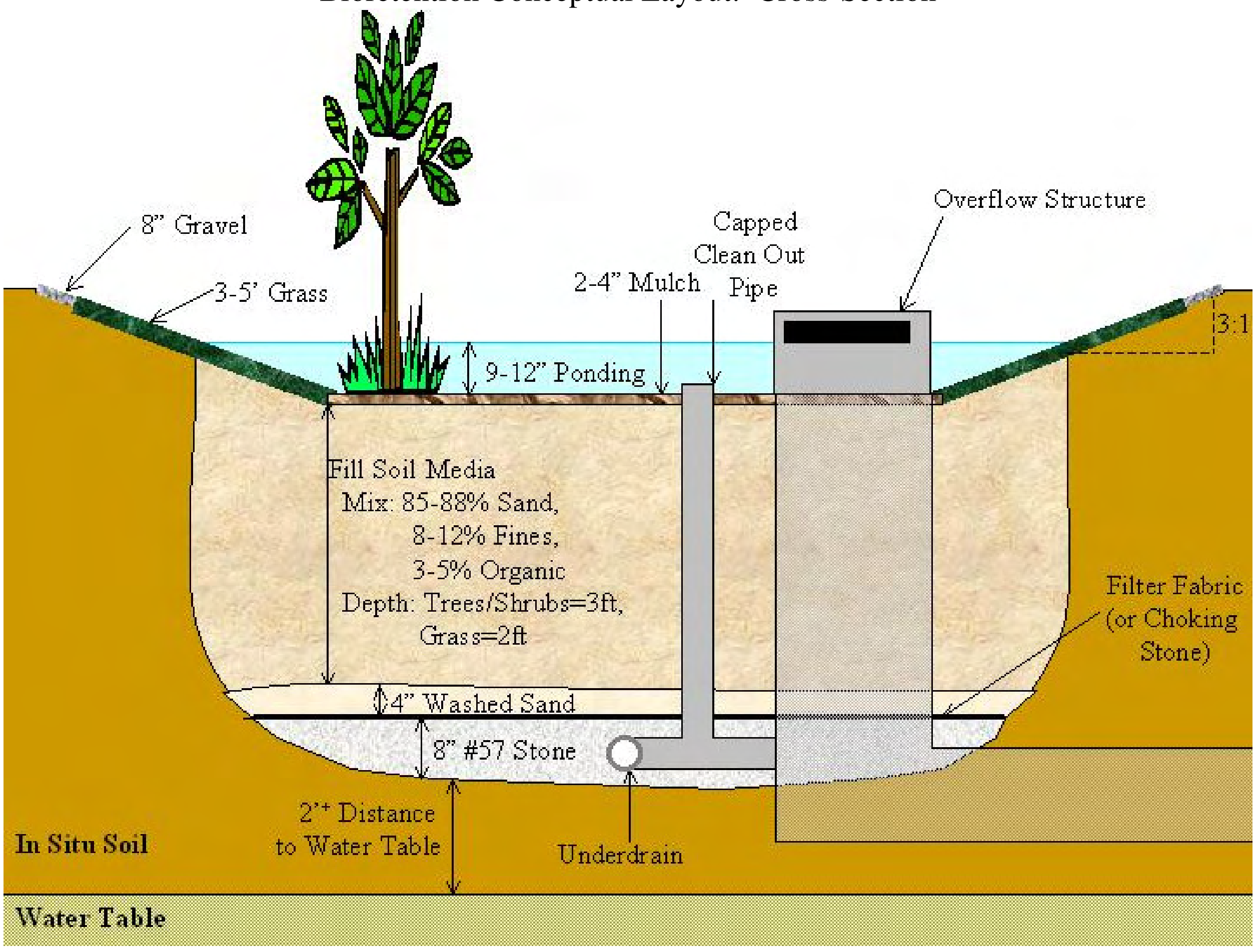
Consider the target pollutants when determining media depth. TSS is removed in pre-treatment and some is removed on the surface of the cell itself. Depth, therefore, is not a factor if TSS is the only target pollutant. Similarly, pathogens such as fecal coliform settle on the surface of the cell, and once the cell has dried, the pathogens are killed by sunlight. However, depth is an issue for other pollutants. Metals are removed in the first 1-2 inches of mulch. Also, two thirds of the phosphorus entering the cell is attached to soil particles. This portion is therefore removed on the surface. However, the remaining third is soluble and is removed 12 inches or more below the surface. Nitrogen is removed 30 inches below the surface. Initial research at NC State shows that using an up-turned underdrain pipe may increase nitrogen removal. The up-turned piped creates an anaerobic zone that may facilitate nitrogen removal. In the future, the Division may consider the effect of this technology on nitrogen credit, though it is not available at this time. Temperature is removed at approximately 48 inches below the surface. Consider the types of pollutants to be removed, and select an appropriate media depth.

The ponding depth above the media shall be 12 inches or less (9 inches or less is recommended). This is based on both the typical inundation tolerance of the vegetation used in bioretention facilities, as well as the ability of the ponded water to drain into the soil within the required time.

The depth of the media in a bioretention cell should be between 2 and 4 feet. This range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil and that excavations deeper than 4 feet become more expensive. The depth should accommodate the vegetation (shrubs or trees). If the minimum depth of 2 feet is used, then only shallow-rooted plants can be planted. Grassed bioretention cells can be as shallow as 2 feet. However, if nitrogen is the target pollutant then the cell should have at least 30 inches of media because, as previously discussed, nitrogen is removed 30 inches below the surface. Bioretention facilities where shrubs or trees are planted can be as shallow as 3 feet. If large trees are to be planted in deep fill media, care should be taken to ensure that they would be stable and not fall over. If underdrain piping is used (which is only for cases where the infiltration rate is less than 2 in/hr), then the media is as shown in Figure 12-5. This figure shows a cross-sectional design. The gravel and grass pretreatment option is presented in this figure because it is the most commonly used pretreatment in North Carolina. This design is for a bioretention cell in a non-developing area. Bioretention cells should only be used in non-developing areas. If there is any concern that the surrounding area may be developed in the future, then consider using an alternate BMP. If this is only a nominal concern, then use 2 inches of #8 or #89 washed choking stone in place of the filter fabric shown in Figure 12-5. For further information on designing bioretention cells with choking stone layers, consult Hunt and Lord, 2006. If an underdrain system is not used, then the cross-section will be the same though the underdrain is omitted. Figure 12-5 is shown using the gravel and grass pretreatment option, though it could be modified to use any of the pretreatment methods. This figure also shows an overflow structure. Typically, an overflow structure is adapted from an existing drainage culvert inlet.

The vertical sides of the bioretention cell do not have to be at a specified angle. However, the surface area of the bottom of the cell should be maximized.

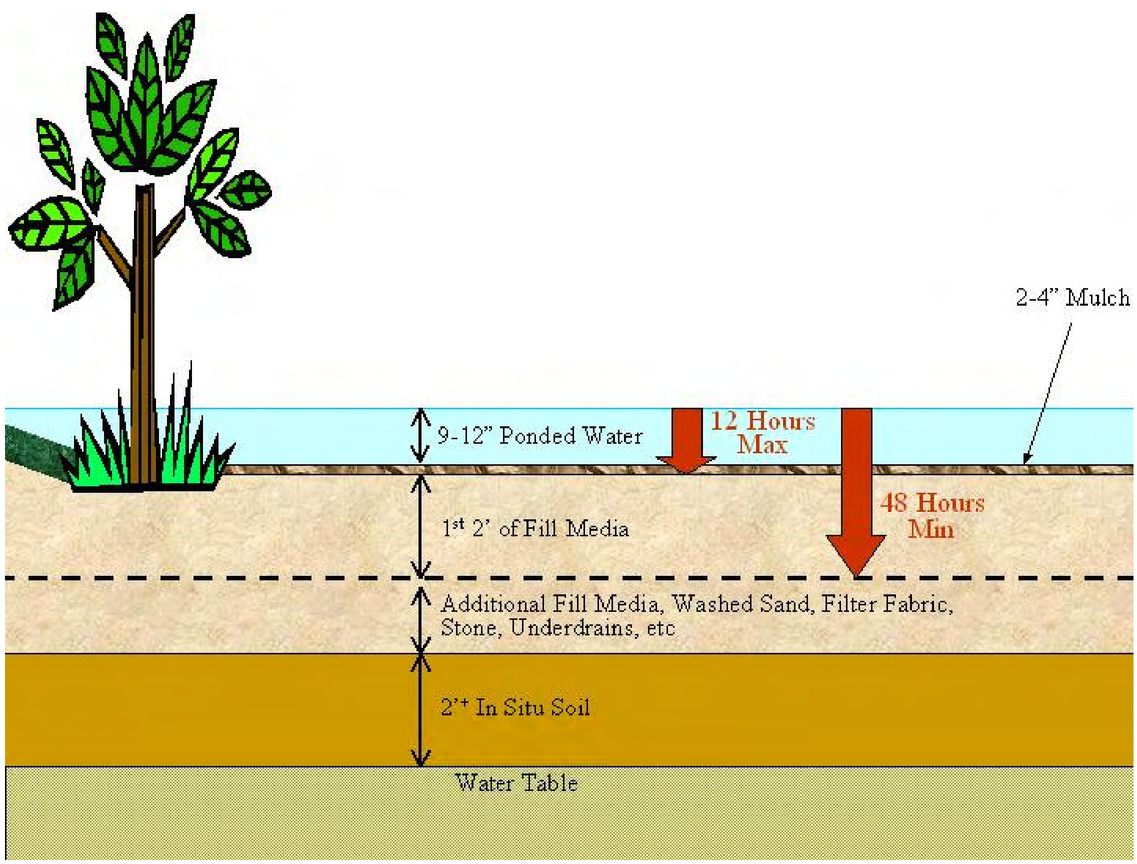
Figure 12-5
Bioretention Conceptual Layout: Cross-Section



Sediment Accumulation
There should be very little sediment accumulation, if any, in a bioretention cell, since the upstream drainage basin must be stabilized prior to bringing the bioretention cell into service, and since pretreatment is required prior to the BMP.

Drainage Considerations
The duration of ponding shall be a maximum of 12 hours. The ponded water must drain to a level 24 inches below the surface of the cell within a minimum of 48 hours in order to allow the appropriate contact time for pollutant removal. This is requirement is demonstrated in Figure 12-6. The length of time that it takes to drain the ponding volume of a bioretention cell is either controlled by the infiltration rate of the media if it has an underdrain, or it is controlled by the lesser of either the infiltration rate of the media or the infiltration rate of the native soil if it is an infiltration type system. The time to drain the ponded volume is simply the depth of the ponding in inches, divided by the limiting drainage rate. Bioretention areas do not effectively remove nitrate. Where nitrate is a concern, the underdrain can be elevated from the bioretention cell and within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. Denitrification within the anaerobic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration. Adding a suitable carbon source (e.g., wood chips) to the gravel layer provides a nutrition source for the microbes, enables anaerobic respiration, and can enhance the denitrification process (Kim, Seagren, and Davis, 2003).

Figure 12-6
Bioretention Drain Time



12.3.6. Step 6: Size the Underdrains (if required)

The need for an underdrain is driven by the permeability of the in-situ soil. If the in-situ soil has a high permeability, the system can be designed as an infiltration type bioretention facility and does not require any underdrain. If the in-situ soil permeability is less than 2 in/hour the bioretention facility shall have an underdrain system. In general, bioretention BMPs in the Piedmont region of North Carolina will require underdrains. The underdrain system will connect to another BMP or to the conveyance system. Due to the risk of underdrain clogging, designers are encouraged to install more than one underdrain of smaller diameter in order to facilitate drainage. The minimum diameter of pipe for underdrain systems is four inches. As previously discussed, an up-turned elbow may be used for the entrance to the underdrain. Initial research shows that this may increase nutrient removal.

Clean-out pipes must be provided (minimum one per every 1,000 square feet of surface area). Clean out pipes must be capped. An example of a clean out pipe is provided in Figure 12-7.

Figure 12-7
Bioretention Cell Clean Out Pipe

12.3.7. Step 7: Select the Appropriate Overflow Structure

The overflow structure should be sized to accommodate storm volumes in excess of the first flush. The first available outlet on the outlet structure should therefore be placed at the height of the first flush, which is the ponded level of the bioretention cell. Use the weir equation to consider the height of the water above the weir during overflow from large storm events. Typically, water can rise about 2 inches above the ponded water level. But, this height can be higher, about 4-6" above the ponded water level, if required by design restraints. A particular design storm is not specified for overflow structure design. Professional judgment should be used when considering potential flooding risks outside of the bioretention cell.

12.3.8. Step 8: Select Plants and Mulch

Plants are an integral element of the bioretention system's pollutant removal and water filtration process. Plant roots aid in the physical and chemical bonding of soil particles necessary to form stable aggregates, improve soil structure, and increase infiltration capacity. Vegetated soils are more capable of more effective degradation, removal, and mineralization of total petroleum hydrocarbons (TPHs), polycyclic aromatic hydrocarbons (PAHs), pesticides, chlorinated solvents, and surfactants than are non-vegetated soils (US EPA 2000).

The primary design considerations for plant selection include:

1. *Soil moisture conditions*: Soil moisture conditions will vary widely within the bioretention facility from saturated (bottom of cell) to relatively dry (rim of cell) as well as over time. Therefore, the predominant plant material utilized should be facultative species adapted to stresses associated with both wet and dry conditions (Prince Georges County, 2002).
2. *Pollutant loadings*: Since bioretention is often specified for use in impaired and/or nutrient sensitive watersheds, strategic use of particular plants for phytoremediation purposes is crucial. Plants should tolerate typical pollutants and loadings from the surrounding land uses.
3. *Above and belowground infrastructure in and near the bioretention facility*: Plant selection should consider the surrounding conditions including: light pollution tolerance, wind, above and below ground utilities. Slotted or perforated pipe should be more than 5 feet away from tree locations. Plants with taproots should not be used.
4. *Adjacent plant communities* and potential invasive species control.
5. Site distances and setbacks for roadway applications.
6. *Visual buffering*: Plants can be used to buffer structures from roads, enhance privacy among residences, and provide an aesthetic amenity for the site.
7. *Aesthetics*: Visually pleasing plant designs add to the property and encourage community and homeowner acceptance. Public education and participation in the plant selection and design should be encouraged to promote greater involvement in long-term care.

Planting design will vary with the surrounding landscape context and design objectives. For example, the use of plants in bioretention areas could replicate a variety of native terrestrial ecosystems including forests, ornamental gardens, meadows, hedgerows, and wetlands, as well as wildlife habitats.

A minimum of three (3) trees, three (3) shrubs, and three (3) herbaceous groundcover species should be incorporated in the bioretention planting plan. A diverse plant community is necessary to avoid susceptibility to insects and disease.

The plants selected should be able to tolerate typical stormwater pollutant loads, variable (often very dry) soil moisture, temporary submergence, and extended wet conditions. Bioretention facilities in the Piedmont and mountains tend to become wetter over time; coastal bioretention facilities tend to be very dry (plants suitable for xeriscapes may be more appropriate).

Plants suitable for North Carolina BMP sites are listed in Table 12-1.

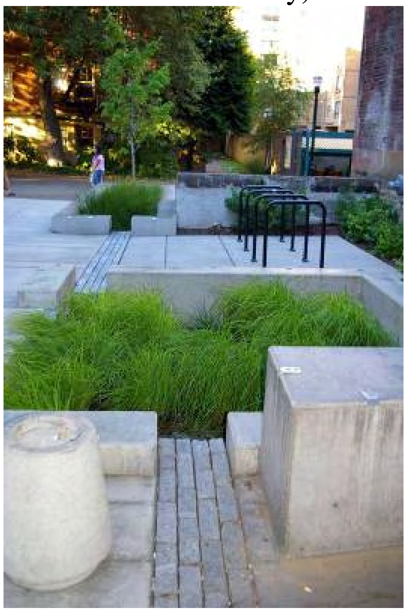
Landscape design can add aesthetic appeal to stormwater treatment as shown in Figures 12-8a and 12-8b.

Figure 12-8a

Aesthetic Appeal, Street Side Project (Courtesy of Stuart Patton Echols, Pennsylvania State University)

Figure 12-8b

Aesthetic Appeal, Courtyard Project (Courtesy of Stuart Patton Echols, Pennsylvania State University)



To increase survival rates and ensure quality of plant materials, the following general guidelines for plantings within bioretention facilities are recommended:

- All plant material should conform to the standards of the current edition of American Standard for Nursery Stock as approved by the American Standards Institute, Inc. All plant grades shall be those established by the current edition of American Standards for Nursery Stock [http://www.anla.org/applications/Documents/Docs/ANLAStandard2004.pdf].
- All plant materials should have normal, well-developed branches and vigorous root systems, and be free from physical defects, plant diseases, and insect pests.
- All plant materials should be tagged for identification when delivered.
- Optimum planting time is fall. Winter planting is acceptable (will vary for western Piedmont and mountains of NC). Spring is acceptable but will require more summer watering than fall planting. Summer planting is the least desirable as it drastically increases plant mortality and requires regular watering immediately following installation.

Plant size should be no less than 2.5" dbh for trees; 3-gallon for shrubs; and 1-quart for herbaceous plants.

- Woody vegetation should not be planted at inflow locations.

Local jurisdictions often have specific guidelines for the types and location of trees and other landscape plants planted along public streets or rights-of-way. Additionally, local landscape ordinances must be followed. Contact local authorities to determine if there are guidelines or restrictions to consider when making plant selections for your project.

The mulch layer plays an important function in the performance of the bioretention system by: reducing weed establishment; regulating soil temperatures and moisture; reducing soil compaction from rainfall, preventing erosion, and promote an environment suitable for soil microorganisms at the mulch/soil interface (important for filtering nutrients and other pollutants). Mulches prevent soil and possible fungi from splashing on the foliage, reducing the likelihood of soil-borne diseases (Evans, 2000). Mulch serves as a pretreatment layer by trapping the finer sediments that remain suspended after the primary pretreatment. Additionally, most attenuation of heavy metals in bioretention facilities occurs in the first 1-2 inches of the mulch layer (Hinman, 2005). Mulch should be:

- Free of weed seeds, soil, roots, and other material that is not bole or branch wood or bark.
- Commercially available double or triple-shredded hardwood mulch should be used. This mulch has been found to be less likely to wash away than other forms of mulch.

- Mulch depths depend on the type of material used and the drainage and moisture holding -capacity of the soil. A 2-4 inch layer (after settling) is adequate for most applications. Excessive application of mulch can result in a situation where the plants are growing in the mulch and not the soil. Over-mulched plants are easily damaged during periods of drought stress. Mulching in an area that is poorly-drained can aggravate the condition (Evans, 2000).
- Mulch can be applied any time of year, however, the best time to mulch is late spring after the soil has warmed.
- At least 6 months old (12 months is ideal).
- Uniformly placed about 3 inches deep.
- Renewed as needed to maintain a 2-4" depth; on previously mulched areas, apply a one-inch layer of new material. Added 1-2 times per year and completely removed/replaced once every two years.

Table 12-1

BIORETENTION PLANTS—TREES

SPECIES / COMMON NAME	EXPOSURE	HEIGHT/ SPREAD	COMMENTS
Acer negundo Boxelder	Sun	35-50 ft. 35-50 ft.	Western piedmont-mountains. Urban light sensitive; wet to droughty soils.
Acer rubrum Red Maple	Sun/part shade	75-100 ft. 50-75 ft.	Piedmont-Mountains. Urban light & salt sensitive; many good cultivars.
Amalanchier canadensis Shadberry/Serviceberry	Sun	35-50 ft. 35-50 ft.	Entire state. Salt resistant; moist to average soils; high wildlife value
Betula nigra River Birch	Sun	50-75 ft. 50-75 ft.	Entire state. Drought & heat resistant
Cercis canadensis Eastern Redbud	Sun/part shade	20-35 ft. 20-35 ft.	Entire state. Moist soils but not too wet; Drought tolerant; many good cultivars.
Chionanthus virginicus Fringetree	Sun or shade	20-35 ft. 20-35 ft.	Entire state. Moist soils; excellent small urban tree
Cornus alterniflora Pagoda Dogwood	Sun or shade	20-35 ft. 20-35 ft.	Western NC. Prefers moist soils; intermediate flood tolerance
Fraxinus americana White Ash	Sun or shade	75-100 ft. 50-75 ft.	Entire state. Moist to average soils; urban light resistant
Fraxinus pennsylvanica Green Ash	Sun	50-75 ft. 35-50 ft.	Entire state. Moist to average soils; light & drought resistant
Pinus palustris Longleaf pine	Sun	75-100 ft 25-35 ft.	Eastern piedmont-Coast. Wet to average soils; drought resistant.
Pinus taeda Loblolly pine	Sun	75-100 ft. 25-35 ft.	Entire state. Wet to average soils; drought resistant
Platanus occidentalis American Sycamore	Sun/part shade	75-100 ft. 75-100 ft.	Entire state. Wet to average soils; drought resistant
Populus deltoides Eastern Poplar	Sun	75-100 ft. 75-100 ft.	Entire state. Wet to average soils; drought and salt resistant
Quercus bicolor Swamp White Oak	Sun or shade	75-100 ft. 50-75 ft.	Entire state. Wet to moist soils; drought & salt resistant
Quercus phellos Willow Oak	Sun	50-75 ft. 50-75 ft.	Entire state. Wet soils; drought & salt resistant
Rhododendron maximum Rosebay Rhododendron	Sun/Shade	25-35 ft. 20-35 ft.	Western piedmont/mountains; poor to well-drained soils; flood tolerant; salt sensitive

BIORETENTION PLANTS—TREES

SPECIES / COMMON NAME	EXPOSURE	HEIGHT/ SPREAD	COMMENTS
Taxodium distichum Bald cypress	Sun	50-75 ft. 20-35 ft.	Piedmont to Coast; wet-moist soils. drought resistant; not salt tolerant
Ulmus americana American Elm	Sun/part shade	75-100 ft. 75-100 ft.	Entire state. Moist to dry soils; drought resistant
Viburnum prunifolium Blackhaw Viburnum	Sun	20-35 ft. 20-35 ft.	Piedmont-Western NC; average to droughty soils; lighting resistant
Viburnum rufidulum Rusty Blackhaw Viburnum	Sun	20-35 ft. 20-35 ft.	Piedmont-Eastern NC; average to droughty soils

BIORETENTION PLANTS—SHRUBS

SPECIES / COMMON NAME	EXPOSURE	HEIGHT/ SPREAD	COMMENTS
Aesculus parviflora Bottlebrush Buckeye	Sun/Shade	6-12 ft. 12-25 ft.	Piedmont-mountains; moist to average soils; drought & flood tolerance; salt resistant
Aesculus octandra Yellow Buckeye	Sun/Shade	6-12-ft. 12-20 ft.	Western Piedmont-Mountains. Wet to moist soils; drought resistant
Amorpha fruticosa Indigobush Amorpha	Sun	6-12 ft. 12-20 ft.	Entire state. Very flood tolerant; salt tolerant very drought-heat resistant
Aronia arbutifolia Red Chokeberry	Sun/shade	6-12 ft. 3-6 ft.	Entire state. Very flood tolerant; salt tolerant drought-heat resistant
Betula lenta Cherry Birch	Sun	15-25 ft. 6-12 ft.	Piedmont-coast. Flood tolerant; drought resistant
Callicarpa americana American Beautyberry	Sun/shade	6-215 ft. 12-20 ft.	Entire state. Average to droughty soils
Ceanothus americanus Jerseytea Ceanothus	Sun/shade	3 ft. 6 ft.	Entire state. Average to droughty soils; salt resistant
Clethra alnifolia Summersweet Clethra	Sun/shade	6-12 ft. 6-12 ft.	Piedmont-Coast. Flood tolerant; salt, drought, & heat resistant
Cornus amomum Silky Dogwood	Sun	6-12 ft. 6-12 ft.	Entire state. Flood tolerant; intermediate drought & heat resistant
Cornus sericea Red-ossier Dogwood	Sun/shade	15 ft. 6-12 ft.	Entire state. Prefers wet to moist soils; drought & heat resistant; red twigs

BIORETENTION PLANTS—SHRUBS

SPECIES / COMMON NAME	EXPOSURE	HEIGHT/ SPREAD	COMMENTS
Corylus americana American Filbert	Sun/shade	6-12 ft. 6-12 ft.	Entire state. Prefers moist-dry soils; drought & heat resistant
Cyrilla racemiflora Swamp Cyrilla	Sun/shade	12-20 ft. 12-20 ft.	Entire state. Wet to moist soils; drought & salt resistant
Diospyros virginiana Persimmon	Sun/shade	10-15 ft. 6-10 ft.	Entire state. Wet to average soils. Can be hard to transplant.
Fothergilla gardeni Dwarf Fothergilla	Sun/shade	3 ft. 6 ft.	Entire state. Wet to average soils; multi-season landscape interest
Halesia carolina Carolina Silverbell	Sun/shade	20 ft. 12 ft.	Entire state. Moist, well-drained soils
Hammamelis spp. Witchhazel I	Sun/shade	15-20 ft. 6-12 ft.	Entire state. Moist soils; does well in poorly-drained soils; many fine cultivars
Hypericum densiflorum Dense Hypericum	Sun	3 ft. 6 ft.	Entire state. Does extremely well in dry soils Very flood & salt tolerant
Hypericum prolificum Shrubby St. Johnswort	Sun	3 ft. 6 ft.	Entire state. Does extremely well in dry soils Very flood & salt tolerant
Ilex decidua Possumhaw	Sun/shade	12-20 ft. 12-20 ft.	Piedmont-coast. Very flood tolerant Very drought & salt resistant
Ilex glabra Inkberry	Sun/shade	6-12 ft. 6-12 ft.	Piedmont. Very flood tolerant Salt resistant
Ilex verticillata Winterberry	Sun/shade	6-12 ft. 6-12 ft.	Piedmont. Very flood tolerant intermediate drought resistance
Itea virginica Virginia Sweetspire	Sun or shade	6-12 ft. 6-12 ft.	Piedmont-coast. Very flood & drought tolerant; salt resistant; many fine cultivars
Kalmia angustifolia Lambkill Kalmia	Sun or shade	3 ft. 3-6 ft.	Piedmont-coast. Very flood & drought tolerant; lavender-purple flowers
Kalmia latifolia Mountain laurel	Sun or shade	12-20 ft. 12-20 ft.	Entire state. Very flood tolerant; intermediate salt & drought resistance
Myrica cerifera Wax Myrtle	Sun	12-20 ft. 6-12 ft.	Entire state. Very flood tolerant; excellent salt & drought resistance

BIORETENTION PLANTS—SHRUBS

SPECIES / COMMON NAME	EXPOSURE	HEIGHT/ SPREAD	COMMENTS
Rhododendron canescens Piedmont Azalea	Sun	6-12 ft. 6-12 ft.	Piedmont. Intermediate tolerance to flood, drought, & lighting
Rhododendron nudiflorum Pinxter Azalea	Sun/shade	6-12 ft. 6-12 ft.	Entire state. Intermediate tolerance to street lighting & prolonged drought
Rhododendron viscosum Swamp Azalea	Sun/shade	6-12 ft. 6-12 ft.	Piedmont-coast. Intermediate tolerance to street lighting & prolonged drought
Rosa carolina Carolina Rose	Sun	3 ft. 3-6 ft.	Entire state. Very drought resistant; deep pink flowers
Sabal minor Palmetto	Sun/shade	6-12 ft. 6-12 ft.	Coast. Flood tolerant; some salt tolerance; drought & heat resistant
Vaccinium corymbosum Highbush blueberry	Sun/shade	6-12 ft. 6-12 ft.	Entire state. Very flood tolerant; intermediate drought tolerant; salt resistant
Viburnum dentatum Arrowwood Viburnum	Sun/shade	6-12 ft. 6-12 ft.	Entire state. Very flood tolerant & drought tolerant; salt resistant
Viburnum nudum Possumhaw Viburnum	Sun/shade	6-12 ft. 6-12 ft.	Entire state. Very flood tolerant & drought tolerant; salt resistant

BIORETENTION PLANTS—GROUNDCOVER, PERENNIALS, & ORNAMENTAL GRASSES

Note: Grass should never be seeded, use sod instead.

SPECIES / COMMON NAME	EXPOSURE	HEIGHT/ SPREAD	COMMENTS
Achillea Yarrow	Sun .	1.5 ft.	Entire state; dry to moist soils; many cultivars available
Acorus calamus Sweet flag	Sun	1 ft.	Entire state. Wet to moist soils; drought resistant
Amsonia ciliata Creeping blue star	Sun	6” 2 ft.	Entire state. Very drought & heat resistant; pale blue flowers
Amsonia hubrichtii Narrow Leaf Blue Star	Sun	36”	Entire state. Very drought & heat resistant; Carolina blue flowers
Amsonia ludoviciana Louisiana blue star	Sun	24” 2 ft.	Entire state. Very drought & heat resistant; pale blue flowers

BIORETENTION PLANTS—GROUNDCOVER, PERENNIALS, & ORNAMENTAL GRASSES

SPECIES / COMMON NAME	EXPOSURE	HEIGHT/ SPREAD	COMMENTS
Asclepias tuberosa Butterfly weed	Sun	20"	Entire state. Very drought & heat resistant; yellow-gold flowers
Baptisia alba White false indigo	Sun		Coast. White flowers.
Boltonia apalachicolensis Apalachicola Doll's Daisy	Sun	48"	Piedmont-coast. White flowers late summer
Boltonia diffusa Doll's Daisy	Sun	5 ft.	Entire state. White flowers late summer
Carex spp. Sedge	Sun	6-12".	Entire state. Tolerates a wide variety of conditions; many different cultivars
Coreopsis spp. Tickseed	Sun	1-3 ft.	Entire state. Tolerates a wide variety of conditions; many different cultivars
Echinacea purpurea Coneflower	Sun	1-2 ft.	Entire state. Drought tolerant; wide variety of cultivars
Gaillardia spp. Blanket Flower	Sun	1-2 ft.	Entire state. Drought tolerant; variety of species and hybrids
Gaura lindheimeri Gaura	Sun	2-4 ft.	Entire state. Thrives in hot, dry climate; many select cultivars
Geranium sanguineum Geranium	Sun	10-14"	Entire state. Tolerates wide range of conditions including drought
Hemerocallis spp. Daylily	Sun	2-4 ft.	Entire state. Tolerates a wide variety of conditions; many different cultivars
Heuchera spp. Coral bells	Sun	12-18"	Entire state. Sun-tolerant; well-drained soils; many different cultivars
Pennisetum spp. Fountain grass	Sun	2-5 ft.	Entire state. Extremely tolerant of adverse conditions; many species & cultivars
Penstemon australis Beard's Tongue	Sun	15"	Entire state. Tolerant of heat/humidity; mauve flowers
Potentilla gracilis Cinquefoil	Sun	1-2 ft.	Entire state.Moist to dry soils; yellow flowers
Rudbeckia hirta Black-eyed susan	Sun	2-4 ft.	Entire state. Moist to dry soils; showy flowers; other species & cultivars
Solidago spp. Goldenrod	Sun	1-4 ft.	Entire state. Extremely tolerant of adverse conditions; many species & cultivars

12.4. Maintenance

12.4.1. Common Maintenance Issues

Bioretention facilities require plant, soil, mulch, and under-drain maintenance to ensure optimal infiltration, storage, and pollutant removal capabilities. Bioretention maintenance requirements are typical landscape care procedures and include:

1. *Watering*: Plants should be selected to be tolerant of the bioretention facility's particular conditions. Watering should not be required after establishment (about 2 to 3 years). However, watering may be required during prolonged dry periods after plants are established.
2. *Erosion Control*: Inspect flow entrances, ponding area, and surface overflow areas periodically. Replace soil, plant material, and/or mulch in areas where erosion has occurred. Erosion problems should not occur with proper design except during extreme weather events. If erosion problems do occur, the following issues should be re-assessed: flow volumes from the contributing drainage area and bioretention size; flow velocities and gradients within the bioretention facility; flow dissipation and erosion protection methods in the pretreatment and in-flow areas. If sediment is deposited in the bioretention facility, immediately determine the source, remove excess deposits, and correct the problem.
3. *Plant Material*: Depending on plants selected and aesthetic requirements, occasional pruning and removal of dead plant material may be necessary. Replace all dead plants. However, if specific plants consistently have a high mortality rate, assess the cause and replace with appropriate species. Periodic weeding is necessary until groundcover plants are established. Weeding should become less frequent if an appropriate plant density has been used.
4. *Nutrients and Pesticides*: The soil media and plant material should have been selected for optimum fertility, plant establishment, and growth within the particular conditions of each bioretention facility. Nutrient and pesticide inputs should NOT be required and will degrade the pollutant processing capability of the bioretention facility, as well as contribute to additional pollutant loading to receiving waters. By design, bioretention facililities are typically specified in watersheds where phosphorous and nitrogen levels are often elevated. Therefore, these should not be limiting nutrients with regard to plant health. If in question, have the soil analyzed for fertility.
5. *Mulch*: Replace mulch annually in bioretention facilities where heavy metal deposition is likely (e.g., drainage areas that include commercial/industrial uses, parking lots, or roads). In residential or other settings where metal deposition is not a concern, replace or add mulch as needed to maintain a 2 to 4 inch depth at least once every two years.
6. *Soil media*: Soil mixes for bioretention facilities are design to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research indicates that metal accumulation should not present a toxicity concern for at least 20 years in bioretention facilities (USEPA 2000). Further, replacing mulch where heavy metal deposition is likely provides an additional factor of

safety for prolonged bioretention performance. If in question, have soil analyzed for fertility and pollutant levels.

When the filtering capacity diminishes substantially (e.g., when water ponds on the surface for more than 12 hours), remedial actions must be taken. One possible problem is that underdrain pipe systems can become clogged. Annual flushing through pipe cleanouts is recommended to facilitate unclogging of the pipes without disturbing the bioretention areas. If the water still ponds for more than 12 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.

Examples of When to Perform Maintenance

- Replace gravel when it has become clogged with sediment.

Figure 12-9a
Gravel Pretreatment is Clogged with Sediment

- Replace mulch when it becomes thin or is taken over by grass.

Figure 12-9b
Thin Mulch in the Bioretention Cell

- Remove top layer of fill media when the pool does not drain quickly. The pool is designed to drain within 12 hours.

12.4.2. Sample Inspection and Maintenance Provisions

Important Operation and Maintenance procedures:

- Immediately after the bioretention cell is established, the plants will be watered twice weekly if needed until the plants become established (commonly six weeks).
- Snow, mulch or any other material will NEVER be piled on the surface of the bioretention cell.
- Heavy equipment will NEVER be driven over the bioretention cell.
- Special care will be taken to prevent sediment from entering the bioretention cell.
- Once a year, a soil test of the soil media will be conducted.

After the bioretention cell 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 12-2

Sample Inspection and Maintenance Provisions for Bioretention Areas

BMP element:	Potential problems:	How to remediate the problem:
The entire BMP	Trash/debris is present.	Remove the trash/debris.
The perimeter of the bioretention cell	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.
The inlet device: pipe, stone verge 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.
	Stone verge is clogged or covered in sediment (if applicable).	Remove sediment and clogged stone and replace with clean stone.

Table 12-2, continued
Sample Inspection and Maintenance Provisions for Bioretention Areas

BMP element:	Potential problems:	How to remediate the problem:
The pretreatment area	Flow is bypassing pretreatment area and/or gullies have formed.	Regrade if necessary to route all flow to the pretreatment area. Restabilize the area after grading.
	Sediment has accumulated to a depth greater than three inches.	Search for the source of the sediment and remedy the problem if possible. Remove the sediment and restabilize the pretreatment area.
	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.
The bioretention cell: vegetation	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.
	Tree stakes/wires are present six months after planting.	Remove tree stake/wires (which can kill the tree if not removed).
The bioretention cell: soils and mulch	Mulch is breaking down or has floated away.	Spot mulch if there are only random void areas. Replace whole mulch layer if necessary. Remove the remaining much and replace with triple shredded hard wood mulch at a maximum depth of three inches.
	Soils and/or mulch are clogged with sediment.	Determine the extent of the clogging - remove and replace either just the top layers or the entire media as needed. Dispose of the spoil in an appropriate off-site location. Use triple shredded hard wood mulch at a maximum depth of three inches. Search for the source of the sediment and remedy the problem if possible.
	An annual soil test shows that pH has dropped or heavy metals have accumulated in the soil media.	Dolomitic lime shall be applied as recommended per the soil test and toxic soils shall be removed, disposed of properly and replaced with new planting media.

Table 12-2, continued

Sample Inspection and Maintenance Provisions for Bioretention Areas

BMP element:	Potential problems:	How to remediate the problem:
The underdrain system (if applicable)	Clogging has occurred.	Wash out the underdrain system.
The drop inlet	Clogging has occurred.	Clean out the drop inlet. Dispose of the sediment off-site.
	The drop inlet is damaged	Repair or replace the drop inlet.
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.

13. Filter Strip

Description

A filter strip is a section of land capable of sustaining sheet flow, either forested or vegetated with turf grasses or other plants, which provides pollutant removal as the stormwater passes through it.

Regulatory Credits

Pollutant Removal

25-40%*	Total Suspended Solids
20%	Total Nitrogen
35%	Total Phosphorus

Water Quantity

no	Peak Attenuation
no	Volume Capture

Feasibility Considerations

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

*See Section 13.2 for information on variable rate.

Major Design Elements

* Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
* The BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
* A distribution device shall be used to provide even distribution of runoff across the BMP.
* The filter strip must be densely vegetated.
** An appropriately licensed design professional must prepare the grading and vegetation plan.
** The length and width of a filter strip shall be in accordance with the requirements of the applicable stormwater regulatory program.
** Sustained sheet flow is required, typically through the use of a level spreader.

* *This provision is specified in the NC Administrative Code rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*
** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the pollutant removal efficiencies provided in this Manual.*

Advantages	Disadvantages
– Can reduce particulate pollutants such as sediment, organic matter, and trace metals. – Slows down the water and promotes infiltration. – Can be implemented as part of landscaping requirements. – Meshes well in residential areas to provide open space for recreation, help maintain riparian zones, and reduce stream bank erosion.	– Not resistant to high velocity flows, so generally not applicable in large areas with intense development or with steep slopes. – Requires sheet flow to operate effectively. May be difficult to avoid flow re-concentration. – Does not provide enough runoff storage or infiltration to significantly reduce peak discharge or volume of storm runoff, so typically functions only as one component in a stormwater management system.

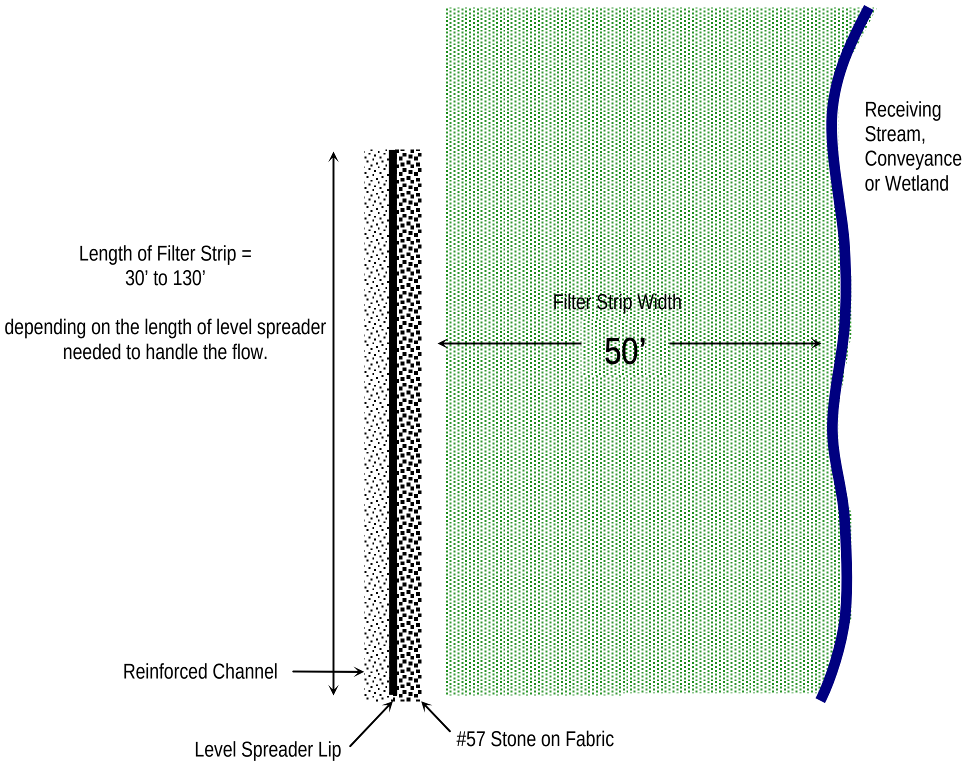
13.1. General Characteristics and Purpose

Any natural vegetated area, from grassy meadow to small forest, may be adapted for use as a filter strip. Man-made filter strips (on graded, prepared, and planted areas) can be just as effective as some natural areas. Many types of plants or natural vegetation can be used in filter strips ranging from close-growing grasses to shrubs and trees. However, the vegetation must have dense foliage and a thick root mat to be effective. Filter strips are designed to accept runoff from overland sheet flow from upgradient development. The filter strips trap sediment and sediment-bound pollutants. Because they disconnect impervious surfaces from storm sewers and lined channels, filter strips reduce effective imperviousness and help reduce peak discharge rates by increasing travel times and by increasing abstractions from the total flow. Figure 13-1 illustrates the basic elements of a filter strip.

Filter strips may be used to treat runoff from highways, roofs, parking areas, and in general, between upgradient development and receiving waters, frequently in residential areas, or where the development density is low. Filter strips can also be used as pretreatment for infiltration BMPs such as bioretention and infiltration trenches. They are also part of the outer zone of riparian stream buffers. Additionally, for projects under North Carolina’s State Stormwater Management Program rules, a filter strip may be a required companion BMP for the discharge from other BMPs, such as wet detention basins and infiltration BMPs.

A level spreader is required with every filter strip, unless permanent, sustained sheet flow can be otherwise demonstrated. Chapter 8 addresses the design requirements for level spreaders.

Figure 13-1
Filter Strip Schematic for Receiving the Stated Pollutant Removal Credits



13.2. Meeting Regulatory Requirements

Every filter strip must meet the major common design requirements presented on the first page of this chapter. Additionally, to receive the pollutant removal rates listed in the front of this section, the filter strip also must meet the requirements of the regulatory program that governs the installation.

Pollutant Removal Calculations
The pollutant removal calculations for filter strips are as described in Section 3.4, and use the pollutant removal rates shown below.

The removal rates for TSS are variable based on the type of vegetation:

- 40 percent for natural wooded vegetation
- 30 percent for planted wooded vegetation
- 25 percent for grass and thick ground cover

The removal rates for nutrients are:

- 20 percent for total nitrogen
- 35 percent for total phosphorus

Volume Control Calculations
Filter strips do not have any water storage component, so they do not provide any active volume control. Filter strips do provide passive volume control capabilities through a couple of mechanisms. First, they provide pervious surface to reduce the total runoff volume to be controlled. Second, if designed in such a way, they can increase the time of concentration and therefore reduce the peak discharge rate.

Filter strips can provide some runoff peak attenuation, largely by increasing the time of concentration in a subbasin, and by creating disconnected imperviousness. The effectiveness of filter strips in reducing runoff peak rates can be improved by: siting them over the most permeable soils thereby reducing the NRCS curve number (CN) associated with the filter strip, placing them so as to receive runoff from impervious surfaces, and interconnecting them with grassed swales or bioretention areas to increase the time of concentration.

13.3. Design

13.3.1. Siting Issues

Filter strips perform well in all areas of North Carolina where dense, vegetative growth can be established. High dune areas of coastal counties are too dry to support dense vegetative cover and are not appropriate for filter strips. Also, slopes must be in the appropriate range: less than 5 percent slope is preferable; in no cases, may slope exceed 15 percent.

13.3.2. Contributing Drainage Basin

Where filter strips receive the runoff directly from the drainage basin, they should be limited to relatively small tributary areas. Relevant considerations include the ultimate imperviousness of the drainage basin, the amount of flow delivered to the filter strip, the permeability and erodibility of the underlying soil, the type and condition of vegetation present in the filter strip, the presence or absence of small rills, and the slope of the filter strip.

Filter strips can be used for larger areas if they are used in series, or interspersed between impervious surfaces (for example, by incorporating filter strips between parking lanes). The design of filter strips in larger areas should be supported by calculations that acknowledge and address the potential vulnerabilities associated with such installations.

13.3.3. Sheet flow

If flow is allowed to concentrate before it reaches the filter strip, or as it crosses over the filter strip, the rates at which pollutants are removed will be reduced significantly, gullies will develop, and the filter strip will be ineffective. To achieve the benefits of reduced runoff rates, pollutant removal, and increased infiltration, it is essential that the flow be transitioned to sheet flow through the use of a level spreader. A level spreader is required for all filter strips unless it can be proven that the inflow will be evenly distributed sheet flow without the use of a level spreader.

13.3.4. Length and Width for Pollutant Removal Credit

The top edge of the filter strip should follow an elevation contour. If a section of the top edge of the strip dips below the contour, runoff eventually may form a channel at the low spot. Under some site topography and grading circumstances, runoff may travel along the top of the filter strip rather than through it. Berms may be placed at intervals perpendicular to the top edge of the strip to prevent runoff from bypassing any portion of the filter strip.

The length (perpendicular to flow) of a filter strip is based on the same criteria as the length of a level spreader presented in Chapter 8 Level Spreaders. The length of the filter strip must be between a minimum of 13 feet and a maximum of 130 feet. The length must be calculated as follows.

- For vegetation characterized as grass or thick ground cover: 13 feet of length per 1 cfs of flow on slopes 0-8%.
- For vegetation characterized as forested: 65 feet of length per 1 cfs of flow for slopes from 0-6%.
- If the forest vegetation is 100-150 feet in width, then the length can be reduced to 50 feet of filter strip per 1 cfs of flow.
- If the forest vegetation is more than 150 feet in width, then the length can be reduced to 40 feet of filter strip per 1 cfs of flow.

Forested filter strips must be significantly wider than those with grass or thick ground cover, due to the forest's greater susceptibility to erosion.

If the filter strip has discrete sections with grass or thick ground cover in one part and forest vegetation in another, then the length should be determined by calculating the weighted average of the lengths required for each vegetation type. For example, if a filter strip that has 20 feet of the width maintained as grass and 30 feet of the width is existing forested vegetation, the appropriate filter strip 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 width (parallel to flow) of a filter strip shall in all cases be a minimum of 50 feet.

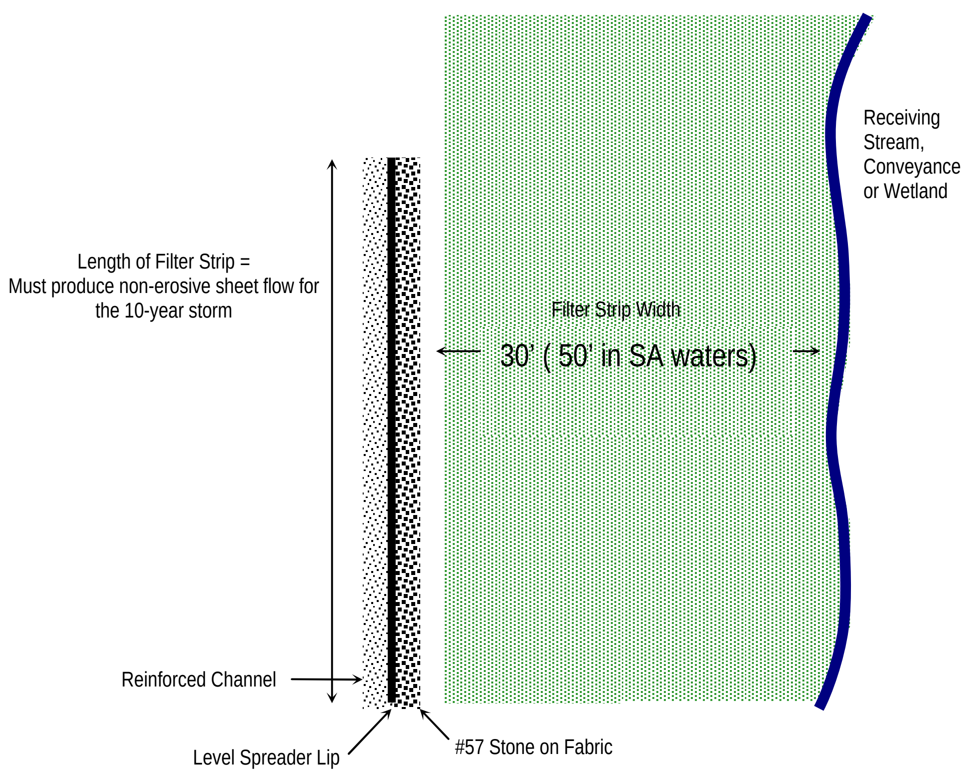
13.3.5. Length and Width for Compliance with the State Stormwater Program

In most circumstances under the State Stormwater Management Program rules at NCAC 15A 2H .1000, a filter strip is a required additional component of a control system based on another BMP. For example, the discharge of a wet detention basin must flow through a companion vegetated filter strip. No specific numerical value of pollutant removal is assigned for the filter strip alone, but the filter strip must be included in the stormwater control system. *(Note that in the 2H .1000 rules the convention for designating* *the length and width of the filter strip is reversed from the terminology used in the several buffer rules. This section observes the more prevalent buffer rules convention in order to avoid confusion with other parts of the manual.)*

The slope and length (perpendicular to flow) of the filter strip shall be designed and constructed so as to provide a non-erosive velocity through the filter strip for the 10-year storm. The slope shall be 5% or less where practicable. In no cases shall the slope be greater than 15%.

The width (parallel to flow) of the filter strip shall be 50 feet when installed on the discharge from an infiltration system or other BMP for projects that drain to SA waters. The width of the filter strip shall be 30 feet when installed on the discharge from a wet detention basin or other BMP for other projects. Figure 13-2 presents the basic elements of a filter strip used as a companion BMP.

Figure 13-2
Filter Strip Schematic as a Companion BMP



13.3.6. Sediment Accumulation

Filter strips can handle low amounts of sediment accumulation by capturing the sediment in the root areas of the vegetation and incorporating it into the soils of the filter strip. Filter strips should not be installed until the contributing drainage area is stabilized. In most instances, a forebay is required prior to the level spreader to capture the sediment prior to entering the filter strip. For filter strips downstream of wet detention basins and infiltration devices, a forebay may not be required if sediment capture is effectively accomplished by the upstream BMP.

13.3.7. Slopes and Velocities

In general, filter strips are most effective on sites with mild slopes. Regulatory program limitations on maximum slopes are identified in section 13.3.4 above.

A key design objective is that the design overland flow velocity must be non-erosive. Overland flow velocity may be managed by the following methods: maintaining low slopes and uniformly sloping grades, limiting flow volumes to appropriate levels, providing good flow distribution, repairing erosion features immediately upon discovery, and maintaining a dense and healthy vegetative cover. Non-erosive velocity is also dependent on soil type, and the designer must consider soil type in evaluating design velocities. Typical non-erosive velocities range from 4 fps if the vegetation is dense grass or undergrowth, and less than 2 fps if the filter strip is wooded.

13.3.8. Plant and Landscape Requirements

To realize the benefits of filter strips, it is essential to maintain a dense, vigorous stand of vegetation. For forest or shrub vegetation, it is recommended that the vegetation generally be deep-rooted, have well-branched top growth, and resistant to damage from either saturation or drought. Vegetation on filter strips receiving street and parking lot runoff must be resistant to deicing chemicals, salts, and heavy metals (tall fescue has been shown to be quite resistant to road salts).

Well-drained soils are preferred, however, with proper soil preparation and selection of appropriate plant species, filter strips can be established successfully on poorly drained soils.

A natural forested area provides good long-term removal of pollutants and priority should be given to preventing the unnecessary removal of trees. Native vegetation often takes longer to establish than turf grass; however, this can be managed by planting the native vegetation early and allowing it to become properly established prior to allowing stormwater onto the BMP.

A grading and vegetation plan must be prepared by an appropriately licensed design professional for all filter strips.

13.4 Construction

Accurate grading is necessary to develop sheet flow through the filter strip. Filter strip soil compaction by equipment or vehicles during construction should be minimized. Over time, the permeability of compacted soil can be restored through the action of vegetation root systems. However, the restoration takes 5 to 10 years and the vegetation may be difficult to establish without a good layer of topsoil.

13.5 Maintenance

13.5.1. Common Maintenance Issues

During the first 1 or 2 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 1 or 2 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:

13.5.2. Sample Operation 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 13-2
Sample Inspection and Maintenance Provisions for Filter Strips

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 ripap 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.

Table 13-2, continued
Sample Inspection and Maintenance Provisions for Filter Strips

BMP element:	Potential problem:	How to remediate the problem:
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.

14. Grassed Swale

Description:
A water quality grassed swale is a shallow open-channel drainageway stabilized with grass or other herbaceous vegetation that is designed to filter pollutants.

Curb Outlet Systems for Low Density Projects

Regulatory Credits		Feasibility Considerations	
Pollutant Removal			
0%	Total Suspended Solids	Small	Land Requirement
0%	Nitrogen	Small	Cost of Construction
0%	Phosphorus	Small	Maintenance Burden
Water Quantity		Small	Treatable Basin Size
no	Peak Runoff Attenuation	Some	Possible Site Constraints
no	Runoff Volume Reduction		

Conveyance Swales Seeking Pollutant Credit*

Regulatory Credits		Feasibility Considerations	
Pollutant Removal			
35%	Total Suspended Solids	Small	Land Requirement
20%	Nitrogen	Small	Cost of Construction
20%	Phosphorus	Small	Maintenance Burden
Water Quantity		Small	Treatable Basin Size
no	Peak Runoff Attenuation	Some	Possible Site Constraints
no	Runoff Volume Reduction		

Conveyance Swales *Not* Seeking Pollutant Credit*

Regulatory Credits		Feasibility Considerations	
Pollutant Removal			
0%	Total Suspended Solids	Small	Land Requirement
0%	Nitrogen	Small	Cost of Construction
0%	Phosphorus	Small	Maintenance Burden
Water Quantity		Small	Treatable Basin Size
no	Peak Runoff Attenuation	Some	Possible Site Constraints
no	Runoff Volume Reduction		

*May include roadside swales, lot line swales, and primary outlet swales

- Roadside swales: These swales are usually on both sides of a road. They are typically interconnected with cross pipes, and empty into a primary outlet swale(s) carrying runoff off site. These swales often collect runoff from lot line swales, and therefore carry heavy hydraulic and pollutant loads.
- Lot line swales: These swales are usually located between houses and run the length of the lot. They typically receive sheet flow from lots, and flow directed from gutters.
- Primary outlet swales: These swales usually collect drainage from roadside swales and lot line swales, though they are sometimes located along lot lines. Because of the heavy hydraulic load, they are usually deeper, wider, and longer than roadside or lot line swales. These swales usually serve the same function as low-density curb outlet swales.

Major Design Elements

All Swales

- * Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
- * BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
- * The design must non-erosively pass the peak runoff rate for the 10-year storm.
- * Where practicable, the maximum longitudinal slope shall be 5%.
- ** The Simple Method shall be used to calculate treatment volume.
- ** Swales shall convey the design discharge while maintaining a 0.5-foot freeboard and without exceeding the maximum permissible velocity.
- ** Swales shall have a 1-ft minimum distance from the bottom of the swale to the seasonably high water table (SHWT).

Curb Outlet Systems for Low Density Projects

- * Side slopes shall be no steeper than 5:1.
- * Swale length will be 100 ft/acre drainage.
- ** The maximum velocity shall be as specified in the NC Erosion and Sediment Control Manual (and replicated in this document, Table 14-2).
- ** A maintenance agreement is required.

Conveyance Swales Seeking Pollutant Credit

- ** The maximum velocity shall be 1 ft/sec.
- ** Side slopes shall be no steeper than 5:1.
- ** A maintenance agreement is required.
- ** Swale length will be 150 ft/acre drainage

Conveyance Swales *Not* Seeking Pollutant Credit

- ** The maximum velocity shall be as specified in the NC Erosion and Sediment Control Manual (and replicated in this document, Table 14-2).
- ** Side slopes shall be no steeper than 3:1.
- ** Swale length will be 100 ft/acre drainage.

* *This provision is specified in the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

Advantages

- – Can reduce the use of costly development infrastructure, e.g., curb and gutter.
- – Can be aesthetically pleasing.
- – Low-slope swales can create wetland areas.
- – Unmowed systems not adjacent to roadways can provide valuable “wet meadow” habitat.

Disadvantages

- – Could be subject to standing water and mosquito infestations.
- – May be subject to channelization due to concentrated flows.
- – Low pollutant removal rates and essentially no volume control. Must be used with other BMPs to meet most stormwater rule requirements.

14.1. General Characteristics and Purpose

Grassed swales are typically long open drainage channels integrated into the surrounding development or landscape that are lined with grass or other vegetation. They are often used in residential and commercial developments as well as along highway medians as alternatives or enhancements to conventional storm sewers (see Figure 14-1). Swales are suitable for many types of development, but are most practical for campus-type developments and single-family residential sites.

Figure 14-1

Grassed Swale in Residential Area, Pembroke Woods Subdivision in Emmittsburg, MD (Courtesy of Mike Clar, Ecosite, Inc., Columbia, MD)

Swales remove pollutants from stormwater by biofiltration, settling, and infiltration. Grassed swales filter pollutants as stormwater runoff moves through the leaves and roots of the grass. By reducing flow velocities and increasing a site's time of concentration, grassed swales contribute to reducing runoff peaks. Grassed swales that are designed with check dams or incorporate depression storage promote infiltration and can help contribute to satisfying a site runoff capture/storage requirement.

The effectiveness of a swale in both reducing the flow rates and volume of runoff, and removing pollutants, is a function of the size and composition of the drainage area, the slope and cross section of the channel, the permeability of the soil, the density and type of vegetation in the swales, and the swale dimensions. Broad swales on flat slopes with dense vegetation are the most effective. Removal efficiencies are highest for sediment-bound pollutants.

Figures 14-2 through 14-4 show examples of grassed swales used for primary drainage of residential subdivisions, parking lots, and commercial developments, respectively. Figure 14-5 shows a more detailed sketch of swales in a parking lot, as well as optional raised storm sewer inlets.

Figure 14-2
Schematic of Plan for Retrofit of Grassed Swales in Residential Subdivision

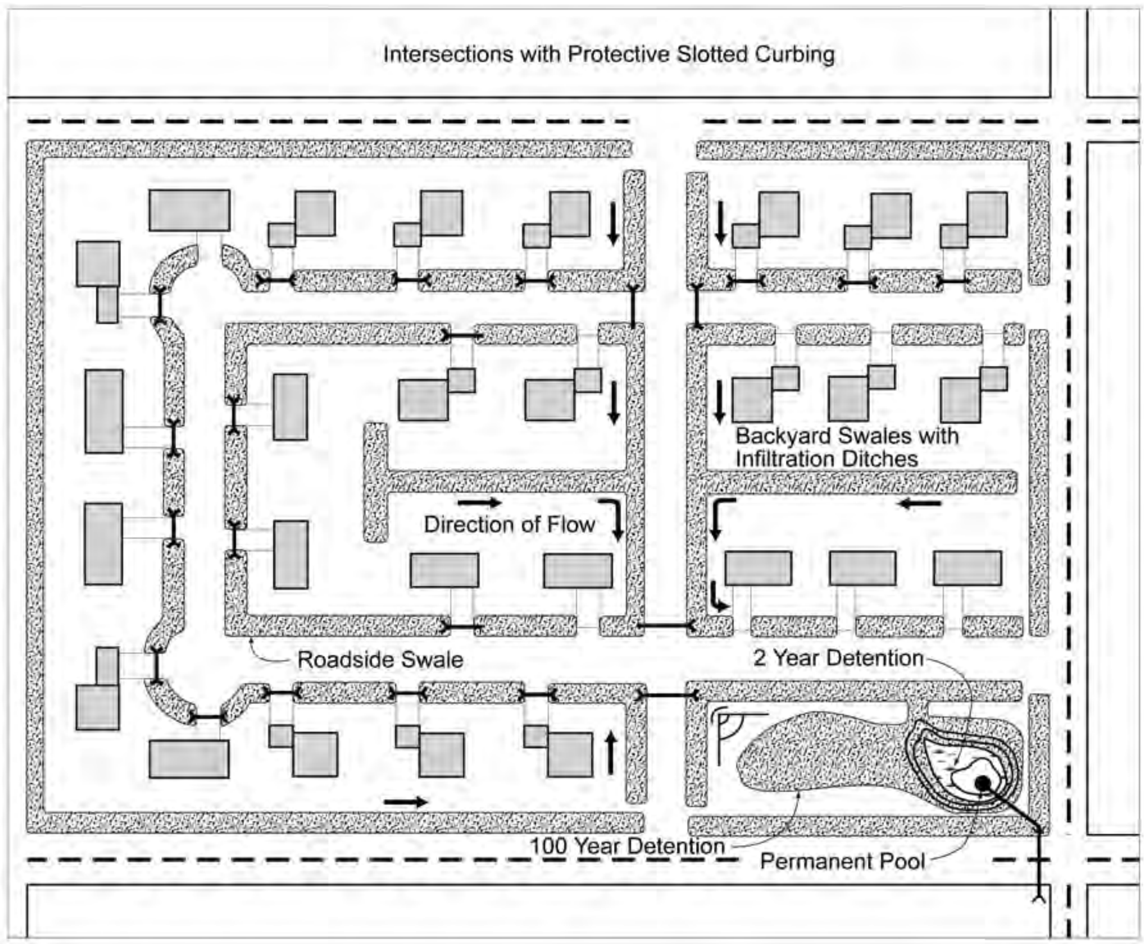


Figure 14-3
Example of Grassed Swale Used for Parking Lot

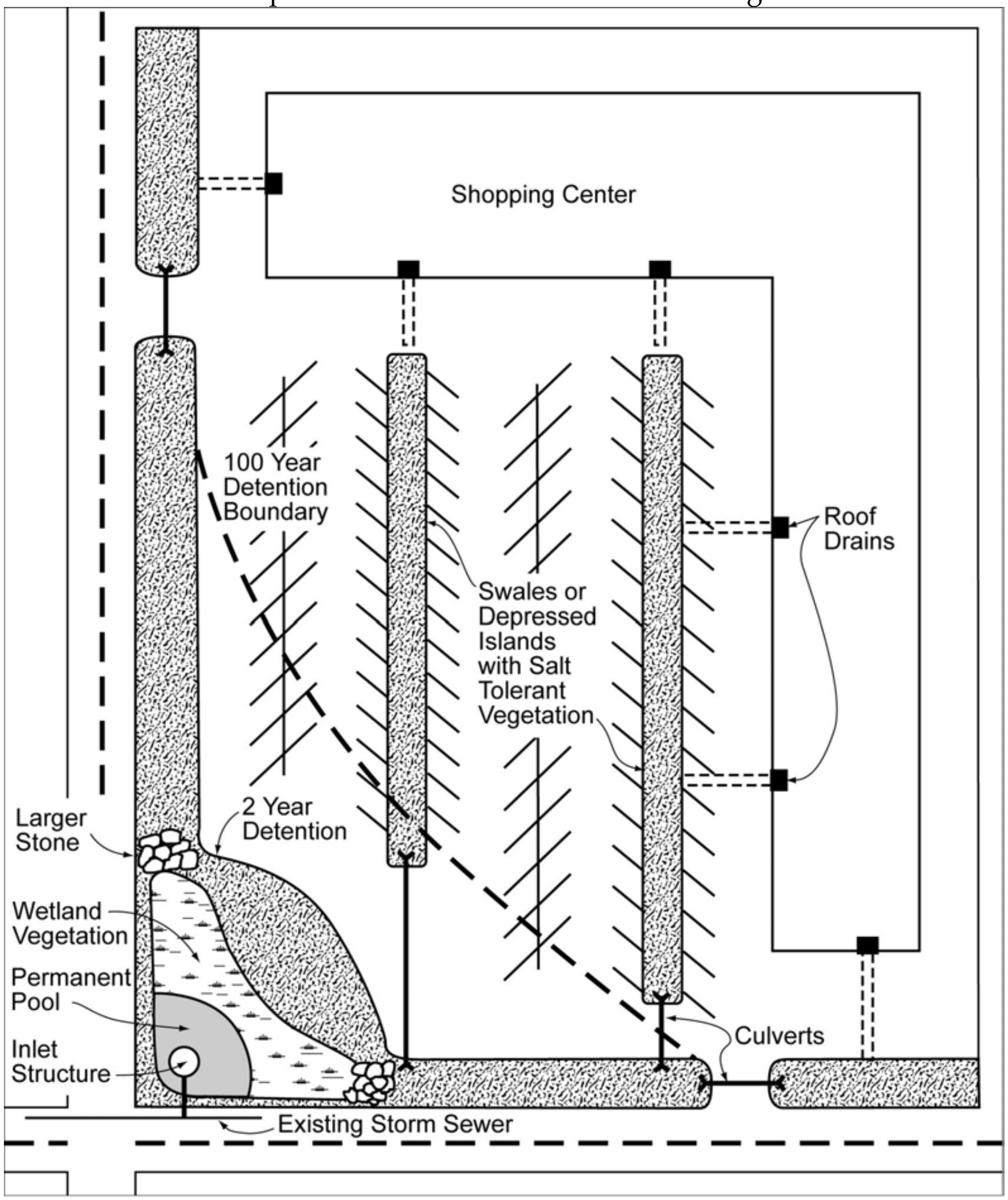


Figure 14-4
Schematic Showing Use of Grassed Swale for Primary Drainage of Commercial Development

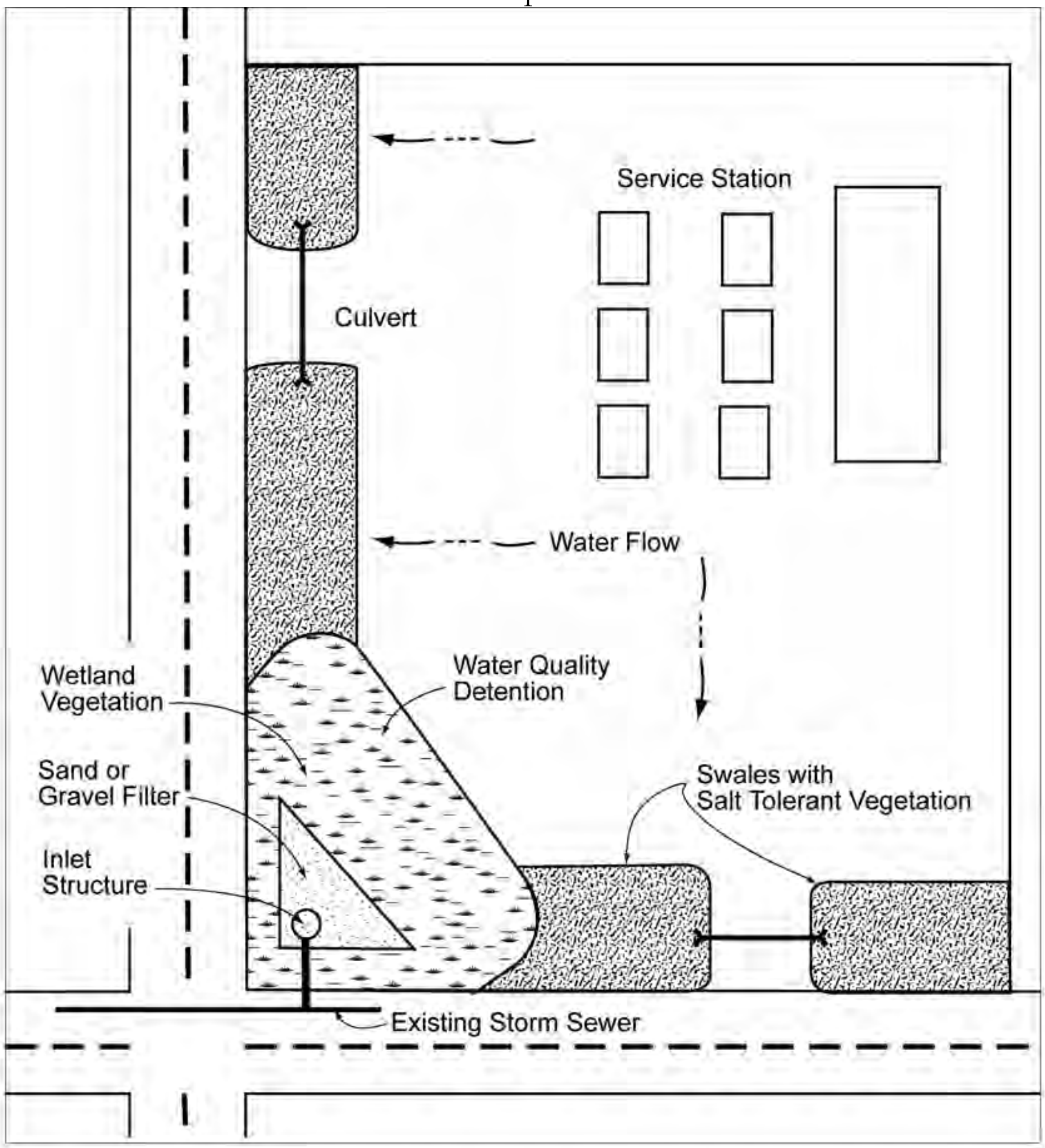
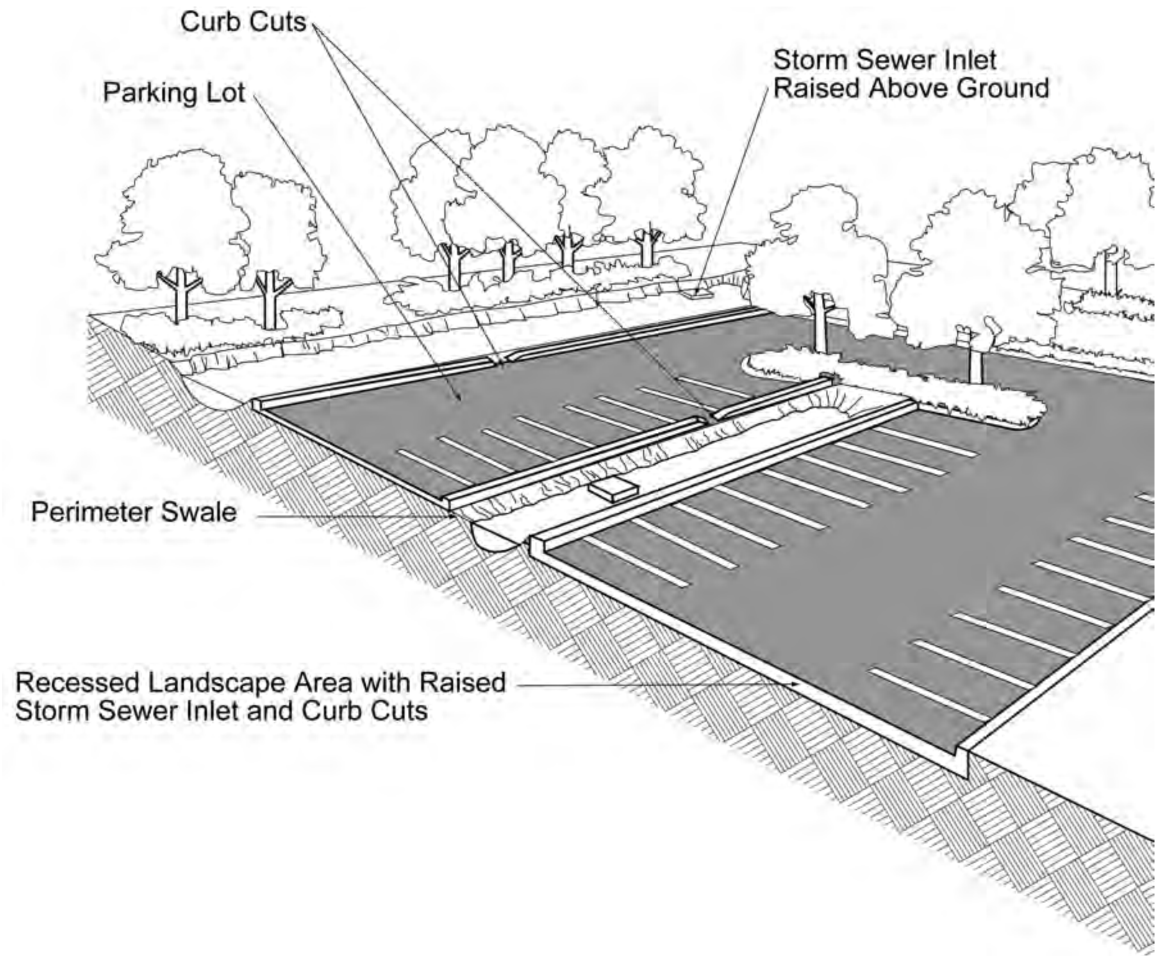


Figure 14-5
Parking Lot Swale Drainage (from NIPC, 1993).



14.2. Meeting Regulatory Requirements

A listing of the major design elements is provided on the first page of this section.

Types of grassed swales
There are three types of grassed swales addressed in this chapter. The design requirements and the credit granted is specific to the type of grassed swale designed. Designers who wish to get credit for TN, TP, and TSS for curb outlet systems for low-density projects must meet both sets of requirements. Where these requirements conflict, the more stringent requirement takes precedence.

- Curb Outlet Systems for Low Density Projects: Swales designed into these systems are intended to convey stormwater through low-density projects as outlined in NCAC 15A 02B .1008(g).
- Conveyance Swales Seeking Pollutant Credit: These swales are intended to be mechanisms for pollutant removal. They may include roadside swales, lot line swales, and primary outlet swales

- Conveyance Swales *Not* Seeking Pollutant Credit: These swales are not intended to be mechanisms for pollutant removal. They may include roadside swales, lot line swales, and primary outlet swales. Water in swales meeting the requirements for this design is allowed to travel through the swale faster and the side slopes are allowed to be steeper than for swales that seek pollutant removal credit.

Pollutant Removal Calculations
The pollutant removal calculations for grassed swales are as described in Section 3.4, and use the pollutant removal rates shown at the beginning of this Section. Construction of a grassed swale also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading.

Volume Control Calculations
A grassed swale typically does not provide any active volume capture or peak flow attenuation. A grassed swale provides some passive volume control capabilities by providing pervious surface and therefore reducing the total runoff volume to be controlled. In addition, a grassed swale can be constructed with check dams, depression storage, etc., that can provide a small amount of volume control.

14.3. Design

The design of a grassed swale must comply with the requirements outlined in this section, and appropriate local channel design provisions. A diagram of the grassed swale requirements is provided in Figure 14-6. If a swale is trapezoidal, having the bottom of the swale two or more feet wide is recommended for maintenance purposes.

14.3.1. Converting Sediment and Erosion Control Devices

Swales are often used as part of the site construction sediment and erosion control plan. The same swales can be later used as grassed swale BMPs, however, all of the sediment must be removed, the channel configuration and slope must be re-established (if necessary), and the proper vegetation must be established.

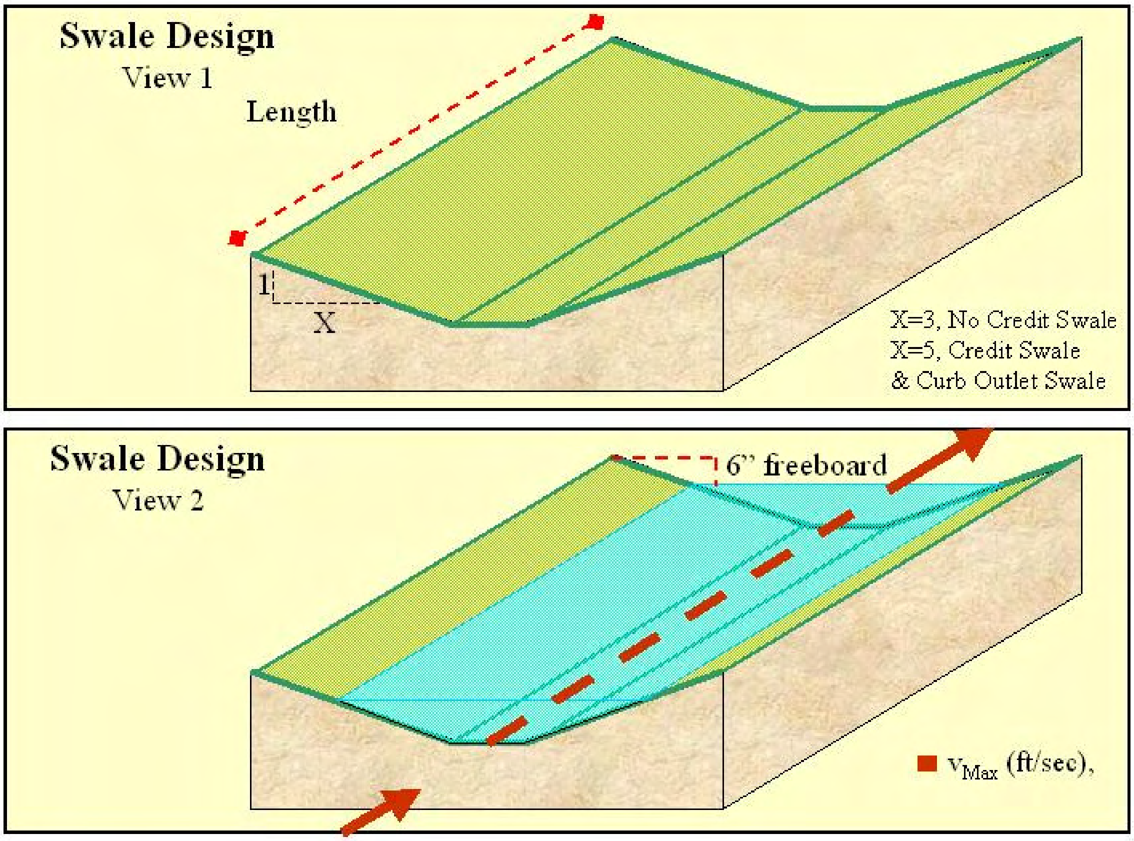
14.3.2. Siting Issues

The location of swales should be based on site topography and natural features. Where possible, natural drainage ways on the site should be maintained and integrated into the swale drainage system.

Swales should be sited in areas where the seasonal high water table is at least 1 foot below the bottom of the swale. If the seasonal high water table is less than 1 foot below the bottom of the swale the swale will likely be chronically wet. Swales should not carry dry-weather flows or constant flows.

Sites with steep slopes can be can be difficult to design due resulting high velocities of flow. Roadside swales may pose traffic hazards in residential subdivisions. Shallow swales and curbs with diversion devices can help alleviate this problem.

Figure 14-6
Diagram of Water Quality Grassed Swale Requirements



14.3.3. Contributing Drainage Basin

There are no minimum or maximum size requirements on the drainage basin for a grassed swale. A swale serving a tributary area more than 10 or 20 acres, or with very high impermeable surface percentages, can be difficult to design due to high volumes of flow and/or high velocities of flow.

14.3.4. Swale Design

The swale should be designed as either a curb and gutter system for a low-density project or as a water treatment swale. The requirements are outlined under Major Design Elements at the beginning of this chapter. Curb and gutter designs that also seek pollutant removal credit shall meet the requirements of both designs. Where requirements conflict, the more stringent requirement takes precedence. See Table 14-1 for a summary of the design requirements.

Table 14-1
Summary of Swale Design Requirements

	Curb Outlet	Conveyance Swale (Seeking Credit)	Conveyance Swale (*Not* Seeking Credit)
Sizing shall take into account all runoff at ultimate build-out including off-site drainage.	X	X	X
BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.	X	X	X
The design must non-erosively pass the peak runoff rate for the 10-year storm.	X	X	X
The Simple Method shall be used to calculate treatment volume.	X	X	X
1^{+}ft from bottom swale to SHWT	X	X	X
Where practicable, the maximum longitudinal slope shall be 5%.	X	X	X
Swales shall convey the design discharge while maintaining a 0.5-foot freeboard and without exceeding the maximum permissible velocity.	X	X	X
Maintenance agreement required.	X	X	
Max velocity as in E&SC Manual, see Table 14-2	X		X
Max velocity, 1 ft/sec		X	
Max side slopes, 3:1			X
Max side slopes, 5:1	X	X	
Swale length shall be 100 ft/acre	X		X
Swale length shall be 150 ft/acre		X	

Where necessary, particularly for curb outlet systems for low-density projects, include a supplement sheet containing pertinent design information when applying for a State Stormwater permit. Such a supplement may be necessary in other instances as well. If the design uses check dams, elevated drop inlets, elevated culverts, underdrains, or other advanced design options include this information in the supplement.

The Simple Method shall be used to calculate runoff volume. The swale is typically parabolic or trapezoidal in cross section for ease of construction and maintenance and for reducing the potential for scour. However, V-shaped swales are also allowed for curb and gutter systems for low-density projects. To reduce maintenance and prevent scour, the bottom width should be no less than 2 feet. The maximum bottom width should be 6 feet to prevent erosion making a smaller, better-defined flow path.

Table 14-2

Curb Outlet Systems for Low Density Projects: Maximum Allowable Velocities (Slopes 0-5%) (Derived from the NC E&SC Manual)

Soil Characteristics	Grass Lining	Permissible Velocity[3] for Established Grass Lining (ft/sec)
Easily Erodible Non-Plastic (Sands & Silts)	Bermudagrass	5.0
	Tall Fescue	4.5
	Bahiagrass	4.5
	Kentucky bluegrass	4.5
	Grass-legume mixture	3.5
Erosion Resistant Plastic (Clay mixes)	Bermudagrass	6.0
	Tall Fescue	5.5
	Bahiagrass	5.5
	Kentucky bluegrass	5.5
	Grass-legume mixture	4.5

[1] Permissible Velocity based on 10-yr storm peak runoff.

[2] Soil erodibility based on resistance to sil movement from concentrated flowing water.

[3] Before grass is established, permissible velocity is determined by

The longitudinal slope of the swale shall be as flat as possible to minimize velocities and improve pollutant filtering. The maximum slope shall be 5 percent; however, if slopes are less than 1 percent, ponding may occur in minor depressions, which may be objectionable to some residents. If slopes are flatter than 1 percent, an underdrain below the bottom of the swale can help to drain the swale. If ponding is not a concern to residents, vegetation that is suited to wetter conditions should be used. If land surface slopes are too steep for grassed swales, the slopes can be modified with check dams (see Figure 14-6) to reduce the slope and velocities or to enhance detention.

The designer also should evaluate the potential for transitioning from supercritical flow to subcritical flow at grade transitions. When evaluating the flow regime, the designer should consider the range of discharge rates up to and including the design rate. At grade transitions, hydraulic jumps may cause scouring of the channel and flooding of the banks. For locations where hydraulic jumps are anticipated, the designer should consider using turf reinforcement, energy dissipaters, or lined channel segments.

The methodology for channel liner design is presented in the DENR *Erosion and Sediment Control Planning and Design Manual*. If this procedure is used, a channel geometry must be selected that does not exceed either the maximum permissible velocity or the maximum allowable flow depth for the design flow rate.

The capacity of the swale must also be checked to ensure that it will be adequate after vegetation is fully established. The resistance to flow should be evaluated using the NRCS retardance factor for the vegetation selected (consult the DENR *Erosion and Sediment Control Planning and Design Manual*).

The flow depth of the design event should be evaluated using Manning's equation for the swale type used (parabolic, trapezoidal, or V-shaped). The design requirement is that the swales convey the design discharge while maintaining a 0.5-foot freeboard and without exceeding the maximum permissible velocity.

If driveways or roads cross the swale, the capacity of the culvert crossing the road or driveway may determine the depth of flow for the design event. In these instances, the culverts should be checked to establish that the backwater elevation does not exceed the banks of the swale. If the culvert discharges to a minimum tailwater condition, the exit velocity for the culvert should be evaluated for design conditions. If the maximum permissible velocity is exceeded at the culvert outlet, riprap or another measure to prevent scour must be used.

14.3.5. Plant and Landscape Requirements

Landscape design is based on specific site, soils, and hydric conditions along the channel. A dense grass cover is the best vegetation to maximize the performance of a grass swale. However, native plants and wetland vegetation, where they already exist or where they can be established before substantial discharge begins, can be effective, provided that swale capacity is not hindered.

Standard turf grasses may be used if a lawn appearance is desired. The turf grasses include standard mixtures such as those recommended in the DENR *Erosion and Sediment Control Planning and Design Manual* and the recommended vegetation tables in Section 6 of this document. The recommendation is to use taller growing grasses to improve the filtering capability of the swale. Bluegrass should be avoided for areas where salt loading is high.

Flat slopes, intentionally created minor depressions, and sufficient runoff volumes improve the ability of the swale to support wetland vegetation. Swales that are ideally suited for wetland vegetation include those that are routinely inundated by backwater, have bottoms at or near the groundwater table, or receive sustained base flows. Please refer to the recommended vegetation tables in Section 6 for lists of appropriate Zone II (shallow water) and III (emergent) plants.

Soil with a high infiltration rate is typically most appropriate for grassed swale BMPs. Topsoil should be suitable for healthy turf growth. Where the existing soil is unsuitable for growth (such as clayey or rocky soil), applying about 12 inches of loamy or sandy soil is beneficial.

14.3.6. Ponding and Infiltration

Ponding can be beneficial if intended and accepted, or it can be a negative if unintended. If unintended and not designed for, extended periods of standing water may result in nuisance conditions and create complaints from residents. Mosquitoes are typically the biggest concern, however, they should generally not be a problem because of the frequent flushing of the ponded water, and if wetland vegetation develops, mosquito predators such as other insects and birds often mitigate the mosquito problem. If wetland vegetation and standing water are persistent concerns, these problems can be reduced by maintaining more uniform, steeper slopes in the swale invert or by installing underdrains.

If temporary retention of small amounts of water is desired for enhanced treatment of the stormwater and ecological and visual diversity, there are many ways to achieve that goal. The paragraphs below discuss several methods for retaining water or otherwise modifying the typical swale hydrology. The retained water will infiltrate, be lost through evapotranspiration, or slowly released downstream. It should be noted that the maximum allowable ponding time within a channel is 48 hours and an underdrain system must be provided if that requirement cannot be met.

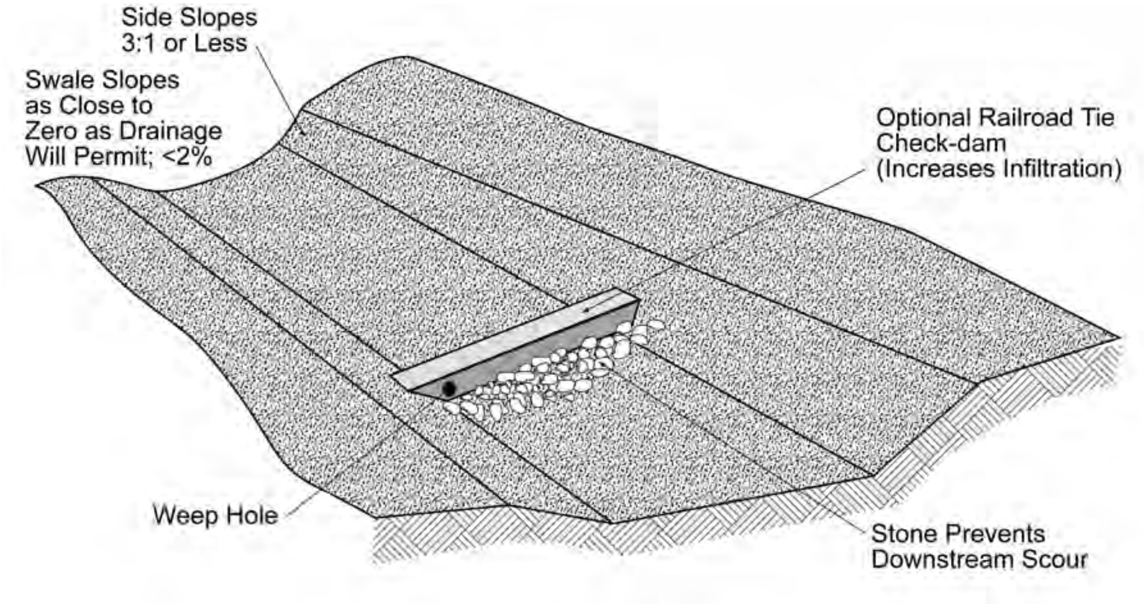
Check Dams
A check dam is constructed of earth, stone, or timber 3 to 6 inches high to retain runoff from routine events. A weep hole may be added to enable the area behind an earthen or timber dam to drain slowly. However, the weep hole may be subject to clogging. Shorter check dams can act as level spreaders to help distribute the flow along the swale's cross section. See Figure 14-6.

Elevated Drop Inlets
A drop inlet can be used when a combined system of swales and storm sewers is being used. The swales would serve as the collector system, and the inlet into the main storm sewer system would be elevated slightly to retain runoff from routine events. The height of elevation would depend on the soil, the slope of the swale, and the tolerance for ponding. Wetland vegetation may develop in the ponded areas if the underlying soils are poorly drained.

Elevated Culverts
Elevated culverts are used for the same purpose as check dams and elevated drop inlets, to retain runoff from routine events. As with elevated drop inlets, wetland vegetation may develop in the ponded areas if the underlying soils are poorly drained.

Depression storage
Small depressions along the bottom of the swale will trap and store stormwater for later infiltration into the soils. These depressions will also likely accumulate sediment at a quicker pace than other parts of the swale, and will also probably develop wetland vegetation.

Figure 14-7
Schematic of Grassed Swale with Check Dam (from NIPC, 1993 and Schueler, 1987)*.



*Side slopes must be 5:1 or less to attain water quality credit

Underdrains
Underdrains can enhance the performance of swales by providing additional filtration through soil similar to the process that takes place in bioretention facilities. These "bioretention" swales have a layer of engineered soil underlain by a gravel layer surrounding a perforated pipe. This configuration also reduces ponding time where standing water may be a concern. No additional removal credit is given for the addition of underdrains. If a system is designed with an underdrain and operates similar to a bioretention system and higher removal rates are desired, the system must meet the requirements of a bioretention BMP as described in Section 8.

14.4. Construction

To maximize the infiltration capacity of the swale, compaction of the soil underlying the swale should be avoided. For example, equipment for excavating or grading should operate from the side of the swale instead of the bottom of the swale.

Before vegetation is established in a swale, the swale is particularly vulnerable to scour and erosion. Therefore, protecting the seedbed with a temporary erosion-resistant lining, such as a geosynthetic, fiberglass roving, or other suitable erosion controls is generally necessary. Most vendors will furnish information about the Manning’s coefficient, n, and will also specify the maximum permissible velocity or allowable unit tractive force (also referred to as the “tractive stress”) for the lining material. Swales should be constructed and vegetated early in the construction schedule, preferably before area grading and paving increase the rate of runoff.

Temporary erosion-resistant channel linings should be used to stabilize the swale until the vegetation becomes established. The vendor's instructions for installing channel linings should be followed. If velocities will be high, designers should consider sodding the swale or diverting runoff until vegetation is established.

14.5. Maintenance

14.5.1. Common Maintenance Issues

Maintenance of grassed swales involves grooming the vegetation and occasionally removing trash. If native vegetation is used instead of turf, vegetation has to be mowed only seasonally to retard the growth of woody vegetation. Routine mowing is required if turf grasses are used. The recommendation is that grass be cut no lower than 5 inches. In addition, the grass should be allowed to grow to the maximum height consistent with the species and aesthetic requirements. Swales populated with wetland vegetation or other low-maintenance ground cover do not require mowing of the channel. The frequency of trash removal depends on the location and attractiveness of the swale as a disposal site.

Excessive sediment should not accumulate if erosion is controlled adequately upstream. However, if excessive siltation occurs, the sediment must be removed periodically (no less than once annually). Sediment that accumulates in the swale may be prone to resuspension during large storm events and can kill the grass. Sediment should be removed when it reaches a depth of 4 inches or when it covers the grass.

Additional annual maintenance activities are as follows:

- Repair erosion and regrade the swale to ensure that runoff flows evenly in a thin sheet through the swale.
- Revegetate the swale as needed to maintain a dense growth.

14.5.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- The drainage area of the grassed swale will be carefully managed to reduce the sediment load to the grassed swale.
- After the first-time fertilization to establish the grass in the swale, fertilizer will not be applied to the grassed swale.

The grassed swale will be inspected **once a quarter**. 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.

BMP element:	Potential problems:	How to remediate the problem:
The entire length of the swale	Trash/debris is present.	Remove the trash/debris.
	Areas of bare soil and/or erosive gullies have formed.	Regrade the soil if necessary to remove the gully, and then re-sod (or plant with other appropriate species) and water until established. Provide lime and a one-time fertilizer application.
	Sediment covers the grass at the bottom of the swale.	Remove sediment and dispose in an area that will not impact streams or BMPs. Re-sod if necessary.
	Vegetation is too short or too long.	Maintain vegetation at a height of approximately six inches.
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.

15. Restored Riparian Buffer

Description

Restored riparian buffers are natural or constructed low-maintenance ecosystems adjacent to surface water bodies, where trees, grasses, shrubs, and herbaceous plants function as a filter to remove pollutants from overland stormwater flow and shallow groundwater flow prior to discharge to receiving waters.

Regulatory Credits

Pollutant Removal

60%	Total Suspended Solids
30%	Total Nitrogen
35%	Total Phosphorus

Water Quantity

no	Peak Flow Attenuation
no	Volume Capture

Feasibility Considerations

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

Major Design Elements

* Sizing shall take into account all runoff at ultimate build-out including off-site drainage.

* BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.

** The buffer must be constructed directly adjacent to a perennial or intermittent surface water as shown on the most recent NRCS Soil Survey or the USGS 1:24,000 scale (7.5 minute) quadrangle topographic map.

** The existing riparian buffer must be "impaired." An "impaired" riparian buffer includes: fields and pastures that have been actively used within the last 3 years, and wooded buffers that have been cutover within the last 5 years or where the woody vegetation is absent or sparse (less than 100 stems per acre that are greater than 5 inches diameter at breast height).

** The restored riparian buffer must be used only when the flow to the level spreader is less than 3 cfs. This flow could be coming directly from the drainage area during the one inch per hour storm or the drawdown flow from another BMP.

** Level spreaders (designed in accordance with Chapter 8 of this Manual) are required if it cannot be proven that the stormwater entering the riparian buffer is sheet flow.

** The width shall be 50 feet, which must be divided into two zones. The 30 feet closest to the stream (Zone 1) must be wooded and the outer 20 feet (Zone 2) must be grassed.

** The buffer must be a minimum of 13 feet and a maximum of 130 feet in length, and is set by the level spreader length requirements.

** The slope of a riparian buffer must not be greater than 6%.

* *This provision is specified in the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

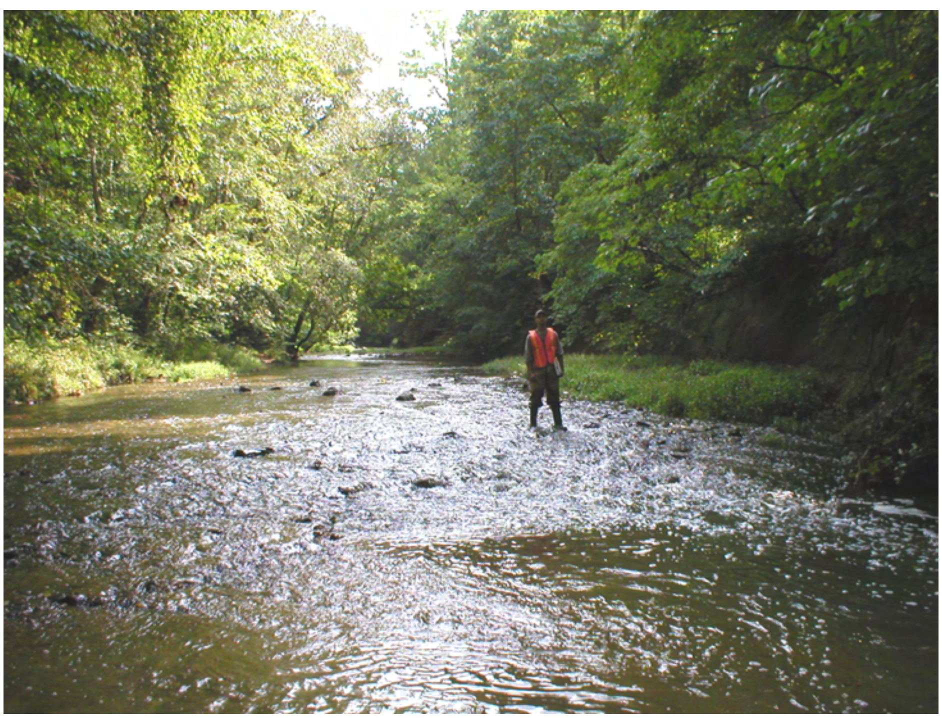
Advantages	Disadvantages
– Offers numerous aesthetic and passive recreational benefits. – Provides water quality treatment, erosion control, and water temperature benefits. – Maintaining trails that are constructed, marked, and signed well can build support for greenways within riparian buffers in urban and suburban watersheds.	– Sometimes seen as unkempt public areas. – Can be perceived as interfering with views of streams, especially with shrubby bank-side vegetation. – In the worst cases, can be abused as places for dumping trash and litter.

15.1. General Characteristics and Purpose

Riparian buffers are natural vegetated areas along a streambank (see Figure 15-1). They improve riparian habitat by:

- Providing food and cover for wildlife and aquatic organisms,
- Stabilizing stream banks,
- Filtering pollutants from stormwater,
- Attenuating the rate of runoff into streams, and
- Increasing infiltration and recharge to groundwater and surface water bodies.

Figure 15-1
Forested Riparian Buffer with Well-Developed Streambank Vegetation.



15.2. Meeting Regulatory Requirements

To receive the pollutant removal rates listed in the front of this Section, the restored riparian buffer must meet all of the major design requirements listed in the beginning of this Section. If restored riparian buffer will not meet the regulatory requirements of the site by itself, other BMPs can be used in conjunction to provide enhanced pollution removal rates or volume control capabilities.

Pollutant Removal Calculations
A properly sited, designed, constructed and maintained restored riparian buffers has the following associated pollutant removal rates:

- 60% Total Suspended Solids
- 30% Total Nitrogen
- 35% Total Phosphorus

Construction of a restored riparian buffer also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading.

Volume Control Calculations
A restored riparian buffer typically does not provide any active volume capture or peak flow attenuation. A restored riparian buffer provides some passive volume control capabilities by providing pervious surface and therefore reducing the total runoff volume to be controlled.

15.3. Design

15.3.1. Siting Requirements

All of the following siting requirements must be met in order for a restored riparian buffer to be constructed and receive the stated pollutant removal efficiencies:

1. They may only be constructed directly adjacent to a perennial or intermittent surface water. A perennial or intermittent surface water is considered to be present if the feature is approximately shown on either the most recent version of the Soil Survey Map prepared by the Natural Resources Conservation Service of the United States Department of Agriculture or the most recent version of the 1:24,000 scale (7.5 minute) quadrangle topographic maps prepared by the United States Geologic Survey (USGS).

2. The existing riparian buffer must be “impaired.” An “impaired” riparian buffer includes: fields and pastures that have been actively used within the last 3 years, and wooded buffers that have been cutover within the last 5 years or where the woody vegetation is absent or sparse (less than 100 stems per acre that are greater than 5 inches diameter at breast height).

3. The slope of the riparian buffer must not be greater than 6 percent.

4. The restored riparian buffer must be used only when the flow to the level spreader is less than 3 cfs. This flow could be coming directly from the drainage area during the one inch per hour storm or the drawdown flow from another BMP.

All restored riparian buffers must be placed in permanent easement so it will not later be decreased or removed from the site.

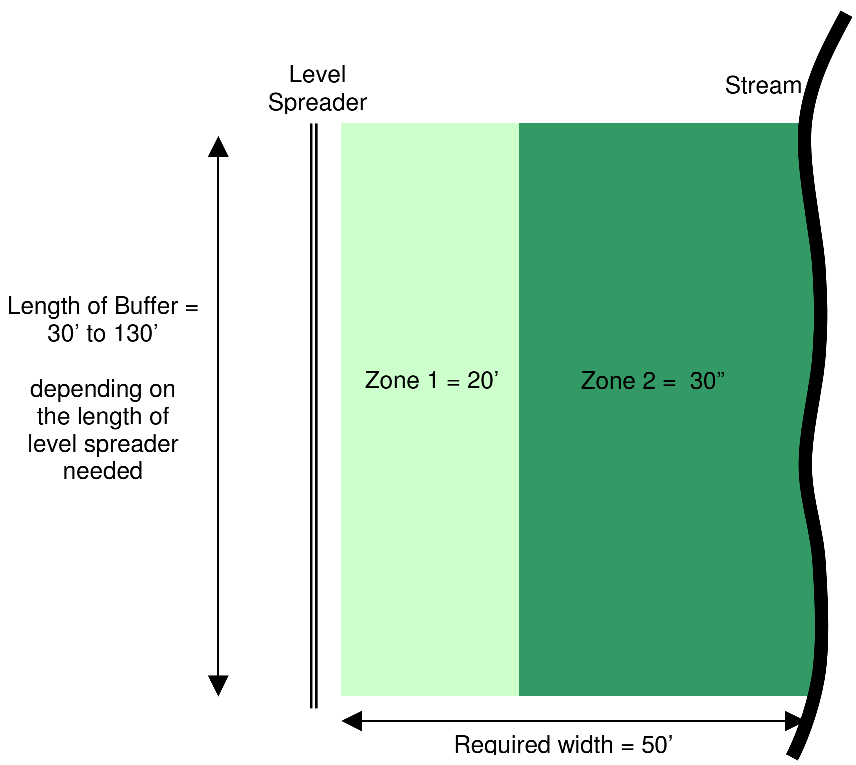
15.3.2. Length and Width

The restored riparian buffer must a total of 50 feet in width and it must be composed of a zone of grass (20 feet wide) and a zone of forest vegetation (30 feet wide) as described in Section 15.3.3 below.

The length of level spreader is determined by calculating the weighted average of the lengths required for each vegetation type as shown below.

(20/50) x (13 ft/1cfs) + (30/50) x (65 ft/1 cfs) = 44.2 or 44 feet per cfs of flow

Since the maximum length of a level spreader is 130 feet, this means that each restored riparian buffer is able to treat 3 cfs of flow. The level spreader may be designed to treat the one inch per hour storm with a bypass channel or the 10-year, 24-hour storm without a bypass channel. See chapter 8 for information about properly designing level spreaders. A restored riparian buffer will not receive approval from DWQ unless it is accompanied by a properly designed level spreader or it is proven that the flow entering the restored riparian buffer is already diffuse.



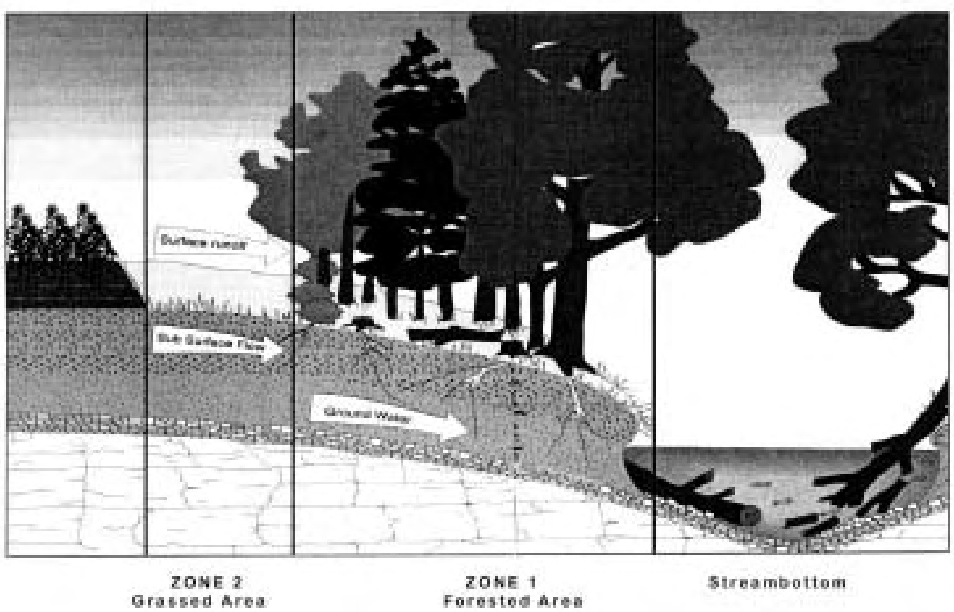
Designers have the option of placing two or more restored riparian buffers adjacent to one another along a stream channel in order to treat higher flows of stormwater. Restored riparian buffers can be used downslope of a detention/retention BMP, which will attenuate the flow from a larger drainage area and allow the drawdown flow to receive additional treatment without overwhelming the level spreader and restored riparian buffer.

15.3.3. Two-Zone Riparian Buffer System

Restored riparian buffers must be 50 feet wide and include two zones of vegetation. Zone 1 starts from the top of bank for streams (and from mean high water for other waterbodies) and extends landward a distance of 30 feet perpendicular to the stream. Zone 1 consists primarily of wooded vegetation that may not be disturbed except for removal of nuisance vegetation (see Section 15.3.6). Zone 2 extends a minimum of 20 additional feet beyond Zone 1. Zone 2 is intended to diffuse and infiltrate runoff and filtering of pollutants. It may be grassed, and other vegetation and periodic maintenance are allowed.

Figure 15-2

Two Zone Buffer (modified from Lowrance *et al*., 1995)



15.3.4. Site Assessment

The riparian area to be restored should be evaluated with respect to these factors that control the viability of riparian plants:

- Soil moisture
- Soil pH
- Soil texture
- Seasonal high water table depth
- Flooding potential
- Aspect, topography, and microtopographic relief

15.3.5. Zone 1 Planting Requirements

Based on the site assessment, the designer should choose 10-12 species of native trees and shrubs appropriate for site based on site assessment and reference conditions. Typically, there should be at least three or four understory trees for every canopy tree to provide structural diversity similar to mature forests. Where shrub species are incorporated into the planting plan, they should be distributed more densely at outer edge of riparian buffer to reduce light penetration and recolonization by invasive exotic species.

Please refer to Table 15-1 below for plant lists broken down by plant type, physiographic region, and hydrologic zone. Most plants for the buffer should be compatible with Zone 4, Upland Area, with some plants, depending on the site, from Zone 3, Shallow Land. Please note that these lists are alphabetical and do not take into account the assemblages of plants found in nature.

Trees should be planted approximately at a density sufficient to provide 320 trees per acre and shrubs should be planted at a spacing to provide 1,200 shrubs per acre. To achieve this density, trees should be planted at a spacing of 8x8 to 10x10 feet. Shrubs should be planted at a spacing of 3x3 to 5x5 feet.

The minimum size for trees that are planted in the restored riparian buffer is 2.5 inches dbh (diameter breast height). Trees should be bare root or balled and burlapped (not containerized stock). The minimum size for shrubs planted in the restored riparian buffer is a one-gallon container.

Table 15-1

Planting List for Zone 1 (Ecosystem Enhancement Program 2004)

Native Regions		Light Requirements		Moisture Requirements	
M=	Mountains	S=	Shade	L=	Low Moisture
P=	Piedmont	P=	Partial Sun	M=	Moderate Moisture
C=	Coastal Plain	F=	Full Sun	H=	High Moisture
				A=	Aquatic

Scientific Name	Common Name	Region			Light			Moisture			
		M	P	C	S	P	F	L	M	H	A
Medium to Large Trees											
Acer barbatum	Southern sugar maple		X	X	X	X			X		
Acer saccharinum	silver maple		X		X	X	X		X		
Acer saccharum	sugar maple	X				X	X		X		
Betula alleghaniensis	yellow birch	X			X	X			X		
Betula lenta	cherry birch, sweet birch	X			X	X			X		
Betula nigra	river birch	X	X	X		X	X		X	X	
Carya aquatica	water hickory			X		X	X			X	
Carya cordiformis	bitternut hickory	X	X	X	X	X	X		X	X	
Carya glabra	pignut hickory	X	X	X	X	X	X	X	X		
Carya ovata	shagbark hickory	X	X	X	X	X	X		X		
Carya tomentosa	mockernut hickory	X	X	X	X	X	X	X	X		
Celtis laevigata	sugarberry, hackberry		X	X	X	X			X		
Chamaecyparis thyoides	Atlantic white cedar			X		X	X		X	X	
Cladrastis kentuckea	yellowwood	X			X	X			X		
Diospyros virginiana	persimmon	X	X	X	X	X	X	X	X		
Fagus grandifolia	American beech	X	X	X	X	X			X		
Fraxinus americana	white ash	X	X	X	X	X			X		
Fraxinus pennsylvanica	green ash	X	X	X	X	X			X	X	
Fraxinus profunda	pumpkin ash, red ash		X	X		X				X	
Juglans nigra	black walnut	X	X	X	X	X			X		
Liriodendron tulipifera	tulip poplar, yellow poplar	X	X	X	X	X	X		X		
Magnolia acuminata	cucumber magnolia	X	X		X	X			X		
Magnolia fraseri	Fraser magnolia	X				X			X		
Nyssa aquatica	water tupelo			X	X	X	X			X	X
Nyssa sylvatica	black gum	X	X	X	X	X	X	X	X		
Nyssa sylvatica var. biflora	swamp black gum			X	X	X	X			X	
Oxydendrum arboreum	sourwood	X	X	X		X	X	X	X		
Picea rubens	red spruce	X			X	X	X		X		
Pinus echinata	shortleaf pine	X	X	X		X	X	X			
Pinus palustris	longleaf pine		X	X			X	X	X		
Pinus rigida	pitch pine	X					X	X			

Scientific Name	Common Name	Region			Light			Moisture			
		M	P	C	S	P	F	L	M	H	A
Pinus serotina	pond pine			X			X		X	X	
Pinus strobus	white pine	X	X			X	X		X		
Platanus occidentalis	sycamore	X	X	X		X	X		X	X	
Populus deltoides	eastern cottonwood		X	X			X			X	
Populus heterophylla	swamp cottonwood			X		X	X			X	
Prunus serotina	black cherry	X	X	X	X	X	X	X	X		
Quercus alba	white oak	X	X	X		X	X	X	X		
Quercus bicolor	swamp white oak		X		X	X				X	
Quercus coccinea	scarlet oak	X	X		X	X		X			
Quercus falcata	Southern red oak	X	X	X	X	X		X	X		
Quercus pagoda	cherrybark oak		X	X	X	X			X	X	
Quercus laurifolia	laurel oak			X	X	X	X		X	X	
Quercus lyrata	overcup oak		X	X	X	X				X	
Quercus margaretta	sand post oak			X		X	X	X			
Quercus marilandica	black jack oak	X	X	X	X	X		X			
Quercus michauxii	swamp chestnut oak		X	X	X	X	X		X	X	
Quercus nigra	water oak		X	X	X	X	X	X	X		
Quercus phellos	willow oak		X	X	X	X	X		X	X	
Quercus prinus	chestnut oak	X	X		X	X		X			
Quercus rubra	Northern red oak	X	X		X	X		X	X		
Quercus shumardii	shumard oak		X	X	X	X			X	X	
Quercus stellata	post oak	X	X	X	X	X		X			
Quercus velutina	black oak	X	X	X	X	X		X			
Quercus virginiana	live oak			X		X	X	X			
Robinia pseudoacacia	black locust	X	X	X		X	X		X		
Taxodium ascendens	pond-cypress			X		X	X				X
Taxodium distichum	bald-cypress			X		X	X				X
Tilia americana var. heterophylla	basswood	X	X		X	X			X		
Tsuga canadensis	Eastern hemlock	X	X		X	X	X		X		
Tsuga caroliniana	Carolina hemlock	X	X			X	X	X			
Ulmus alata	winged elm		X	X	X	X	X	X	X		
Ulmus americana	American elm	X	X	X	X	X			X		
Small Trees											
Amelanchier arborea	downy serviceberry, shadbush	X	X	X	X	X			X		
Amelanchier canadensis	Canada serviceberry			X			X		X	X	
Amelanchier laevis	smooth serviceberry	X				X	X	X	X		
Asimina triloba	pawpaw	X	X	X	X	X			X		
Carpinus caroliniana	ironwood, American hornbeam	X	X	X	X	X			X	X	
Cercis canadensis	eastern redbud	X	X	X	X	X			X		
Chionanthus virginicus	white fringetree, old man's beard	X	X	X		X	X		X		
Cornus alternifolia	alternate-leaf dogwood	X			X	X			X		
Cornus florida	flowering dogwood	X	X	X	X	X		X	X		
Crateagus crus-galli	cockspur hawthorn	X	X	X		X	X	X	X		
Crateagus flabellata	fanleaf hawthorn	X	X			X			X		
Crateagus flava	October haw	X	X	X		X	X		X		
Cyrilla racemiflora	titi			X		X	X		X	X	
Fraxinus caroliniana	water ash			X	X	X				X	
Gordonia lasianthus	loblolly bay			X	X	X	X		X	X	

Scientific Name	Common Name	Region			Light			Moisture			
		M	P	C	S	P	F	L	M	H	A
Halesia tetraptera (H. carolina)	common silverbell	X	X		X	X			X		
Ilex opaca	American holly	X	X	X	X	X		X	X	X	
Juniperus virginiana	Eastern red cedar	X	X	X		X	X	X	X		
Magnolia tripetala	umbrella tree	X	X		X				X		
Magnolia virginiana	sweetbay magnolia		X	X	X	X	X		X	X	
Morus rubra	red mulberry	X	X	X	X	X			X		
Osmanthus americana	wild olive, devilwood			X	X	X			X		
Ostrya virginiana	Eastern hop-hornbeam	X	X		X	X			X		
Persea borbonia	red bay			X	X	X	X	X	X		
Persea palustris	swamp bay			X	X	X	X		X	X	
Pinus pungens	table mountain pine	X					X	X			
Prunus americana	American wild plum	X	X			X			X		
Prunus caroliniana	Carolina laurel-cherry			X		X	X	X	X		
Quercus incana	bluejack oak			X		X	X	X			
Quercus laevis	turkey oak			X		X	X	X			
Rhus glabra	smooth sumac	X	X				X	X	X		
Rhus hirta (Rhus typhina)	staghorn sumac	X					X	X			
Salix caroliniana	swamp willow	X	X	X		X	X		X	X	
Salix nigra	black willow	X	X	X		X	X		X	X	
Sassafras albidum	sassafras	X	X	X		X	X	X	X		
Staphylea trifolia	bladdernut		X		X				X	X	
Symplocos tinctoria	horse-sugar, sweetleaf	X	X	X	X	X		X	X		
Ulmus rubra	slippery elm	X	X		X	X			X		
Shrubs											
Aesculus sylvatica	painted buckeye	X	X		X	X			X		
*Alnus serrulata**	common alder	X	X	X	X	X	X			X	X
Aronia arbutifolia	red chokeberry	X	X	X	X	X			X	X	
Baccharis halimifolia	silverling		X	X			X	X	X	X	
Callicarpa americana	American beautyberry		X	X	X	X	X		X		
Calycanthus floridus	sweet-shrub	X	X		X	X			X		
Castanea pumila	Allegheny chinkapin	X	X	X	X	X	X	X			
Ceanothus americanus	New Jersey tea	X	X	X		X	X	X			
Cephalanthus occidentalis	buttonbush	X	X	X		X	X				X
Clethra acuminata	mountain sweet pepperbush	X			X	X			X		
Clethra alnifolia	sweet pepperbush			X	X	X			X	X	
Comptonia peregrina	sweet fern	X	X			X	X				
Cornus amomum	silky dogwood	X	X	X	X	X				X	X
Cornus stricta	swamp dogwood			X	X	X				X	
Corylus americana	American hazel, hazelnut	X	X		X	X			X		
Euonymus americanus	hearts-a-bustin', strawberry bush	X	X	X	X	X		X	X		
Fothergilla gardenii	witch-alder			X		X			X	X	
Gaylussacia frondosa	dangleberry			X	X	X	X		X	X	
Hamamelis virginiana	witch hazel	X	X	X	X	X		X	X		
Hydrangea arborescens	wild hydrangea	X	X		X	X			X		
Ilex coriacea	gallberry			X	X	X			X	X	
Ilex decidua	deciduous holly, possumhaw		X	X	X	X			X		
Ilex glabra	inkberry			X	X	X	X		X	X	
Ilex verticillata	winterberry	X	X	X	X	X	X		X	X	

Scientific Name	Common Name	Region			Light			Moisture			
		M	P	C	S	P	F	L	M	H	A
Ilex vomitoria	yaupon holly			X	X	X	X	X			
Itea virginica	Virginia willow		X	X	X	X				X	
Kalmia angustifolia var. caroliniana	lamb-kill, sheep-kill			X		X	X		X	X	
Kalmia latifolia	mountain laurel	X	X		X	X		X	X		
Leucothoe axillaris	coastal dog-hobble			X	X	X			X		
Leucothoe fontanesiana	dog-hobble	X	X		X				X		
Leucothoe racemosa	fetterbush		X	X	X	X			X	X	
Lindera benzoin	spicebush	X	X		X				X		
Lyonia ligustrina	northern maleberry	X	X	X		X			X	X	
Lyonia lucida	shining fetterbush			X	X	X			X		
*Myrica cerifera**	Southern wax-myrtle		X	X	X	X	X	X	X	X	
*Myrica cerifera var. pumila**	dwarf Southern wax-myrtle			X		X	X	X	X		
*Myrica heterophylla**	bayberry, evergreen bayberry			X	X	X			X		
Pieris floribunda	evergreen mountain fetterbush	X					X	X	X		
Rhododendron atlanticum	dwarf azalea			X		X			X		
Rhododendron calendulaceum	flame azalea	X			X	X			X		
Rhododendron catawbiense	Catawba rhododendron	X	X		X	X	X	X	X		
Rhododendron maximum	rosebay rhododendron	X	X		X	X		X	X		
Rhododendron periclymenoides	pinxter flower, wild azalea	X	X	X	X	X			X		
Rhododendron viscosum	swamp azalea	X		X		X	X		X	X	
Rhus copallina	winged sumac	X	X	X		X	X	X	X		
Rosa carolina	pasture rose, Carolina rose	X	X	X		X	X	X	X		
Rosa palustris	swamp rose	X	X	X		X	X				X
Rubus allegheniensis	Alleghany blackberry	X	X				X	X			
Rubus cuneifolius	blackberry		X	X		X	X	X	X		
Rubus odoratus	purple flowering raspberry	X				X			X		
Salix humilis	prairie willow	X	X				X	X			
Salix sericea	silky willow	X	X	X		X	X				X
Sambucus canadensis	common elderberry	X	X	X			X		X	X	
Spiraea alba	narrow-leaved meadowsweet	X					X		X		
Spiraea latifolia	broad-leaved meadowsweet	X					X		X		
Spiraea tomentosa	meadowsweet	X	X	X		X	X			X	
Stewartia malacodendron	silky camellia			X	X	X			X		
Stewartia ovata	mountain camellia	X	X		X	X			X		
Styrax grandifolia	bigleaf snowbell		X	X	X	X			X		
Vaccinium arboreum	sparkleberry		X	X	X	X		X	X		
Vaccinium corymbosum	highbush blueberry	X	X	X	X	X	X	X	X	X	
Vaccinium crassifolium	creeping blueberry			X		X			X		
Vaccinium elliottii	mayberry			X	X				X		
Vaccinium stamineum	deerberry, gooseberry	X	X	X	X	X		X			
Vaccinium pallidum	lowbush blueberry	X	X		X	X		X			
Viburnum acerifolium	maple-leaf viburnum	X	X		X	X		X	X		
Viburnum dentatum	Southern arrowwood viburnum	X	X	X	X	X	X		X		
Viburnum nudum	possumhaw viburnum	X	X	X	X	X				X	
Viburnum prunifolium	blackhaw viburnum	X	X	X	X	X			X		
Viburnum rafinesquianum	downy arrowwood		X		X	X			X		
Viburnum rufidulum	rusty blackhaw		X	X	X	X		X			
Xanthorhiza simplicissima	yellowroot	X	X	X	X			X	X		

* *These fix nitrogen and should not be used for riparian restoration adjacent to Nutrient Sensitive Waters.*

15.3.6. Zone 2 Planting Requirements

Zone 2 must be planted as a dense cover of grasses. Fescue and bluegrass should not be used because they are invasive species and will compete with native vegetation for nutrients. Do not work under frozen, muddy or saturated conditions. There are a number of acceptable ways to establish grass in Zone 2.

Centipede and Zoysia grasses should be planted in mid-May until late August. If Centipede is being planted, it is ideal to use sod. If plugs are used, they should be 6-12" apart (closer to a 6-inch separation for Zoysia since it doesn't spread as well as Centipede), in a grid or checkerboard pattern. Plugs should be placed at a depth of one inch.

15.4. Construction

Buffer restoration may include stabilization of the stream channel, site preparation, and planting the vegetation. Streambank stabilization involves a combination of vegetative and structural techniques. Vegetative techniques create a natural appearance and provide habitat to aquatic organisms and wildlife. These options include live stakes, tree revetments, live fascines, and brush mattresses. Other features such as boulders, logs, sandbags, or gabions can be combined for additional stability. Structural measures such as riprap and concrete structures are not as desirable but may be needed in some situations to protect infrastructure such as roads and buildings. If streambank stabilization is proposed as part of the project, please contact the North Carolina Division of Water Quality 401 Unit for permitting information at (919) 733-1786.

After the streambank has been stabilized, site preparation, including treatment of existing vegetation and soil preparation, is usually required before planting begins. The degree of site preparation needed depends on the existing vegetation and whether the site is being completely redone or if the existing buffer is merely being "enhanced". They may require mechanical and chemical treatment (proposals for pesticide use should always be reviewed by the North Carolina Division of Water Quality staff to insure compliance with the Neuse and Tar-Pamlico Riparian Buffer Rules). In addition to controlling invasive species, sod-forming grasses such as fescue and Kentucky bluegrass that will compete with plantings for nutrients need to be controlled.

Soil disturbance within the buffer should be minimized (preferably done by hand). Operation of land disturbing equipment within the buffer should be limited to light machinery. If complete reconstruction is being performed, the site should be plowed or ripped to improve compacted soil and/or eliminate areas where channelized flow has developed. After soil disturbance activities, areas of bare soil must be stabilized as quickly as possible using the grass species listed in Table 15-2. Please note that fescue grasses should not be used for soil stabilization. Fescue grasses, particularly tall fescue, are competitive and will inhibit the eventual re-establishment of native species.

When planting seedlings, it is helpful to mark the plants with colored flagging to make them easier to locate during maintenance tasks. The flagging can also be color-coded to mark plants that have died for replacement at a later date.

Tree protectors are also helpful for locating plants. Tree seedlings should be kept moist and should not be exposed for extended periods of time. A correctly planted tree should have the following general characteristics:

- Planted so that the root collar is slightly below the soil surface.
- Have the main roots nearly straight or spread out.
- Have soil firm around the roots.
- Have the tree in an upright position and have it nearly even with the general ground level, not sunk in a hole or raised on a mound.

When planting in Zone 2, scarify native soil to a minimum depth of 4". If required, add additional imported topsoil. All areas for sodding or grass plugs shall be raked to a uniformly fine texture. Moisten prepared lawn areas before planting if soil is dry. Water thoroughly and allow surfaces to dry before planting.

Please note that the Neuse and Tar-Pamlico Riparian Buffer Rules allow for a one-time fertilizer application to establish newly planted vegetation. Ongoing fertilizer application is prohibited.

15.5. Maintenance

15.5.1. Common Maintenance Issues

Riparian buffers require maintenance to fill gullies, remove weeds, repair streambank erosion, and protect against wildlife damage and insect and disease problems. Maintenance must be carried out with minimal impact in Zone 1.

Removal of natural leaf litter from the buffer is strongly discouraged. Where this natural material is not present, organic mulch such as wood chips, tree bark, and pine needles should be maintained at a minimum depth of 2 inches over the entire buffer.

Watering may be necessary in the initial year or during periods of drought, especially if bare root material is installed. Some seedling mortality is expected but replanting may be necessary to maintain the stand density.

After the trees are established, periodic thinning and harvesting of mature trees is recommended to maintain health and growth. Thinning of trees within the buffer can be allowed provided that the minimum tree density requirement specified above is fulfilled and no trees larger than 2-inch diameter are removed except when dead or diseased. The thinning of vines and thick undergrowth to provide a better view or a more aesthetically pleasing natural landscape is allowed.

On-going maintenance activities include selective cutting, replanting to maintain forest structure, and weed control. Fertilization and liming are recommended during plant establishment. Long term fertilization and chemical weed control, however, should not be necessary if the proper vegetation has been selected, and in some cases is not allowed by regulations.

In the early stages of riparian buffer establishment, competition for nutrients by adjacent grasses and herbs will substantially inhibit seedling growth. Release from herbaceous competition has been demonstrated as the most cost-effective method to accelerate the growth of seedlings. The plan for buffer establishment should incorporate control of the herbaceous layer. Options for weed control include four to six inches of well-aged hardwood mulch, weed control fabrics, or pre-emergent herbicide. Typically, mowing to control weeds will be impractical based on the random distribution of plantings. Weed control should be continued for three years from the time of planting, at which time it should be somewhat self-controlling.

It is also necessary to control of invasive, exotic plants that would hinder the re-establishment of woody vegetation. Division of Water Quality staff should review proposals for pesticide use within the Neuse and Tar-Pamlico Riparian Buffer Rules if applicable. Common invasive plants for North Carolina are listed in Table 15-2.

Table 15-2

Common Invasive Plants (Ecosystem Enhancement Program 2004)

Scientific Name	Common Name
Ailanthus altissima	Tree-of-Heaven
Albizia julibrissin	Mimosa
Elaeagnus umbellata	Autumn Olive
Hedera helix	English Ivy
Lespedeza cuneata	Korean or Sericea Lespedeza
Ligustrum sinense	Chinese Privet
Lonisera japonica	Japanese Honeysuckle
Microstegium vimineum	Japanese Grass
Paulownia tomentosa	Princess Tree
Pueraria lobata	Kudzu
Rosa multiflora	Multiflora Rose
Wisteria sinensis	Chinese Wisteria

If the streambank structure is not maintained by riparian vegetation, then additional measures should be used such as live staking, intercepting runoff before it enters the riparian forested buffer, or using stabilization techniques.

In suburban and urban areas, maintenance personnel may require additional training to ensure that riparian buffers are not reduced by aggressive mowing, pruning, or herbicide regimes.

15.5.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- Immediately after the restored riparian buffer is established, any newly planted vegetation will be watered twice weekly if needed until the plants become established (commonly six weeks).
- Once a year, Zone 2 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 restored riparian buffer.
- Two to three times a year, Zone 2 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)..
- Once a year, the soil in Zone 2 will be aerated if necessary.
- Once a year, soil pH will be tested and lime will be added if necessary.

After the restored riparian buffer 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 15-3

Sample Inspection and Maintenance Provisions for 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.

Table 15-3, continued
Sample Inspection and Maintenance Provisions for Restored Riparian Buffers

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 ripap 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 are 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 401 Oversight Unit at 919-733-1786.

Table 8-2, continued

Sample Inspection and Maintenance Provisions for Filter Strips

BMP element:	Potential problem:	How to remediate the problem:

16. Infiltration Devices

Description

Infiltration devices are trenches or basins that fill with stormwater runoff and allow the water to exfiltrate, i.e., exit the device by infiltrating into the soil.

Regulatory Credits

Pollutant Removal

85%	Total Suspended Solids
30%	Total Nitrogen
35%	Total Phosphorus

Water Quantity

possible	Peak Runoff Attenuation
possible	Runoff Volume Reduction

Feasibility Considerations

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

Major Design Elements

* Side slopes stabilized with vegetation shall be no steeper than 3:1.
* BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
* Overflows shall pass through a minimum 30 feet long vegetative filter.
* BMP shall be a minimum of 30 feet from surface waters, 50 feet from Class SA waters, and 100 feet from water supply wells.
* The bottom shall be a minimum of 2 feet above the seasonal high water table.
* Runoff in excess of the design volume must bypass the BMP.
* The storage volume must completely draw down to the seasonally high water table under seasonally high water conditions within 5 days.
* Trenches must be shallower than their largest surface dimension to prevent categorization as an "injection well."

** BMP shall be installed at a 0-0.05% grade (level).

** BMP shall be located a minimum of 15 feet downgradient of any structure.

** A single device shall handle a maximum of 2 acre-inches of runoff.

** The bottom shall min. of 2 feet above any underlying impervious soil horizon or bedrock.

** BMP shall be used only after entire upstream area has been stabilized.

** BMP shall not be used on industrial sites or designated contaminated land uses or activities such as areas subject to frequent oil or other petroleum contamination.

** Pretreatment devices must be provided.

** Trench depths must be between 3 and 8 feet.

** Minimum of 1 observation well shall be provided.

* *This provision is specified in NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

Advantages	**Disadvantages**
– Reduce frequency of flooding by increasing the amount of water entering the soil. – Help recharge groundwater, which supports dry-weather flows in streams. – Particulate pollutant removal efficiencies generally as good as other BMPs.	– Often fail relatively quickly compared to other types of BMPs. – Restricted to areas with permeable soils. – May cause undesirable groundwater seepage into basements and foundations if not properly sited. – Infiltration of stormwater may contaminate groundwater.

16.1. General Characteristics and Purpose

"Infiltration," in the context of BMPs, refers to the process of stormwater soaking into the soil. Infiltration devices enhance percolation to groundwater by directing surface runoff to locations where it can come into contact with pervious underlying soils and then detaining that runoff until it can soak into the underlying soil. Infiltration devices reduce runoff volume, recharge groundwater, and have high removal efficiencies for sediment and for pollutants adsorbed onto sediment particles. A number of infiltration devices with differing designs have been used in various locations throughout the country, and are appropriate in the majority of the coastal counties of North Carolina and as an alternative practice in other areas with suitable soils.

Infiltration devices transfer more stormwater to the soil than any other type of BMP, and they more closely mimic the natural hydrology of the area by taking a portion of concentrated flow and allowing it to infiltrate into the soil. They work best in relatively small drainage areas and drainage areas that are completely impervious or stable (to minimize the amount of sediment going to the BMP).

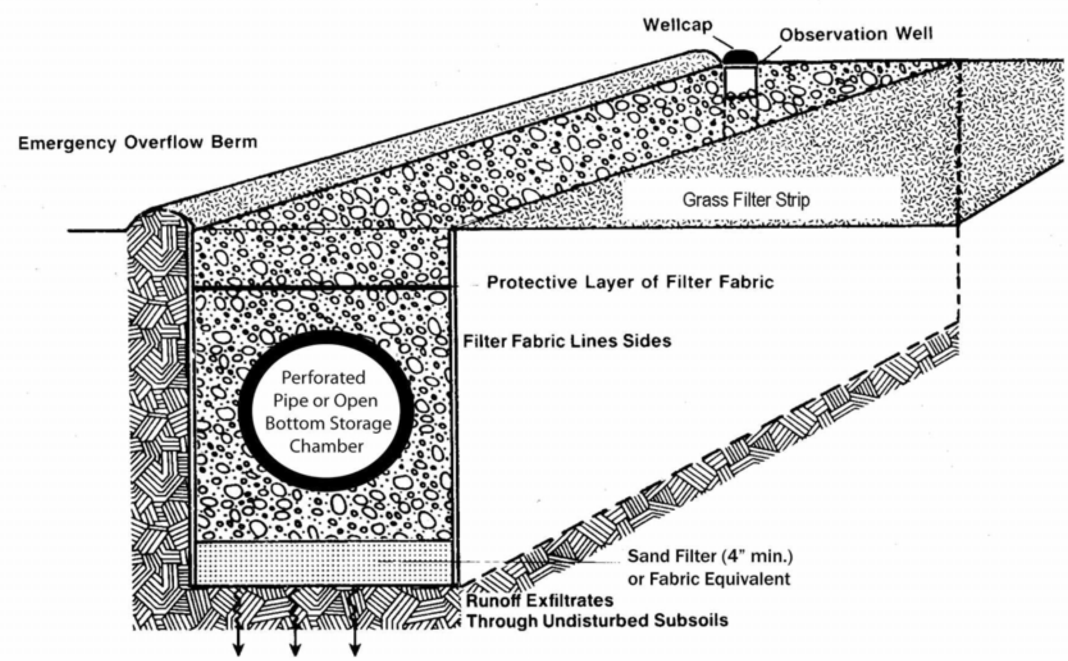
Infiltration devices are frequently used to infiltrate runoff from adjacent impervious surfaces, such as parking lots. In these cases, a filter strip should be installed between the pavement and the device to trap sediment and litter before it is washed into the device. Another approach is to construct infiltration devices at the downgradient edges of areas with permeable pavement. In this case, the permeable pavement is the inlet to the device. Because water also will infiltrate through the base of the pavement, the size of the infiltration devices can be reduced significantly.

This section discusses two types of infiltration devices: infiltration trenches (see Figure 16-1) and infiltration basins (see Figure 16-2).

Infiltration Trenches

Infiltration trenches are filled with large crushed stone or other media to create storage for the stormwater in the voids between the media. Other versions use precast concrete vaults with open bottoms to provide a large storage volume to hold stormwater for infiltration into the soil. Infiltration trenches are usually used to manage the runoff from parking lots and buildings.

Figure 16-1
Typical Infiltration Trench
(Adapted from Schueler et al., 1992)



Infiltration Basins
Infiltration basins are normally dry basins, much like extended dry detention basins, with the exception that the stormwater does not flow out into a receiving stream. Rather, the stormwater is only allowed to infiltrate into the soils and eventually to the groundwater.

16.2. Meeting Regulatory Requirements

To obtain a permit to construct an infiltration device in North Carolina, the infiltration device must meet all of the Regulatory Design Requirements listed in the beginning of this Section. All of the Regulatory Design Requirements are from the North Carolina Administrative Code.

To receive the pollutant removal rates listed in the front of this Section, the infiltration device must meet all of the Regulatory Design Requirements and Pollutant Removal Credit Design Requirements listed in the beginning of this Section.

Pollutant Removal Calculations

The pollutant removal calculations for infiltration devices are as described in Section 3.8, and use the pollutant removal rates provided in Table 4-2 in Section 4.0. Construction of an infiltration device also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading.

Volume Control Calculations

An infiltration basin typically can be designed with enough storage to provide active storage control, calculations for which are provided in Section 3.4. Infiltration trenches may not have enough water storage to meet the volume control requirements of the particular stormwater program so they may need to be used in series with another BMP with volume control capabilities. All infiltration devices provide some passive volume control capabilities by providing pervious surface and therefore reducing the total runoff volume to be controlled.

16.3. Design

16.3.1. 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 an infiltration basin. 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. A minimum of 6 inches of bottom material (below the design bottom of the original sediment and erosion control device) must be removed prior to conversion to a stormwater BMP, so appropriate design bottom depth changes must be considered. Infiltration trenches shall not be used as sediment and erosion control devices. It is essential that the site be completely stabilized before the erosion and control devises are removed or converted.

16.3.2. Siting Issues

Infiltration devices must be constructed level (at a 0-0.05% grade). It is recommended that they not be located on slopes greater than 15 percent. They shall not be located within fill soils except that recent state legislation (SL 2006-246 Sec. 9(k)) specified that a minimum of one foot of naturally occurring soil would be required above the seasonal high-water table. Infiltration devices shall not be placed in locations with less than 2 feet between the bottom of the infiltration device and the seasonal high groundwater, underlying impervious soil horizon, or bedrock (a 4 foot separation distance is recommended). On a case by case basis exceptions may be made if the detailed hydrogeologic analysis and opinion from a qualified design professional shows that the proposed system will operate as intended and will not have a negative impact on the environment or human health.

Potential mounding of the water table caused by the infiltration of the BMP is also a potential problem. If the mounded water table encroaches above the bottom of the infiltration device the hydraulic gradient is greatly reduced. Designing infiltration devices according to the requirements and guidelines presented in this manual should avoid this condition.

A common cause of failure among infiltration devices is clogging due to excessive sediment loads. Infiltration devices shall be used only once upstream areas have been properly stabilized.

Infiltration devices should not be placed in locations that cause water problems to downgradient properties. They must be a minimum of 15 feet downgradient from structures. The facilities must be located a minimum of 100 feet horizontally from any water supply well, 50 feet from Class SA waters, and 30 feet from surface water, as required by applicable North Carolina regulations (15A NCAC 2H .1008 (d) Infiltration System Requirements).

Infiltration of stormwater may contaminate groundwater (Schueler et al., 1992). To protect groundwater from possible contamination, runoff industrial sites and from designated contaminated land uses or activities (such as areas subject to frequent oil or other petroleum product contamination) cannot be infiltrated without proper pretreatment to remove hydrocarbons, trace metals, and other hazardous substances.

16.3.3. Contributing Drainage Basin

The potential erosion or device overflow created by a large inflow is a concern in the design of infiltration devices. An individual infiltration device shall not receive more than 2.0 acre-inches of runoff, and less than 1.0 acre-inches of runoff is recommended. A general guidance is that the contributing area to an individual infiltration device will often be in the range of 5 acres or less. Also, infiltration devices must be off-line, that is, runoff in excess of the water quality volume should bypass the system.

16.3.4. Pretreatment and Inflow

Pretreatment devices such as filter strips, grassed swales, and forebays (sediment traps) must be used to protect infiltration devices from clogging.

Consideration should be given to the inlet when infiltration facilities are designed. The type of inlet will depend on whether the upgradient source of runoff is overland flow or a concentrated source of discharge. Infiltration trenches require relatively even distribution over their length. An infiltration basin can be designed to accommodate a concentrated influent flow; however, an energy dissipater may be needed.

Infiltration devices that are interconnected with roof downspouts or patio drains must include measures to strain out entrained leaves and other litter.

16.3.5. In-Situ Soil Requirements

A site-specific hydrogeologic investigation should be performed to establish the suitability of the BMP. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inches per hour or greater, as initially determined from NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5,000 ft^2 of infiltrating area, with a minimum of two borings per facility (taken within the proposed limits of the facility). Double-ring infiltrometers or basin flooding tests should be used (EPA, 1981). The highest measurement should be discarded when computing the average hydraulic conductivity for the site.

16.3.6. Length, Width, Depth and Geometry

The sizing of an infiltration device is determined by the dewatering requirements. Infiltration devices must be able to completely dewater in 2 to 5 days. The time to dewater can be estimated roughly as the runoff capture volume for the device divided by the product of the hydraulic conductivity and the effective infiltrating area. This can be rearranged to produce the following equation for determining the effective infiltrating area needed:

$$A = \frac{V}{2 * (K * T)}$$

where:

A = effective infiltrating area (ft2)
V = volume of water requiring infiltration (ft3)
K = hydraulic conductivity of soil (in/hr)
T = dewatering time (days)

The volume of water requiring infiltration (V) is prescribed by the specific stormwater program that applies to the site, and the runoff characteristics of the site (see Section 2.0 and 3.0 for further information). If the infiltration device is not going to meet the volume control requirements, it is simply the volume of water that is diverted and stored for infiltration. The runoff capture storage volume of an infiltration device that is filled with a drainage medium is equal to the volume of the facility, multiplied by the porosity of the medium, plus any temporary ponding that may be allowed before the facility overflows.

The hydraulic conductivity of the soil (K) is the resultant value from the field testing performed on the site. The dewatering time (T) for infiltration devices must be between 2 and 5 days. A value of less than 3 days is recommended for use in the formula.

Once the effective infiltrating area (A) is obtained from the formula, it can still be somewhat difficult to translate that into actual infiltration device dimensions. The value for A used in the formula is actually the larger of either the bottom surface area or one-half of the total (wetted) wall area. The determination of the length, width, and depth dimensions is therefore often an iterative process using the effective infiltrating area (A), the correction factor for true surface areas of the in-situ soil interface, and typical length, width, and depth recommendations. Injection well regulations in 15A NCAC 2C prohibit stormwater drainage wells. In order to avoid falling within the regulatory definition of "injection Well," infiltration trenches must be constructed such that their depth is less than their greatest surface dimension (length or width).

Trench depths must be between 3 and 8 feet. It is recommended that the width of a trench (perpendicular to influent flow direction) be less than 25 feet. Broad, shallow trenches reduce the risk of clogging by spreading the runoff over a larger area for infiltration.

Infiltration basins, on the other hand, may appear in many different geometries. Runoff frequently is piped to these devices from stormwater inlets on patios, parking areas, roofs, and other impervious areas.

16.3.7. Media Requirements

Uniform sand, gravel, or crushed stone (i.e., uniformity coefficient of 2 or smaller) is preferable as a drainage medium. Uniform materials have high porosity and large storage capacities so less material is required. Rounded stone has a larger void ratio than angular crushed stone. The porosity of the material should be determined by laboratory tests and be certified by the supplier. Drainage media materials should be hard, durable, inert particles, free from slate, shale, clay, silt, and organic matter. The material shall be washed, and it is recommended that it be double-washed.

To increase the runoff capture storage volume of trenches, plastic or concrete gallery frames can be inserted. The gallery frames introduce open space inside the trench and help distribute flow.

The bottom of infiltration basins and trenches must be lined with a layer of clean sand with a depth of 4 inches or greater, unless the native soil is equivalent (1-2% fines or less).

Drainage media should be enclosed on all sides by a geotextile filter. Proper specification of the geotextile is critical to prevent two problems: accumulation of soil into the device and clogging at the soil interface. The top surface of the geotextile should be 6-12 inches below to upper surface of the drainage media. The other surfaces of the geotextile should be in contact with the in-situ soil. The fabric, together with the overlying material, can be removed and disposed of when excessive sediments accumulate on the filter and begin to retard flow into the device.

16.3.8. Outlet Design

Infiltration devices, by their very nature, do not have regular outlet devices (the stormwater entering the BMP leaves through the soils). They should, however, be designed with dewatering provisions in the event of failure. This can be done with underdrain pipe systems that can be pumped out or allowed to gravity drain to the surface.

16.4. Construction

Care should be used during installation to minimize compaction of soil on the bottom and walls of infiltration devices since this will reduce the permeability at the soil interface. To avoid compacting the drainage media, light equipment and construction techniques that minimize compaction should be used.

Runoff shall not be directed into an infiltration device until the drainage area is stabilized. A construction sequence must be followed that reflects the need to stabilize the infiltration device. The longevity of infiltration devices is strongly influenced by the care taken during construction.

Infiltration trenches should not be covered by an impermeable surface. Direct access must be provided to all infiltration devices for maintenance and rehabilitation. OSHA safety standards should be consulted for trench excavation. Figure 16-3 shows an example of an infiltration basin under construction.

A minimum of one observation well shall be included in the design of an infiltration trench to periodically verify that the drainage media is fully draining. The monitoring well shall consist of a 4- to 6-inch-diameter, perforated polyvinyl chloride (PVC) pipe with a locking cap. The well should be placed near the center of the facility or in the general location of the lowest point within the facility, with the invert at the excavated bottom of the facility.

16.5. Maintenance

16.5.1. 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 infiltration devices.

For the first year of operation, installations should be inspected quarterly and after each major storm. After the first year, annual inspections, preferably conducted after a storm, are recommended.

Maintenance is very important for infiltration devices. Property owners should be educated in the function and maintenance requirements of infiltration devices. Especially important is the maintenance of vegetated areas that drain to the infiltration system. Areas that are allowed to become bare and unvegetated will contribute excess sediment to the infiltration system and hasten its failure. Any sediment deposits in pretreatment devices should be removed at least annually.

The surface of infiltration trenches must be kept in good condition. Colonization by grass or other plants should be discouraged, since this can lead to reduced surface infiltration rates. In many instances, it is convenient to cover infiltration trenches with concrete grid pavers or similar permeable paving systems that can be removed easily and replaced as necessary to service the trench.

In order to monitor performance of the infiltration device, observations should be conducted to determine how long it takes retained water to infiltrate into the soil after a storm event. The determination can be made in two ways. The most informative way is to read the water level several times over a period of days after a large storm. The alternative is a "one-stop" method, where a single reading is taken and compared with the local rainfall record. Although less accurate than the multiple reading method, the one-stop method will still allow significant deterioration in performance to be recognized.

The top several inches of drainage media and the filter cloth along the top of the drainage media should be replaced annually or at least when the dewatering time is longer than 5 days. If after replacing the top media the infiltration rate is still not in the acceptable range, the entire facility must be dismantled and reconstructed.

Proper disposal of the materials removed is necessary; the aggregate and cloth should be appropriately packaged and delivered to the local landfill, if the operating authority approves the disposal.

Since infiltration trenches and infiltration basins have different configurations and maintenance needs, an appropriate sample inspection and maintenance table is offered for each one.

16.5.2. Sample Inspection and Maintenance Provisions for Infiltration Trenches

Important maintenance procedures:

- The drainage area of the infiltration trench will be carefully managed to reduce the sediment load to the sand filter.
- The water level in the monitoring wells will be recorded once a month and after every storm event greater than 1.0 inches (or 1.5 inches if in a Coastal County).

The infiltration trench will be inspected **once a quarter 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 16-1
Sample Inspection and Maintenance Provisions for Infiltration Trenches

BMP element:	Potential problem:	How to remediate the problem:
The entire BMP	Trash/debris is present.	Remove the trash/debris.
The grass filter strip or other pretreatment area	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 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.
The flow diversion structure (if applicable)	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 trench	Water is ponding on the surface for more than 24 hours after a storm.	Remove the accumulated sediment from the infiltration system and dispose in a location that will not impact a stream or the BMP.
	The depth in the trench is reduced to 75% of the original design depth.	Remove the accumulated sediment from the infiltration system and dispose in a location that will not impact a stream or the BMP.
	Grass or other plants are growing on the surface of the trench.	Remove the plants, preferably by hand. If pesticide is used, wipe it on the plants rather than spraying.
The observation well(s)	The water table is within one foot of the bottom of the system for a period of three consecutive months.	Contact the DWQ Stormwater Unit immediately at 919-733-5083.
	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 emergency overflow berm	Erosion or other signs of damage have occurred at the outlet.	The emergency overflow berm will be repaired or replaced if beyond repair.
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.

16.5.3. Sample Inspection and Maintenance Provisions for Infiltration Basins

Important maintenance procedures:

- The drainage area will be carefully managed to reduce the sediment load to the infiltration basin.
- Immediately after the infiltration basin is established, the vegetation will be watered twice weekly if needed until the plants become established (commonly six weeks).
- No portion of the infiltration basin will be fertilized after the initial fertilization that is required to establish the vegetation.
- The vegetation in and around the basin will be maintained at a height of approximately six inches.

After the infiltration basin is established, it will be inspected **once a quarter 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 16-2
Sample Inspection and Maintenance Provisions for Infiltration Basins

BMP element:	Potential problem:	How to remediate the problem:
The entire BMP	Trash/debris is present.	Remove the trash/debris.
The perimeter of the infiltration 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.
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 16-2, continued

Sample Inspection and Maintenance Provisions for Infiltration Basins

BMP element:	Potential problem:	How to remediate the problem:
The forebay	Sediment has accumulated and reduced the depth to 75% of the original design 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.
	Erosion has occurred or riprap is displaced.	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 pesticides are used, wipe them on the plants rather than spraying.
The main treatment area	A visible layer of sediment has accumulated.	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. Replace any media that was removed in the process. Revegetate disturbed areas immediately.
	Water is standing more than 5 days after a storm event.	Replace the top few inches of filter media and see if this corrects the standing water problem. If so, revegetate immediately. If not, consult an appropriate professional for a more extensive repair.
	Weeds and noxious plants are growing in the main treatment area.	Remove the plants by hand or by wiping them with pesticide (do not spray).
The embankment	Shrubs or trees have started to grow on the embankment.	Remove shrubs or trees immediately.
	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 NC Division of Water Quality 401 Oversight Unit at 919-733-1786.

17. Dry Extended Detention Basin

Description

A dry extended detention basin temporarily stores incoming stormwater, trapping suspended pollutants, and reducing the peak discharge from the site.

Regulatory Credits

Pollutant Removal

50%	Total Suspended Solids
10%	Total Nitrogen
10%	Total Phosphorus

Water Quantity

yes	Peak Attenuation
yes	Volume Capture

Feasibility Considerations

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

Major Design Elements

* Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
* Vegetated side slopes shall be no steeper than 3:1.
* BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
** Seasonally high groundwater table must be at least 2 feet below the bottom of the basin.
** A forebay is required if the design flow to the facility is over 10 acre-inches.
** The energy of the influent flow must be controlled.
** The maximum depth shall be 10 feet.
** Freeboard shall be a minimum of 1 foot above the maximum stage of the basin.
** A minimum length to width ratio of 1.5:1 is required.
** BMP shall have an additional 25% storage volume for sediment deposition.
** A sediment depth indicator must be provided.
** Basin design must include a drain.

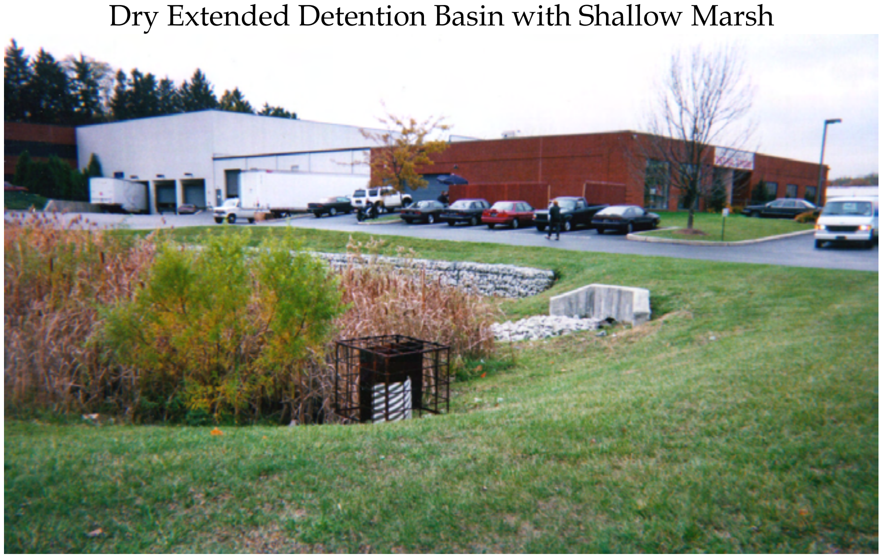
* *This provision is specified in the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*
** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

Advantages	Disadvantages
– Can effectively control peak runoff discharge rates from both small and large drainage areas. – Moderately effective at removing suspended solids and particulate matter. – May allow for recreational and other open-space uses between storms. – Presents fewer hazards to the public than wet basins because of the absence of a permanent pool of water.	– Poor or nonexistent maintenance of dry extended detention basins is common problem throughout the state. – Limited effectiveness in removing dissolved substances. – Tends to develop a soggy bottom or standing water, which hinders facility maintenance and the growth of effective vegetative cover, as well as becoming a perceived eyesore. – Debris can accumulate and not only be an eyesore, but also clog the outlets and cause overflows during large rainfall events. – Can attract children and become a safety hazard. Fencing is typically considered unsightly.

17.1. General Characteristics and Purpose

As the name of this BMP implies, these basins are typically dry between storm events. A low-flow outlet slowly releases water retained over a period of days. This BMP can be applied in residential, industrial, and commercial developments where sufficient space is available. The primary purpose of dry extended detention basins is to attenuate and delay stormwater runoff peaks. They are appropriate where water quality issues are secondary to managing peak runoff, since the overall pollutant removal efficiency of dry extended detention basins is low. Dry extended detention basins are not intended as infiltration or groundwater recharge measures. See Figure 17-1 for an example of a dry detention basin located in a commercial/industrial development.

Figure 17-1
Dry Extended Detention Basin with Shallow Marsh



17.2. Meeting Regulatory Requirements

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

Pollutant Removal Calculations
The pollutant removal calculations for dry extended detention basins are as described in Section 3.4, and use the pollutant removal rates shown at the beginning of this Section. Construction of a dry extended detention basin also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading.

Volume Control Calculations
A dry extended detention basin can be designed with enough storage to provide active volume control (calculations for which are provided in Section 3.4). All dry extended detention basins provide some passive volume control capabilities by providing pervious surface and therefore reducing the total runoff volume to be controlled.

17.3. Design

17.3.1. Converting Sediment and Erosion Control Devices

Sediment basins that are used during construction can be converted into dry extended detention basins after the construction is completed. If used during construction as a sediment basin, the basin must be completely cleaned out, graded, and vegetated within 14 days of completion of construction.

17.3.2. Siting Issues

The seasonally high groundwater table must be at least 2 feet below the bottom of the basin. Less separation distance makes the dry extended detention basin vulnerable to developing ephemeral pools of standing water during wet-weather periods. If the 2-foot minimum separation distance cannot be met, the design of a stormwater wetland or wet detention basin should be considered.

17.3.3. Contributing Drainage Basin

Dry extended detention basins can be utilized on very large sites, but often reach limitations around 25 acres or more. The most common limitation is the bottom of the basin approaching groundwater.

17.3.4. Pretreatment and Inflow

A forebay is required at the inlet of a dry extended detention basin to trap incoming sediment if the design flow to the facility is over 10 acre-inches. The forebay must contain ponded water and be designed as described in Section 5.0 Common Design Elements. A forebay is recommended on all other dry detention basins. With heavy, coarse sediment confined to the forebay area, maintenance is made simpler and less costly and the life of the BMP is extended.

To prevent resuspension of trapped sediment and scour during high flows, the energy of the influent flow must be controlled. This can be in the form of a forebay as mentioned above, a plunge pool, rip-rap, or other energy-dissipating and erosion control measures.

17.3.5. Length, Width, Depth and Geometry

The volume of a dry extended detention basin is driven exclusively by the volume of stormwater that is required to be captured. Once that volume is calculated, the dimensional aspect of the basin is mostly site driven. Below are some dimensional and layout requirements:

- The maximum depth shall be 10 feet.
- A minimum of 1 foot of freeboard shall be provided between the design flow pool elevation and the emergency overflow invert.
- The minimum flow length to width ratio shall be 1.5:1, but 3:1 is recommended. The basin width should preferably expand as it approaches the outlet.
- Side slopes of the basin shall be no steeper than 3H:1V if stabilized by vegetation.
- In addition to detention volume, design must provide for sediment storage equal to 25 percent of detention volume. If it is known that the upstream drainage basin will contribute high sediment loads (e.g. construction) over several years, then additional sediment storage should be provided.

By causing turbulence and eddies in the flow, flow short-circuiting can interfere with the function of the basin outlet system and should therefore be minimized. The most direct way of minimizing short-circuiting is to maximize the distance between the riser and the inlet. Larger length to width ratios should be used if sedimentation of particulates during low flows is desirable. Irregularly shaped basins appear more natural. If a relatively long, narrow facility is not suitable at a given site, baffles constructed from gabions or other materials can be placed in the basin to lengthen the flowpath.

A sinuous low-flow channel should be constructed through the basin to transport dry-weather flows and minor storm flows. Preferably, the channel would be grass-lined and sloped at approximately 2 percent to promote drainage of the basin between storms. The entire bottom of the basin should drain toward the low-flow channel.

17.3.6. Sediment Accumulation

A sediment depth indicator must be provided in the dry extended detention basin, and the forebay if there is one. Sediment will accumulate more quickly in the main detention basin if there is no forebay and also if the upstream drainage basin is not properly stabilized. Sediment shall be removed from the dry extended basin (and forebay if applicable) when the sediment depth indicator shows that the sediment has accumulated to the design sediment accumulation depth of the basin.

17.3.7. Plant and Landscape Requirements

When choosing vegetation for a dry extended detention basin, consideration must be given to the wildflowers or grasses specified because of the frequent inundations, warm and cold seasons, as well as salt, and oil loading. Additionally, the plants should not be fertilized except for a one-time application after seeding. Mowing should be minimal. It has been found that a wet meadow mix or Bermudagrass typically performs well in those locations with the climate able to support it.

The dry extended detention basin must be stabilized within 14 days after the end of construction. The stabilization might be the final vegetation or a temporary stabilization measure until the vegetation becomes established.

17.3.8. Outlet Design

In addition to meeting specific hydraulic requirements for runoff detention and peak attenuation, outlets also must be functionally simple and easy to maintain. Below are design requirements and guidelines for dry extended detention basin outlets:

- Basin design should include a small permanent pool near the outlet orifice to reduce clogging and keep floating debris away from the outlet.
- Basin design must include a drain that will completely empty the basin for clean out.
- Durable materials such as reinforced concrete or plastic are preferable to corrugated metal in most instances.
- The riser should be placed in or at the face of the embankment to make maintenance easier and prevent flotation problems.
- The low-flow orifice should be at least 2 inches in diameter.
- Erosion protection measures should be used at the basin discharge point.
- To prevent piping and internal erosion problems around the spillway/outlet conduit through an embankment system, a filter diaphragm and drainage system is recommended.

17.4. Maintenance

17.4.1. Common Maintenance Issues

The facility should be inspected annually to verify that the facility is operating as designed and to schedule any required maintenance. If possible, inspections should occur during wet weather to verify that the facility is maintaining desirable retention times. In addition to regularly scheduled inspections, maintenance personnel should note deficiencies during any visits. One important purpose of inspections is to ascertain the operational condition and safety of the facility, particularly the condition of embankments, outlet structures, and other safety-related features. Other general objectives are to prevent clogging of the outlets, development of standing water, and growth of weeds and noxious plants.

Maintaining turf grass on the tops of berms and on the exterior slopes of embankments is advisable to facilitate access to the facility and inspection of the embankment, as well as stability of the slopes. The frequency of mowing may need to be greater if the facility is in an area of high visibility. However, if possible, the facility should be managed as an upland meadow with cold season grasses maintained no shorter than 4 inches and warm season grasses maintained no shorter than 3 inches. Cutting grass shorter than the minimum lengths can cause areas of the turf to die off or can require a much higher level of maintenance.

When the sediment depth indicator shows that the sediment has filled the design storage volume, the accumulated sediment, mud, sand, and debris must be cleaned out with earth-moving equipment and disposed of properly. If the facility supports open-space uses during dry weather, the removal may have to take place frequently. Once these materials are removed, the disturbed areas should be stabilized and revegetated immediately, otherwise sediment will move to downstream areas. Freshly seeded areas should be protected with an erosion mat that has been securely staked in place to prevent flotation. In many cases, sodding offers the best approach to stabilization after removal of sediment and debris.

17.4.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- The drainage area will be managed to reduce the sediment load to the dry extended detention basin.
- Immediately after the dry extended detention basin is established, the vegetation will be watered twice weekly if needed until the plants become established (commonly six weeks).
- No portion of the dry extended detention pond will be fertilized after the first initial fertilization that is required to establish the vegetation.
- I will maintain the vegetation in and around the basin at a height of approximately six inches.
- Once a year, a dam safety expert will inspect the embankment.

After the dry extended detention basin is established, it will be inspected **once a quarter 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 17-1
Sample Inspection and Maintenance Provisions for Dry Detention Basins

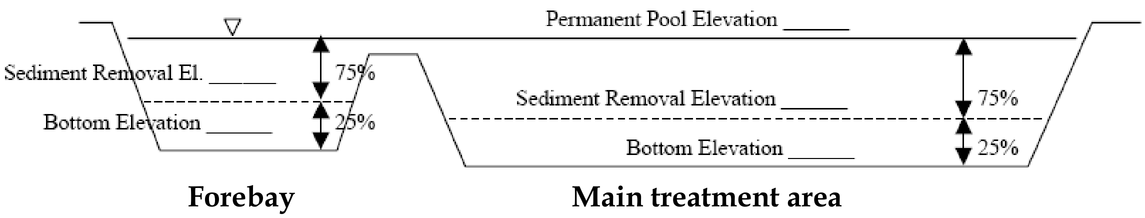
BMP element:	Potential problem:	How to remediate the problem:
The entire BMP	Trash/debris is present.	Remove the trash/debris.
The perimeter of the dry extended detention basin	Areas of bare soil and/or erosive gullies have formed.	Regrade the soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application.
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.
The forebay	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.
	Erosion has occurred or riprap is displaced.	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 pesticides are used, wipe them on the plants rather than spraying.

Table 17-1, continued
Sample Inspection and Maintenance Provisions for Dry Detention Basins

BMP element:	Potential problem:	How to remediate the problem:
The main treatment area	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. Revegetate disturbed areas immediately with sod (preferred) or seed protected with securely staked erosion mat.
	Water is standing more than 5 days after a storm event.	Check outlet structure for clogging. If it is a design issue, consult an appropriate professional.
	Weeds and noxious plants are growing in the main treatment area.	Remove the plants by hand or by wiping them with pesticide (do not spray).
The embankment	Shrubs or trees have started to grow on the embankment.	Remove shrubs or trees immediately.
	Grass cover is unhealthy or eroding.	Restore the health of the grass cover – consult a professional if necessary.
	Signs of seepage on the downstream face.	Consult a professional.
	Evidence of muskrat or beaver activity is present.	Use traps to remove muskrats and consult a professional to remove beavers.
	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 NC Division of Water Quality 401 Oversight Unit at 919-733-1786.

Figure 17-4
Profile of a Dry Detention Basin

Fill in blanks for the dry detention basin.



18. Permeable Pavement

Description

An alternative to conventional concrete and asphalt paving materials that allows for infiltration of storm water into a storage area, with void spaces that provide temporary storage.

Regulatory Credits

Pollutant Removal

0%	Total Suspended Solids
0%	Total Nitrogen
0%	Total Phosphorus

Water Quantity

possible	Peak Attenuation*
possible	Volume Capture*

Feasibility Considerations

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

* Peak runoff attenuation credit is given by lowering the Rational "C" coefficient for runoff calculations. Volume reduction credit is given by lowering the fraction of impervious surfaces for the Simple method.

Major Design Elements

** Completed permeable pavement installation must have a slope less than 0.5%.

** Soils must have infiltration capacity of at least 0.52 in/hr permeability.

** Only 2 acre-feet of soil per acre disturbed can be graded for the permeable pavement
** footprint.

** The top 3-ft of soil must have no finer texture than Loamy Very Fine Sand as determined by a soil analysis.

* *This provision is specified in the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

Advantages

- Replaces completely impervious surfaces with partially impervious surfaces.
- Reduces stormwater runoff rate and volume.
- Reduces loads of some pollutants in surface runoff by reducing the volume of stormwater leaving a site.
- Saves area by using treatment area for parking/driving.

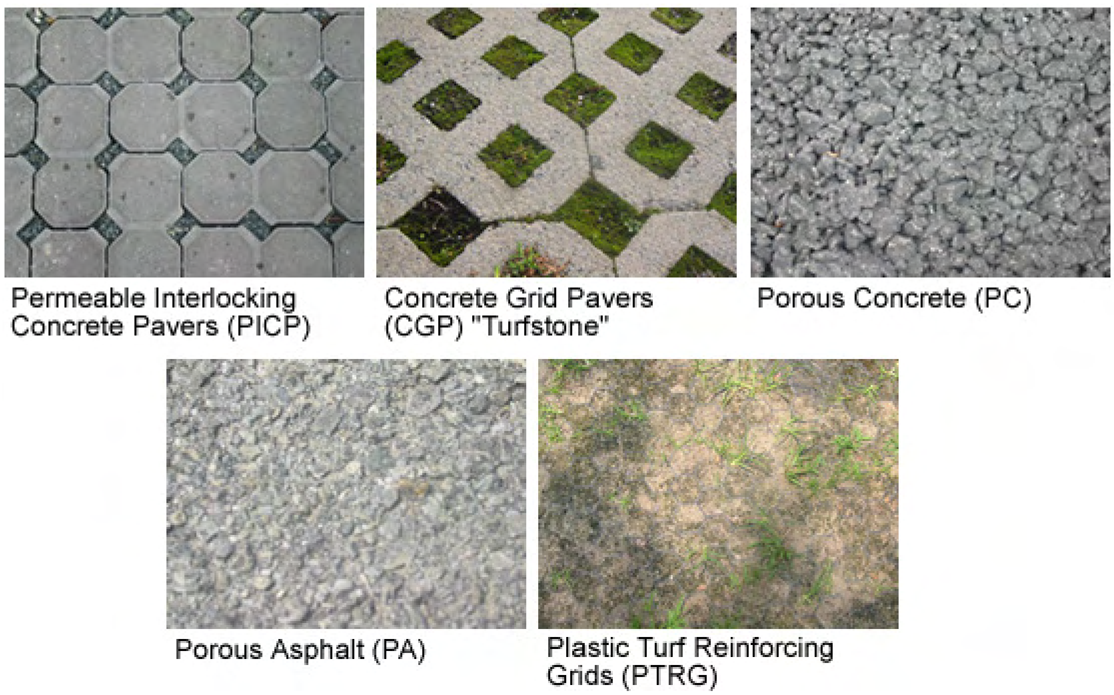
Disadvantages

- Applicability generally limited to the Coastal Plain and Sandhills regions.
- Potential for clogging of porous media by sediment, which could lead to reduced. effectiveness without proper maintenance
- Not applicable for high-traffic areas or for use by heavy vehicles.

18.1. Description and Purpose

Traditional paved surfaces, such as asphalt and concrete, do not allow water to infiltrate and convert almost all rainfall into runoff. If designed and implemented correctly, permeable pavement systems allow at least a portion of stormwater to infiltrate, thus reducing peak runoff volumes and flows. Permeable paving materials include, but are not necessarily limited to, porous concrete, permeable interlocking concrete pavers, concrete grid pavers, and porous asphalt. Compacted gravel will not be considered as permeable pavement. Figure 18-1 shows various permeable pavement systems.

Figure 18-1
Various permeable pavement systems
Courtesy of NC State University – Biological and Agricultural Engineering Department



18.2. Location and Characteristics

There are two primary locational design constraints that affect the applicability of permeable pavement in North Carolina.

1. The *in-situ* soils beneath the permeable pavement must have sufficient infiltration capacity for the permeable pavement to drain. To satisfy this requirement, the following conditions must be met:

    a. The footprint of the permeable pavement installation must have a vertical saturated hydraulic conductivity of at least 0.52 in/hr (as determined by a soil analysis) for the soil horizon located beneath the base of the pavement system to a total depth of 3 ft.

b. The soil beneath the pavement system (to a total depth of 3 ft) must also have no finer texture than Loamy Very Fine Sand as defined by the United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS) and as determined by a soil analysis.

c. Only 2 ac-ft of soil per acre disturbed can be moved for the footprint of the permeable pavement. Mass grading can significantly alter the site's applicability for permeable pavement. If mass grading occurs and conditions (a) and (b) are still met, then an exception for this requirement can be given. However, a soil analysis will be required after the grading is completed to verify the soil properties.

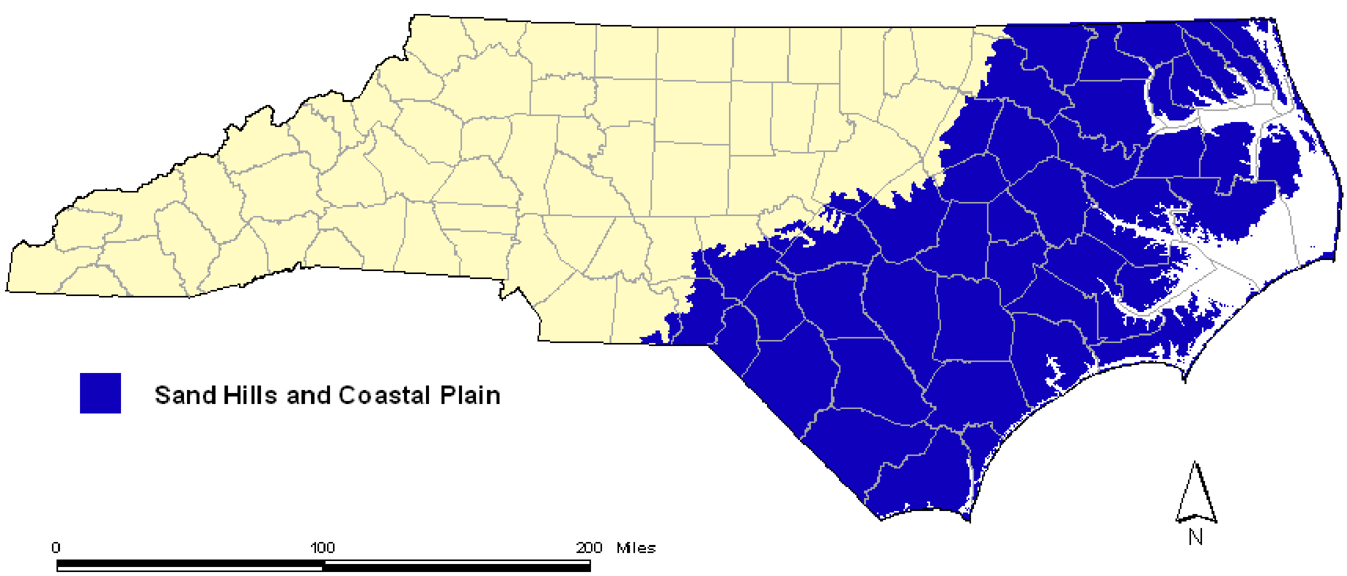
2. Permeable pavement has the potential to be clogged by solids delivered to the permeable pavement surface by vehicular traffic and run-on from adjacent surfaces. To address this concern, the following conditions must be met:

   a. The site must be located in the Sand Hills and Coastal Plains physiographic regions, including all barrier islands (see map in Figure 18-2). Since fine soils are prevalent in other areas of North Carolina, there is a greater possibility that vehicles or run-on from adjacent surfaces could transport fine sediment onto the site and clog the permeable pavement.

   b. An exception to this locational requirement could be made on a case-by-case basis by the permitting authority for sites in other areas of the State if soils within a 1-mile radius of the site are coarser than Loamy Very Fine Sand for the top 3 ft as defined by the USDA-NRCS.

Figure 18-2

The Sand Hills and Coastal Plain physiographic regions of North Carolina.
Map created by DWQ with data from USDA-NRCS, 2002



18.3 Design

18.3.1 Requirements for Regulatory Compliance

Water Quantity Credit

Properly designed and constructed permeable pavement will receive credit in the following ways:

1. **Percent imperviousness reduction for built-upon-area calculations.**

   For permeable pavement systems, credit will be given such that a portion of the permeable pavement will not be counted as impervious for built-upon-area calculations. Depending on the type of system used and its construction (see Table 18-1), a portion of the permeable pavement will be counted as "managed grass." The remainder will be counted as impervious. This credit will reduce the total built-upon area for low-density/high density determinations as well as the impervious area percentage for nutrient load calculations. Permeable concrete can be constructed without a gravel base, but all other systems that require a gravel base (flexible pavements) receive credit as managed grass based on the thickness of the gravel base layer. The increase in gravel base provides more underground storage for stormwater.

Table 18-1
Credit received for various permeable pavement systems
(*See note below regarding reduced credit in SA waters.)

Permeable Pavement System	Credit as Percent Managed Grass
Permeable concrete without gravel base	*40 %
Permeable concrete with at least 6" of gravel base (washed stone)	*60 %
Flexible pavements with at least 4" of gravel base (washed stone)	*40 %
Flexible pavements with at least 7" of gravel base (washed stone)	*60 %

* Permeable pavement systems that drain to, and are located within ½ miles of SA-classified waters, and are installed to achieve compliance with the coastal low-density limitations, will receive only ½ of the credit outlined in this table. The Division will continue to evaluate information regarding system performance and will reconsider this policy at a later date. This precautionary step has been taken because of the continuing trend of degraded and impaired shellfish waters.

2. Peak flow reduction and volume reduction

For methods to calculate peak runoff rate and runoff volume that require percent imperviousness (such as the Simple Method), the reduction in imperviousness as managed grass listed above in Table 18-1 can be used. For example, permeable concrete with at least 6" of gravel will be counted as 40% impervious.

To determine peak runoff rate using the Rational Method, a Rational Coefficient of 0.22 for managed grass and 0.96 for impervious areas can be used. To determine runoff volume using the SCS Method, a Curve Number of 61 for managed grass and 98 for impervious areas can be used. Both the Rational and SCS Methods are to be applied using the ratios of managed grass and imperviousness listed above in Table 18-1. A thorough discussion of some of the research that supports these policies is given by Bean, 2005.

Pollutant Removal Credit

Permeable pavement will not receive direct credit for any pollutant removal (percent reduction, e.g.). However, for the purpose of meeting pollutant control requirements, credit received for reducing percent imperviousness will have the effect of reducing pollutant loads. The extent of pollutant reduction will depend on the site configuration. The means of receiving pollutant removal credit for TSS differs from the means for nutrients.

In DWQ's stormwater programs, TSS is not calculated directly based on site conditions. Instead, individual BMPs receive credit for a certain percentage of TSS reduction, which is applied to the total percentage of TSS removal that must be achieved at a site. This percentage reduction is not credited towards a calculated amount of TSS generated at a site; instead, the runoff generated at a site must receive a certain percentage of treatment (85%, e.g.). Permeable pavement will not receive a percentage credit for reducing TSS, but it will receive credit by reducing the volume of runoff that must be treated for TSS. The effect of permeable pavement will therefore be to reduce the size of BMPs that are to be used for TSS removal.

Example TSS Reduction Calculation

Suppose the runoff from the first inch of rainfall from a 1-acre parking lot must be controlled and treated for 85% TSS removal. If this 1-acre parking lot is completely covered with impervious asphalt, the volume of runoff that must be treated is about 0.95 ac-in, using the Simple method (Schueler, 1987):

$$Rv = 0.05 + 0.009\,(I)$$
$$Rv = 0.05 + 0.009\,(100) = 0.95$$

Where: Rv = runoff coefficient (in/in),
I = percent imperviousness, %

Volume = Design Rainfall * (Rv) * Drainage Area
= 1 in * 0.95 * 1 ac
= 0.95 ac-in

If this site is completely covered with pemeable concrete without a stone base layer, the site will receive credit as 40% managed grass and 60% impervious. Using the Simple method, the runoff that must be treated is 0.59 ac-in.

Rv = 0.05 + 0.009 (I)
Rv = 0.05 + 0.009 (60) = 0.59

where Rv = runoff coefficient (in/in),
I = Percent imperviousness, %

Volume = Design Rainfall * (Rv) * Drainage Area
= 1 in * 0.59 * 1 ac
= 0.59 ac-in.

For stormwater programs requiring nutrient removal, a specific nutrient load must be attained. The post-development nutrient load is calculated based on the land-use types of the site. Permeable pavement systems receive credit for nutrient reduction by reducing the area of impervious land cover. Permeable pavement should receive credit for nutrient removal in the manner described in the example below; however, local authorities may develop their own method as long as it is at least as stringent as the method presented here.

Example Nitrogen Reduction Calculation for the Neuse River Basin

If a site has 1 acre of conventional impervious surfaces, the annual nitrogen load would be computed as follows in the Neuse River Basin (the Tar-Pamlico Basin has slightly different export coefficients, but the principle is the same):

The annual nitrogen load from impervious surfaces is 21.2 lb N/ac/yr (DWQ, 1999). Therefore, the nitrogen load from 1 acre is 21.2 lb N/yr.

However, if there were 1 acre of permeable pavement with at least 6 in. of washed stone base, the nitrogen load would decrease. The nitrogen load from managed grass surfaces is 1.2 lb N/ac/yr.

Under the guidelines above in part one, the acre of permeable pavement would be counted as 40% impervious and 60% managed grass.

Annual Nitrogen Load = 21.2 lb N/ac/yr * 0.4 ac + 1.2 lb N/ac/yr * 0.6 ac
Annual Nitrogen Load = 9.2 lb N/yr

The ratios of impervious and managed grass areas can also be used for phosphorus export calculations. Phosphorus export in urban settings comes from lawns (fertilizers, vegetation decomposition, attached to sediment) and from streets, buildings, and parking lots (atmospheric deposition) (Waschbusch et al., 1999). This understanding is reflected in the Division of Water Quality's phosphorus export coefficients for the Tar-Pamlico river basin – phosphorus export from transportation impervious surfaces is 1.67 lb P/ac/yr and the phosphorus export from managed pervious surfaces is 0.13 lb P/ac/yr (DWQ, 2004). Therefore, phosphorus reduction can be credited for permeable pavement, depending on the site configuration. Permeable pavements that do not rely on subsurface infiltration shall be counted as 100% impervious for the phosphorus export calculations.

18.3.2 Design

The Division has adopted strict guidelines to direct the application of permeable pavement in North Carolina. Adherence to all of the guidelines mentioned in this document are essential for the successful implementation of permeable pavement as a water quality BMP. Design and installation of permeable pavement systems must be performed by appropriate professionals.

The primary factors that should direct permeable pavement design include the following:

1. Providing adequate infiltration and temporary storage
2. Preventing sediment, oils, and greases from reaching the permeable pavement surface where they have the potential to clog
3. Using construction techniques that minimize the compaction of subsurface soils

18.3.3 Design Specifications and Methodology

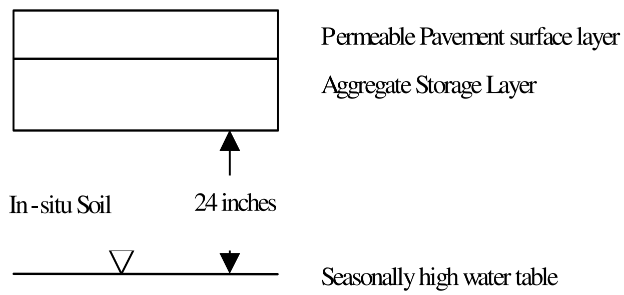
Specific design requirements relating to the structural stability of permeable pavements are beyond the scope of this manual. The reader is referred to the AASHTO Flexible Pavement Method for structural design requirements. The following guidelines are presented to ensure that permeable pavements are properly located, designed, and constructed to meet water quality objectives.

1. A washed aggregate base must be used, and washed 57-size stone is generally acceptable. Fine particles from standard "crusher run" will clog the pores at the bottom of the pavement and will not be allowed.

2. Low traffic volume – less than 100 vehicles per day.

3. As shown in Figure 18-3 below, seasonally high water table must be at least 2 ft from the base of the permeable pavement or gravel storage layer. Water tables approaching the permeable pavement system will not allow water to exfiltrate.

Figure 18-3
Schematic of water table design constraint.



4. Permeable pavement should not be placed where upland land disturbance is occurring or will potentially occur. Land disturbance upland of the lot could result in frequent pavement clogging.

5. Avoid overhanging trees above the permeable pavement installation.

6. The completed permeable pavement must be installed at a grade less than 0.5%. Steeper slopes will reduce the storage capacity of the permeable pavement.

7. During preparation of the subgrade, special care must be made to avoid compaction of soils. Compaction of the soils can reduce the infiltration capacity of the soil.

8. Permeable pavement should not be designed to receive concentrated flow from roofs or other surfaces. Incidental run-on from stabilized areas is permissible, but the permeable pavement should primarily be designed to infiltrate the rain that falls on the pavement surface itself. No credit will be given for volume or peak reduction for run-on from impervious surfaces.

9. Permeable pavement systems are not allowed in areas, such as buffers, where impervious surfaces are not permitted.

10. The construction sequence will be inspected to insure that the surface installation is planned to be completed after adjacent areas are stabilized with vegetation. Run-on to the permeable pavement from exposed areas can cause the system to perform ineffectively.

18.4. Cost

Permeable pavement systems typically cost 25-100% more than traditional asphalt (Hunt, 2006). Implementing permeable pavement systems may reduce the need for other stormwater BMPs or reduce the size of such systems. Therefore, the overall cost burden should be considered for each specific site.

18.5. Maintenance

18.5.1. Common Maintenance Issues

Maintenance requirements are critical for the success of permeable pavement. Even though there are significant locational restrictions on the permeable pavement installations, there is still a potential for permeable pavements to clog with sediment. The following installation and maintenance requirements shown in Table 18.1 are designed to ensure that the permeable pavement system will work effectively. A maintenance agreement with the appropriate local government is required for each permeable pavement installation to receive credit. The maintenance agreement should include specific requirements and responsibilities of the property owner and provide for enforcement.

18.5.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- Stable groundcover will be maintained in the drainage area to reduce the sediment load to the permeable pavement.
- The area around the perimeter of the permeable pavement will be stabilized and mowed, with clippings removed.
- Any weeds that grow in the permeable pavement will be sprayed with pesticide immediately. Weeds will not be pulled, since this could damage the fill media.
- Once a year, the permeable pavement surface will be vacuum swept.

The permeable pavement will be inspected **once a quarter 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 18-2
Sample Inspection and Maintenance Provisions for Permeable Pavement

BMP element:	Potential problem:	How to remediate the problem:
The perimeter of the permeable pavement	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 3 to 6 inches (remove clippings).
The surface of the permeable pavement	Trash/debris is present.	Remove the trash/debris.
	Weeds are growing on the surface of the permeable pavement.	Do not pull the weeds (may pull out media as well). Spray them with pesticide.
	Sediment is present on the surface.	Vacuum sweep the pavement.
	The structure is deteriorating or damaged.	Consult an appropriate professional.
	The pavement does not water between storms.	Vacuum sweep the pavement. If the pavement still does not dewater, consult a professional.

19. Rooftop Runoff Management

Description

Rooftop runoff management is the deployment of vegetated roof covers and roof gardens (also known as green roofs), roof ponding areas and cisterns to detain and promote evapotranspiration of runoff originating from roofs.

Regulatory Credits

Pollutant Removal

0%	Total Suspended Solids
0%	Nitrogen***
0%	Phosphorus***

Water Quantity

possible	Peak Attenuation*
possible	Volume Capture**

Feasibility Considerations

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

* Green roofs shall receive peak attenuation credit. A Rational C Coefficient of 0.65 shall be used for the green roof peak runoff calculation.

** Green roofs shall receive volume reduction credit. Using the Simple Method to calculate volume, the impervious fraction for the green roof will be 50% of the impervious fraction for a standard roof.

*** Green roofs shall not receive nutrient credit. When using the Neuse and Tar-Pamlico nutrient export models, the green roof shall be entered as "roof impervious".

Major Design Requirements

** A vegetation plan prepared by a horticulturalist versed in green roof vegetation is required.

** A structural engineer must be consulted and verify roof and structure strength.

** Access to the roof is required for inspection and maintenance.

** On a roof slope greater than 20 degrees, horizontal strapping or other support systems must be installed to avoid slippage and slumping of the growing medium and plants.

* *This provision is specified in the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*

** *This provision, which is based on available research studies, is what the Division of Water Quality considers necessary to meet the removal efficiencies provided in this Manual.*

Advantages	**Disadvantages**
• Useful in wide range of applications. • Provides effective stormwater management for small to mid-size events. • Conserves space. • Thought to extend life expectancies of roofs, primarily by shielding from UV and temperature. • Insulates sound; 5 inches of green roof medium can reduce sound by 40 decibels (dB). • Reduces heat island effects caused by impervious surfaces, and reduces heating and cooling costs of the building covered. • Proven track record in Europe and numerous applications in North America. • Adds aesthetic value to residential and commercial property; provides attractive textures and colors and creates habitat for birds and insects.	• Can be difficult to retrofit. • Main disadvantage is the potential need to provide additional structural strengthening. • Normal garden maintenance is required for roof gardens, but the location may make it more difficult to inspect and correct problems. • Rooftop detention may lead to leaks through the roof. • Sediment can accumulate near the outlet and cause clogging if not cleaned out periodically. • Cost - These are among the most expensive practices per square foot of treated area.

19.1. General Characteristics and Purpose

Roofs are an important source of concentrated runoff from developed sites; therefore, rooftop runoff management can provide substantial benefits in highly urbanized settings where space for other BMPs is limited. Rooftop runoff management BMPs are typically applied on flat or gently sloping roofs (see Figure 19-1); however, this BMP can also be applied with steep roofs. The techniques can be retrofitted to many conventionally constructed buildings. If roof runoff is at least partly controlled at the source, the size of other BMPs throughout the site can be reduced. Although rooftop runoff management is generally more effective in controlling small storms, since the vast majority of rain events are in this category, rooftop runoff management can be important in planning for comprehensive stormwater management. By retaining this rainfall for evaporation or plant transpiration, some rooftop runoff management measures, such as vegetated roof covers, can achieve significant reductions in total annual runoff.

Although rooftop runoff management BMPs are currently not extensively used in the United States, they do have a proven track record in Europe. In an effort to reduce overloading of sewer systems, several German cities (including Stuttgart, Berlin, Cologne, Dusseldorf, and Hamburg) provide incentives for homeowners to install vegetated roof covers or roof gardens. In addition, numerous applications do exist in North America including Vancouver, BC; Portland, OR; Chicago, IL; Atlanta, GA, and several locations in North Carolina.

The location of the green roof is very important in the design, which is influenced by factors such as height above ground, wind exposure, and sunlight and shade by surrounding buildings. Climate of the area and the expected microclimate created by the roof have a bearing on plant species. For roofs with public access, visual appearance is also important.

Rooftop runoff management not only provides detention and promotes evapotranspiration, rooftop runoff management effectively increases the time of concentration, delaying runoff peaks and lowering runoff discharge rates. It can also be aesthetically and socially beneficial and may provide improved air quality, energy saving, and temperature reduction benefits.

The main drawback is it can sometimes be very costly for the amount of stormwater quality and quantity improvements it provides. This is because of the possibly small fraction of overall site stormwater that can be treated by the rooftop runoff management BMP, as well as the additional cost to the building for construction of the BMP and possible reinforcement of the structure.

Figure 19-1

Rooftop Garden (Photo courtesy of Dr. Bill Hunt, NCSU BAE Dept.)

It should also be noted that safety is a big concern with rooftop runoff management BMPs. Construction and maintenance are obviously performed in a location with potential for dangerous falls. In addition, some rooftop runoff management BMPs, most often roof gardens, are designed to have public access. Other safety concerns include high temperatures, becoming trapped on the roof, and the possibility of the roof structure becoming unsound and causing a fall. Designs should take all safety issues related to the BMP being constructed on a roof into consideration and attempt to reduce as much as possible the level of risk and exposure.

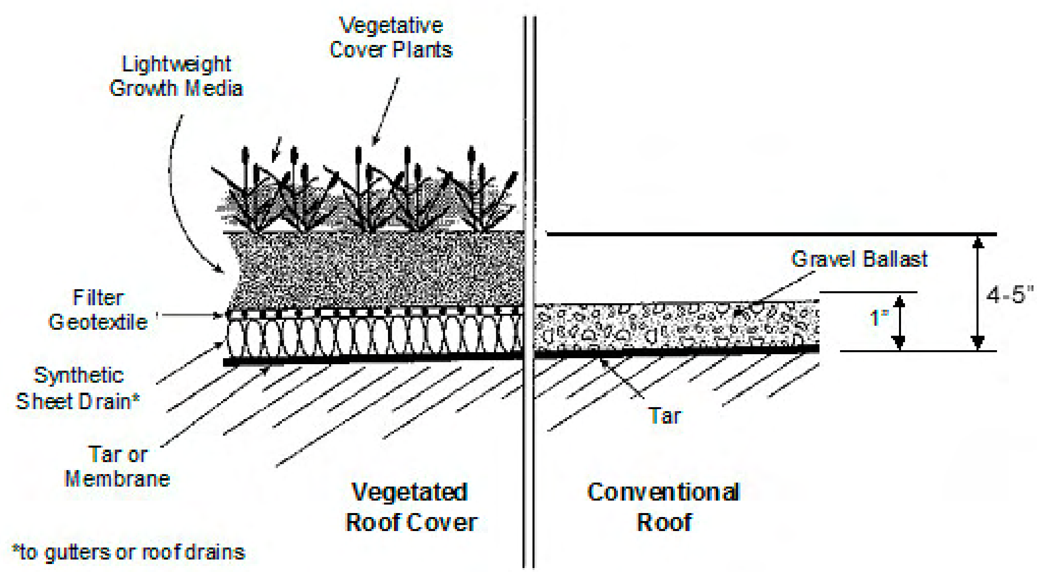
This Section discusses three techniques of rooftop runoff management: vegetated roof covers, roof gardens, and roof ponding areas. Each of these is described briefly below.

Vegetated Roof Covers

Vegetated roof covers (which are also called extensive green roofs and can not be walked on) involve blanketing roofs with a layer of living vegetation. Vegetative roof covers are particularly effective when applied to extensive roofs, such as those commonly used on commercial, multifamily, and institutional buildings. However, they can be applied to virtually any building, including single-family residences. Vegetated roof covers are an effective means of retarding runoff from roof surfaces. Initially during a rainfall event, nearly all precipitation striking the foliage is intercepted. As rain continues, water percolates into and begins to saturate the growth media and root zone of the cover. Significant quantities of water do not begin to drain from the roof until the field capacity of the medium is filled. For small rainfall events, little runoff occurs and most of the precipitation eventually returns to the atmosphere by evaporation and transpiration. For larger storms, vegetated roof covers can delay and attenuate the runoff peak significantly. See Figure 19-2 for a comparison of a conventional roof system and a vegetative roof cover.

Figure 19-2

Comparison Between Vegetative Roof Cover and Conventional Roof System



Roof Gardens
Roof gardens (which are also called intensive green roofs and can be walked on) are landscaped environments that may include planters and potted shrubs and trees. Roof gardens can be custom-made naturalized areas, designed for outdoor recreation, and perched above congested city streets. Because of the special requirements for access, structural support, and drainage, roof gardens are found most frequently in new construction. The services of a professional engineer are required to evaluate the structural and drainage constraints associated with roof garden design.

Roof Ponding Areas
Roof ponding is applicable where the increased load of impounded water on a roof will not increase the building costs significantly or require extensive reinforcement. Water ponding will increase structural costs. Roof ponding generally is not viable for large-area commercial buildings where clear spans are required. Special consideration must be given to ensuring that the roof will remain watertight under a range of adverse weather conditions. Low-cost synthetic membranes can be used to construct an impermeable liner for the containment area.

19.2. Meeting Regulatory Requirements

A listing of the major design elements is provided on the first page of this section. At a minimum, any rooftop runoff management system must meet the major design elements indicated as being from the North Carolina Administrative Code. To receive credit for reduction of volume or peak flow listed in the front of this Section, the rooftop runoff management system must meet all of the major design elements listed in the beginning of this Section. Runoff volume and peak flow calculation methods are discussed in Chapter 3. Green roofs seeking runoff volume reduction credit will use the Simple Method to quantify the credit. Designers shall use an impervious fraction for a green roof equal to half the impervious fraction for a standard roof. Green roofs seeking peak flow reduction shall use a Rational C Coefficient equal to 0.65. Green roofs shall not receive nutrient reduction credit. When using the Neuse and Tar-Pamlico nutrient export models, the BMP designer will enter one of the following land uses into the model; transportation impervious, roof impervious, managed pervious, wooded pervious, or area taken up by the BMP. Each of these land uses has an associated nutrient loading value associated with it. Impervious areas have higher nutrient export values than pervious areas. Because green roofs do not receive nutrient credit, their areas shall be entered into the model as "roof impervious". If they were entered as one of the other land uses with a lower nutrient export value, then they would indirectly receive nutrient credit. This is not permissible.

Pollutant Removal Calculations
Rooftop runoff management BMPs do not provide active pollutant removal and are therefore given 0% pollutant removal rates as shown in the beginning of this Section.

Volume Control Calculations

Some rooftop runoff management BMPs can be designed with enough storage to meet the specific stormwater program volume control requirements (calculations for which are provided in Section 3.4). Others do offer some active storage volume, so if used in series with another BMP with volume control capabilities, they might be able to meet the requirements. All rooftop runoff management BMPs provide some passive volume control capabilities by providing pervious surface (any planted area measured on a horizontally projected footprint basis) and therefore reducing the total runoff volume to be controlled. However, volume control calculations shall not result in a reduction in the nutrient loading.

19.3. Design

19.3.1. Vegetated Roof Covers

Because of recent advances in synthetic drainage materials, vegetated roof covers are now feasible on most conventional flat and gently sloping roofs. A lightweight, efficient drainage layer is placed between the growth medium and the impermeable membrane protecting the roof surface. This layer rapidly conveys water off the roof surface and prevents it from ponding on the roof. Vegetated roof covers also serve to protect roof materials and prolong their life, primarily by shielding from UV and temperature extremes. European data show that green roofs can double the life span of a roof.

Although vegetative roof covers are most effective during the growing season, they are also beneficial during the winter months if the vegetative matter from the dead or dormant plants is left in place and intact.

The emphasis of the design should be to promote rapid roof drainage and minimize the weight of the system. It is advisable to obtain the services of specialized installers because of the many factors that may influence the design.

19.3.1.1. Waterproof Roof Liner

In some instances, the impermeable lining can be the watertight tar surface, which is conventional in flat-roof construction. However, where added protection is desired, a layer of plastic or a rubber membrane can be installed immediately beneath the drainage net or sheet drain.

19.3.1.2. Drainage Net or Sheet Drain

The drainage net or sheet drain is a continuous layer that underlies the entire cover system. A variety of lightweight, high-performance drainage products function well in this environment. The product selected should be capable of conveying the discharge associated with the design storm without ponding water on top of the roof cover. The drainage layer must have a good hydraulic connection to the roof gutters, drains, and downspouts. To prevent the growth medium from clogging the drainage layer and to prevent roots from penetrating the roof surface, a geotextile should be installed immediately over the drainage net or sheet drain. Some products have the geotextile bonded to the upper surface of the drainage material. A root retardant (such as copper sulfate) is typically included in this geotextile.

19.3.1.3. Lightweight Growth Medium

The depth of the growth medium should be as small as the cover vegetation will allow, which is typically 3 to 6 inches. Low-density substrate materials with good water-retention capacity (e.g., mixtures containing expanded slate, expanded shale, expanded clay, and terra cotta) should be specified. Media appropriate for this application will retain 40 to 60 percent water by weight and have bulk dry densities between 35 and 50 lb/ft^3. The make up of the media will vary depending on the types of plants used, but an example media make up would be 55% expanded Slate, 30% root zone sand, and 15% compost. Care should be taken when specifying compost because it will eventually break down over time and the depth of the media will therefore decrease. A photograph of expanded slate is provided in Figure 19-3. Earth and topsoil are too heavy for most applications, as well as being too wet for succulent and other recommended vegetation and too dry for grasses.

Figure 19-3
Expanded Slate

19.3.1.4. Vegetation

A limited number of plants can thrive in the roof environment where periodic rainfall alternates with periods that are hot and dry. Effective plant species must: tolerate mildly acidic conditions and poor soil, prefer very well-drained conditions and full sun, tolerate dry soil, and be vigorous colonizers. It should also be noted that conditions can be much wetter for longer periods near a gutter or drain and dryer near the peaks. Succulents have shown to be very successful in vegetative roof covers, and are preferred to grasses. Both annual and perennial plants can be used. Vegetative roof covers may need provisions for occasional watering (e.g., conventional lawn sprinklers) during extended dry periods. A vegetation plan prepared by a horticulturalist versed in green roof vegetation is required.

19.3.1.5. Hydraulics

Vegetative roof covers influence the runoff hydrograph in two ways: intercepting rainfall during the early part of a storm, and limiting the release rate. Hydrologic properties are specific to the growth medium. If information is not provided by the supplier, prospective media should be laboratory-tested to establish:

- Porosity
- Moisture content at field capacity
- Moisture content at the wilting point
- Saturated hydraulic conductivity

Rainfall retention properties are related to field capacity and wilting point. Appropriate media for this application should be capable of retaining water at the rate of 40 percent by weight, or greater. The medium must be uniformly screened and blended to achieve its rainfall retention potential. During the early phases of a storm, the media and root systems of the cover intercept and retain most of the rainfall, up to the retention capacity. For instance, a 3-inch cover with 40 percent retention potential effectively controls the first 1.2-inch of rainfall. Although some water percolates through the cover during this period, this quantity is generally negligible compared to the direct runoff rate without the cover in place. Studies on several green roofs in North Carolina show capture volumes ranging from 0.5” to 1.2” (Moran et al, 2005). Capture rates are dependent on rainfall intensity, antecedent rainfall, time of year, evapotranspiration, and roof pitch. Green roofs on pitches steeper than 1:12 do not function as well as for water quality and quantity control. Vegetated roof covers should be kept on slopes of 8 percent or less, if they are being used to mitigate water quality or quantity.

Once the field capacity of the cover is attained, water drains freely through the medium at a rate that is approximately equal to the saturated hydraulic conductivity of the medium. The maximum release rate from the roof can be controlled by selecting the appropriate medium. The medium is a mechanism for “buffering” or attenuating the peak runoff rates from roofed areas. The attenuation can be important even for large storms. By using specific information about the hydraulic properties of the cover medium, the effect of the roof cover system on the runoff hydrograph can be approximated with numerical modeling techniques. As appropriate, the predicted hydrographs can be added into site-wide runoff models to evaluate the effect of the vegetative roof covers on site runoff. The hydraulic analysis of roof covers requires the services of a properly licensed design professional experienced in this type of drainage design.

Drainage nets or sheet drains with transmissivities of 15 gallons per minute per foot or higher are recommended. When assessing a drainage layer design, designers should evaluate the roof topography to establish the longest travel distances to a roof gutter, drain, or downspout. If flow converges near drains and gutters, the design unit flow rate should be increased accordingly. The drainage layer should be able to convey the design unit flow rate at the roof grade without water ponding on top of the cover medium.

For storms larger than the design storm, direct roof runoff will occur. The design flow rates should be based on the largest runoff peak attenuation considered in the design of the vegetated roof cover.

19.3.1.6. Weight Considerations

Roof designs are dictated by state and local building codes and standards. They must account for maximum design loads contributed by dead loads, live loads, and snow or water accumulation. The design of a vegetative roof cover can alter the dead loads to the system and it should therefore be closely coordinated with the structural design of the building. Dead loads for vegetated roof covers include the planting medium, vegetation, drainage system, and water in the pore space. However, the additional weight is partly offset by the removal of the gravel ballast.

By using appropriate materials, the total weight of fully saturated vegetated roof covers can readily be maintained below 35 pounds per square foot (psf). Vegetative roof covers in North Carolina tend to weigh between 30 and 35 psf in addition to other dead, live and/or snow loads.

It is also possible that the minimum weight design focus for the vegetated roof cover might be too light to satisfy the ballast requirements for flat tar roofs. As required, deepening the medium can increase the weight of the cover system.

19.3.2. Roof Gardens

Roof gardens generally are designed to achieve specific architectural objectives. The load and hydraulic requirements for roof gardens vary according to the intended use of the space. Intensive roof gardens typically include design elements such as planters filled with topsoil, decorative gravel or stone, and containers for trees and shrubs. Complete designs also may detain runoff ponding in the form of water gardens or storage in gravel beds. A wide range of hydrologic principles may be used to achieve stormwater management objectives, including runoff peak attenuation and runoff volume control.

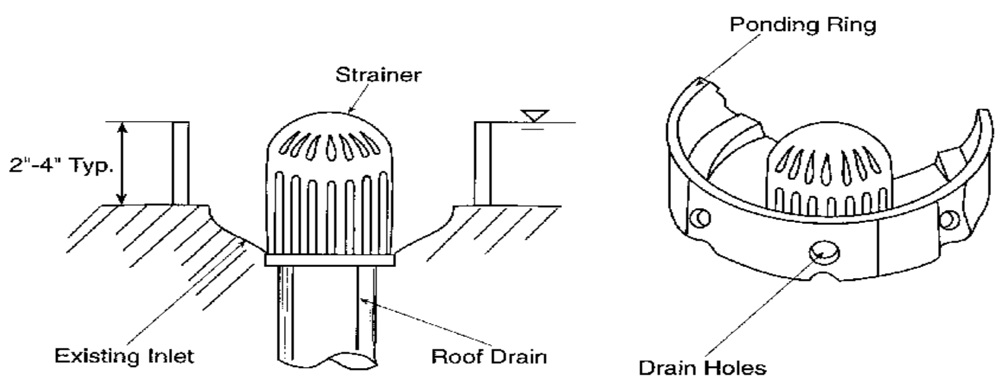
Effective designs ensure that all direct rainfall is cycled through one or more devices before being discharged to downspouts as runoff. For instance, rainfall collected on a raised tile patio can be directed to a medium-filled planter where some water is retained in the root zone and some is detained and gradually discharged through an overflow to the downspout.

19.3.3. Roof Ponding Areas

Roof ponding measures can be designed for rainfall events of all sizes. However, the structural loads associated with the impounded runoff may impose limitations on their use. This is especially true if ponding areas must also accommodate runoff derived from adjacent roof surfaces.

Flat roofs can be converted to ponding areas by restricting the flow to downspouts. Figure 19-4 shows a simple device that can be used to modify downspout inlets. The device features drain holes that retard outflow as the water level rises and a weir ring that allows free drainage once the design ponding level is attained. It is essential that a structural engineer verify that the existing roof can carry this extra weight. Some form of emergency overflow is advisable and can be as simple as a free overflow through a notch in the roof parapet wall.

Figure 19-4
Modification of Downspout Inlet (Adapted from Tourbier, 1974)



The inputs needed for analysis of roof ponding systems are similar to those needed for design of dry ponds and other runoff peak attenuation facilities. The necessary inputs are:

- Input hydrograph
- Depth-storage function
- Depth-discharge function

Because the roof is impermeable, the runoff hydrograph is simply the rainfall distribution for the design storm multiplied by the area of the roof.

The depth to storage relationship can be computed from the topography of the roof. For perfectly flat roofs, the storage volume of a ponding level is equal to the roof area times the ponding level.

The depth-discharge relationship is unique to the outlet device used. For simple ponding rings, the following discharge equation can be used:

$$O = 3.141\ CD(d - H)^{3/2}$$

where:

O = outflow rate (cfs)
D = diameter of the ring (ft)
d = depth of ponding (ft)
H = height of the ring (ft)
C = discharge coefficient (typically 3.0 but may vary depending on the shape of the flow device)

With this information, the attenuation effectiveness of the roof ponding system can be predicted by using the Modified Puls or other storage-routing procedure. The performance of the ponding area can be adjusted by changing the height or diameter of the ponding ring.

19.3.4. Cisterns

Cisterns, or rainbarrels, are a method of collecting and storing rainwater for future use. Uses include irrigation, vehicle washing, toilet flushing, and laundry operation. Cisterns are effective for reducing runoff if they are used correctly. Cisterns must be designed to capture an appropriate volume of water that will be re-used onsite on a regular basis. Cisterns that are not used regularly will remain full, not collect rainfall from future storms, and not reduce runoff. Cistern pumps can be included in a design where an increase in water pressure is needed. Pumps should be designed to accommodate the necessary pressure and flow for the system.

19.4. Construction

The main construction guideline is to engage professionals who are experienced with rooftop runoff management BMP installation, and preferably who can undertake all phases of the project from waterproofing to planting.

Additional loading is one of the main factors controlling the feasibility and cost of a rooftop runoff management BMP. New extensive green roofs can be accommodated in building design for a minor additional cost. Rooftop runoff management BMPs on an existing building need to consider the bearing capacity of the structure. It is also possible to use roof areas where point loading can be increased over columns or along a bearing wall, to allow areas for deeper growing medium and larger plants. A structural engineer must be consulted and verify roof and structure strength.

Access to the roof is required for inspection and maintenance. For example, materials need to be carried to the roof for soil and plant replacements. Suitable exterior or interior access or elevator stops need to be provided to allow this access. For 1 to 3 story structures, blower trucks or shingle lifts may be used.

A waterproof membrane is an essential component of a rooftop runoff management BMP. It is recommended that a membrane be installed as the rooftop runoff management BMP is deployed. In addition, good drainage must be provided to prevent extended contact with water and reduce the possibility for leaks and for plant mortality due to drowning or rotting. Roof appurtenances such as parapets, skylights, mechanical systems, and vents should be well protected with a gravel skirt, and when necessary, weep drains.

If the waterproof membrane contains organic material (e.g., bitumen) plant roots may penetrate it. Also, the chemical composition of the membrane should be compatible with the surfaces with which it will be in contact. Membranes developed specifically for rooftop runoff management BMPs contain a root-deterring chemical or metal foil at the seams to prevent root damage (Peck and Kuhn, 2004).

On a roof slope greater than 20 degrees, horizontal strapping or other support systems must be installed to avoid slippage and slumping of the growing medium and plants.

The timing of planting depends on the local climate and season. Planting in the summer may require additional irrigation. Fall planting depends on the availability of plants and whether there is sufficient time to allow for the plants to become established before late winter. Mid-spring planting (Feb – Apr) is recommended for much of North Carolina. Rooftop runoff management BMPs constructed in the mountains are best planted Mar – May.

19.5. Maintenance

19.5.1. 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 rooftop runoff management BMPs.

Two to three yearly inspections are recommended to check for weeds and damage. After installation, weekly visits may be needed to ascertain the need for irrigation.

Both plant maintenance and maintenance of the waterproofing membrane are required. All rooftop runoff management measures must be maintained periodically. Furthermore, the vegetative measures require routine care and maintenance typical of any planted area. The maintenance includes attention to plant nutritional needs, irrigation as required during dry periods, and occasional weeding. The cost of maintenance can be significantly reduced by judiciously selecting hardy plants that will out-compete weeds. In general, fertilizers must be applied periodically. Fertilizing usually is not a problem on flat or gently sloping roofs where access is unimpeded and fertilizers can be uniformly broadcast. However fertilization is not recommended if the roof is to be used for water quality improvement. Treading on the cover system should not damage properly designed vegetated roof covers. Maintenance contracts for routine care of the vegetative cover frequently can be negotiated with the installer.

Retrofits of existing roofs must incorporate easy access to gutters, drains, spouts, and other components of the roof drainage system. Foreign matter, including leaves and litter, should be removed promptly.

19.5.2. Sample Inspection and Maintenance Provisions

Important maintenance procedures:

- The plants will be watered during extended periods of dry weather.
- Fertilize only once per year as long as the rooftop runoff system is not intended for nutrient removal.

The sand filter will be inspected **once a quarter 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.

BMP element:	Potential problem:	How to remediate the problem:
The plants materials	Weeds are present.	Remove the weeds by hand.
	Vegetation is dead or diseased.	Try to determine the cause of the problem (may wish to consult an expert). Correct the problem and replace the plants.
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.
Gutters, drains and spouts	Clogging has occurred.	Remove leaves, debris, and other foreign matter and dispose of in a manner that will not impact streams or the BMP.
	Damage has occurred.	Repair or replace the damaged conveyances.

20. Proprietary Systems

Description

A proprietary system is a manufactured device in which stormwater receives treatment before being discharged to another BMP or to the receiving water. This is a broad category of BMPs with a variety pollutant removal mechanisms and varying pollutant removal efficiencies.

Regulatory Credits

Pollutant Removal varies with the type of device and its sizing.

varies	Total Suspended Solids
varies	Total Nitrogen
varies	Total Phosphorus

Water Quantity effect varies with the type of device and its sizing.

varies	Peak Attenuation
varies	Volume Capture

Feasibility Considerations

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

Major Design Elements

* Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
* BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
* The BMP may not be located within one mile of and draining to waters classified as HQW; including waters classified as ORW, WS-I, WS-II, SA, and Primary Nursery Areas (PNA).
* Monitoring is required to verify the installed performance of the BMP.
* Alternative stormwater treatment measures must be available and must be installed, upon DWQ's determination that the BMP has failed.
* An operation and maintenance plan is required.
* The system must be designed by a professional licensed in North Carolina. The design professional must also certify that he inspected the system during construction; that the installation conformed to the approved plans and specs; and that the system meets the requirements of the rules.
** Additional design and performance monitoring requirements will be developed on a case-by-case basis by DWQ.

* *These provisions are specified in the NC Administrative Code rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements of the rules.*
** *Under this provision, DWQ will consider the evolving knowledge and experience of proprietary system installations in North Carolina. Design removal rates, design loading rates, dimensional specifications, and specifications of performance evaluation methods may all be established by DWQ.*

Advantages	Disadvantages
– Can be cheaper than traditional technologies for stormwater treatment. – Typically requires less land surface than traditional technologies. – May be engineered to target specific pollutants. – May find applications where available land is extremely limited. – May allow dual use of the land surface, since some systems are underground.	– Generally, performance in North Carolina installations is not yet well documented. – Underground installations are not readily inspected, and typically lack provisions to warn of impending failure. – Because of reduced size compared to traditional technologies, maintenance actions may be more frequent. – The additional monitoring requirements placed on proprietary systems can discourage some potential owners.

20.1 General Characteristics and Purpose

Many different proprietary devices, or manufactured BMPs, are available for the treatment of stormwater. Many, though not all, proprietary BMPs can be classified into two major groups: separation devices and filtration devices. Separation devices can be further subdivided into two types: chambered and hydrodynamic. In chambered BMPs, runoff passes through several chambers where settling of sediment particles and flotation of hydrocarbons takes place. Hydrodynamic devices typically impart a swirling motion to the incoming flow that aids in settling of sediment particles. Filtration BMPs typically pass runoff through filter cartridges or filter media, thereby removing some fraction of the solid pollutants from the stormwater.

In order to prevent re-suspension and subsequent discharge of sediment, many proprietary BMP systems have provisions to allow bypassing of large storm events that are in excess of the design storm.

Regular inspection, maintenance, and clean out of proprietary systems is required for best performance. As with all BMPs, proprietary systems should be inspected after large storm events.

Proprietary devices may be designed as stand-alone BMPs, achieving complete stormwater treatment and control as required by the regulatory program or jurisdiction governing the installation of the unit. Or, they may also be designed as part of a stormwater treatment and control train, in combination with other BMPs.

20.2 Meeting Regulatory Requirements

To obtain a permit to install a proprietary system in North Carolina, the proprietary system must meet all of the Major Design Elements listed in the beginning of this section. Since individual proprietary systems are extremely variable in design details, design concepts, and pollutant removal mechanisms, it is not currently possible to provide a category-wide set of detailed design parameters for proprietary systems. DWQ typically approaches permitting requirements on a case-by-case basis, and determines additional requirements in accordance with site conditions, the specifics of the device, the target pollutants, and the identified pollutant removal requirements for the governing regulatory program.

20.3 The Preliminary Evaluation Period Program (PEP)

In 1997 DWQ established the Preliminary Evaluation Period (PEP) program. The PEP program is designed to allow DWQ to evaluate the performance of proprietary devices with the goal of subsequently being able to qualify successful candidate technologies as permittable on a state-wide basis.

The PEP program requires installation of the candidate technology at a small, limited number of North Carolina permitted sites. For each candidate technology, DWQ will develop the PEP requirements applicable to the technology. Further, DWQ requires a device-specific project plan, a monitoring plan, and an interpretation of the collected data from the permitted site. In past PEP projects DWQ has required a year of data, with an established minimum number of qualifying storm events. DWQ's favorable interpretation of the first set of data allows the candidate technology to continue in the PEP program, but at another in-state location. After the small number of data sets are in hand, DWQ will establish the assigned removal rates, design loading limitations, and design particulars for the candidate proprietary technology. The intent is that with the performance characterizations and constraints derived from the test locations, DWQ can then provide qualified state-wide approval of the particular BMP.

Despite having the PEP program in place since 1997, there have been relatively few enrollees in the program. The program is evolving, and it is likely that the technical requirements and the procedural requirements will be adjusted with experience in the program. DWQ is alert to mixed results from other states as to the success of other programs intended to qualify proprietary devices.

CHAPTER 21

BMP CONSTRUCTION TECHNIQUES

A CHAPTER WILL BE DEVELOPED ON BMP CONSTRUCTION TECHNIQUES

CHAPTER 22

STORMWATER MANAGEMENT PLANS: SUBMITTAL REQUIREMENTS

A CHAPTER WILL BE DEVELOPED ON SUBMITTAL REQUIREMENTS FOR STORMWATER MANAGEMENT PLANS

23. References

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APPENDIX A

Stormwater Links

- **NC Stormwater–Related Rules and Statutes**
  http://www.ncstormwater.org/pages/local_gov_laws.html

- **Universal Stormwater Management Rule**
  http://h2o.enr.state.nc.us/su/usmp.htm

- **North Carolina Stormwater BMP Manual**
  http://h2o.enr.state.nc.us/su/bmp_updates.htm

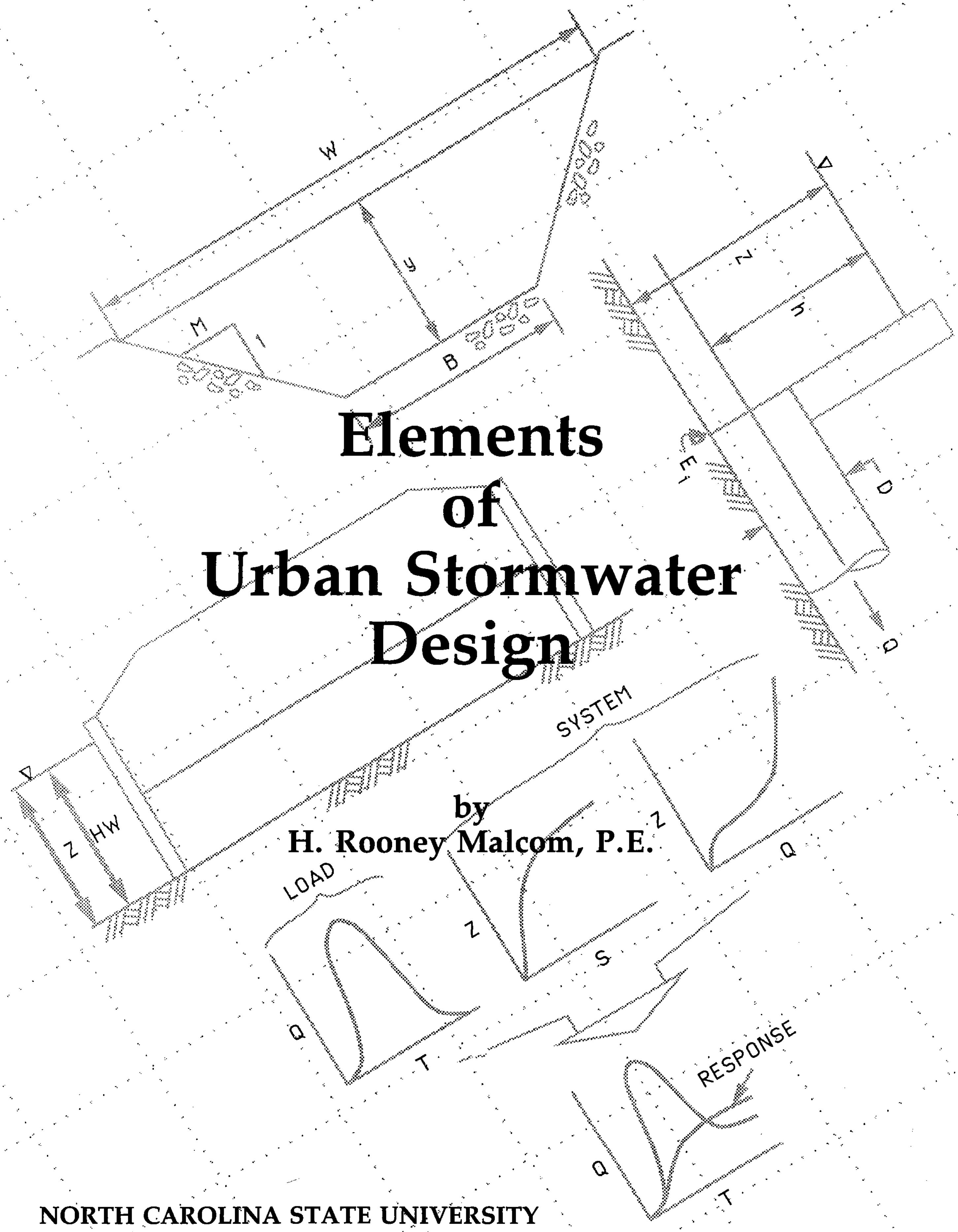
- **NC Administrative Rules Relating to Water Quality including 2H .1000 "Stormwater Management"**
  http://h2o.enr.state.nc.us/admin/rules/codes_statutes.htm

APPENDIX B

Section III
Of
" Elements of Urban Stormwater Design"

Elements of Urban Stormwater Design

by
H. Rooney Malcom, P.E.



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ELEMENTS OF URBAN STORMWATER DESIGN

North Carolina State University, Raleigh 27695-7902

Second printing, 1991. Third printing, 1993.
Printed in the United States of America

ISBN 1-56049-016-0

Library of Congress Catalog Card Number 89-082034

SECTION III

STORMWATER IMPOUNDMENTS

GENERAL

Stormwater impoundments serve several purposes in urban watersheds. Impoundment types include flood-control reservoirs, stormwater detention ponds, aesthetic or recreational ponds, sediment-control basins, water-quality-control ponds, and even culverts. Multipurpose facilities are common, and there are many variations on the theme. Irrespective of purpose, impoundments are subjected to flood-wave loading. The elementary design of impoundments for the control or passage of flood waves is treated in this section.

The process of design and analysis of stormwater detention systems has emerged as a routine activity in stormwater management in recent years. Stormwater detention is essentially flood control at small scale. Flood water is stored temporarily in an impoundment and released such that the maximum release rate is reduced to some satisfactory level below that which would have been expected without the detention facility. The design objective in a typical stormwater detention regulation might require that the ten-year peak discharge from a site after development be no greater than the ten-year peak discharge from the same site prior to development. The design storm for detention varies from place to place, but the ten-year storm seems to predominate. Application of detention policy on a watershed basis requires careful consideration of whether to distribute control facilities widely at small scale or to develop larger scale flood-control reservoirs at strategic points in the stream system.

Facilities take several forms. The larger scale ponds usually involve placing flood storage above a normal pool. Smaller scale facilities may use normally dry ponds designed in conjunction with other uses: storage on parking lots, in parks, perhaps behind culverts. Rooftop storage, though sometimes used, seems to the author rarely justifiable.

The design process includes formulation of the inflow hydrograph, selection of the size and shape of the storage container, and selection of the type and size of the outlet device.

For an impoundment, there are virtually always two design storms to consider. One is the control storm for which the principal spillway is designed. The other is the emergency storm, a large storm for which an emergency spillway is designed to pass the excess discharge without overtopping the dam. In some facilities the principal spillway incorporates the emergency capacity.

The basis for analyzing detention facilities is the flood-routing algorithm. It derives from the continuity principle which states that, at every instant during the passage of a flood, the rate of change of storage in the reservoir is equal to the rate of inflow minus the rate of outflow. There are several procedures available for executing the routing algorithm. All involve a numerical solution of the differential equation:

$$\frac{ds}{dt} = I - O$$

where:

$\frac{ds}{dt}$ = Rate of change of storage with respect to time.

I = Rate of inflow.

O = Rate of outflow.

A detention basin or reservoir or impoundment consists of a storage volume and outlet devices which together cause the inflow hydrograph to be flattened as it comes through the basin. A hydrograph is a record (graph or table) of discharge versus time. In a flood, the discharge increases from some negligibly low rate to a peak, and then it falls away gradually to a small rate again. The area under the curve plotted as the hydrograph is equal to the volume of water constituting the flood. That same volume is preserved under the outflow hydrograph. In the usual detention impoundment, the volume of water in the flood is not reduced. The shape of the hydrograph is made longer and flatter such that the peak flow is satisfactorily reduced.

In view of this brief discussion, it may be inferred that all routing procedures, in order to model a reservoir, must involve three sets of source data on which to operate. One set represents the inflow hydrograph. Another represents the size and shape of the storage container. The third represents the hydraulics of the set of outlet devices. In the discussion below, the formulation of the source data is first treated, followed by a discussion of routing procedures. Design is discussed following analysis.

MATHEMATICAL MODELS

The principal mathematical models used in the design of stormwater impoundments are:

1. Hydrograph formulation procedures -- Several options exist for modeling the storm hydrograph representing the loading of the impoundment.

2. Weir equations -- used for modeling important elements of outlet devices that behave as weirs.

3. Orifice equation -- used for modeling elements of outlet devices judged to behave as orifices.

4. Energy balance -- used to model outlet behavior in systems having high tailwater.

5. Continuity principle -- the guiding principle for modeling the passage of a flood wave through a reservoir.

SOURCE DATA

Inflow Hydrograph

The formulation of the inflow hydrograph is the most difficult of the tasks comprising flood routing. Hydrograph formulation procedures involve a great deal of uncertainty. The objective is to obtain the hydrograph for say the ten-year storm at a given point of interest. But one can show, for example, that the ten-year storm is not a unique event and that there is a spectrum of storms that would qualify under statistical analysis as a ten-year storm. A ten-year storm can be one that is brief, producing a steep hydrograph of small volume, or it may be a storm of long duration, producing the same peak in a long hydrograph of large volume. If these storms have peaks equal to the discharge associated with the ten-year flood, they both qualify as such, but if one routes each of them through a given impoundment, the outflow hydrographs produced will be quite different. In the face of such uncertainty, hydrograph formulation procedures necessarily include arbitrary judgments, and the various procedures make different arbitrary judgments. So, adoption of a method becomes a matter of local consensus. Methods that prevail in one location find no favor in another.

Alternate Hydrograph Formulation Methods

Methods exist in large variety. Perhaps the most detailed are the computerized watershed models such as HEC1 of the Corps of Engineers and TR-20 of the Soil Conservation Service. For smaller watersheds, the methods of TR-55 are useful (SCS, 1986). Desktop methods, such as unit-hydrograph synthesis, are described in most hydrology texts. Many of these require a heavy investment of time and effort in field data gathering and data set preparation. Such precision may not be justified for small facilities and early feasibility studies.

Small-Watershed Hydrograph-Formulation Method

The author has proposed a method for use in routine design of small systems and for feasibility studies and site selection studies of larger watersheds (Malcom, et al, 1986). A variation of the method was adopted for use in design of facilities in the Houston area (Harris County, TX, 1984).

The method is based upon the observation that there are three important aspects of the hydrograph on which the design will depend. These are the peak discharge, the volume of water under the hydrograph, and the shape of the hydrograph. Separate decisions may be made regarding these, and the hydrograph will be determined. The necessary decisions, and the author's suggestions are:

1. Accept as a pattern function a step-function approximation to the SCS dimensionless unit hydrograph (see McCuen, 1982, for a listing and discussion). The step-function devised by the author is

For $0 \leq t \leq 1.25\ Tp$

$$Q = \frac{Qp}{2}\left[1 - \cos\left(\frac{\pi t}{Tp}\right)\right] \qquad \text{(III-1)}$$

For $t > 1.25\ Tp$

$$Q = 4.34\ Qp \exp\left[-1.30\left(\frac{t}{Tp}\right)\right] \qquad \text{(III-2)}$$

in which

Qp = Peak discharge of the design hydrograph

Tp = Time to peak of the design hydrograph, measured from the time of significant rise of the rising limb to the time at which the estimated peak occurs

t = Time of interest at which the discharge is to be estimated.

The argument of the cosine is in units of radians.

The volume of water under this hydrograph is, in consistent units,

$$Vol = 1.39\ Qp\ Tp \qquad \text{(III-3)}$$

From this, the appropriate time to peak may be estimated as

$$Tp = \frac{Vol}{1.39\ Qp} \qquad \text{(III-4)}$$

Having accepted the pattern function, estimates of peak discharge and hydrograph volume may be made to allow computation of the time to peak. Use of the peak discharge and time to peak in the step function will provide a hydrograph that peaks at the estimated peak discharge and possesses the estimated volume.

2. Estimate the peak discharge by any applicable means. For small systems, the author usually obtains acceptable results with the Rational Method (see Section I), but other methods of peak estimation may be used as appropriate. The idea is to decide at what discharge the hydrograph is to reach its peak.

3. Estimate the volume under the hydrograph by any applicable means. Here is the arbitrary judgment similar to that which is imbedded in any design hydrograph formulation technique. The author has found that hydrographs can be matched reasonably closely with the significant center portions of those of methods that use a 24-hour center-weighted design storm. It is usually satisfactory to include under the hydrograph the volume of runoff from the six-hour precipitation of the return period of interest. The depth of precipitation may be obtained from Exhibit 2, or similar. Runoff depth may be estimated from the Soil Conservation Service Curve Number Method, in which a Curve Number estimate is obtained for the soil type and cover conditions of the watershed (McCuen, 1982). The following equations yield an estimated depth of runoff:

$$S = \frac{1000}{CN} - 10 \qquad \text{(III-5)}$$

$$Q^* = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \qquad \text{(III-6)}$$

in which:

S = Ultimate soil storage (in)

P = Precipitation depth (in)

Q* = Runoff depth (in), the asterisk being added by the author to distinguish this use of Q, which is depth, from the usual use of Q, which is discharge.

Volume of runoff is found by multiplying runoff depth by watershed area.

Stage-Storage Function

The stage-storage function represents the most important aspects of the size and shape of the storage container in its influence on the shape of the outflow hydrograph. The stage-storage function may be presented as a graph of stage plotted versus storage. Stage is the elevation of the water surface in the reservoir, most conveniently referred to the lowest point or reservoir bottom. Storage is the volume of water held in the reservoir, most conveniently expressed in cubic feet, when water level is at the associated stage.

The stage storage function can be formulated either as a graph or as a mathematical expression.

In many cases, the detention storage container is a natural stream valley, a ravine or a draw that has evolved to its current topographic shape over time. The source of information for the stage-storage function is usually a topographic map.

A representative set of storage volumes can be computed by applying the average-end-area method vertically from contour to contour. A conventional stage-storage curve may thus be plotted. If one plots storage versus stage on log-log axes, the resulting line is usually remarkably straight, suggesting that the reservoir stage-storage function may be adequately represented by a power-curve fit of the form

$$S = Ks\ Z^{b} \qquad \text{(III-7)}$$

in which

S = Storage volume (cu ft)

Z = Stage (ft) referred to the bottom of the reservoir

The computation of such a function is perhaps best illustrated by an example. Figure III-1 shows the contours digitized from city topo for a location in piedmont North Carolina. The site is just upstream of a road crossing thought to be suitable as a detention basin. The computation is carried out in Table III-1.

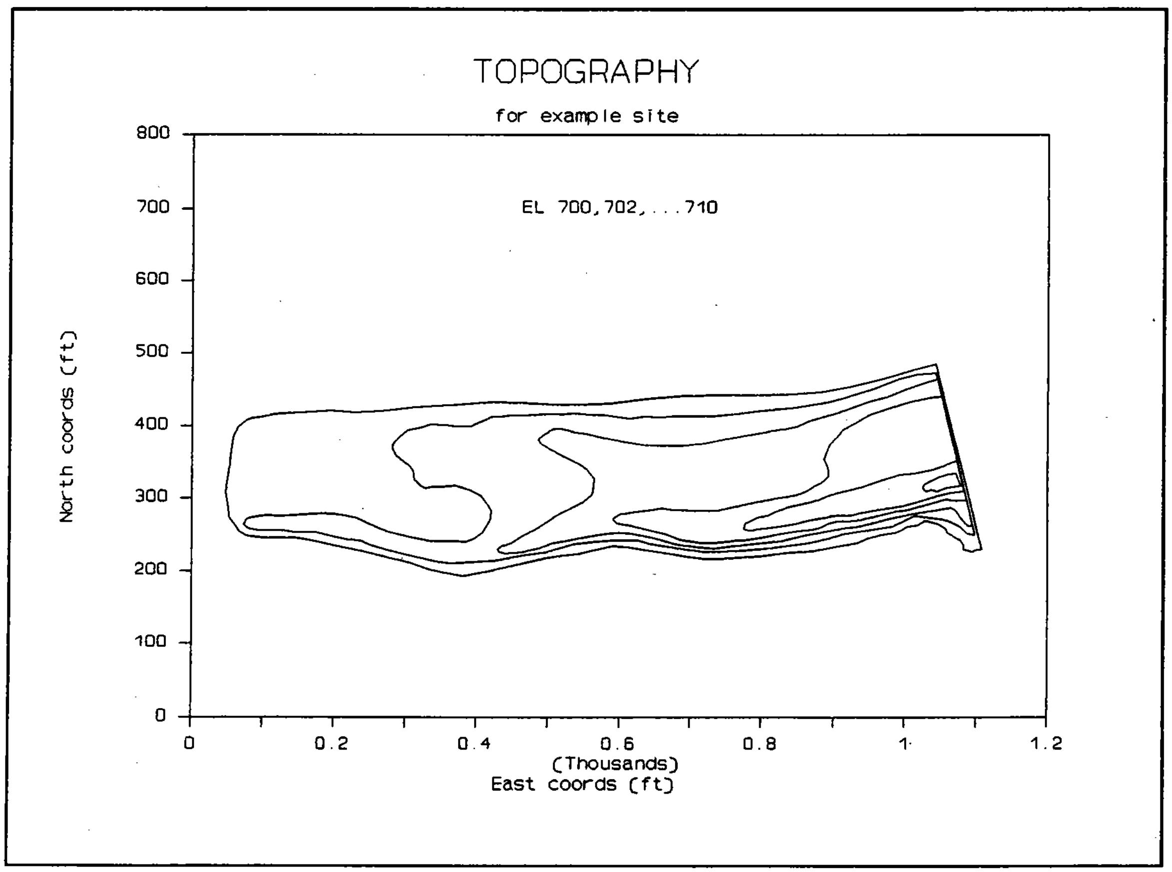

Figure III-1

Table III-1
Computation of a Stage-Storage Function

1	2	3	4	5	6	7	8
CONTOUR	CONTOUR AREA	INCR VOL	S ACCUM VOL	Z STAGE	ln S	ln Z	Z est
	[sq ft]	[cu ft]	[cu ft]	[ft]			[ft]
699	0		0	0			
700	784	392	392	1	5.9713	0.0000	1.10
702	9402	10186	10578	3	9.2665	1.0986	2.99
704	37140	46542	57120	5	10.9529	1.6094	4.99
706	83730	120870	177990	7	12.0895	1.9459	7.05
708	141746	225476	403466	9	12.9078	2.1972	9.03
710	213184	354930	758396	11	13.5390	2.3979	10.93

Regression Output:

Constant	5.647433 ==>	Ks = 284
Std Err of Y Est	0.018680	b = 3.30
R Squared	0.999908	
No. of Observations	5	
Degrees of Freedom	3	↑
X Coefficient(s) 3.299632 ------------------------------		
Std Err of Coef. 0.018209		

The following notes describe the numbered columnar computations:

1. Enter the contour elevations for which areas are measured. Elev 699 is the estimated invert of the depression.
2. Enter the measured contour areas, most conveniently expressed in square feet.
3. Compute the incremental storage volume (between the contours) by the average-end-area method applied vertically. The incremental volume is the average of the upper and lower contour areas multiplied by the vertical separation of the contours. The result is in cubic feet.
4. Enter the accumulated volume, obtained by adding each incremental volume to the sum of the lower increments. The result is the total storage available at each contour.
5. Enter the stage, or depth, referred to the invert of the pond.

One may usefully plot a stage-storage curve by using the data of columns 4 and 5. However, there is much more information readily obtainable from the stage-storage function of the form of Equation III-7. The columnar computations of Table III-1 continue:

6. Enter the natural logarithm of Storage (the accumulated volume of col. 4).
7. Enter the natural logarithm of Stage (col. 5).

There are two reasonable ways to determine the values of Ks and b of Equation III-7. Both depend upon the assumption that the logarithm of storage is linear with the logarithm of stage. The first few times one does the calculation, it is instructive to plot storage versus stage on log-log axes; or, if a spreadsheet program is being used, to plot ln S versus ln Z, as in Figure III-2.

It is usually true that the lowest point lies somewhat off the line of best fit. The purists among the readers will argue rightly that the fit would be improved by computing the lowest incremental volume by a pyramidal approximation (volume being estimated as one-third of the base area times the height). The author observes that the lowest increment trivially influences the the outcome of the routing, and that it is reasonable to disregard the lowest point in subsequent computations. (We're not making watches; we're merely toting water.)

Algebraic Estimation of Stage-Storage Parameters: One may select two representative points on the curve, preferably in the upper end of the range of stage, and compute values of Ks and b. Writing the logarithmic form of Equation III-7 for two points and solving simultaneously yields

$$b = \frac{\ln\left(\frac{S_2}{S_1}\right)}{\ln\left(\frac{Z_2}{Z_1}\right)} \qquad \text{(III-8)}$$

and

$$Ks = \frac{S_2}{Z_2^{\,b}} \qquad \text{(III-9)}$$

Linear-Regression Estimation of Stage-Storage Parameters: Many spreadsheet programs and programmable calculators have built-in procedures for regression analysis. For the fundamentals of regression analysis, the reader is referred to any basic statistics text. To carry out the operation in a spreadsheet or on a programmable calculator, refer to the operating manual.

NOTES

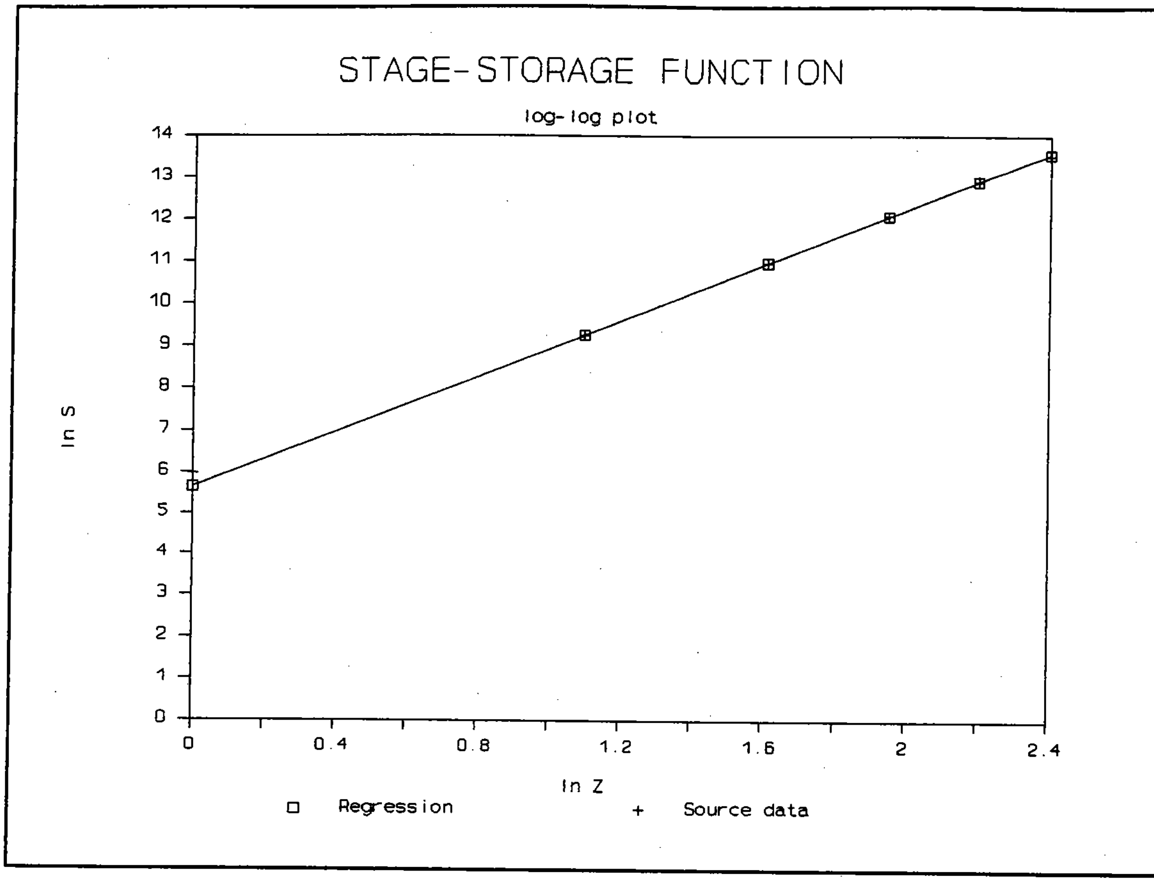

Figure III-2

In the stage-storage function, the independent variable (X- axis) is ln Z, and the dependent variable (Y-axis) is ln S. The value of the exponent, b, is the regression coefficient of the independent variable. The value of the coefficient, Ks, is the antilogarithm of the intercept. These values, as computed in the spreadsheet for the example problem, are shown below the columnar computations.

Validation of the function: Given the assumption of linearity of the logarithms of stage and storage, and given the inherent coarseness of topographic data, it is prudent to test the derived function against the original data. Returning to the columnar computations:

8. Enter estimates of stage as computed for the storage values of col. 4 by Equation III-7 rearranged:

$$\hat{Z} = \left[\frac{S}{Ks}\right]^{1/b} \qquad \text{(III-10)}$$

Compare the values obtained in col. 8 with those of col. 5. If the differences are tolerable, the stage-storage function is valid.

The stage-storage function as derived is plotted in Figure III-3, with the original data values also indicated. Clearly, the function is a valid representation of the topographic data.

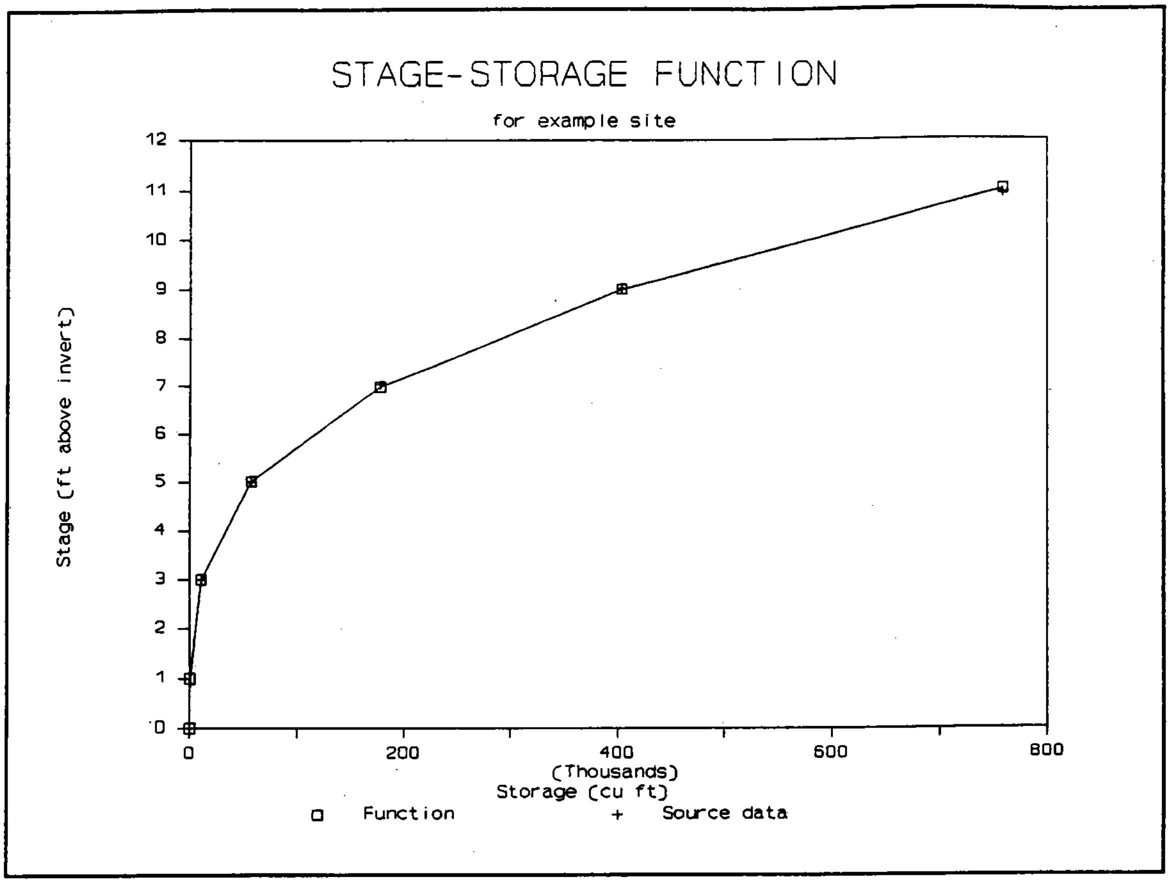

Figure III-3

The stage-storage function may be put to other uses:

1. It is useful early in the design process to consider the impoundment to be a vertical-sided reservoir. To do so, set b equal to one and Ks equal to the surface area in square feet.

2. A stage-area function may be obtained from the stage-storage function by taking the first derivative of storage with respect to stage. The results may be used to determine the area of inundation at a given stage, or to find the stage for a desired surface area. See the example problem.

3. Sometimes the average water depth is of interest. Using the definition of average depth as the volume divided by the surface area, average depth is Z/b.

Stage-Discharge Function

The stage discharge function represents the most important aspects of the hydraulic performance of the outlet device in its influence on the shape of the outflow hydrograph. The stage-discharge function may be presented as a graph of stage (referred to the same datum as the stage-storage function) versus discharge, or reservoir outflow.

The stage-discharge function is derived by hydraulic analysis of the set of outlet devices comprising the spillway system of the reservoir. Usually, these devices can be adequately analyzed by considering the individual outlets as orifices and weirs. For a sample of stages throughout the expected range of water level variation in the reservoir, the total outflow downstream of the dam is computed for each value of stage, and stage versus total discharge is plotted.

Weirs

Most popularly, two kinds of weirs are used -- sharp-crested and broad-crested weirs. For both, the basic equation is:

$$Q = Cw\,L\,H^{3/2} \qquad \text{(III-11)}$$

where:

Q = Discharge (cfs).

Cw = Weir coefficient (dimensionless). See sketches 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.

The weir coefficient depends on the conditions that exist at the crest. For sharp-crested weirs, the value of Cw is theoretically 3.33. For broad-crested weirs Cw is 3.0. For the case of the free overfall, use Cw = 3.0. A useful reference is King, 1963.

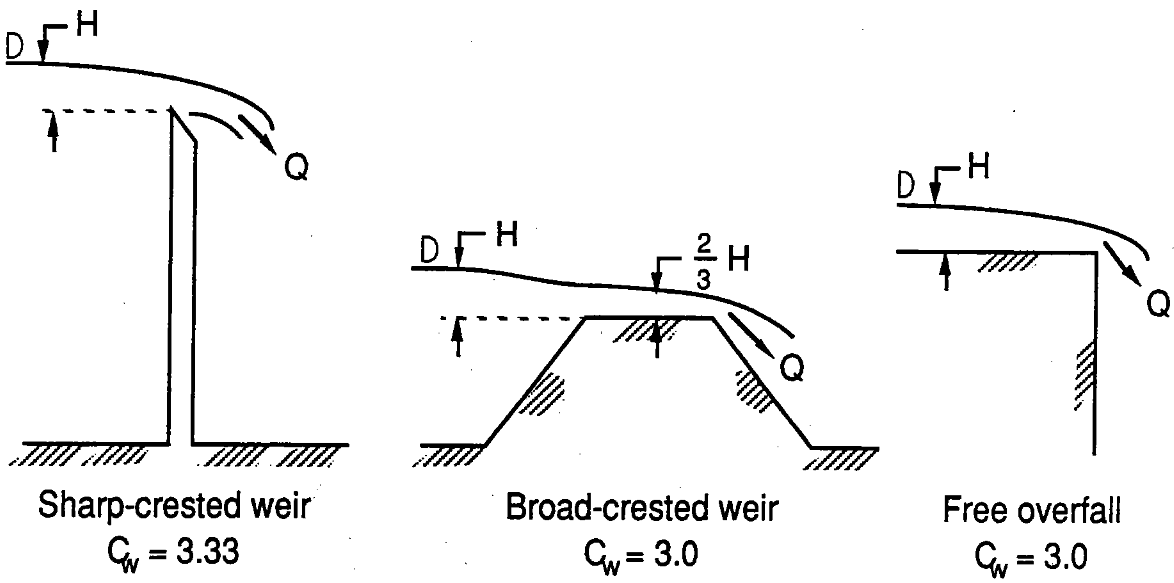

Figure III-4 Schematic sections through weirs.

<u>Orifices</u>

The basic equation for orifices is:

$$Q = C_D A \sqrt{2gh} \qquad \text{(III-12)}$$

where:

Q = Discharge (cfs).

C_D = Coefficient of discharge (dimensionless). See below.

A = Cross-sectional area of flow at the orifice entrance (sq ft).

g = Acceleration of gravity (32.2 ft/sec2).

h = Driving head (ft), measured from the centroid of the orifice area to the water surface.

An idealized sketch of a culvert under inlet control illustrates the orifice application.

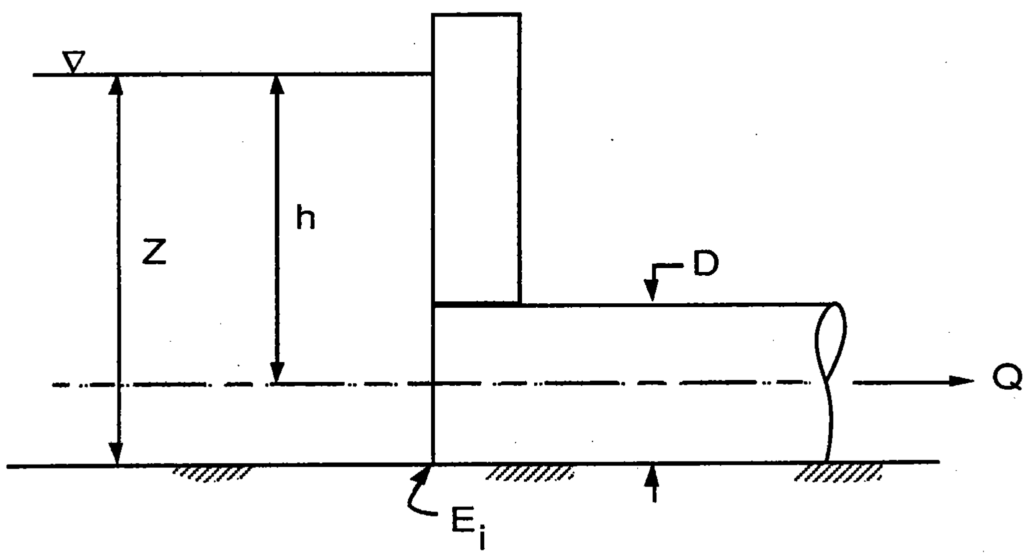

Figure III-5 Schematic section through an orifice.

Table III-2

Values of Coefficient of Discharge, Cd

Entrance Condition	Cd
Typical default value	0.60
Square-edged entrance	0.59
Concrete pipe, grooved end	0.65
Corr mtl pipe, mitred to slope	0.52
Corr mtl pipe, projecting from fill	0.51

Source: These values were back-calculated from the inlet-control culvert-capacity charts of Exhibits 11 and 12 for HW/D = 2.

The orifice equation applies only when the orifice is submerged. When the water surface is below the top of the pipe, a useful approximation of the behavior can be obtained by assuming discharge to be proportional to the three-halves power of depth and fitting the expression to the orifice result at full depth.

The following is a summary step function of stage-discharge for a culvert under inlet control arranged for use in commonly encountered units:

For $Z \leq Ei$ (III-13)

$$Q = 0$$

For $Ei \leq Z \leq \left(\frac{D}{12} + Ei\right)$

$$Q = 0.372\, C_D\, D\, (Z - Ei)^{3/2}$$

For $Z > \left(\frac{D}{12} + Ei\right)$

$$Q = 0.0437\, C_D\, D^2 \left(Z - \frac{D}{24} - Ei\right)^{1/2}$$

Q = [cfs] Z = [ft]

D = [in] Ei = [ft] See Figure III-5

The stage-discharge function for pipes under inlet control can be obtained using the Culvert Capacity Charts of the Federal Highway Administration (See Exhibits 11-14 and FHWA, 1985). Figure III-6 illustrates the differences likely to be experienced with the function and chart. While the differences appear to be large, there is usually no significant difference between the two versions in routing results.

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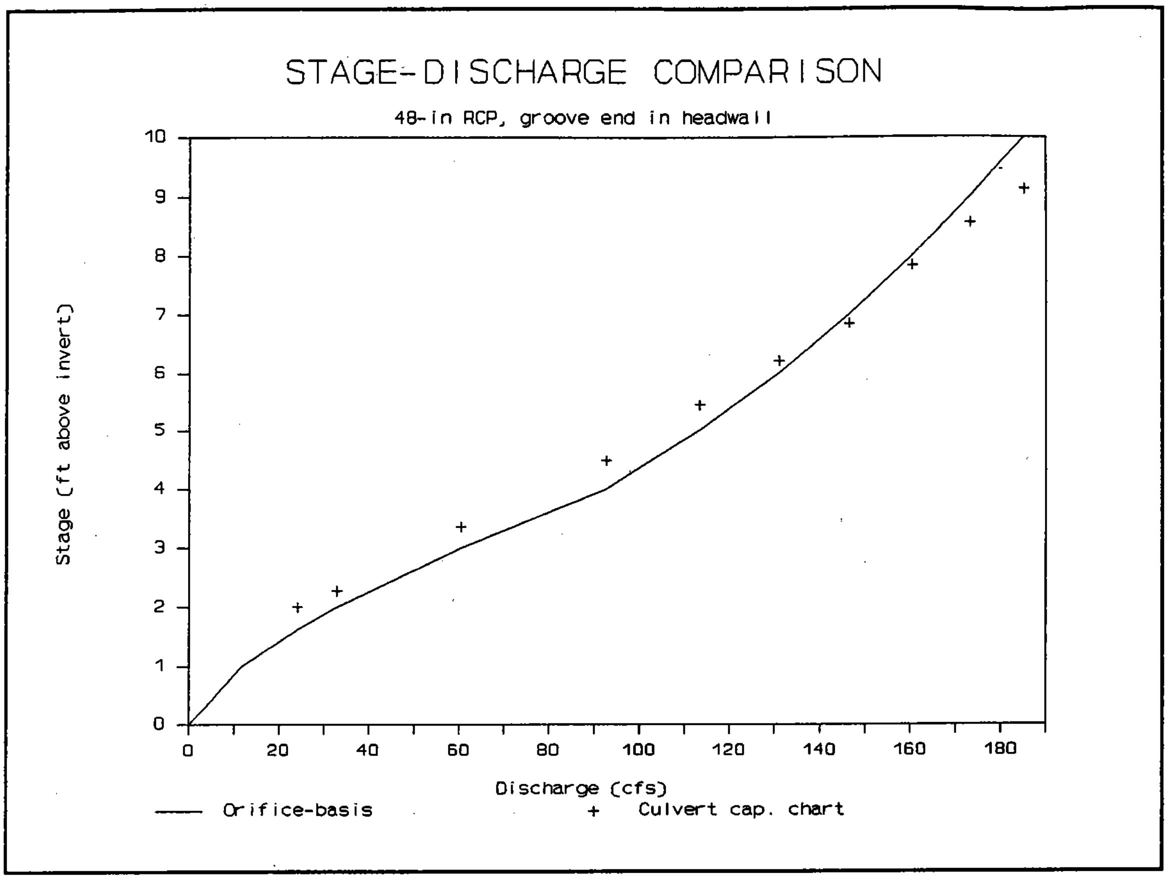


Figure III-6

Composite Stage-Discharge Functions

The typical case to be routed involves combinations of the fundamental orifices and weirs. The composite stage-discharge function can be prepared by applying the fundamental relationships to the outlet components and combining the results as the system behaves. Frequently encountered cases are the overtopped roadway at a culvert, and various combinations of pond spillways, including the riser/barrel spillway.

Culvert and Overtopped Road: The case of a pipe or pipes under a road or dam is illustrated in the schematic section of Figure III-7. For upstream water levels at or below the crest of the weir (top of road), outflow is computed for the pipe acting under inlet control. After the crest of the weir is overtopped, the outflow below the facility is the sum of the flow through the pipe and the flow over the broadcrested weir. Thus for any upstream water level, the outflow can be determined.

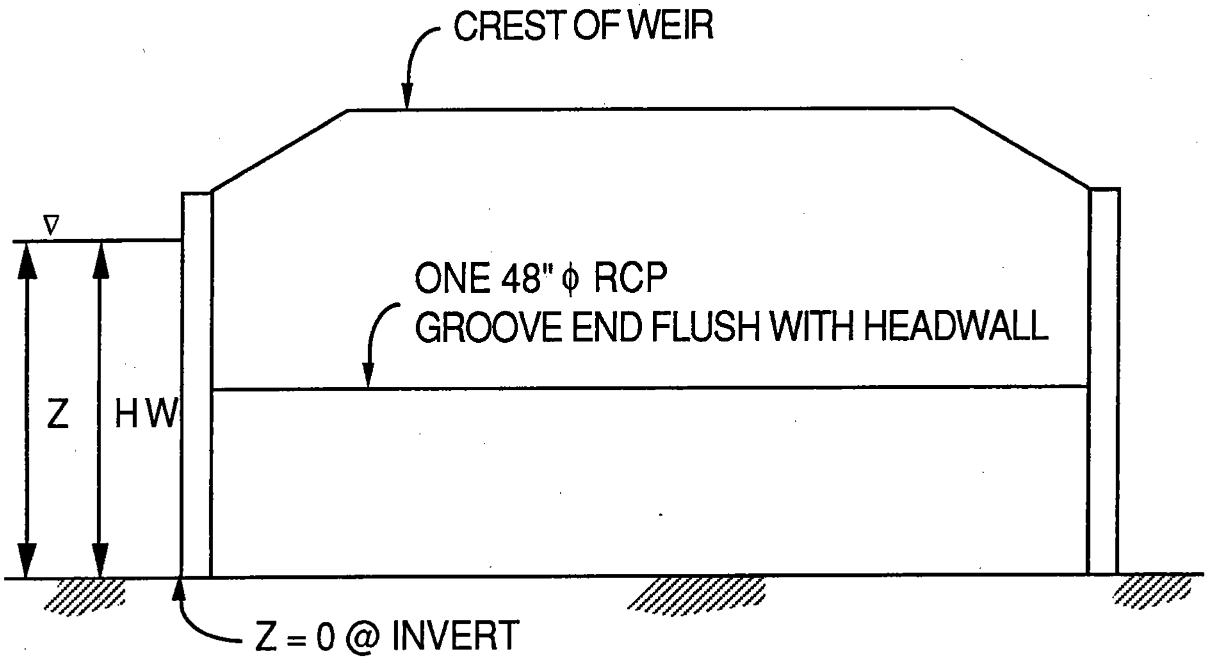


Figure III-7 Schematic Section Culvert Under Road

Riser/Barrel Spillway: A typical configuration for the outlet of a stormwater detention pond is a riser/barrel principal spillway and an emergency weir. There are three modes of behavior in which the riser/barrel can act as the water rises in the pond. One and only one mode of behavior will control at a given stage. Each mode can be analyzed by weir and orifice equations. A schematic of the riser/barrel system is shown in Figure III-8.

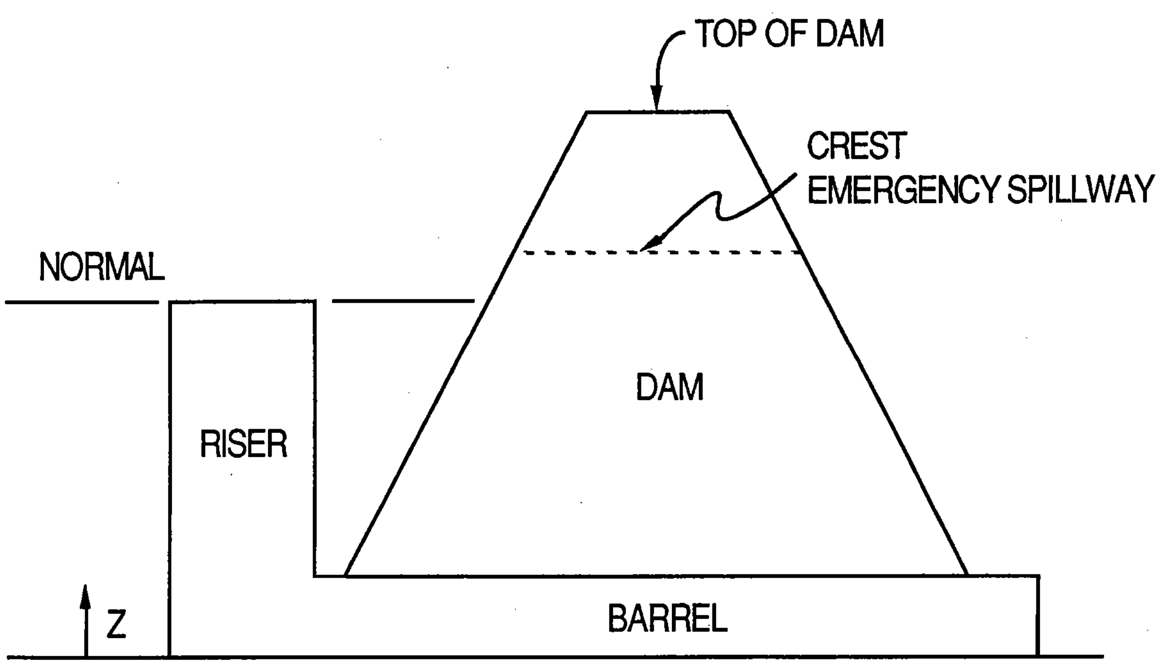


Figure III-8 Schematic Riser/Barrel Spillway

It is instructive to picture the behavior as water rises. To begin, water drops over the rim of the riser. The riser rim acts as a weir with length equal to its circumference and driving head equal to the water-surface elevation minus the elevation of the crest of the riser. As the head increases, one would likely observe a vortex to form as control makes the transition from riser acting as a weir to riser acting as an orifice. The orifice is formed by the top entrance of the riser, the area being the cross-sectional area of the riser. The driving head is measured from the water surface to the horizontal plane of the crest of the riser. These behaviors may be separately computed, as in Table III-3, and plotted, as in Figure III-9. In the figure, the action of the riser as a weir is indicated by the plus signs, and that of the riser as an orifice by the diamonds. Independently of the action at the top of the riser, there is the action of the barrel, which is behaving as a culvert under inlet control. In order to drive the flow through the barrel, water backs up in the inside of the riser. If the barrel is small relative to the riser, the water may rise to submerge the crest of the riser, superseding the action of the riser as a weir. If the barrel is relatively large, the action at the top of the riser may go through the transition from weir to orifice control before barrel control asserts itself. In Figure III-9, the barrel action is plotted with triangles.

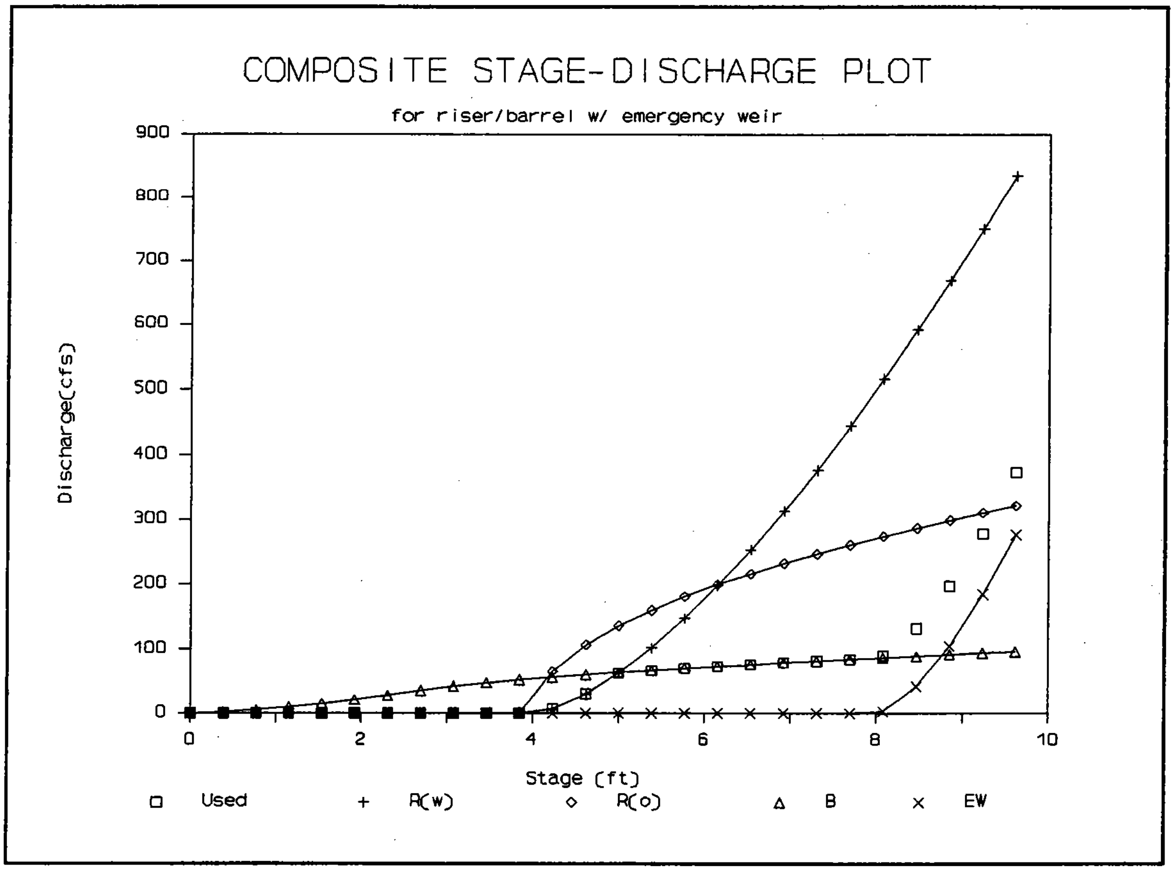


Figure III-9

The three behaviors of the barrel may be computed separately, but at a given stage one will control. At a given stage, choose the least of the discharges. At a given discharge, choose the highest of the three stages.

When the emergency weir is overtopped, the contribution of the weir is added to the contribution of the riser/barrel. In Figure III-9, the values used in the composite function are enclosed in rectangles. The net stage-discharge function is shown in Figure III-10, plotted with stage on the vertical axis and discharge on the horizontal axis as is more conventional.

Table III-3

STAGE-DISCHARGE FOR RISER/BARREL SPILLWAY W/ EMERGENCY WEIR

RISER/BARREL:

Dr	=	72 Riser dia (in)
Etop	=	4.00 Elev top riser (ft)
Cwr	=	3.33 Riser weir coeff
Cdr	=	0.60 Riser orifice coeff
Db	=	36 Barrel dia (in)
Einv	=	0.00 Elev invert barrel (ft)
Cdb	=	0.60 Barrel orifice coeff

EMERGENCY WEIR:

Cw	=	3.0 Weir coeff
Ecr	=	8.00 Elev weir crest (ft)
Lw	=	45 Weir length (ft)

1	2	3	4	5	6	7
Stage	Riser (weir)	Riser (orifice)	Barrel	Principal Spillway	Emergency Weir	Total Outflow
[ft]	[cfs]	[cfs]	[cfs]	[cfs]	[cfs]	[cfs]
0.00	0	0	0	0	0	0
0.38	0	0	2	0	0	0
0.77	0	0	5	0	0	0
1.15	0	0	10	0	0	0
1.54	0	0	15	0	0	0
1.92	0	0	21	0	0	0
2.31	0	0	28	0	0	0
2.69	0	0	35	0	0	0
3.08	0	0	43	0	0	0
3.46	0	0	48	0	0	0
3.85	0	0	52	0	0	0
4.23	7	65	56	7	0	7
4.62	30	107	60	30	0	30
5.00	63	136	64	63	0	63
5.38	102	160	67	67	0	67
5.77	148	181	70	70	0	70
6.15	198	199	73	73	0	73
6.54	254	217	76	76	0	76
6.92	314	232	79	79	0	79
7.31	378	247	82	82	0	82
7.69	445	261	85	85	0	85
8.08	517	274	87	87	3	90
8.46	592	287	90	90	42	132
8.85	670	299	92	92	105	197
9.23	751	311	94	94	184	279
9.62	835	322	97	97	277	374

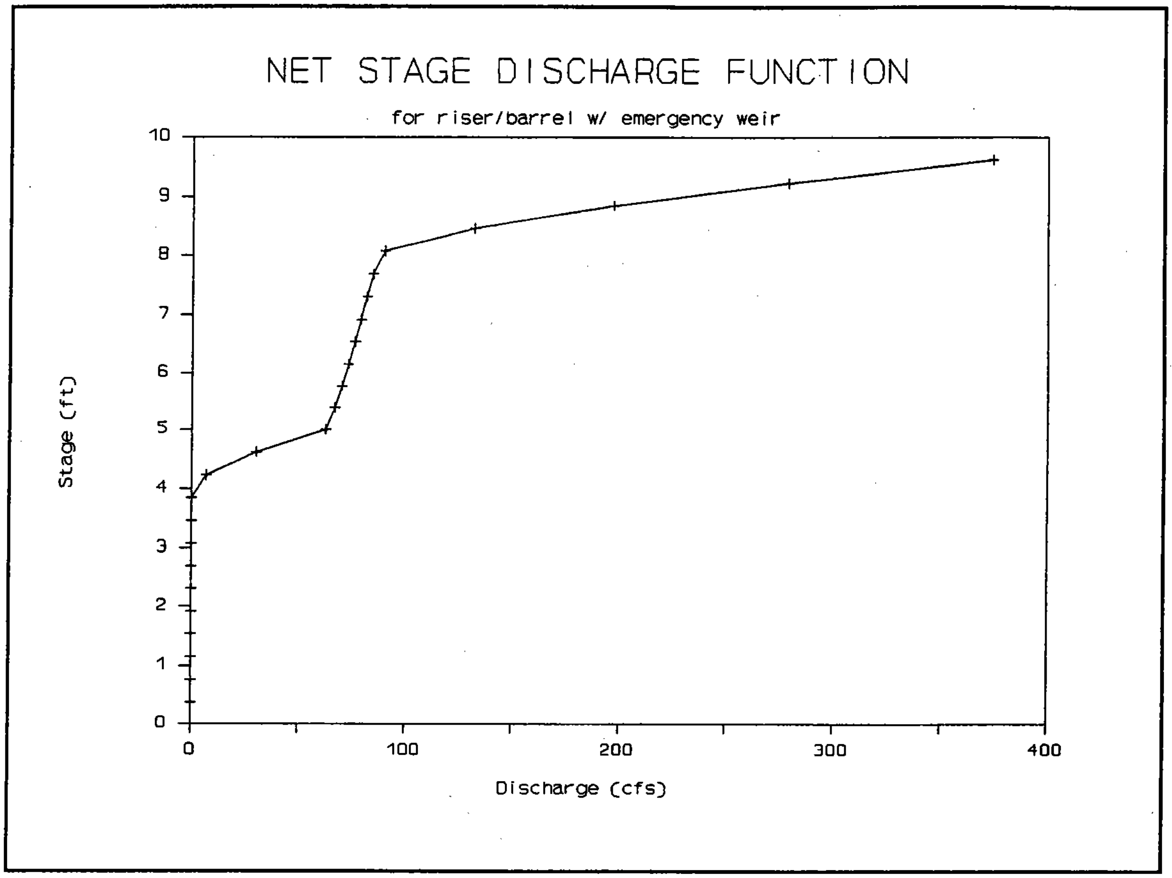


Figure III-10

ROUTING PROCEDURES

Two routing procedures will be discussed. The most widely recognized routing procedure is called the storage-indication method. A second method, devised by the author, is included for its inherent simplicity and efficiency. Several names have been suggested for it: Chainsaw Routing (it's rough and quick), California Routing (it does have its faults). Some of the author's students have given it clever names that are regrettably inappropriate for public documentation. Of them all, the author currently prefers Chainsaw Routing as a reminder of the coarseness of the information on which analysis and design of these systems are based. Our tools are like chainsaws, and we aren't making watches.

To execute either of the methods, one first formulates the three sets of source data described above.

Routing of the flood proceeds by time steps. At each step in time during the passage of the inflow hydrograph through the reservoir, the outflow is computed. The result is a list of values of outflow at stated times -- the outflow hydrograph.

Chainsaw Routing

The continuity principle states that the rate of change of storage with respect to time is the difference between inflow and outflow:

$$\frac{ds}{dt} = I - O \qquad \text{(III-14)}$$

Over a time increment:

$$\frac{\Delta s}{\Delta t} = I - O \qquad \text{(III-15)}$$

The incremental change in storage can be estimated as:

$$\Delta S_{ij} = (I_i - O_i)\, \Delta T_{ij} \qquad \text{(III-16)}$$

in which:

ΔS_{ij} = change in storage in the time increment i to j

I_i = Inflow at time i

O_i = Outflow at time i

ΔT_{ij} = Time increment

The simplification of this method is to consider that the change in storage may be adequately estimated by viewing the time increment as a parallelogram, whereas it is more precisely viewed as a trapezoid (the view taken in the Storage-Indication method). Equation III-16 becomes the basis for taking a step through time in the routing. Note the Equation III-16 is in consistent units. If inflow and outflow are in cfs and if the time increment is in seconds, then storage will be computed in cubic feet. These are the most convenient units.

The routing is conventionally carried out in a table, such as Table III-4, which was executed in a spreadsheet.

The reservoir in this case is a normally dry detention basin designed as a culvert. The inflow hydrograph peaks at 368 cfs and 36 minutes and follows the step function given above. The stage-storage function for the area upstream of the culvert was formulated such that Ks = 284 and b = 3.30. The culvert consists of one 48-inch diameter reinforced concrete pipe with grooved end flush with a headwall for which the coefficient of discharge is estimated at 0.65. There is a roadway that serves as an overflow spillway. The crest elevation is at stage of 10.0 feet, the weir length is 120 feet and the weir coefficient is 3.0 (broadcrested case). The stage reference (Z = 0) is to the invert of the entrance of the culvert which is also the bottom of the dry pond.

A Word about Spreadsheets: In the tabular computations that follow, the values shown in the cells of the tables were rounded back to the precision displayed. Internally in the spreadsheet program, the computations were carried out to several significant figures. As the reader computes values in a given cell based on displayed values in other cells, some differences may be noticed.

Selection of the Time Increment: The time increment should be about one tenth of the time to peak (Tp), where time to peak is considered to be measured from the time of significant rise of the rising limb to the time at which the peak occurs. In this case the time to peak is 36 minutes, so the time increment was conveniently selected at 4 minutes. Note that in calculations the time increment was expressed in seconds.

Table III-4

CHAINSAW ROUTING APPLIED TO A SITE WITH CULVERT AND OVERFLOW WEIR

Input data:

Qp	368
Tp	36
dT	4
Ks	284
b	3.3
N	1
Cd	0.65
D	48
Zi	0
Cw	3
L	120
Zcr	10

RESULTS

OUTFLOW PEAK	173
MAX STAGE	8.94

Routing:

1 TIME [min]	2 INFLOW [cfs]	3 STORAGE [cu ft]	4 STAGE [ft]	5 OUTFLOW [cfs]	6 CULVERT [cfs]	7 WEIR [cfs]
0	0	0	0	0	0.0	0.0
4	11	0	0.00	0	0.0	0.0
8	44	2718	1.98	32	32.4	0.0
12	94	5484	2.45	44	44.1	0.0
16	155	17396	3.48	80	79.7	0.0
20	219	35378	4.31	100	99.7	0.0
24	279	64046	5.17	117	116.6	0.0
28	328	103103	5.97	130	130.5	0.0
32	358	150432	6.69	142	141.9	0.0
36	368	202386	7.32	151	151.1	0.0
40	354	254328	7.84	158	158.4	0.0
44	320	301293	8.26	164	163.9	0.0
48	277	338670	8.56	168	167.8	0.0
52	239	364822	8.75	170	170.2	0.0
56	207	381358	8.87	172	171.7	0.0
60	179	389740	8.93	172	172.5	0.0
64	154	391210	8.94	173	172.6	0.0
68	133	386828	8.91	172	172.2	0.0
72	115	377506	8.84	171	171.4	0.0
76	100	364032	8.75	170	170.2	0.0
80	86	347094	8.62	169	168.6	0.0
84	74	327290	8.47	167	166.6	0.0

Initialization of the Routing Table: In every routing method the routing table must be initialized to represent the state of the system at time zero. In this case, along the row at time zero, the following were set:

Col 2: The initial inflow is zero; the system starts with no inflow. In some cases there may be some trivially low flow to be entered here.

Col 5: The initial outflow is set equal to initial inflow (Col 2) at time zero.

Col 4: Initial stage is set to reflect the water level in the reservoir at the beginning of the storm. In this case the pond is dry, and the stage is zero. In some cases, there is a normally wet pond. Then the stage is set to the initial stage of the water surface.

Col 3: Initial storage is the volume of water (cubic feet) in the reservoir at time zero. In this case, the system is dry and the volume is zero. In the case of a normally wet pond, the initial volume can be computed from the stage-storage function using the stage of the initial water surface.

Taking a Time Step: In every time step, the objective of the computation is to determine the outflow at the end of the time interval. So in this case, one would use the information at time zero and compute the values at time 4 min. Then use the 4 min values to find those at 8 min, and so on. Let time i be the time at the beginning of the interval and time j be the time at the end of the interval. In the chainsaw routine, one begins by using values at time i to estimate the change in storage at time j and to update the storage volume. Then with the known storage at time j, the stage can be computed from the stage-storage function, and from stage the outflow can be computed from the stage-discharge function, all at time j.

As an example, in the interval from time 28 to time 32 min, here is the order of computation:

Col 3: The change in storage, from Equation III-16, is inflow at time i (time 28 min) minus outflow at time i multiplied by the time increment (240 sec). The change is 47,520 cu ft, which is added to the storage at time i (103,103 cu ft) to yield the storage at time j (150,432 cu ft). (The numbers do not agree as printed because the spreadsheet program calculates all values to maximum precision, and the values are rounded for display.)

Col 4: At time j (32 min), calculate stage from updated storage using the rearranged stage-storage function, Equation III-10. At 32 min water has risen to stage 6.69 ft.

Col 6: At time j (32 min), calculate the flow through the pipe by Equation III-13, or by the culvert capacity charts. For stage of 6.69 ft, the equation yields 141.9 cfs.

Col 7: At time j (32 min), calculate the flow over the weir by Equation III-11. Note that for this whole routing, the water level never rises above the crest of the weir, so there is no weir flow.

Col 5: At time j (32 min), the outflow is the sum of the contributions of the pipe (Col 6) and the weir (Col 7).

Col 2: At time j (32 min), the inflow is updated by using the step function (Equations III-1 and -2) to compute the discharge at time 32 min. Alternatively, one could read inflow values from a plotted hydrograph obtained by any other means. (Rounded values are displayed.)

One can run the routing table as far as needed to determine the system responses of interest. Usually, these are the peak outflow, the largest value in Col 5, and the maximum stage, the largest value in Col 4.

Sometimes this method is subject to numerical instability. It will occur if the outlet system is of high discharge capacity and the storage container is of low storage capacity. In the real situation, the outflow hydrograph is tracking closely the inflow hydrograph. The effect of\storage upon outflow is negligible. In the routing table, it will present itself when outflow exceeds inflow on the rising limb of the inflow hydrograph. In the extreme,\change in storage becomes negative and large, perhaps large enough to make total storage go negative, and the computation of stage becomes impossible. Should this happen, it may be corrected by re-initializing the system on the line where the fault occurs as follows:

1. Set outflow (Col 5) equal to inflow (Col 2).
2. Set Stage (Col 4) equivalent to outflow (Col 5), by reference to the stage-discharge function.
3. Set Storage (Col 3) equivalent to stage (Col 4), by using the stage-storage function.
4. Restart the routing, repeating the re-initialization if necessary until the system behaves.

If instability occurs while stage is low in a multiple pipe outlet, it is reasonable to re-initialize where stage is near the top of the pipe. If instability persists to the inflow peak, it indicates that storage is ineffective in the system -- there is no detention effect.

The dry pond routed here would thus reduce the peak of the hydrograph from 368 cfs to 173 cfs by storing water to just under nine feet deep. The hydrographs are shown in Figure III-11. In Figure III-12, the stage-discharge function is plotted showing the points used in the routing.

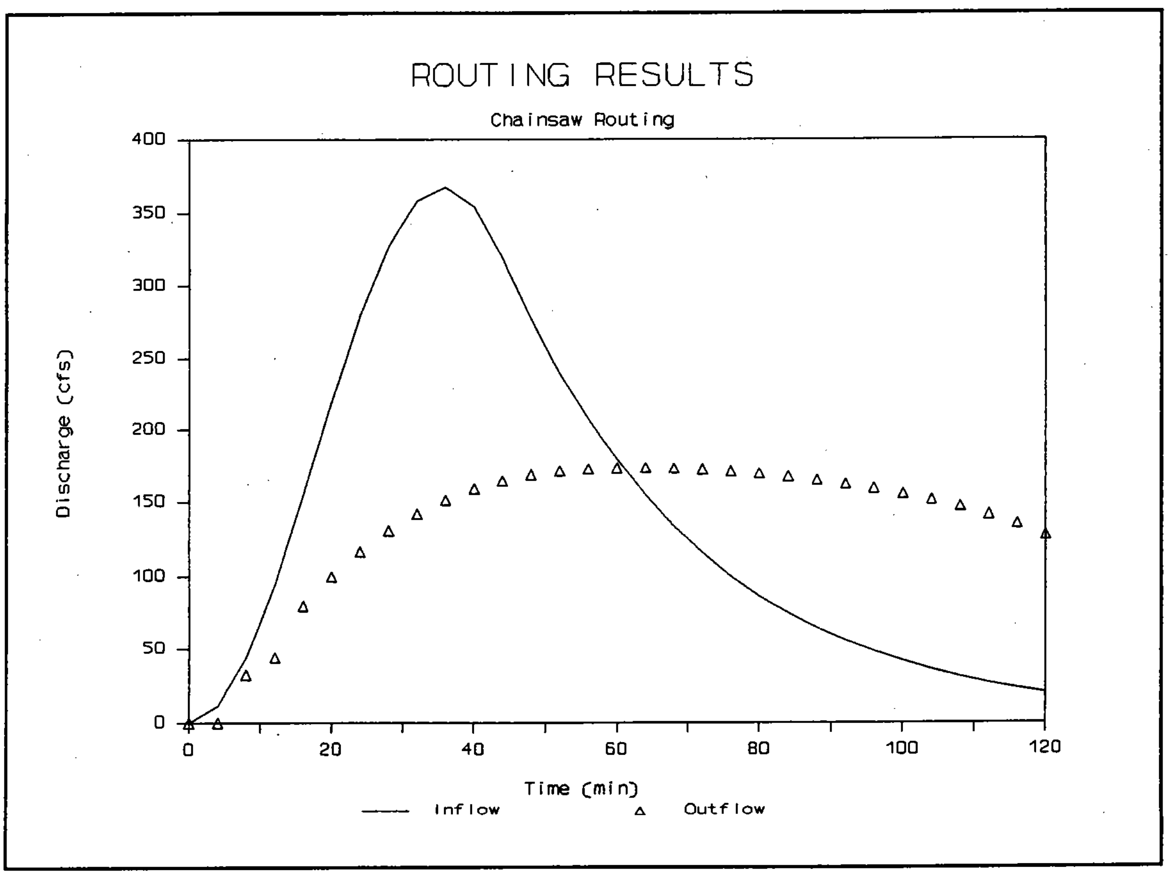


Figure III-11

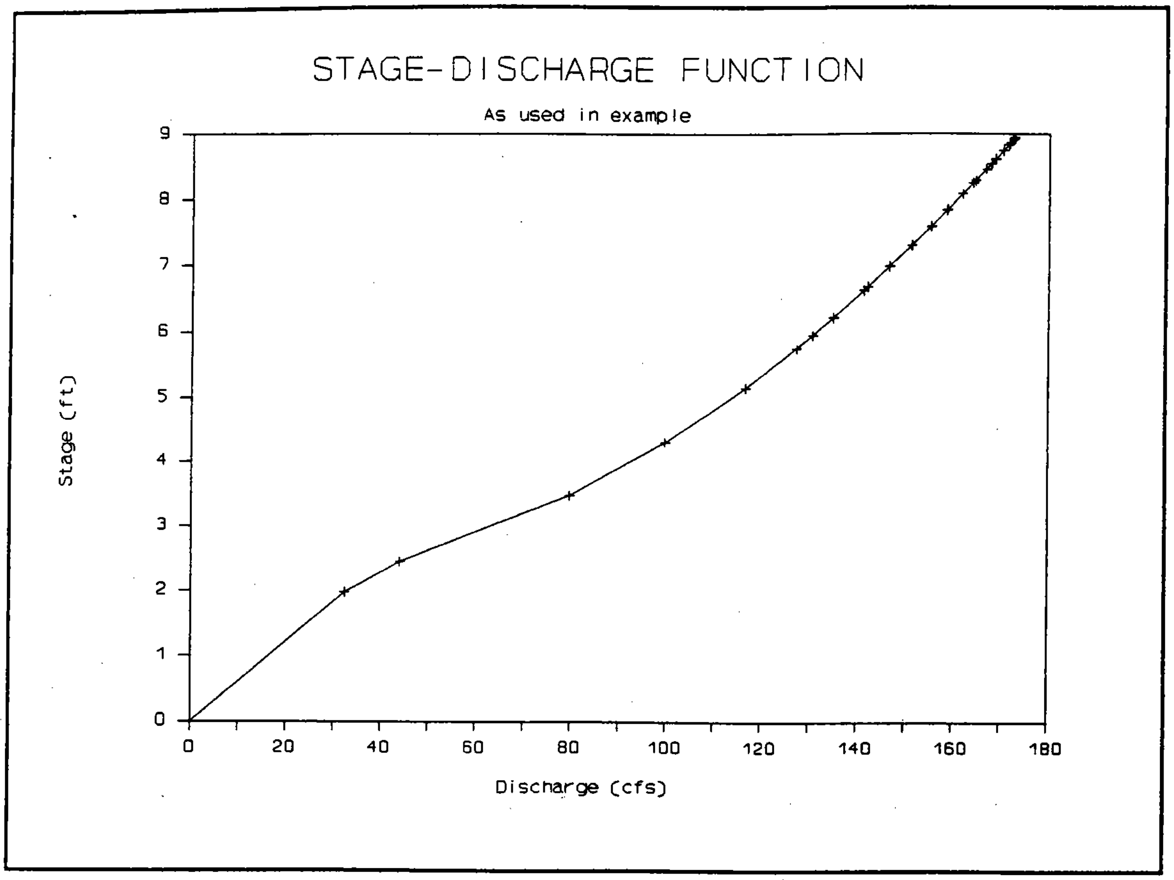


Figure III-12

Storage-Indication Method

The routing procedure most widely accepted is the Storage-Indication method. It is treated in most basic hydrology texts. Like all routing procedures, it proceeds from the continuity principle. To repeat, the continuity principle states that the rate of change of storage with respect to time is the difference between inflow and outflow:

$$\frac{ds}{dt} = I - O \qquad \text{(III-17)}$$

Over a time increment:

$$\frac{\Delta S}{\Delta T} = I - O \qquad \text{(III-18)}$$

The incremental change in storage can be estimated as the area of a trapezoidal element:

$$\Delta S_{ij} = (\bar{I} - \bar{O})\, \Delta T_{ij} \qquad \text{(III-19)}$$

in which:

ΔS_{ij} = change in storage in the time increment i to j

$\bar{I}$ = Average inflow from time i to time j

$\bar{O}$ = Average outflow from time i to time j

ΔT_{ij} = Time increment

Equation III-19 can be manipulated algebraically to obtain the following basis for taking a time step in this procedure:

$$I_i + I_j + \left[\frac{2S_i}{\Delta T} - O_i\right] = \left[\frac{2S_j}{\Delta T} + O_j\right] \qquad \text{(III-20)}$$

in which:

I_i = Inflow at the beginning of the interval

I_j = Inflow at the end of the interval

S_i = Storage at the beginning of the interval

S_j = Storage at the end of the interval

O_i = Outflow at the beginning of the interval

O_j = Outflow at the end of the interval

ΔT = Time increment

The equation is put in this form to collect on the left side the variables known at the beginning of the interval. From these, the sum on the right side may be computed. Note that that the right side has a storage term tied up with the outflow. The outflow may be determined from the value of the right side by means of a chart, or function, prepared from two of the sets of source data, stage-storage and stage-discharge. This chart is\called the storage-indication curve. It is a curious function when first viewed, but its usefulness becomes clear in the tabular computations of the routing. The storage indication curve is a plot of a certain expression, twice the storage divided by the time increment to which is added the outflow, versus the outflow.

The time increment must be selected prior to formulating the storage indication curve.

It is instructive to route the same example problem as was used in illustrating the previous method. The inflow hydrograph, stage-storage and stage-discharge functions remain the same.

Preparation of the Storage-Indication Curve: The curve is plotted by arbitrarily selecting stages and computing the values as shown in Table III-5.

Table III-5

STORAGE-INDICATION CURVE CALCULATION

dT = 240 sec

1	2	3	4	5	6
Stage	Storage	Q Culvert	Q Weir	O Total Q	(2S/dT)+O
[ft]	[cu ft]	[cfs]	[cfs]	[cfs]	[cfs]
0.00	0.00E+00	0	0	0	0
1.00	2.84E+02	12	0	12	14
2.00	2.80E+03	33	0	33	56
3.00	1.07E+04	60	0	60	149
4.00	2.75E+04	93	0	93	322
5.00	5.75E+04	113	0	113	593
6.00	1.05E+05	131	0	131	1006
7.00	1.75E+05	146	0	146	1602
8.00	2.71E+05	160	0	160	2421
9.00	4.00E+05	173	0	173	3508
10.00	5.67E+05	185	0	185	4907
11.00	7.76E+05	196	360	556	7024
12.00	1.03E+06	207	1018	1225	9844

In the table, the columnar computations are:

Col 1: Stages are arbitrarily selected at a convenient interval.

Col 2: Storage (cu ft) is computed at each stage.

Col 3: Discharge through the culvert is computed for each stage by Equation III-13, or equivalent.

Col 4: Discharge is computed at each stage for the weir by Equation III-11.

Col 5: Total outflow is obtained by summing Cols 3 and 4.

Col 6: Enter twice the storage (Col 2) divided by dT (240 sec), plus total outflow (col 5).

For use in the routing computations, these data are usually plotted as a curve. Plot the values of Col 6 versus the values of Col 5 as the storage-indication curve. For the example problem, the storage-indication curve appears as Figure III-13. If values are to be read from the curve for use in routing, the curve should be carefully plotted on good graph paper at large scale. In the routing example here, the actual calculation was done in a spreadsheet with the storage-indication curve computed in a detailed table and interrogated by means of a "lookup" function.

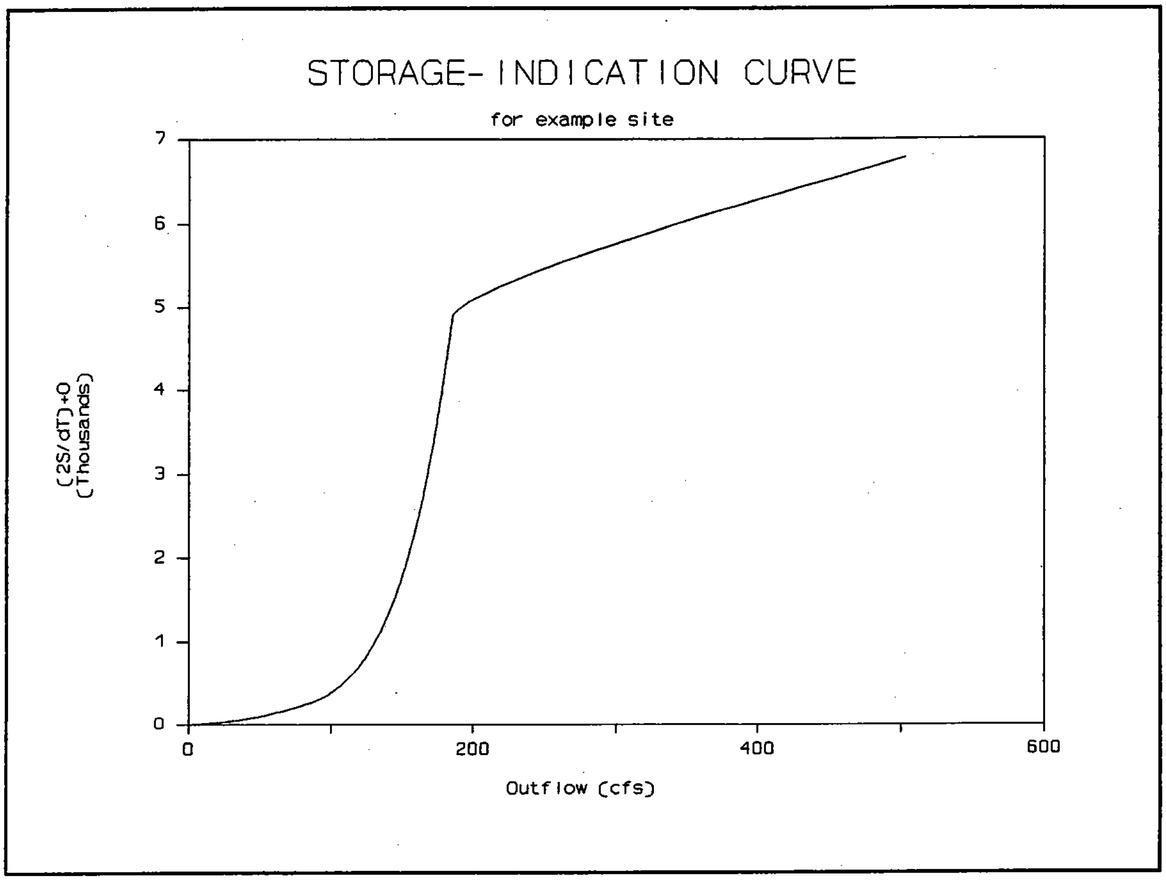


Figure III-13

The routing is carried out in a table such as that in Table III-6. The columns of the table are selected for efficient application of Equation III-20.

Initialization of the Routing Table: As in all such methods, the state of the system must be set at the beginning of the storm. On Line 1, the table is initialized as follows (note the similarity to the previous method):

Col 2: Set initial inflow from hydrograph. Here, at time zero, inflow is zero.

Col 5: Set initial outflow equal to initial inflow.

Col 3: Compute the value of twice the initial storage divided by the time increment (here 240 sec), minus initial outflow. In this case, since at time zero both storage and outflow are zero, the result is zero. If there is a normally wet reservoir, or if initial outflow were non-zero, then a non-zero result would be expected.

Col 4: This cell of the table is not used.

Table III-6

STORAGE-INDICATION ROUTING APPLIED TO A CULVERT AND WEIR

Input data:

Qp = 368
Tp = 36

dT = 4

Ks = 284
b = 3.3

N = 1
Cd = 0.65
D = 48

Cw = 3
L = 120
Zcr = 10

RESULTS:
Max Qo = 171 cfs

Routing:

	1	2	3	4	5
Line	Time	Inflow	(2S/dT)-O	(2S/dT)+O	Outflow
	[min]	[cfs]	[cfs]	[cfs]	[cfs]
1	0	0	0	na	0
2	4	11	-7	11	9
3	8	43	-9	47	28
4	12	92	17	126	54
5	16	152	96	261	83
6	20	216	255	464	105
7	24	276	506	747	121
8	28	325	840	1107	133
9	32	357	1234	1522	144
10	36	368	1653	1959	153
11	40	357	2059	2378	160
12	44	325	2412	2740	164
13	48	282	2684	3019	167
14	52	244	2870	3211	170
15	56	211	2985	3326	171
16	60	183	3037	3379	171
17	64	158	3035	3378	171
18	68	137	2988	3331	171
19	72	119	2904	3244	170
20	76	103	2788	3125	169
21	80	89	2645	2979	167
22	84	77	2481	2811	165
23	88	67	2299	2625	163
24	92	58	2102	2423	160

Taking a Time Step: A time step follows Equation III-20, followed by use of the storage-indication curve. Let us take as an example the entries on Line 3, the time step from time 4 to ime 5 min. Line 2 contains values for time i; Line 3 contains values for time j.

On Line 3:

Col 2: Enter the computed inflow for the time of Col 1. Here, the value was computed by the step function (Equations III-1 and -2). (Differences between inflow values in this table and the chainsaw table are due to the use of rounded values for Qp and Tp in this table, whereas quite precise values were used in the chainsaw table. Again -- a manifestation of the spreadsheet.)

Col 4: Compute the value of the right side of Equation 20. Inflow at time i (4 cfs) plus inflow at time j (8 cfs) plus the value in col 3 at time i (-7 cfs) is entered in col 4 at time j (47 cfs). (Again, the numbers may not add exactly due to rounding of the spreadsheet values.)

Col 5: Enter the storage-indication curve with the value in Col 4, time j (47 cfs), and find the associated outflow (28 cfs).

Col 3: Compute this value from the values at the same time in Cols 4 and 5. Col 4 (47 cfs) minus twice Col 5 (28 cfs) yields the value for Col 3 (-9 cfs).

The routing continues line by line until the response of interest is obtained.

Note that the peak outflow of 173 cfs obtained by chainsaw routing agrees closely with the 171 cfs computed here. The two sets of results of the two methods are plotted in Figure III-14.

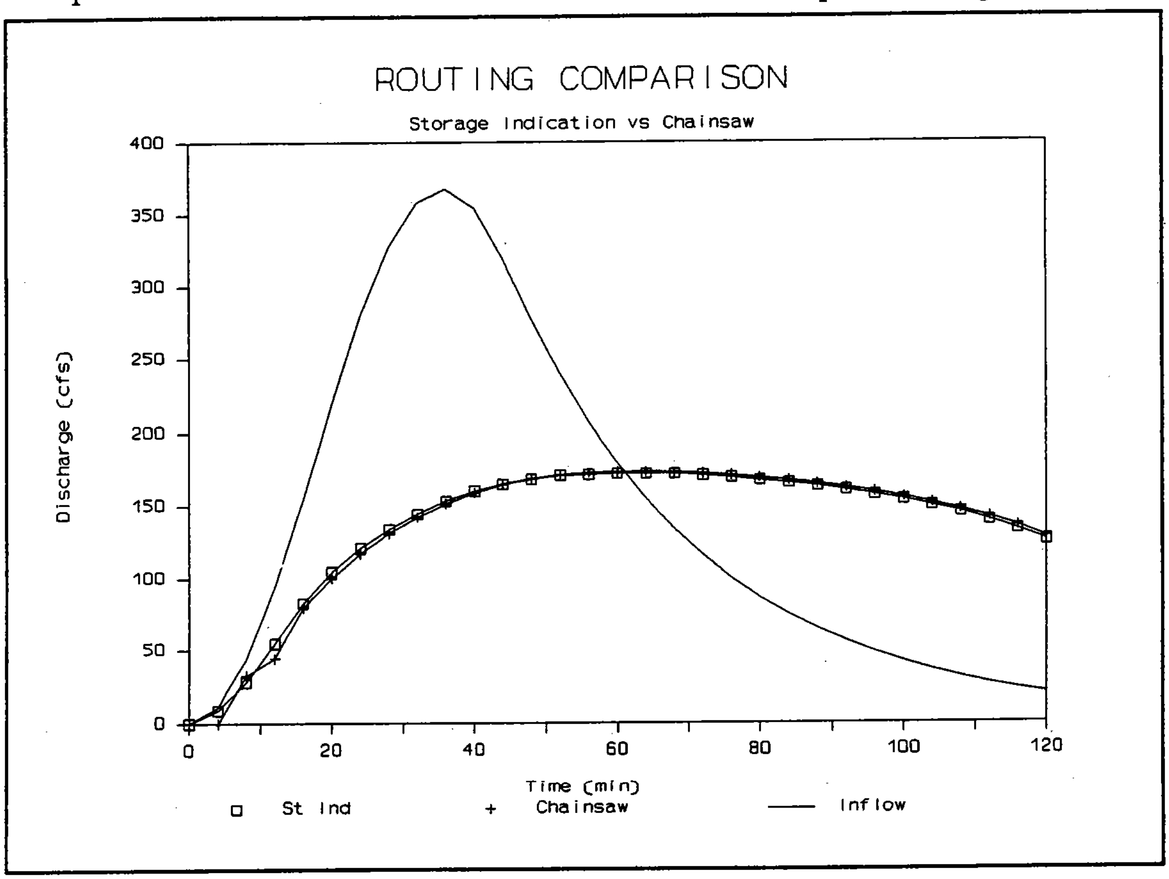


Figure III-14

PRELIMINARY DESIGN

Reservoir design is an indeterminate problem. In order to analyze a reservoir for performance in a design storm, the system must be routed. In order to route, the system must be known. In design, the system is being sought. It is necessary, therefore, to select a tentative system, and then route it. If the site must be selected from a number of alternatives, multiple routings can be laborious. A technique for tentative sizing of a system is useful in reducing the number of alternatives to be routed.

A very good approximation of orifice-based detention reservoirs can be obtained by a gross linearization of the inflow and outflow hydrographs. Let the inflow hydrograph rise linearly from the origin to the peak, Qp, and time to peak, Tp. Let the falling limb descend linearly from the peak to zero discharge at time of twice Tp. Let the outflow hydrograph rise linearly from the origin to its peak, Qo, at its intersection with the falling limb of the inflow hydrograph. In the triangular system thus contrived, the storage is the area between the triangles above the outflow hydrograph. By the triangular relationships, the storage required to reduce Qp to Qo can be estimated as:

$$S = (Qp - Qo)\,Tp \qquad \text{(III-21)}$$

in which:

S = Estimated storage required

Qp = Peak discharge of the inflow hydrograph

Qo = Peak discharge of the outflow hydrograph

Tp = Time to peak of inflow hydrograph, measured from time of significant rise of the rising limb to the time to peak.

The expression is in consistent units. If discharges are in cfs, then time must be in seconds to yield storage in cubic feet.

Equation III-1 may be thought of as PDQ routing. It roughly estimates the storage needed to reduce Qp to the target outflow, Qo, without knowing the system. The storage device may be configured accordingly, and the stage-storage function developed.

The outlet device may also be tentatively sized. In order to pick a pipe, one needs a discharge and driving head. With these, the FHWA culvert capacity charts or the orifice equation may be used to select the pipe or pipes to serve as the outlet. From the stage-storage function, determine the stage necessary to provide the estimated storage required. Using that stage and the target peak outflow, select the pipe or pipes. It is emphasized that the technique is approximate, and that the resulting system should be routed to confirm that it will perform satisfactorily.

SUMMARY

The methods of this section have been assembled to support the design of detention systems. Many jurisdictions have preferred methods for hydrograph formulation and flood routing. The final design must be presented using their methods for acceptance. For preliminary site selection, even design refinement, as in spreadsheets, the methods shown here can improve design efficiency. In some cases, they are acceptable for design submission.

The step-function hydrograph formulation is very quickly executed, and it can be shown to match reasonably well longer methods that use the 24-hr center-weighted design storm. Chainsaw routing is an excellent spreadsheet application. The triangular hydrograph approximation can reduce the number of routings required.

EXAMPLE III-1	DETENTION DESIGN	HRM	1/7

OBJECT: TO EXECUTE A PRELIMINARY DESIGN FOR A DETENTION BASIN IN WHICH STORAGE EXISTS ABOVE THE NORMAL WATER SURFACE OF AN AESTHETIC/RECREATIONAL POND.

GIVEN: (PROBLEM IS HYPOTHETICAL.)

LOCATION: RALEIGH, NC
WATERSHED AREA = 152 AC
HEIGHT OF MOST REMOTE POINT IN WATERSHED ABOVE OUTLET = 61 FT
HYDRAULIC LENGTH OF WATERSHED = 3640 FT
COMPOSITE RUNOFF COEFFICIENT AFTER DEVELOPMENT = 0.62
COMPOSITE RUNOFF COEFFICIENT BEFORE DEVELOPMENT = 0.21
SCS CURVE NUMBER AFTER DEVELOPMENT = 85

STAGE-STORAGE FUNCTION FOR LAKE AREA:

$$S = 332\, Z^{3.15}$$

S = STORAGE (FT^3)
Z = STAGE (FT ABOVE POND INVERT)
POND INVERT = EL 241.17

DESIGN CONSTRAINTS:

1. PEAK OUTFLOW FROM POND MAY NOT EXCEED PEAK FROM WATERSHED PRIOR TO DEVELOPMENT; DESIGN STORM IS 10-YR.

2. NORMAL SURFACE AREA OF POND SHALL BE 4.0 ACRES.

3. OUTLET SHALL BE RISER/BARREL OF CMP. RISER SHALL BE ~~8~~ 72"Ø CMP.

APPROACH:

1. FORMULATE INFLOW HYDROGRAPH & PERMISSIBLE OUTFLOW PEAK.
2. SET CREST OF RISER TO YIELD 4.0 AC SURFACE AREA.
3. ESTIMATE STORAGE REQ'D; COMPUTE EXPECTED 10-YR STAGE.
4. SELECT OUTLET BARREL FOR 10-YR STAGE & PERMISSIBLE OUTFLOW.
5. CROSS FINGERS & ROUTE.

FORMULATE 10-YR DESIGN HYDROGRAPH:

USE SMALL WATERSHED METHOD (SECTION III):

1. ACCEPT STEP FUNCTION (EQNS III-1,2) AS PATTERN.
2. SET PEAK EQUAL TO AFTER-DEVELOPMENT RATIONAL ESTIMATE.
3. SET VOLUME EQUAL TO RUNOFF FROM 6-HR, 10-YR STORM.

ESTIMATE PEAK:

$$Q_p = C\,I\,A$$

$C = 0.62$ (GIVEN)

$$T_c = \frac{\left[\frac{L^3}{H}\right]^{0.385}}{128} \quad \text{(EQN I-2)}$$

$$T_c = \frac{\left[\frac{(3640)^3}{61}\right]^{0.385}}{128}$$

$T_c = 20.8$ USE 21 MIN.

$$I_{10} = \frac{195}{22+T} \quad \text{10-YR, RALEIGH (EXHIBIT 2)}$$

$$I_{10} = \frac{195}{22+21} = 4.53 \text{ IN/HR}$$

$A = 152$ AC (GIVEN)

$Q_p = (0.62)(4.53)(152) = 427$ CFS

USE $Q_p = 430$ CFS ← PEAK, INFLOW HYDROGRAPH

COMPUTE DEPTH OF RUNOFF:

$P = 3.90$ IN 10-YR, 6-HR PRECIP, RALEIGH (EXHIBIT 2)
$CN = 85$ (GIVEN)

$$S = \frac{1000}{CN} - 10 \quad \text{(EQN III-5)}$$

$$S = \frac{1000}{85} - 10 = 1.76$$

EXAMPLE III-1	DETENTION DESIGN (CONT.)	HRM	3/7

FORMULATE 10-YR HYDROGRAPH (CONT.)

COMPUTE DEPTH OF RUNOFF (CONT.)

$$Q^* = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} = \frac{[3.90 - 0.2(1.76)]^2}{3.90 + 0.8(1.76)} \qquad \text{(EQN III-6)}$$

$Q^* = 2.37$ IN ← 10-YR, 6-HR RUNOFF DEPTH

SET VOLUME & COMPUTE TIME TO PEAK:

$$T_p = \frac{VOL}{1.39\,Q_p} \qquad \text{(CONSISTENT UNITS)} \qquad \text{(EQN III-4)}$$

$$T_p = \frac{(2.37\ \text{IN})(152\ \text{AC})}{(1.39)\ (430\ \frac{FT^3}{SEC})} \left[\frac{1\ \text{FT}}{12\ \text{IN}}\right]\left[\frac{43560\ \text{FT}^2}{1\ \text{AC}}\right]\left[\frac{1\ \text{MIN}}{60\ \text{SEC}}\right]$$

$T_p = 36.5$ SAY 37 MIN ←

USE AS 10-YR HYDROGRAPH AFTER DEVELOPMENT:

$Q_p = 430$ CFS
$T_p = 36.5$ MIN

SHAPE FOLLOWS STEP FUNCTION EQNS III-1,2

SET CREST OF RISER FOR 4.0-AC SURFACE AREA:

INVERT OF POND = EL 241.17 (GIVEN)

STAGE·STORAGE: $S = 332\,Z^{3.15}$ (GIVEN)

Z REFERRED TO EL 241.17

IF STORAGE, $S = K_s Z^b$

THEN SURFACE AREA, $A = \frac{dS}{dZ} = b K_s Z^{(b-1)}$

(THIS FOLLOWS FROM CONSIDERATION OF AVG END AREA METHOD.)

SET CREST OF RISER (CONT.):

SO $A = b K_s Z^{(b-1)}$, OR FOR THIS CASE

$A = (3.15)(332) Z^{(2.15)}$

$Z = \left[\frac{A}{(3.15)(332)}\right]^{1/2.15}$ 4 AC = 174 240 SQFT

$Z = \left[\frac{174\,240}{(3.15)(332)}\right]^{1/2.15}$

Z = 10.80 FT ABOVE INVERT OR EL 241.17 + 10.80 = EL 251.97

SET RISER AT EL 252.0   FOR 4.0 AC NORMAL LAKE SURFACE

COMPUTE ALLOWABLE OUTFLOW:

Q = CIA (USE BEFORE-DVLPMT C, LET I & A REMAIN SAME.)

Q = (0.21)(4.53)(152) = 144.6 USE 145 CFS ←

ESTIMATE STORAGE NEEDED:

$S = (Q_p - Q_o) T_p$ (CONSISTENT UNITS) (EQN III-21)

Q_p = 430 CFS
T_p = 36.5 MIN
Q_o = 145 CFS

S = (430 - 145)(36.5 MIN) [60 SEC/MIN]

S = 624,150 CU FT STORAGE REQD ←

(ESTIMATE — MUST ROUTE TO CONFIRM.)

CONFIGURE OUTLET:

AT TOP OF RISER, $Z = 10.83$ FT

$$S = 332 Z^{3.15} = 332(10.83)^{3.15} = 602\,862 \text{ FT}^3$$

AT TOP OF 10-YR STORAGE, TOTAL STORAGE IS

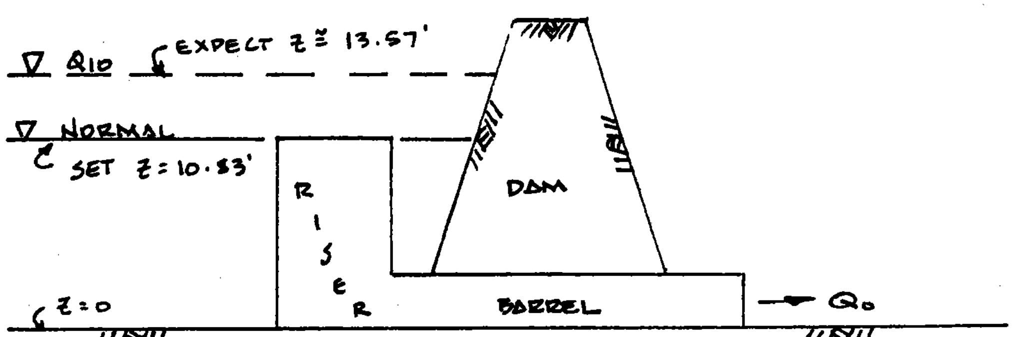
$$S = 602\,862 \text{ FT}^3 + 624,150 \text{ FT}^3$$

TOTAL $S = 1,227,000 \text{ FT}^3$ WHEN 10-YR STORAGE IS FULL.

THE STAGE FOR TOP OF 10-YR STORAGE IS

$$Z = \left[\frac{S}{K_S}\right]^{\frac{1}{b}} = \left[\frac{1,227,000}{332}\right]^{\frac{1}{3.15}}$$

$Z = 13.57$ FT ← EXPECT POND TO BE THIS DEEP IN 10-YR.



NOT TO SCALE

WHEN $Z = 13.57'$, RISER/BARREL SHOULD DELIVER $Q_O = 145$ CFS.

SELECT PIPE (BARREL) BY APPLYING ORIFICE EQN (COULD USE EXHIBIT 12).

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

$$\sqrt{h} = \frac{Q}{C_D A \sqrt{2g}} = \frac{4Q}{C_D D^2 (\pi \sqrt{2g})} = \frac{0.159\,Q}{C_D D^2}$$

$$h = \left[\frac{0.159\,Q}{C_D D^2}\right]^2$$

h IS REFERRED TO ℄ BARREL.

CONFIGURE OUTLET (CONT.):

BARREL MAY BE SELECTED BY

$$h = \left[\frac{0.159\, Q}{C_D\, D^2} \right]^2$$

LET $C_D = 0.59$ (TABLE III-2)
$Q = 145$ CFS

SELECT D IN FT ; COMPUTE h
TRY FOR $Z = 13.57'$

D (IN)	D (FT)	h (FT)	Z $h + D/2$	
24	2	95+	–	WOW.
36	3	18.85	20.3	TOO SMALL
42	3.5	10.18	11.9	TOO BIG

THE SIZE NEEDED IS BETWEEN 36" & 42".
SINCE WE ARE DETAINING, TRYING TO REDUCE OUTFLOW,
SELECT 36" ϕ CMP FOR BARREL.

EXPECT ROUTED $Q_0 < 145$ CFS, $Z_{MAX} > 13.57'$ OR > EL 254.74

SEE NEXT PAGE FOR SPREADSHEET ROUTING OUTPUT.

RESULTS WERE AS EXPECTED $Q = 118$ CFS < 145 CFS OK
$Z_{MAX} = 255.21$

(NOTE: A SECOND ROUTING WAS RUN W/ 42"ϕ BARREL. $Q_0 = 157$ CFS ← NG)
(THE PRELIM DESIGN SEQUENCE POINTED TO A GOOD SOL'N.)

DESIGN DECISION:

1. SET TOP OF RISER @ EL 252.00 (AREA = 4.03 AC)

2. USE BARREL = 36"ϕ CMP. PEAK OUTFLOW = 118 CFS VERSUS ALLOWED 145 CFS.

3. EXPECT MAX 10-YR STAGE = EL 255.21.

4. SET CREST OF EMERGENCY SPILLWAY ABOVE EL 255.21.

ROUTING SPREADSHEET: EXAMPLE III-1

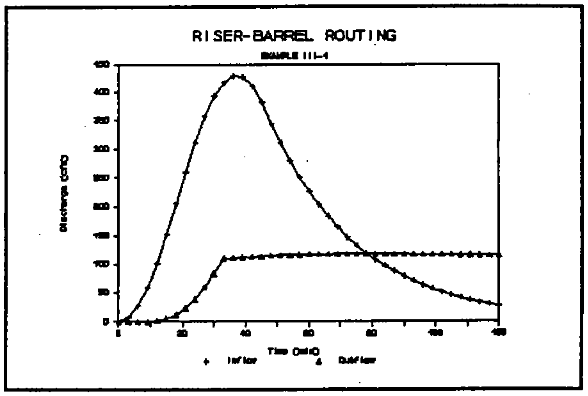
INPUT DATA:

Qp = 430 cfs
Tp = 37 min
dT = 3 min

Ks = 332
b = 3.15
Zo = 241.17 ft (Rf)

Dr = 72 in — Wksht assumes riser acts as weir.

Cw = 3.3
Zcr = 252 ft
Db = 36 in
Zi = 241.17 ft
Cd = 0.59



TIME [min]	INFLOW [cfs]	STORAGE [cu ft]	STAGE [ft]	OUTFLOW [cfs]	RISER [cfs]	BARREL [cfs]
0	0	6.03E+05	252.00	0	na	na
3	7	6.03E+05	252.00	0	0.0	102.2
6	27	6.04E+05	252.01	0	0.0	102.2
9	60	6.09E+05	252.03	0	0.4	102.4
12	102	6.20E+05	252.10	2	1.8	102.7
15	152	6.38E+05	252.20	5	5.4	103.2
18	206	6.64E+05	252.34	12	12.2	104.0
21	260	6.99E+05	252.52	23	23.4	105.0
24	312	7.42E+05	252.74	39	39.3	106.1
27	357	7.91E+05	252.97	60	59.8	107.4
30	393	8.44E+05	253.22	84	84.0	108.7
33	418	9.00E+05	253.47	110	110.7	109.9
36	429	9.55E+05	253.70	111	138.4	111.1
39	427	1.01E+06	253.94	112	167.8	112.3
42	411	1.07E+06	254.16	113	197.5	113.4
45	382	1.12E+06	254.36	114	226.0	114.4
48	346	1.17E+06	254.54	115	251.9	115.3
51	311	1.21E+06	254.69	116	274.3	116.0
54	280	1.25E+06	254.81	117	293.4	116.6
57	252	1.28E+06	254.91	117	309.4	117.1
60	227	1.30E+06	255.00	117	322.6	117.4
63	204	1.32E+06	255.06	118	333.3	117.8
66	184	1.34E+06	255.11	118	341.8	118.0
69	165	1.35E+06	255.15	118	348.2	118.2
72	149	1.36E+06	255.18	118	352.8	118.3
75	134	1.36E+06	255.20	118	355.8	118.4
78	120	1.36E+06	255.21	118	357.3	118.5
81	108	1.37E+06	255.21	118	357.5	118.5
84	98	1.36E+06	255.20	118	356.5	118.4
87	88	1.36E+06	255.19	118	354.5	118.4
90	79	1.35E+06	255.17	118	351.5	118.3
93	71	1.35E+06	255.15	118	347.6	118.2
96	64	1.34E+06	255.12	118	343.0	118.0
99	58	1.33E+06	255.09	118	337.7	117.9
102	52	1.32E+06	255.05	118	331.8	117.7
105	47	1.31E+06	255.01	118	325.3	117.5
108	42	1.29E+06	254.97	117	318.3	117.3

Norm Surf Area = 4.03 ac
Peak outflow = 118 cfs
Peak stage = 255.21 ft,msl

APPENDIX C

Sample Access and Maintenance Easement Agreement

Return to: Thomas L. Horstman, CPESC
Erosion Control Supervisor
DEVELOPMENT REVIEW
Town of Cary
PO Box 8005, Cary, NC 27512

NORTH CAROLINA

WAKE COUNTY

STORMWATER CONTROL STRUCTURE AND ACCESS EASEMENT AND AGREEMENT (Corporate)

THIS STORMWATER CONTROL STRUCTURE AND ACCESS EASEMENT AND AGREEMENT, made this day 1 of 1, 191, **(DATE OF AGREEMENT**) by 2 **(NAME OF OWNER)**, a North Carolina corporation whose principal address is 2a , (hereafter "Grantor"), with, to, and for the benefit of the Town of Cary, a municipal corporation of the State of North Carolina, whose address is P.O. Box 8005, Cary North Carolina 27512-8005 (hereinafter "Grantee" or "Town").

W I T N E S S E T H:

WHEREAS, Grantor is the owner in fee simple of certain real property, situated in the Town of Cary, County of Wake, North Carolina and more particularly described as follows:

3 **(LEGAL DESCRIPTION OF PROPERTY)**

It being the same land conveyed to the Grantor by deed recorded in Book 3a at page 3a in the Office of the Register of Deeds for Wake County (hereafter referred to as "Property"); and

WHEREAS, the property is located within the planning jurisdiction of the Town of Cary, and is subject to certain requirements set forth in the Land Development Ordinance of the Town, (hereafter "Cary LDO"), as such may be amended from time to time; and

WHEREAS, one of the conditions for development of Property is the granting or dedication of a Stormwater Control Structure easement, which includes the implementation of certain stormwater practices such as, but not limited to, the construction, operation and maintenance of engineered stormwater control structure(s) as provided in Cary LDO; the dedication of an access easement for inspection and maintenance of the Stormwater Control Structure easement area and engineered structures; and the assumption by Grantor of certain specified maintenance and repair responsibilities; and

WHEREAS, this Easement and Agreement has been procured in accordance with the requirements of N.C. G.S. Sec 143-211 *et. seq*. and Chapter 4, Part 4.6 of the Cary LDO.

NOW, THEREFORE, for a valuable consideration, including the benefits Grantor may derive therefrom, the receipt of which is hereby acknowledged, Grantor has dedicated, bargained and conveyed and by these presents does hereby dedicate bargain, sell, grant and convey unto the Grantee, its successors and assigns, a perpetual, and irrevocable right and easement in, on, over, under, through and across Property (1) for a STORMWATER CONTROL STRUCTURE easement ("hereafter SCS Easement") of the nature and character and to the extent hereinafter set forth, more particularly shown and described on Attachment 4 **(NAME OF AS BUILT DRAWING)** which is attached hereto and incorporated herein by reference; upon which Grantor shall construct, maintain, repair and reconstruct stormwater control structure(s), including detention pond(s), pipes and water control structures, berms and dikes, and shall establish and maintain vegetative filters and groundcovers; and (2) an access easement more particularly shown and described on Attachment 4a **(ATTACHMENT NUMBER 1 OR 2)**, , for the purpose of permitting Town inspection and, if necessary, maintenance and repair of the SCS Easement and engineered structure(s) as more fully set forth herein and in Cary LDO.

The terms, conditions, and restrictions of the Stormwater Control Structure Easement and Access Easement are:

1. The requirements pertaining to the SCS Easement are more fully set forth in Chapter Chapter 4, Part 4.6 of Cary LDO and the "Operation and Maintenance Manual for 5 (hereafter "Operations and Maintenance Manual"), Cary, NC, prepared by 5a, and dated 5b a copy of which is on file in the Town of Cary Engineering Department. Grantor further agrees Grantor shall perform the following, all at its sole cost and expense:

I. Monthly or after every runoff producing rainfall, whichever comes first:

a. Remove debris from trash rack.
b. Check and clear orifice of any obstructions.
c. Check pond side slopes; remove trash, repair eroded areas before next rainfall.

II. Quarterly

a. Inspect the collection system (i.e., catch basin, piping, grassed swales) for proper functioning. Clear accumulated trash from basin grates, and basin bottoms, and check piping for obstructions.
b. Check pond inlet pipes for undercutting. Repair if necessary.
c. Repair any broken pipes.
d. Replace rip rap that is choked with sediment.
e. Reseed grassed swales twice yearly. Repair eroded areas immediately.

III. Semi-Annually

a. Remove accumulated sediment from bottom of outlet structure.
b. Check available ponding depths at several locations. If depths are reduced to 75% of original design depths, remove sediment to original design depth.

IV. General

a. Mow side slopes according to the season and species of vegetation.
b. Cattails and other invasive species shall be removed when they cover the entire surface area of bioretention area.
c. All components of the engineered structures are to be kept in good working order.
d. In case the ownership of the Stormwater Control Structure transfers, the current owner shall, within thirty (30) days of transfer of ownership, notify the Town of Cary Engineering Department, Stormwater Management Division of such ownership transfer.
e. This property and structure are also subject to the Operation and Maintenance Manual filed with the register of deeds.

2. Grantor represents and warrant that Grantor is financially responsible for construction, maintenance, repair and replacement of all stormwater control structures, appurtenances and vegetation, including the impoundment. Grantor agrees to perform the maintenance as outlined above and in the Operations and Maintenance Manual in consideration of the Certificate of Compliance with stormwater regulations received for Property.

3. If Grantor fails to comply with these requirements, or any other obligations imposed herein, in Cary LDO or Operations and Maintenance Manual the Town of Cary may perform such work as Grantor is responsible for and recover the costs thereof from Grantor.

4. This Easement and Agreement gives the Grantee the following affirmative rights:
Grantee, its officers, employees, and agents may enter Stormwater Control Structure and Access Easement whenever reasonably necessary for the purpose of inspecting same to determine compliance herewith, to maintain same and make repairs or

replacements to the engineered stormwater control structure(s) and appurtenances and conditions as may be necessary or convenient thereto in the event Grantor defaults in its obligations and to recover from Grantor the cost thereof, and in addition to other rights and remedies available to it, to enforce by proceedings at law or in equity the rights, covenants, duties, and other obligations herein imposed.

The Grantor shall in all other respects remain the fee owner of Property and area subject to these easements, and may make all lawful uses of Property not inconsistent with these easements.

The Grantee does not waive or forfeit the right to take action to ensure compliance with the terms, conditions and purposes of this Easement and Agreement by a prior failure to act.

The Grantor agrees that the terms, conditions and restrictions of this easement will be inserted by Grantor in any subsequent deed or other legal instrument by which he divests himself of either the fee simple title to or possessory interests in the subject property. The designation Grantor and Grantee shall include the parties, their heirs, successors and assigns.

TO HAVE AND TO HOLD the aforesaid rights, privileges, and easements herein granted to the Grantee, its successors and assigns forever and the same Grantor does covenant and that Grantor is seized of said premises in fee and has the right to convey the same, that except as set forth below the same are free from encumbrances and that Grantor will warrant and defend the said title to the same against claims of all persons whosoever.

The covenants agreed hereto and the conditions imposed herein shall be binding upon the Grantor and its agents, personal representatives, heirs and assigns and all other successors to Grantor in interest and shall continue as a servitude running in perpetuity with the above described land.

IN WITNESS WHEREOF, the Grantor has caused this instrument to be signed in its corporate name by its duly authorized officers and its seal to be hereunto affixed by authority of its Board of Directors, the day and year first above written.

____________7____________
(Grantor)

____________7a____________
7b President

Attest:

______7c_____________________

______________Secretary (Corporate Seal)

NORTH CAROLINA
WAKE COUNTY

I, the undersigned Notary Public, do hereby certify and State aforesaid, do hereby certify that __________ ________________ personally appeared before me this day and acknowledged the execution of the foregoing instrument.
Witness my hand and official seal this __ day of ___________________________, 19___.

My commission expires: ____

____
Notary Public

[Official Seal]

ckc
Easement&Deed/Corporate.doc