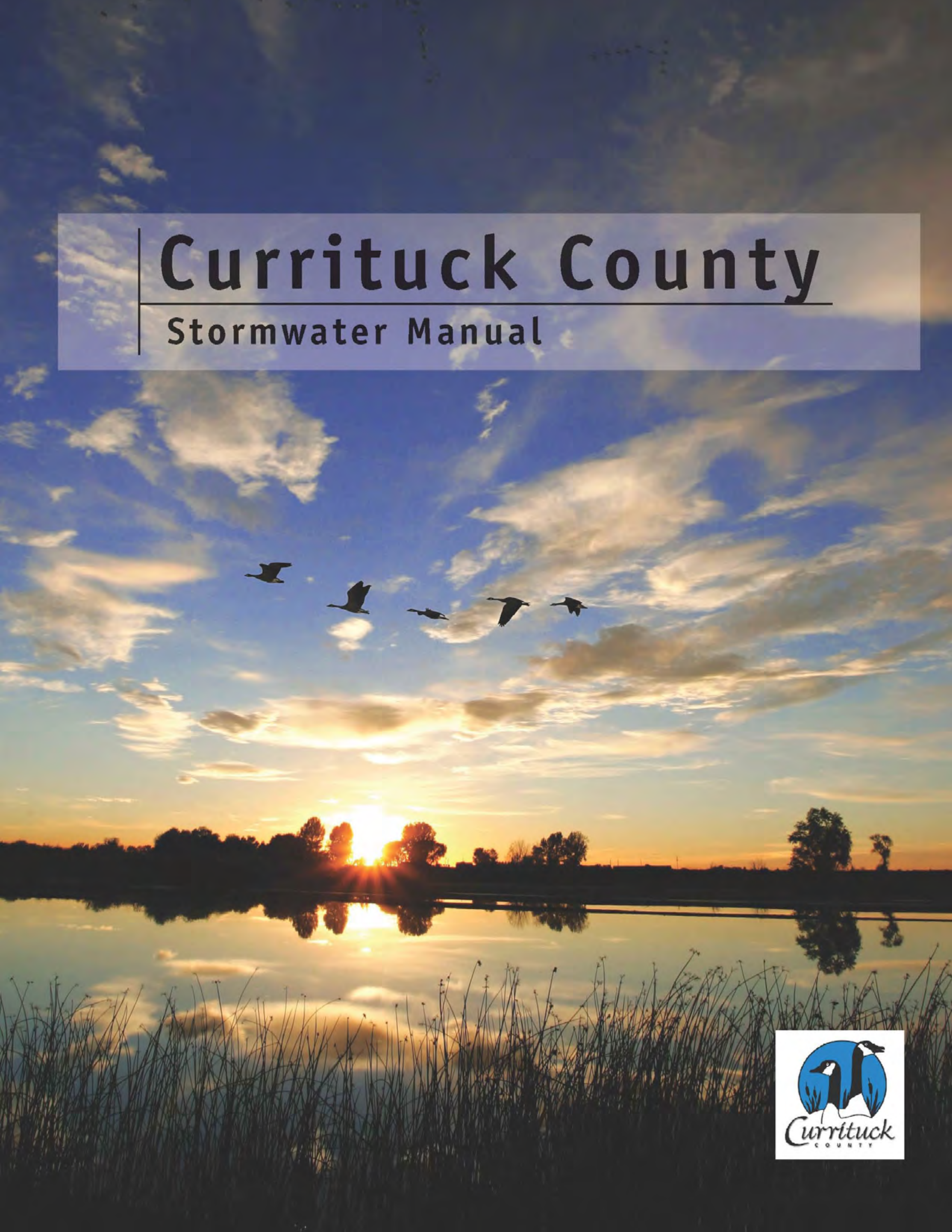
Currituck County

Stormwater Manual



Intentional Blank Page

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

CHAPTER 1. INTRODUCTION

Currituck County is a rapidly growing coastal county, which experienced an overall population growth rate of 41.5% from 2000-2010 according to the North Carolina Office of State Budget and Management. In association with its coastal setting, Currituck County is blessed with a variety of high-value natural resources that provide the basis for a thriving tourism industry and act as the driving forces that make Currituck County such a desirable place to live. The attractive natural setting has combined with other factors, including lower property tax rates than neighboring Virginia communities and recent roadway improvements, to increase Currituck County's popularity as a bedroom community for the Hampton Roads area.

Population growth pressure will be an ongoing challenge for Currituck County for a couple of reasons. First, while the total land area of Currituck County is approximately 261 square miles, much of that area is wetlands or low-lying areas, often with poorly drained soils. Much of the suitable land (i.e. land that is not within wetland boundaries and poorly drained soils) has already been developed. Approximately 19.2% of Currituck County's "suitable land" is currently undeveloped or has the potential to be platted. Future development is likely to be pushed onto marginal lands. Second, it has been widely recognized that Currituck Sound has experienced a decline in water quality and ecological health over the past few decades. Efforts to better understand and address the problems, including a long-term study by the US Army Corps of Engineers, are currently ongoing.

1.1. PURPOSE OF THE MANUAL

In order to manage the growth pressure while addressing the need to protect the sensitive natural systems on which it depends, Currituck County seeks to improve the stormwater management portions of their Unified Development Ordinance (UDO) to raise the level of water quality protection and reduce nuisance flooding problems. Currituck County also seeks to facilitate the use of low impact development (LID) as a tool to achieve these goals. In order to ensure the effectiveness of the new development ordinances toward achieving those goals, Currituck County has developed this Stormwater Manual. The purpose of the Manual is to instruct Currituck County's developers, design professionals, and citizens as to the proper application of the new ordinances, and to educate them regarding the potential benefits of LID.

Additionally, the manual is intended to provide guidance in appropriate BMP selection, design criteria to meet applicable stormwater regulations, and proper BMP maintenance. However, this manual does not cover every situation or every possible stormwater solution. The design professional shall consider unique site conditions before selection of a BMP. The design professional is responsible for the design and construction of a properly functioning BMP that meets all applicable state and local regulations. Additional guidance for BMP design criteria, construction, and maintenance can be found in the North Carolina Division of Water Quality *Stormwater Best Management Practices Manual* (NCDWQ, 2007).

In general, if any part of this manual differs from any other ordinance, rule, regulation, or other provision of law, whichever provision that imposes the higher protective standard for human or environmental health, safety, and welfare, shall control.

1.2. NATURAL AND GEOGRAPHIC SETTING

Currituck County is located in the northeast corner of North Carolina's Coastal Plain region. The mainland of Currituck County is bounded by the North River to the west, the Albemarle Sound to the south, and Currituck Sound to the east (Figure 1-1). The Currituck Outer Banks is an environmentally sensitive region along the North Carolina coast. Currituck County is part of the Pasquotank River Basin, which is characterized by low-lying areas with extensive areas of open water.

Perhaps the most important geographic feature and natural asset in Currituck County is the Currituck Sound, a shallow, 153 square mile estuary separated from the Atlantic Ocean by the Currituck Outer Banks. The Sound has an average depth of 5 feet and maximum depth of about 13 feet. The most significant freshwater inputs to Currituck Sound include North Landing River and Northwest River, both originating in the Great Dismal Swamp of North Carolina and Virginia. Back Bay, a 35 square mile estuary located in Virginia, also discharges water into the Sound through shallow water channels on the back side of the Outer Banks. Water level fluctuations in Currituck Sound are a function of prevailing winds and possible point source inputs of brackish water from Federal navigation canals which also influences the salinity of the sound.

Figure 1-1. Geographic Setting for Currituck County

1.3. STORMWATER MANAGEMENT ZONES

Stormwater management is a challenging exercise in North Carolina's coastal counties, often complicated by low topographic relief, high groundwater tables, and poorly drained soils. Currituck County is no exception. Addressing stormwater management issues in Currituck is facilitated by dividing Currituck County into stormwater management zones, each with its own unique set of characteristics with regard to soils, hydrology, and topography (Figure 1-2). The key characteristics, challenges, and management strategies for each zone are presented below, with appropriate stormwater management approaches including suitable modeling methods to calculate stormwater needs and size, as well as identification of the appropriate suite of BMPs for each zone.

1.3.1. Outer Banks

This zone includes the entire barrier islands portion of Currituck County, which are characterized by predominately sandy, highly porous soils with connectivity between surface waters and the groundwater table. In low lying areas, there are some mucky, poorly drained soils. The barrier islands are also characterized by areas with some topographic relief low spots that are subject to flooding as a result of storm events and prolonged high groundwater table conditions.

Challenges

- Southern portion of the Outer Banks is characterized by high-density development of residential/vacation properties and commercial land uses with only minimal stormwater controls
- Northern portion of the Outer Banks currently exhibits minimal development and lack of infrastructure to sustain significant growth, but is subject to development pressure
- Limited space for stormwater management practices and high land costs
- Lot fill practices have aggravated flooding problems in low-lying areas

Management Strategies

- Better management of, or restrictions on, lot filling to minimize impacts to adjacent lower properties
- Requirements for retrofitting stormwater management systems in conjunction with redevelopment or existing lots, even at the individual lot scale
- Facilitate/encourage use of low impact development methods to reduce runoff and water quality impacts at the source
- Emphasize BMPs that promote infiltration where practical to reduce both quantity and quality impacts

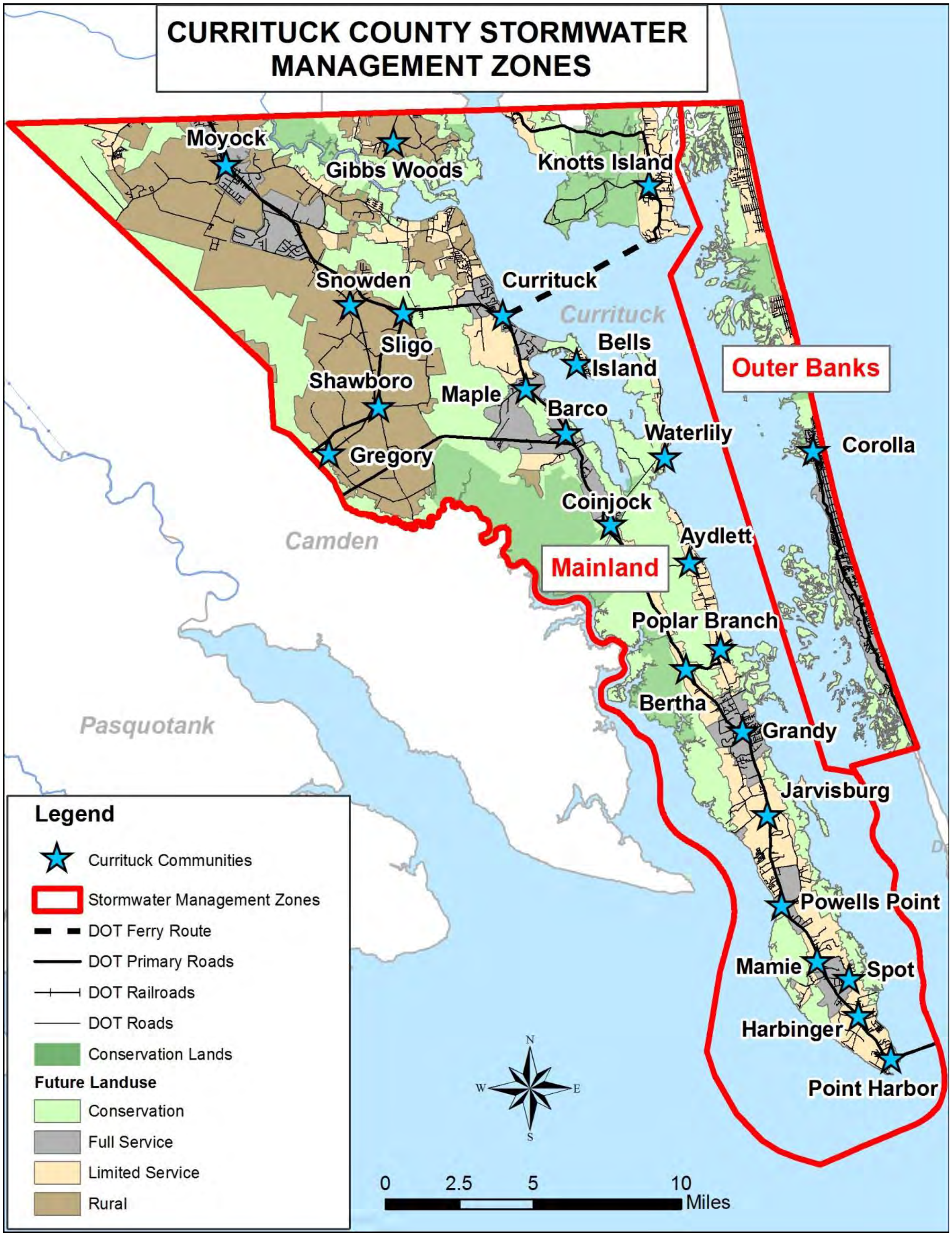


Figure 1-2: Currituck County Stormwater Management Zones

1.3.2. Mainland

This zone includes Knotts Island, Bells Island, and all other portions of Currituck County not directly connected to the Outer Banks peninsula. This zone is characterized by expansive areas of wetlands and land areas designated for conservation, with narrow ridges exhibiting some topographic relief and soils more conducive to drainage. The major roadways tend to track the ridgelines and Currituck County's land use plan includes several full service areas that will focus urban development primarily along these ridges. Modification of the natural drainage network in this zone has been minimal to moderate.

Challenges

- Small areas contiguous with the ridge lines still have pockets with high groundwater tables and poorly drained soils, requiring tailored management on a case-by-case basis
- Intermittent low lying areas, many of which are already developed near shorelines

Management Strategies

- Implementation of improved water quality performance standards and density restrictions to direct development away from poorly drained or environmentally sensitive areas
- Requirements for retrofitting stormwater management systems in conjunction with redevelopment of existing single commercial lots
- Facilitate/encourage use of low impact development methods to reduce runoff and water quality impacts at the source, especially in full service areas
- Emphasize BMPs that promote infiltration where practical to reduce impacts and promote water quality
- Employ retention/detention BMPs where necessary

This northwest portion of the Mainland, approximately from Tulls Creek west, is predominated by expansive low-lying areas with mucky and peaty soils with poor drainage. Extensive agricultural lands are present within this zone, and modification of the natural drainage network is extensive throughout. Relative to the rest of the Mainland, the distinct soils and hydrology within this northwest portion of Currituck County offer their set of challenges and management objectives, which are enumerated as follows:

Challenges

- High seasonal groundwater table and low soil permeability in most of the zone
- Despite soils and topography not conducive to development and stormwater management, a significant amount of development has occurred in this zone. Currituck County's land use plan includes two full service areas in central Moyock and immediately southeast

<u>Management Strategies</u>

- Emphasize retention/detention BMPs as a means of managing the quality and quantity of runoff
- Employ low impact development methods with infiltration BMPs accompanied by under-drains where soil and topography will allow and encourage water harvesting and reuse where possible
- Define clear criteria for stormwater plans that will promote sufficient downstream drainage capacity
- Establish drainage districts and easements as necessary to promote and protect adequate drainage infrastructure
- Emphasize improved design criteria to ensure that BMPs will have proper sizing and function

Chapter 2: Stormwater Management

CHAPTER 2. STORMWATER MANAGEMENT

2.1. BACKGROUND

As a low lying coastal county, Currituck County has historically experienced flooding problems during significant storm events. In recent years, such flooding events have been exacerbated in portions of Currituck County that have experienced significant growth, along with the associated increases in impervious surfaces and stormwater runoff. Several aggravating factors contributing to the flooding issues include: low elevations, flat topography, high groundwater tables, and poorly drained soils. As a result of these key factors, significant storm events can easily generate sufficient runoff volumes to overwhelm existing drainage networks, especially when levels of impervious cover are increased.

Figure 2-1: Example of Flooding on the Outer Banks

Many areas, and particularly the northwest portion of Currituck County in the vicinity of Moyock, have seen dramatic development as a result of suburban sprawl. In many cases, new developments have had to rely on the limited capacity of remnant agricultural drainage ditches to convey stormwater after the BMPs have reached their holding capacity. Engineering analysis has determined that the discharge capacity of these existing ditches is approximately equal to peak runoff from the 2-year, 24-hour storm event emanating from a wooded site with good soils.

For this reason, Currituck County requires all major subdivisions to implement sufficient structural controls to reduce the peak discharge from the 10-year storm event to a level equal to the peak runoff anticipated from a 2-year event under wooded conditions. Similarly, all commercial, institutional and other developments submitting Major Site Plans are required to implement sufficient structural controls to reduce the peak discharge from the 5-year storm event to a level equal to the peak runoff anticipated from a 2-year event under wooded conditions. In addition, single-family lots wishing to exceed the allowable percentages of lot coverage established in the UDO may achieve additional lot coverage, up to 15%, by implementing stormwater controls as defined in Section 2.3 of this Manual. Single family lots that employ the use of fill to raise elevation beyond surrounding grades will also be required to implement stormwater controls. All minor

subdivisions located on the Outer Banks and all minor subdivisions (regardless of location) that employ the use of fill to raise elevation beyond surrounding grades will also be required to implement stormwater controls.

By adopting these standards, Currituck County seeks to eliminate the legal and jurisdictional issues associated with requiring developers to improve existing drainage channels beyond their project site and mitigate the effect of development on future flooding levels.

In preparation for revision of the stormwater performance standards to reduce runoff volumes to levels that could be effectively transported by the existing drainage capacity, Currituck County conducted a hydrologic modeling study which simulated different pre- and post-development scenarios to determine an acceptable standard which would reduce flooding. Test scenarios for major subdivision developments were modeled using a theoretical 100-acre site typical to Currituck County and were aggregated by soil hydrologic group. Figure 2-2 presented below illustrates the portion (as a percentage) of the theoretical site required to reduce the 10-year, 24-hour peak discharge from the proposed developed condition down to that from the wooded condition for the 2-year, 24-hour storm event. As can be seen from the graph, reducing the discharge from the 10-year storm will require between 5-10% of the land area for most development patterns while current regulations would require approximately 3-6% of the site. In all cases, the new requirement is more stringent than the DWQ standard of 1.5" of rainfall.

Because the County was concerned about overly constraining development on small commercial sites due to the amount of land consumed by the stormwater controls necessary to capture the runoff from the 10-year storm event (as described above), a separate modeling analysis was conducted to examine the amount of land that would be required to reduce the reduce the 5-year, 24-hour peak discharge from the proposed developed condition down to that from the wooded condition for the 2-year, 24-hour storm event. The results of the modeling analysis examining the implication of capturing the 5-years storm event are shown in Figure 2-2. Just as with the results from the 10-year storm event, the new requirement is more stringent than, or equally stringent to, the DWQ standard of 1.5" of rainfall. However, with capture of the 5-year storm event, the land area required for stormwater detention facilities at 65% built-upon area ranges from approximately 4.5-7.5%, instead of the 8-10% of the site required to capture the 10-year event at the same development intensity.

2.1.1. Stormwater Management on the Outer Banks

Substantial areas within the southern portion of the Currituck Outer Banks (from the Corolla Area south) have been developed without significant water quantity controls or water quality protection requirements for stormwater runoff, and the development there has occurred at fairly high densities. The water quality impacts of this development are compounded by the fact that the barrier islands have the most immediate hydrologic connection to the adjacent Currituck Sound. Achievement of stormwater volume reductions and water quality protection in this zone will require retrofitting of stormwater BMPs within areas that are already developed through requirements for stormwater BMPs on individual residential lots as infill properties are developed and as existing properties are redeveloped.

The northern portion of the Currituck Outer Banks (from the Corolla Area north), often referred to as the Four-Wheel Drive Area, is far less developed and is characterized by a lack of paved roads from just north of the Corolla Light up to the Virginia state line. While the vast majority of parcels remain undeveloped, over 3,000 lots are already platted and sold in the Four-Wheel Drive Area with a typical lot size in the range of one third to one half acre. Full development of this portion of the Outer Banks, along with the roadways and other infrastructure necessary to support that development, will result in large increases in impervious surface and the associated stormwater runoff. Preventing the adverse impacts of this additional stormwater runoff will require that runoff volumes are treated and reduced on individual single-family residential lots as they are developed.

Requirements for stormwater detention and infiltration on individual single family residential lots on the Outer Banks are addressed in Section 2.2 below.

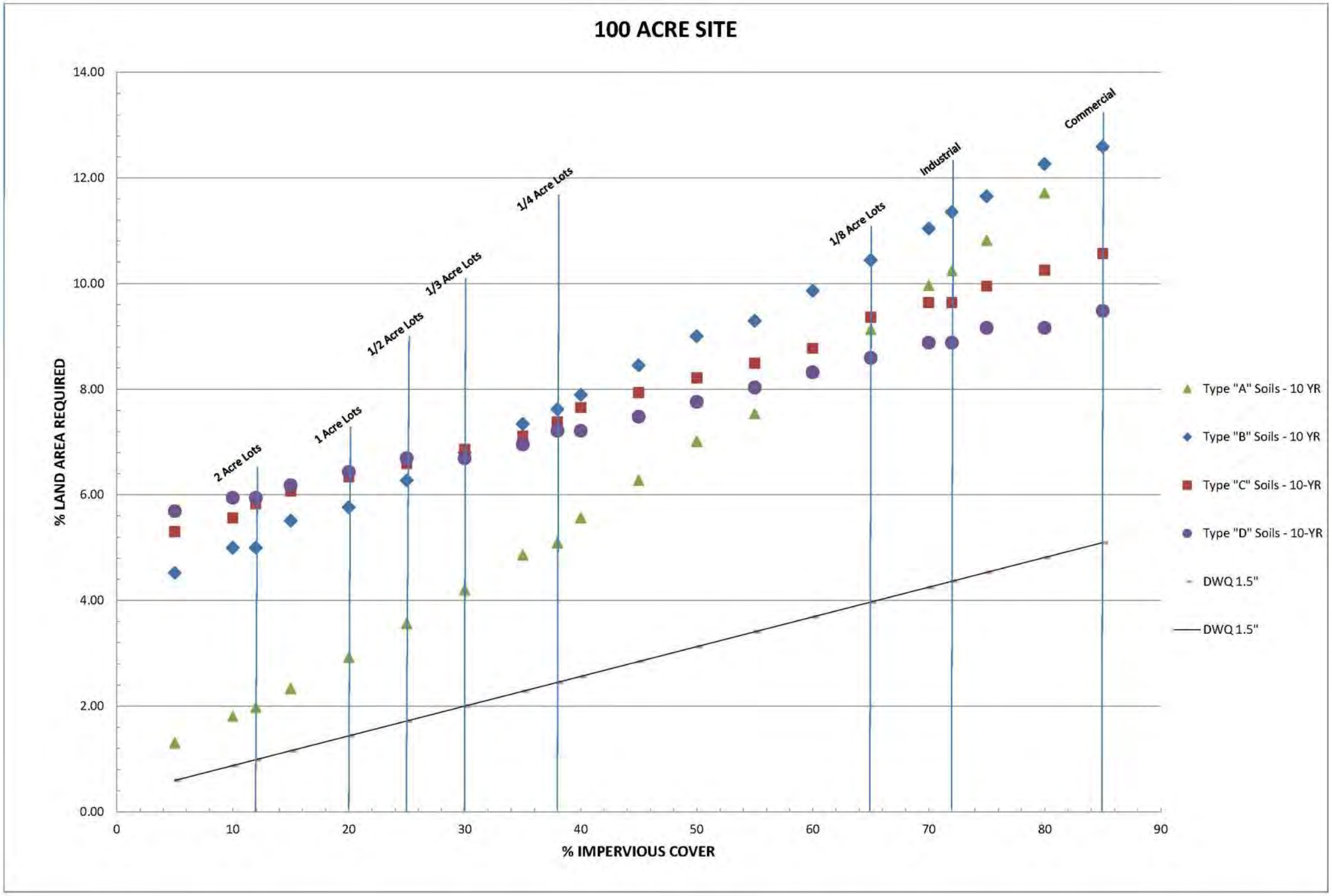


Figure 2-2: Percent Land Area Required to Reduce Post-Development Peak Runoff Rate from a 10-Yr, 24-Hr Event to a Level Equal to the Pre-Development Peak Runoff from a 2-Yr, 24-Hr Event under Forested Conditions

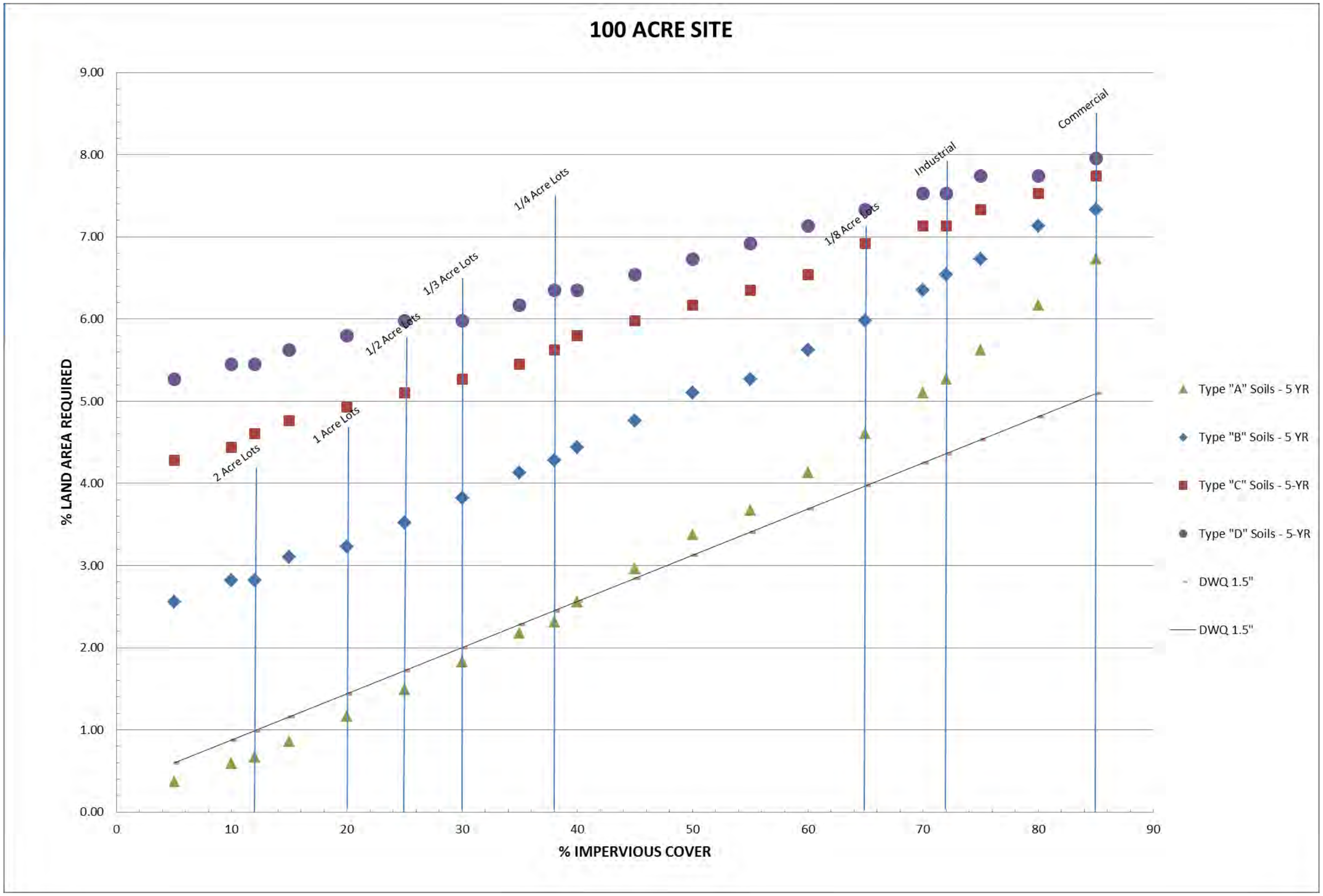


Figure 2-3: Percent Land Area Required to Reduce Post-Development Peak Runoff Rate from a 5-Yr, 24-Hr Event to a Level Equal to the Pre-Development Peak Runoff from a 2-Yr, 24-Hr Event under Forested Conditions

2.2. STORMWATER PLAN REQUIREMENTS

The Currituck County UDO stipulates the submittal of Stormwater plans in conjunction with major site plans, major subdivisions, and specified development on the Outer Banks. Alternative stormwater plans are allowed for specified deviations from stormwater standards. The Stormwater plan requirements reflected below are to apply to all land development and lot improvement activities that are subject to the stormwater performance standards set forth in the UDO. The following subsections are intended to enumerate those development activities that will be required to submit Stormwater plans. Development activities that are exempt from the requirement to submit Stormwater plans are also enumerated. The elements required in those Stormwater plans are described in detail in the following sections.

There are two types of Stormwater plans required; 1) those required for development or improvement of individual single-family residential lots, minor subdivisions on the Outer Banks and single-family residential lots and minor subdivisions, regardless of location, with fill above maximum allowed, which are described in Section 2.2.1; and 2) those required for major subdivisions and major site plans throughout Currituck County, which are described in Section 2.2.2

2.2.1. Minor Stormwater Plan Applicability

Development meeting the following requirements shall submit a Minor Stormwater Plan (Form SW-001) and follow the requirements set forth in Section 2.3 below:

A. New or existing single-family residential lots adding impervious area resulting in total impervious cover (based on lot size) greater than the thresholds set forth in Section 2.7 of the UDO, as shown in Table 2.1 (such lots may have an additional 15% impervious cover, up to the increased thresholds given);

Table 2-1: Allowable Impervious Cover on Residential Lots (UDO Section 2.7)

Lot Size	Allowable Impervious Cover	Allowable Cover with Stormwater Controls (per SW-001)
Less than 10,000 sf	45%	60%
10,000-19,000 sf	35%	50%
Greater than 19,000 sf	30%	45%

B. New or existing single-family residential lots located within the Outer Banks Stormwater Management Zone adding new impervious area resulting in 10,000 square feet or more total impervious cover (regardless of lot size);

C. New or existing lots that propose fill to achieve elevations above surrounding grades as outlined in Section 2.5; or

D. New minor subdivisions located within the Outer Banks Stormwater Management Zone or that (regardless of location) propose fill to achieve elevations above surrounding grades as outlined in Section 2.5.

2.2.2. Major Stormwater Plan Applicability

Development meeting the following requirements shall submit a Major Stormwater Plan (Form SW-002) and follow the requirements set forth in Section 2.4 below:

A. Development or expansion on a nonresidential, multi-family, or mixed use lot by 5,000 square feet or more of impervious coverage or resulting in 10% or more total impervious coverage (based on lot size); or

B. Major subdivisions.

2.2.3. Stormwater Plan Exemptions

The following types of development projects and activities are exempt from the requirement to submit a Stormwater plan (stormwater detention requirements):

A. Improvements or additions made to existing single-family residential lots resulting in total impervious cover (based on lot size) less than the thresholds set forth in Section 2.7 of the UDO, as shown in Table 2.1.

B. Improvements or additions made to lots with an approved state stormwater permit, which do not exceed the allowable coverage.

C. Any new single-family residential lot developed within the Outer Banks Stormwater Management Zone having total impervious cover (based on lot size) less than the thresholds set forth in Section 2.7 of the UDO, as shown in Table 2.1, and less than 10,000 square feet of total impervious cover;

D. Any new or existing lot that proposes fill below the maximum allowed as outlined in Section 2.5;

E. Any minor subdivision located within the Mainland Stormwater Management Zone that proposes fill below the maximum allowed as outlined in Section 2.5;

F. The division of five or fewer additional lots with an average lot size greater than three acres located within a single-family residential subdivision platted prior to January 1, 2013; or

G. Development or expansion on a nonresidential, multi-family, or mixed-use lot by less than 5,000 square feet of impervious surface or resulting in less than 10 percent total lot coverage. This exemption does not include multiple, incremental expansions that result in a reduction of stormwater management standards.

2.3. MINOR STORMWATER PLANS

2.3.1. Application and Review Process

All applicants required to submit a Minor Stormwater Plan (refer to Section 2.2.1) must meet the required plan elements outlined in this manual and Unified Development Ordinance. Applicants submitting Minor Stormwater Plans are **not required** to have professional engineering and design assistance, except that increases in lot coverage and alternative BMPs must be designed and sealed by a registered engineer. The burden of proving compliance with the stormwater standards and the cost associated with providing such proof is the responsibility of the applicant. It is the responsibility of the applicant to provide sufficient information on the plan so that Currituck County or its agents can reasonably evaluate the characteristics of the disturbed areas, the potential impacts or the proposed development on existing water courses, and the effectiveness of the proposed stormwater control measures proposed. The Stormwater plan must be **submitted and approved** before:

- An existing drainage system is altered;
- Any land disturbing activity is performed; or
- A building permit is issued.

Applicants developing a Stormwater plan for individual lots shall use the guidance in Sections 2.3.3 – Rain Gardens and 2.3.4 – Swales for sizing the required stormwater feature or Best Management Practice (BMP) based on the required volume calculated below. Rain gardens or stormwater swales are recommended, as they are the easiest to implement; however, applicants may use alternative BMP designs. Design guidance for alternative BMPs can be found in Appendix B.

It should be noted that fill and land disturbing activities, excluding clearing, grubbing and landscaping, shall not be permitted within ten feet from any lot line with the exception of drainage and stormwater improvements as approved by the County Engineer.

2.3.2. Minor Stormwater Plan Design Requirements

Minor Stormwater Plan Design Standards Checklist		
	General	
1	Property owner name and address.	
2	Site address and parcel identification number.	
3	North arrow and scale to be 1" = 100' or larger.	
	Site Features	
4	Scaled drawing showing existing and proposed site features: Property lines with dimensions, acreage, streets, easements, structures (dimensions and square footage), fences, bulkheads, septic area (active and repair), utilities, driveways, and sidewalks.	
5	Approximate location of all designated Areas of Environmental Concern (AEC) or other such areas which are environmentally sensitive on the property, such as Maritime Forest, CAMA, 404, or 401 wetlands as defined by the appropriate agency.	

6	Square footage of all impervious areas (structures, sidewalks, walkways, vehicular use areas regardless of surface material).	
7	Description of surface materials.	
8	Stormwater storage volume calculations using the following formula: Volume = Impervious Area (ft^2) * 4" rainfall * $\frac{1\ \text{foot}}{12\ \text{inches}}$	
9	Existing and proposed drainage patterns.	
10	Location and capacity of existing and proposed stormwater management features.	
11	Plant selection	
12	Alternative stormwater runoff storage analysis, if applicable	
Fill		
13	Purpose of proposed fill.	
14	Existing and proposed ground elevations shown in one foot intervals. All elevation changes within the past six months shall be shown on the plan. The toe of the fill slope shall be indicated on the plan.	
Certificate		
15	The minor stormwater plan shall contain the following certificate: I, _______________, owner/agent hereby certify the information included on this and attached pages is true and correct to the best of my knowledge. On the site plan entitled _________________, stormwater drainage improvements shall be installed according to these plans and specifications and approved by Currituck County. Yearly inspections are required as part of the stormwater plan. The owner is responsible for all maintenance required. Currituck County assumes no responsibility for the design, maintenance, or performance of the stormwater improvements. Date:______________ Owner/Agent:__________________	

Following construction of all improvements required by an approved minor stormwater plan, the below certification must be executed and submitted prior to issuance of a certificate of occupancy.

Based upon site observations and/or information provided by the design professional, I hereby certify that all proposed drainage improvements, grading, structures, and/or systems have been completed in substantial conformance with the approved plans and specifications.

____ _______________

Owner/Agent *Date*

____ _______________

Design Professional *Date*

2.3.3. Rain Garden Design Guidance

The primary goal of rain garden design and implementation for individual lots is to encourage rainfall to infiltrate the soil, rather than allow it to leave the site as stormwater runoff. This approach more closely mimics the natural hydrology on the Outer Banks. It reduces the demand on the existing drainage infrastructure, and reduces the amount stormwater pollution entering the surrounding surface waters as a result of development. This section is organized as a series of steps for a designer to determine the appropriately-sized rain garden for a site.Rain gardens that are not designed to meet these standards will not be considered an acceptable BMP in the Stormwater plan.

Figure 2-4: Example Rain Garden (Image courtesy of NCSU-BAE)

A. Rain Garden Area Sizing

Rain garden areas shall be sized to either infiltrate or detain the approximate runoff generated from the impervious areas during a 4-inch rain event. The areas must be dedicated permanent stormwater treatment and cannot be developed at a later time. Recognize that drainage areas to rain garden areas can be adjusted by diverting water to or away from the areas using berms or channels. The areas must not overlay septic system drain fields. Following are steps to guide the designer through the calculation:

Step 1: Determine the impervious area draining to the rain garden area, in square feet.

Step 2: Determine the required storage volume for the site (from Form SW-001), in cubic feet.

Step 3: The required area is calculated as follows: *Stormwater Storage Area* (ft^2) = *Stormwater Storage Volume* (ft^3) / *Depth of Rain Garden (ft)*

The depth of the rain garden is depended on the depth to the water table, which is site-specific. However, the maximum allowable depth of the rain garden is 2.0 feet. If the depth to the water table is less than 2 feet, the designer must adjust the depth to match the site conditions.

Step 4: Determine where the rain garden is most suited for the available space (Figure 2-5). If the area required is too large to fit within the available space within the lot, try diverting stormwater from impervious areas through swales or channels to several smaller areas spaced throughout the property. Or utilize alternative types of BMPs described in *Appendix B - Best Management Practices.*

Step 5: While not required for functionality, rain gardens can be aesthetically pleasing features with careful selection of native and ornamental plants. Guidance for plant selection is provided below.

B. Plant Selection

Selecting plants for stormwater BMPs requires knowledge and strategy. The water conditions within BMPs can be difficult to predict and can follow an extreme range from very dry to ponding water for days. These characteristics limit the variety of plants suitable for use in BMPs. General strategies to help improve plant survival include:

(1) A diverse selection of plants so that if some perform poorly, others may thrive, still leaving a well-vegetated BMP.
(2) Creating zones within the rain garden with a range of water ponding times, for example by varying the bottom elevation, by planting some plants on soil mounds, or by planting some plants on the banks of the rain garden.
(3) Watering during droughts if plants appear stressed.
(4) Use of native species.

Refer to Appendix E – *Rain Garden Plantings* for a short list of the most proven plants for rain gardens in Eastern North Carolina. The plants are numbered according to its water tolerance. Plants in the "l" or "2" range typically are for rain gardens that drain quickly. These plants are hardier during periods of drought. Plants within the "3" range prefer wetter conditions, and are ideal for rain gardens that will retain water for several days. *Appendix D - Recommended Plantings* also provides a more extensive list of plants suitable for rain gardens.

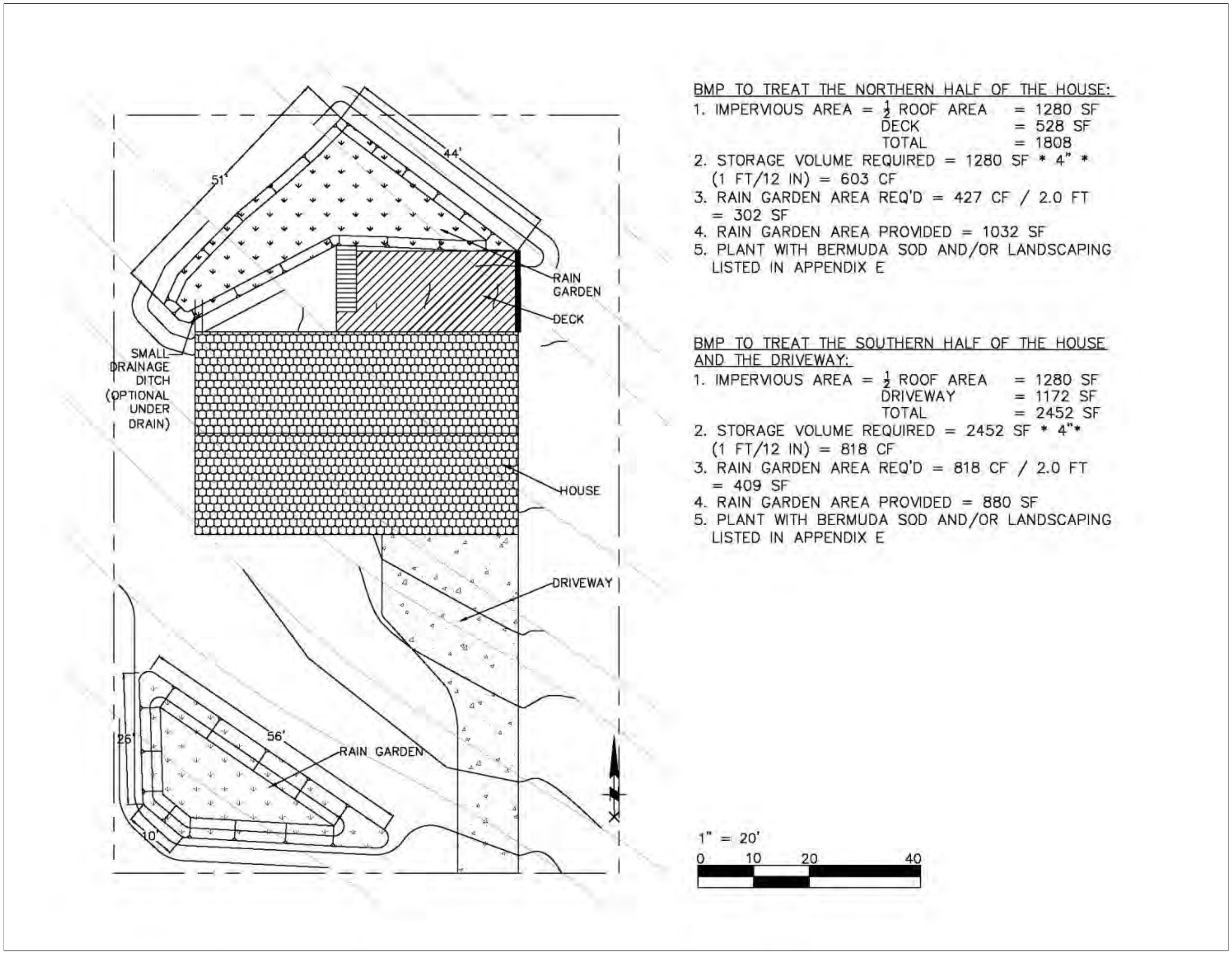


Figure 2-5: Example Rain Garden Design and Layout

2.3.4. Stormwater Swale Design Guidance

Figure 2-6: Example of a Stormwater Swale

Swales are shallow, open channels that are graded and landscaped with plants or grass. When designed correctly, swales provide effective stormwater treatment for small impervious areas by slowing down runoff and allowing for more infiltration.

Lot-line swales are located typically along property lines and are graded to meet site plan requirements.

Applicants may choose to use swales as part of the individual single-family residential Stormwater plan; however, swales not designed to meet these standards will not be considered an acceptable BMP in the Stormwater plan.

A. Swale Area Sizing

Swales shall be sized to either infiltrate or detain the approximate runoff generated from the impervious areas during a 4-inch rain event. The area must be dedicated permanent stormwater treatment and cannot be developed at a later time. The swales must not overlay septic system drain fields. Following are steps to guide the owner through the calculation:

Step 1: Determine the impervious area draining to the swale, in square feet.

Step 2: Determine the required storage volume for the site (from Form SW-001), in cubic feet.

Step 3: Swales are typically trapezoidal in shape with a two (2) foot base and 5:1 side slopes. The maximum allowable depth is two (2) feet. Determine the length of swale necessary to treat the required volume by the following equation: *Cross-sectional Area of Swale* (ft^2) = *Base (ft) * Depth (ft) + Depth * 5 * Depth*
Length (ft) = Stormwater Storage Volume (ft^3) */ Cross-sectional Area of Swale*

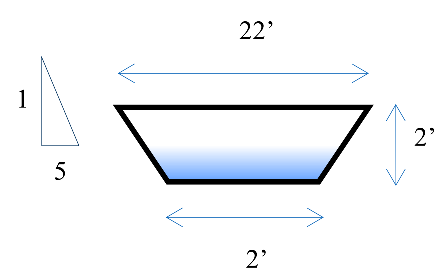


Figure 2-7: Cross-Sectional Area of Swale

Step 4: To keep velocities low and allow for maximum infiltration, the maximum longitudinal (along the length of the swale) slope allowed is 0.5%.

Step 5: Determine where the swale is most suited for the available space (Figure 2-8). If the length required is too long to fit within the available space within the lot, try diverting stormwater from impervious areas to several smaller swales or rain gardens spaced throughout the property. Or utilize alternative types of BMPs described in *Appendix B - Best Management Practices.*

Step 6: While not required for functionality, swales can be aesthetically pleasing features with careful selection of native and ornamental plants. Guidance for plant selection is provided below.

B. Plant Selection

Generally, grass is more suited to swales as a ground cover. Typically, Bermuda sod is ideal as it is drought-tolerant. Swales that act more as rain gardens, (i.e. where water will pond for 24-48 hours), ornamental and native plants can make a swale an aesthetic feature for landscaping. Ground cover shall also be planted along the side slopes of the swale. General strategies to help improve plant survival include:

(1) A diverse selection of plants so that if some perform poorly, others may thrive, still leaving a well-vegetated BMP.

(2) Watering during droughts if plants appear stressed

(3) Use of native species

For grasses, other than Bermuda sod, to use in swales, refer to *Appendix D-Recommended Plantings*: *Turf Gasses for Grassed Swales.* For ornamental and native species, refer to Appendix E – *Rain Garden Plantings* for a short list of the most proven plants for swales in Eastern North Carolina. The plants are numbered according to its water tolerance. Plants in the “l” or “2” range typically are for swales that drain quickly. Plants within the “3” range prefer wetter conditions, and are ideal for swales that will retain water for several days. *Appendix D - Recommended Plantings* also provides a more extensive list of plants.

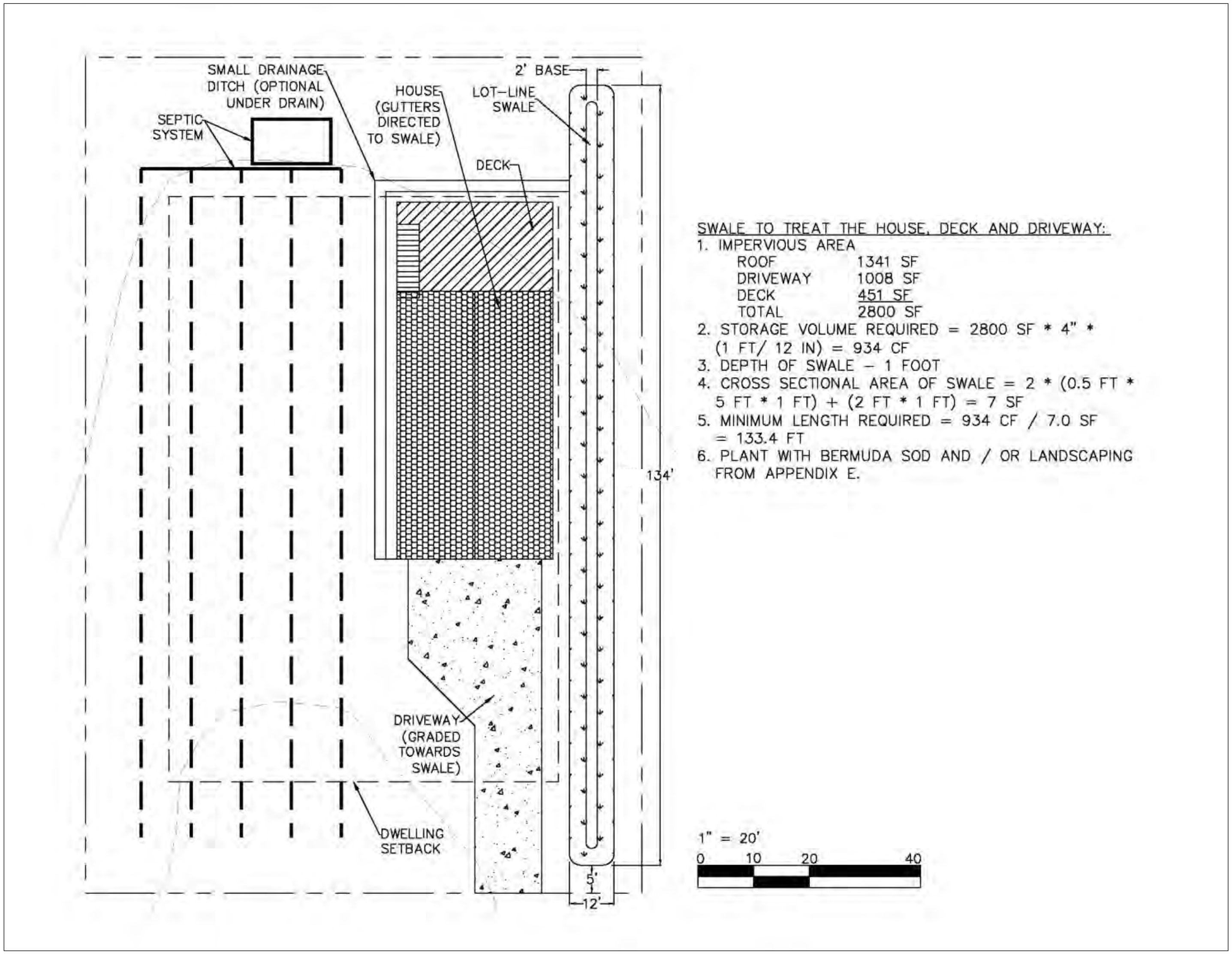


Figure 2-8: Example Swale Design and Layout

2.3.5. Alternative Stormwater Runoff Storage Analysis (Minor)

Soils can have significant capacity to store stormwater runoff naturally within the existing soil profile. An applicant may submit and alternative analysis demonstrating and accounting for the natural storage capacity of the soils on their site. The natural soil storage capacity may be counted toward increased amounts of impervious surface, reduction in the size of the required stormwater BMP, or elimination of the BMP altogether, if sufficient natural soil storage capacity is present. Stormwater plans which include and account for the natural soil storage capacity are **required to be sealed by a professional engineer,** and shall include the following elements in addition to those enumerated in Section 2.3.2 in conjunction with a Minor Stormwater Plan (Form SW-001):

- Site Plan indicating topographic contours of the finished site at 1-foot intervals or less with arrows indicating flow directions and paths of stormwater runoff and how the impervious surfaces of the site drain to pervious areas
- A site soils analysis performed by a licensed soil scientist indication the depth to seasonal high water table as well as the soil porosity and soil infiltration rates.

The BMP (swale or rain garden) may be reduced in size, or even eliminated through demonstration of sufficient infiltration and storage capacity to capture the required runoff volume. Credit toward rapid infiltration rates may only be achieved when infiltration rates exceed 0.52 inches/hour, which is the minimum rate necessary to prevent excessive periods of standing water.

In order to receive credit for the natural soil storage available on the site, the site must be graded such that the portions of the site counted for natural storage are fully accessed by runoff emanating from the impervious surfaces. Storage within pervious portions of the site that do not receive runoff cannot be credited.

2.4. MAJOR STORMWATER PLANS

2.4.1. Application and Review Process

All applicants required to submit a Major Stormwater Plan (refer to Section 2.2.2) must meet the required plan elements outlined in this manual and Unified Development Ordinance, and any other applicable state and federal stormwater regulations. A professionally designed Stormwater plan designed and sealed by a North Carolina licensed Professional Engineer (PE) shall be required for all major subdivision and major site plan projects. It is the responsibility of the applicant to provide sufficient information in the plan so that Currituck County or its agents can reasonably evaluate the characteristics of the disturbed areas, the potential impacts or the proposed development on existing water courses, and the effectiveness of the proposed stormwater control measures proposed. The Stormwater plan must be **submitted and approved** before:

- An existing drainage system is altered;
- Any land disturbing activity is performed; or
- Before construction documents are approved.

2.4.2. Major Stormwater Plan Design Requirements

Minor Stormwater Plan Design Standards Checklist		
	General	
1	Property owner name and address.	
2	Site address and parcel identification number.	
3	North arrow and scale to be 1" = 100' or larger.	
	Site Features	
4	Scaled drawing showing existing and proposed site features: Property lines with dimensions, acreage, streets, easements, structures (dimensions and square footage), fences, bulkheads, septic area (active and repair), utilities, vehicular use areas, driveways, and sidewalks.	
5	Approximate location of all designated Areas of Environmental Concern (AEC) or other such areas which are environmentally sensitive on the property, such as Maritime Forest, CAMA, 404, or 401 wetlands as defined by the appropriate agency.	
6	Existing and proposed ground elevations shown in one foot intervals. All elevation changes within the past six months shall be shown on the plan.	
8	Limits of all proposed fill, including the toe of fill slope and purpose of fill.	
9	Square footage of all existing and proposed impervious areas (structures, sidewalks, walkways, vehicular use areas regardless of surface material), including a description of surface materials.	
10	Existing and proposed drainage patterns, including direction of flow.	
11	Location, capacity, design plans (detention, retention, infiltration), and design discharge of existing and proposed stormwater management features.	
12	Elevation of the seasonal high water level as determined by a licensed soil scientist.	
13	Plant selection.	
	Permits and Other Documentation	
14	NCDENR stormwater permit application (if 10,000sf or more of built upon area).	
15	NCDENR erosion and sedimentation control permit application (if one acre or more of land	

	disturbance).	
16	NCDENR coastal area management act permit application, if applicable.	
17	Stormwater management narrative with supporting calculations.	
18	Rational Method Form SW-003 or NRCS Method Form SW-004	
19	Alternative stormwater runoff storage analysis and/or downstream drainage capacity analysis, if applicable	
20	Design spreadsheets for all BMPs (*Appendix F – Currituck County Stormwater Manual*).	
21	Detailed maintenance plan for all proposed BMPs.	

Following construction of all improvements required by an approved minor stormwater plan, the below certification must be executed and submitted prior to issuance of a certificate of occupancy.

Based upon site observations and/or information provided by a licensed surveyor, I hereby certify that all proposed drainage improvements, grading, structures, and/or systems have been completed in substantial conformance with the approved plans and specifications.

____________________________________ ______________

Registered Engineer *Date*

2.4.3. Guidance for Determining Runoff Rate Requirements

Currituck County requires that all major subdivisions (10-year, 24-hour rate) and major site plans (5-year, 24-hour rate) provide adequate stormwater controls to retain the post-development peak discharge so that it does not release a peak discharge greater than the 2-year, 24-hour peak discharge using a **wooded** site condition, regardless of actual pre-development site conditions. The required storms are defined as a total volume of precipitation equal to a certain depth of rainfall in a 24-hour period and have a SCS Type III distribution of precipitation (NRCS, 1986). Average antecedent moisture conditions are assumed for all peak discharge calculations.

Currituck County requires that one of the below methods (Rational or NRCS) be used to calculate the peak discharge from the above-mentioned design storms.

For development where the final build-out will impact less than 10 acres, the Rational Method may be used. The Peak Discharge Method described by the *Natural Resources Conservation Service Technical Release 55* (NRCS, 1986) and/or the methods given in the Hydrology section of the *Natural Resources Conservation Service National Engineering Handbook Technical Release 20* (NRCS, 1985) and included in the TR-20 model, shall be used for drainage areas larger than 10 acres and may also be used for drainage areas smaller than 10 acres if desired.

A. Rational Method

The Rational Method may only be used for development where the final build-out will impact less than 10 acres. A blank form (Form SW-003) for calculating peak runoff using the Rational Method and example calculations are included in *Appendix A- Required Forms*.

Step 1: Determine the drainage area, A, in acres

Step 2: Determine the runoff coefficient, C, for the drainage area under pre-development wooded conditions (see Table 2-2 for appropriate runoff coefficients)

Table 2-2: Runoff Coefficients for Currituck County

Cover Description	C
Single-family Residential	0.40
Detached Multi-family Residential	0.50
Attached Multi-family Residential	0.68
Apartment Buildings	0.75
Commercial	0.85
Industrial	0.75
Open Space	0.25
Impervious Area (Driveways, Roofs, Roads, etc.)	0.95
Row Crops	0.35
Pasture	0.30
Woods	0.20

Step 3: Determine the time of concentration, T_C, for the drainage area using the segmental method:

Sheet Flow

$$T_{C1} = \frac{0.42(nL)^{0.8}}{P^{0.5}S^{0.4}}$$

Where:

T_{C1} = time of concentration of sheet flow in minutes

n = Manning's roughness coefficient (see Table 2-4: Manning's Roughness Coefficients)

P = 4.0 inches (rainfall depth for the 2-yr, 24-hr design storm)

S = slope of hydraulic grade line (feet/feet), usually taken as the land slope

L = length of sheet flow (less than 300 feet)

Shallow Concentrated Flow

$$T_{C2} = \frac{L}{V}$$

Where:
T_{C2} = time of concentration of shallow concentrated flow in minutes
L = length of shallow concentrated flow in feet (Typically, shallow concentrated flow is between sheet flow and a noticeable channel or ditch.)
V = shallow concentrated flow velocity in feet per minute (see Table 2-3)

Table 2-3: Shallow Concentrated Flow Velocity

Land Use	Velocity Equation
Paved Areas	$V = 1302S^{0.53}$; Where $S = water\ flow\ slope$
Unpaved Areas	$V = 972S^{0.53}$; Where $S = water\ flow\ slope$

Channel Flow

To determine the velocity associated with channel flow, determine whether the channelization occurs in an open channel or a piped channel. Determine the cross sectional area of either the open channel or pipe (in square feet). Then determine the wetted perimeter of the open channel or pipe.

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

Where:
R = hydraulic radius in feet
A = cross sectional area of channel in square feet
W = wetted perimeter in feet

$$V = 1.49\,\frac{R^{0.67}S^{0.5}}{n}$$

Where:
V = channel velocity in feet per second
R = hydraulic radius in feet
S = slope of hydraulic grade line
n = Manning's roughness coefficient (see Table 2-4: Manning's Roughness Coefficients)

$$T_{C3} = \frac{L}{60V}$$

Where:
T_{C3} = time of concentration of channel flow in minutes
L = length of shallow concentrated flow in feet
V = channel flow velocity in feet per minute

Total Time of Concentration

$$T_C = T_{C1} + T_{C2} + T_{C3}$$

Table 2-4: Manning's Roughness Coefficients

Surface Description	n
Smooth surfaces (concrete, asphalt, etc.)	0.013
Row crops	0.04
Grass	0.035
Natural channels	0.04
Woods	0.1

Step 4: Determine the peak rainfall intensity, i, using Table 2-5. Current rainfall intensities can also be downloaded from the NOAA website:
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nc

Table 2-5: Rainfall Intensity for Currituck County (NOAA, 2011)

	Time of Concentration									
T (yrs)	5 min	10 min	15 min	30 min	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	6.06	4.84	4.06	2.80	1.76	1.03	0.731	0.434	0.254	0.156
5	6.82	5.46	4.60	3.27	2.10	1.26	0.897	0.534	0.313	0.201
10	7.82	6.26	5.28	3.82	2.49	1.51	1.09	0.645	0.381	0.239

Step 5: Determine the peak discharge, Q

$$Q = CiA$$

Where:

Q = peak discharge in cubic feet per second
C = runoff coefficient
i = rainfall intensity in inches per hour for time of concentration found in Step 4
A = drainage area in acres

Step 6: Determine the weighted runoff coefficient, C_w, for the post-development conditions using Table 2-2. To calculate a weighted curve number:

$$C_W = \frac{\sum(A * C)}{\sum A}$$

Where:
C_W = weighted runoff coefficient
A = area in acres
C = runoff coefficient

Repeat Steps 2 through 5 for the post-development conditions, using the weighted runoff coefficient and the 10-year design storm for subdivisions, or the 5-year storm for all other Major Stormwater Plans.

B. NRCS Peak Discharge Method (TR-55 & TR-20)

The NRCS Peak Discharge Method may be used to calculate peak discharges for any development. The TR-55 blank forms (Form SW-004) for calculating peak runoff using NRCS Method are included in *Appendix A - Required Forms*. If using a computer model, an engineering summary of the calculations shall be prepared and/or computer input and simulation results shall be submitted in both printed and electronic forms, along with Form SW-004. Example calculations are also included in Appendix A.

Step 1: Determine the drainage area, hydraulic length (the distance from the most remote point to design point), hydrologic soil type, and average slope (percent) of the pre-developed watershed.

Step 2: Determine the curve number, CN, for the drainage area under pre-development wooded conditions based on soil type (see Table 2-6 for appropriate curve numbers)

Table 2-6: Currituck County Curve Numbers

Cover Description	Hydrologic Soil Type			
	A	B	C	D
Residential -1/8 acre or less	77	85	90	92
Residential -1/4 acre	61	75	83	87
Residential -1/3 acre	57	72	81	86
Residential -1/2 acre	54	70	80	85
Residential -1 acre	51	68	79	84
Residential -2 acre	46	65	77	82
Commercial	89	92	94	95
Industrial	81	88	91	93
Open Space	49	69	79	84
Newly Graded (no vegetation)	77	86	91	94
Impervious Area (asphalt, concrete, roofs, pools, etc.)	98	98	98	98
Impervious Area (gravel road, including Right-of-Way)	76	85	89	91
Impervious Area (dirt road, including Right-of-Way)	72	82	87	89

Cover Description	Hydrologic Soil Type			
	A	B	C	D
Row Crops	72	81	88	91
Pasture	68	79	86	89
Woods	30	55	70	77

Step 3: Select design storm and determine the runoff depth, Q

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

Where:

Q = runoff depth in inches

P = rainfall depth for the pre-development design storm (see Table 2-7)

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

CN = curve number for wooded condition (see Table 2-6)

Table 2-7: Depth of Precipitation for Required Design Storms

Design Storm	Inches of Rainfall
2-YR, 24-HR	4.0
5-YR, 24-HR	5.0
10-YR, 24-HR	6.0

Step 4: Determine the time of concentration, Tc, for the drainage area using the segmental method:

Sheet Flow

$$T_{C1} = \frac{0.42(nL)^{0.8}}{P^{0.5}S^{0.4}}$$

Where:

T_{C1} = time of concentration of sheet flow in minutes

n = Manning's roughness coefficient (see Table 2-9)

P = 4.0 inches (rainfall depth for the 2-yr, 24-hr design storm)

S = slope of hydraulic grade line (feet/feet), usually taken as the land slope

L = length of sheet flow (less than 300 feet)

Shallow Concentrated Flow

$$T_{C2} = \frac{L}{V}$$

Where:

T_{C2} = time of concentration of shallow concentrated flow in minutes

L = length of shallow concentrated flow in feet

V = shallow concentrated flow velocity in feet per minute (see Table 2-8)

Table 2-8: Shallow Concentrated Flow Velocity

Land Use	Velocity Equation
Paved Areas	$V = 1302S^{0.53}$; Where $S = water\ flow\ slope\ (feet/feet)$
Unpaved Areas	$V = 972S^{0.53}$; Where $S = water\ flow\ slope\ (feet/feet)$

<u>Channel Flow</u>

To determine the velocity associated with channel flow, determine whether the channelization occurs in an open channel or a piped channel. Determine the cross sectional area of either the open channel or pipe (in square feet). Then determine the wetted perimeter of the open channel or pipe.

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

Where:
R = hydraulic radius in feet
A = cross sectional area of channel in square feet
W = wetted perimeter in feet

$$V = 1.49\frac{R^{0.67}S^{0.5}}{n}$$

Where:
V = channel velocity in feet per second
R = hydraulic radius in feet
S = slope of hydraulic grade line
n = Manning's roughness coefficient (see Table 2-9)

$$T_{C3} = \frac{L}{60V}$$

Where:
T_{C3} = time of concentration of channel flow in minutes
L = length of shallow concentrated flow in feet
V = channel flow velocity in feet per minute

Total Time of Concentration

$$T_C = T_{C1} + T_{C2} + T_{C3}$$

Table 2-9: Manning's Roughness Coefficients

Surface Description	n
Smooth surfaces (concrete, asphalt, etc.)	0.013
Row crops	0.04

Grass	0.035
Woods	0.1

Step 5: Determine the pond / swamp adjustment factor (see Table 2-10)

Table 2-10: Pond Adjustment Factor

Portion of Watershed that is a pond or swamp (%)	Pond Adjustment Factor (F_P)
0	1.0
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Step 6: Compute the initial abstraction, I_a

$$I_a = 0.2(\frac{1000}{CN} - 10)$$

Where:
I_a = initial abstraction in inches
CN = curve number for wooded condition (see Table 2-6)

Step 7: Compute I_a/P; where P = 4.0 inches rainfall depth for the 2-year, 24-hour storm.

Step 8: Compute the unit peak discharge, q_u, using Figure 2-9.

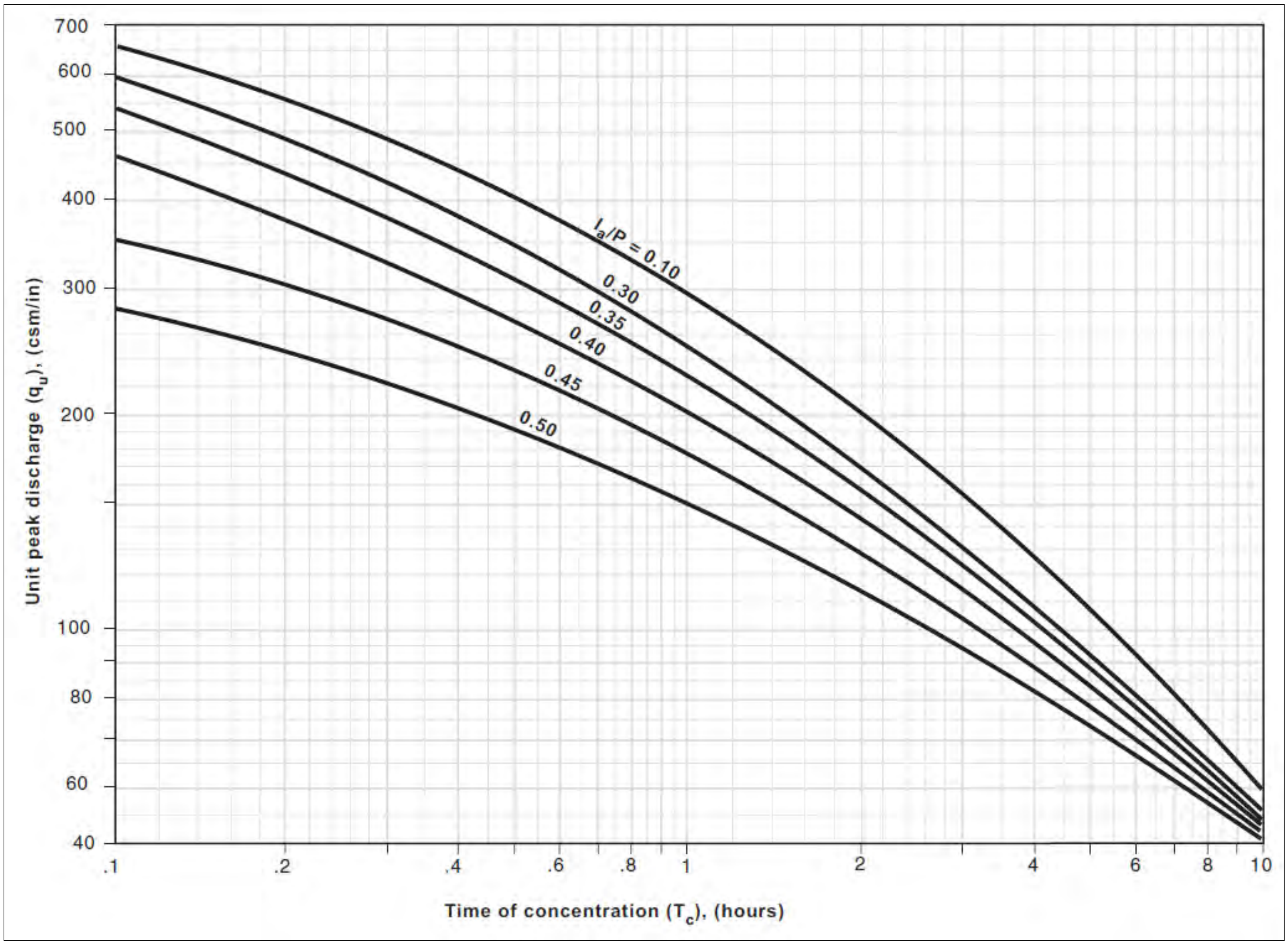


Figure 2-9: Unit Peak Discharge (NRCS, 1986)

Step 9: Compute the peak runoff discharge

$$Q_0 = q_u A Q F_P$$

Where:

Q_0 = peak discharge in cubic feet per second for pre-development conditions
q_u = unit peak discharge
A = drainage area in square miles
Q = runoff depth (see Step 3)
F_P = pond adjustment factor

Step 10: Determine the weighted curve number, CN, for the post-development conditions using Table 2-6. To calculate a weighted curve number:

$$CN_W = \frac{\sum(A * CN)}{\sum A}$$

Where:

CN_W = weighted curve number
A = area in acres

C = curve number

For Subdivisions, repeat Steps 3 through 9 for the 10-year, 24-hour design storm and the correct weighted curve number, CN_W, calculated in Step 10. For all other Major Stormwater Plans repeat Steps 3 through 9 for the 5-year, 24-hour design storm and the correct weighted curve number, CN_W, calculated in Step 10

2.4.4. Simple Volume Calculations for Small Sites (under 10 acres)

Currituck County allows for small sites that are less than 10 acres total drainage area to calculate a storage volume required for retention of the post-development 10-year, 24-hour storm (for Subdivisions), or the post-development 5-year, 24-hour storm (for all other Major Stormwater Plans), and release it at the required wooded, 2-year, 24-hour rate.

To determine the required volume, first follow the steps outlined in Section 2.4.3.A to determine the pre- and post-development peak flows. Also, determine the depth of runoff outlined in Steps 2 and 3 in Section 2.4.3.B.

Compute the runoff volume, V_r

$$V_r = \frac{Q}{12} * A$$

Where:

V_r = Runoff Volume, acre-feet

Q = Runoff Depth found in Steps 2 & 3, inches

A = Drainage Area, acres

Compute the required volume, V_s in cubic yards (for Subdivisions):

$$V_s = 1613.33 * V_r * \left(1 - \frac{Q_{2-pre}}{Q_{10-post}}\right)$$

OR

Compute the required volume, V_s in cubic yards (for other Major Stormwater Plans):

$$V_s = 1613.33 * V_r * \left(1 - \frac{Q_{2-pre}}{Q_{5-post}}\right)$$

Where:

V_s = Storage Volume Required, cubic yards

V_r = Runoff Volume, acre-feet

$Q_{2\text{-}pre}$ = Peak Flow Rate for the predevelopment 2-year, 24-hour storm found in Section 2.4.3.A

$Q_{5\text{-}post}$ = Peak Flow Rate for the post-development 5-year, 24-hour storm found in Section 2.4.3.A

$Q_{10\text{-}post}$ = Peak Flow Rate for the post-development 10-year, 24-hour storm found in Section 2.4.3.A

This simplified calculation methods will result in a higher storage volume than if engineering software or other routing methods are used. In other words, the size of the required stormwater BMP may be reduce through the application of commercially available engineering software, which account for the dynamic relationship between downstream release rates and required storage volumes..

2.4.5. Alternative Stormwater Runoff Storage Analysis and Downstream Drainage Capacity Analysis (Major)

One of the main purposes of requiring new major developments to capture an adequate volume so that the peak post-development discharge for a 10-yr, 24-hr storm (for Subdivisions), or the 5-yr, 24-hr storm (for other Major Stormwater Plans), is equal to the peak pre-development, wooded condition discharge for a 2-yr, 24-hr storm is because of concerns of flooding within Currituck County that have been increasing over time. This criterion was based upon a desktop study of multiple developments and receiving streams within Currituck County and discussions with County staff. As development has progressed and now more of the marginal lands within Currituck County are subject to development pressure, this issue is only going to become more of an issue over time.

Nonetheless, there are instances where this criterion may not be applicable. The goal in providing the option for an alternative runoff storage capacity analysis is to allow designers to claim that the discharge capacity of the receiving channel is higher than the 2-yr, 24-hr storm peak discharge and that the release of additional discharge above this level will not increase flooding levels upstream or downstream of the proposed development. **Please note that in no case shall the BMP treatment volume be less than required by NCDWQ.**

In order to prove that the BMP volume can be reduced and not cause additional impacts upstream and downstream of the proposed site, the applicant must provide a HEC-RAS model to Currituck County of the receiving stream for a minimum distance of 1500' upstream and downstream of the proposed site. Survey cross-sections to be used as input to the model shall be collected at major section changes or at a 500' spacing (whichever is less) and model cross-sections (interpolated within the model) shall be approximately 150' apart. The 2-yr, 24-hr and the 10-yr, 24-hr (or 5-yr, 24-hr, if appropriate) flows **for the receiving stream at the furthest upstream section, the junction with the proposed development site, and the furthest downstream section** shall be computed based on the procedures outlined previously. Manning's "n" values for various stream conditions shall be based upon the **normal** values located within Table 3-1 of the HEC-RAS Hydraulic Reference Manual, Version 4.1, March 2010 (USACE, 2010). Expansion and contraction coefficients shall be left as the model defaults of 0.1 and 0.3.

The existing condition HEC-RAS model for the receiving stream shall be run for both storm event flows with a normal depth downstream boundary condition. For the project conditions, the model storm flows shall be increased to account for the additional flows leaving the proposed development for both storms at both the junction and the furthest downstream section. The resulting water surface elevations for both the existing and project models shall then be compared. If the maximum rise in water surface elevation anywhere in the model is equal to or more than 0.01 feet between the project and existing conditions, the BMP volume must be increased until the maximum increase in water surface elevation is less than 0.01 feet.

2.5. FILL REQUIREMENTS

2.5.1. Concerns Regarding Fill

Currituck County is faced with two competing issues regarding the amount of fill allowable on a certain property. The first issue is due to the topography of Currituck County. Low topographic relief, high groundwater tables, and poorly drained soils require development to be elevated to not only create grade separation between the ground level and the seasonal high water table to ensure proper septic tank function; but also to elevate the site to meet regulatory flood protection elevation requirements. Unfortunately, this practice has led to the second issue, where the fill has aggravated flooding problems in adjacent, lower-lying areas. As more fill is added to the surrounding area, the worse the flooding becomes. This issue is especially pronounced in the Outer Banks, and the photograph in Figure 2-10 is highly indicative of the problem.

Figure 2-10: Fill on Surrounding Lots Exacerbates Flooding

2.5.2. Use of Fill

The Unified Development Ordinance sets forth the requirements for the use of fill in conjunction with development activities. It is the intent of Currituck County to allow the use of fill when it is necessary and appropriate but to apply sufficient controls to the application of fill, such that it does not aggravate flooding conditions on adjacent lots or in neighboring communities. In that interest, the use of fill **is allowed** in the various zones of Currituck County according to the below requirements and any additional standards included in the Unified Development Ordinance.

A. Fill and Other Land Disturbance Requirements

(1) When two or more adjoining properties exhibit consistently higher elevations, fill may be utilized on a lot being developed or redeveloped in order to achieve consistency with adjacent grades.

(2) Fill may be utilized when the placement of fill is located at least 100 feet from all lot lines.

(3) A lot shall not be filled or graded higher than the average adjacent grade of the first 30 feet of adjoining property. Through approval of an alternative stormwater plan the following exceptions are permitted:

(a) When Albemarle Regional Health Services (ARHS) determines that fill is necessary for a septic system to function properly. The maximum fill area shall be limited to the septic system and drainfield areas and shall not exceed 24 inches. An additional 12 inches of fill above the septic system and drainfield may be allowed for the house pad to ensure adequate flow from the building to the septic system.

(b) In the Mainland Stormwater Management Zone when fill is required to raise the lot elevation to the regulatory flood protection elevation.

(c) In the Outer Banks Stormwater Management Zone when fill is required to raise the lot elevation to the regulatory flood protection elevation, not to exceed a maximum of three feet.

(d) When fill is essential to meet the required building pad elevation as shown on approved construction drawings or stormwater plans.

Fill may be added to a lot prior to application for development activities; however, upon receipt of an application for site plan, subdivision, or zoning compliance permit adequate stormwater practices must be implemented to capture stormwater runoff from all proposed impervious surfaces, as specified in the Unified Development Ordinance.

2.6. MAINTENANCE REQUIREMENTS

2.6.1. Responsibility for Maintenance

The Unified Development Ordinance stipulates the responsibility for maintenance of stormwater practices and facilities as well as requirements for easements for maintenance access. For each of the stormwater BMPs enumerated in the design guidelines in Appendix B, there are specific inspection and maintenance guidelines also included. The Manual also includes a required Inspection Checklist in Appendix C.

A. Stormwater plans must address maintenance of stormwater management devices and the party responsible for maintaining the devices. The developer shall be responsible for maintenance of stormwater management devices until another responsible entity (such as a homeowners or property owners association), assumes the responsibility for maintenance

B. Stormwater management devices, facilities, and best management practices shall be maintained to assure proper performance and operation as defined in the stormwater plan and the Currituck County Stormwater Manual.

C. The owners or managers of any stormwater management devices, facilities, and best management practices are required to perform routine maintenance inspections and complete all pertinent sections of the Inspection Checklist in Appendix C to be kept on file. In the case of stormwater management devices which receive runoff from more than 5 acres, an annual maintenance inspection shall be performed by a registered engineer, licensed surveyor or landscape architect.

D. The county reserves the right to conduct periodic inspections of all stormwater management devices and to request copies of annual Inspection Checklists.

E. Maintenance access easements shall be required for all waterway conveyance systems (i.e., ditches, canals, streams, creeks, and major waterways). Maintenance access easements, including required widths, shall be established in accordance with the standards included in the Unified Development Ordinance.

F. Improvements permitted within easement areas are allowed as long as they do not impede the flow of stormwater. Native vegetation shall remain undistributed to the greatest extent practicable.

Chapter 3: Best Management Practices

CHAPTER 3. BEST MANAGEMENT PRACTICES

The overall objective of BMPs is to minimize the adverse effects of development on the surrounding environment. Selecting the appropriate BMP is an art, as well as a science. A properly designed BMP shall mimic, as closely as possible, the natural hydraulic conditions of the undeveloped site. For this reason, there is no single BMP that is best for every site. Different BMPs are suited for different aspects of stormwater control and pollutant removal. One BMP might not provide all the necessary treatment goals that apply to a specific site. Other BMPs might not be suited for a site's unique characteristics, such as slope, soils, available area, depth to seasonal high groundwater table, etc.

Before selecting a BMP, a designer or developer shall first consider whether a structural BMP is necessary. Reducing the impervious surfaces can minimize or eliminate the need for structural BMPs. Also, a designer shall consider using a series of smaller BMPs throughout a development as opposed to a single, large BMP. Strategies for using these and other LID features are discussed in *Chapter 4: Low Impact Development*.

If a structural BMP is required, the following steps shall be taken for selecting an appropriate BMP to use:

- Determine the treatment requirements for a site (TSS removal, nutrient removal, peak flow control, etc.) that is required.
- Determine which BMP will meet the treatment requirements determined in Step 1 and create a short list.
- Determine which of the short-listed BMPs will fit the physical site characteristics.
- Consider additional factors such as cost, maintenance, and community acceptance.

Section 3.1: Selection of Appropriate BMPs provides a table with acceptable BMPs for Currituck County. This table shall be used as a quick reference when creating a short list of appropriate BMPs for a site. Several design elements that are useful for different BMPs can be found in Appendix B. More detailed features and siting requirements for each BMP can be also be found in Appendix B.

3.1. SELECTION OF APPROPRIATE BMPS

TABLE 3-1: AUTHORIZED STORMWATER MANAGEMENT CONTROLS (NCSU, 2010)		
DEVICE TYPE	**PERFORMANCE / APPLICATIONS [1]**	**Preferred Stormwater Management Zone [2]**
Bioretention 	Ideal for small sites with significant impervious area and sites that cannot incorporate larger BMPs due to site constraints. Good for where space is a premium. Best suited for in-situ soil permeability rates greater than 2 in/hr [3]	Mainland *; Outer Banks
Cisterns 	Ideal for residential and commercial areas where domestic water is a premium. Useful for irrigation, vehicle washing, and other uses that do not require potable water. Indoor use for flushing toilets or washing clothes requires treatment and compliance with the International Building Code.	Mainland; Outer Banks
Extended Dry Detention Basins 	Ideal for sites where primary goal is peak runoff attenuation and volume capture and for large drainage areas (25 acres or more).	Mainland; Outer Banks
Green Roofs 	Ideal for urban areas where space is a premium. Can help reduce energy costs, provide additional living space, and wildlife habitats. Credited towards open space set-aside requirements and recognized as a sustainable development feature.	Mainland; Outer Banks

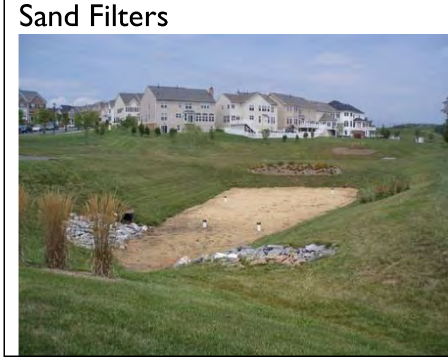
TABLE 3-1: AUTHORIZED STORMWATER MANAGEMENT CONTROLS (NCSU, 2010)		
DEVICE TYPE	**PERFORMANCE / APPLICATIONS [1]**	**Preferred Stormwater Management Zone [2]**
Infiltration Devices 	Ideal for small drainage areas that are highly impervious and most effective on flat sites. Best suited for in-situ soils with high permeability (hydraulic conductivity = 0.52 in/hr or greater) [3] Not suitable for hydric soils or soils with low infiltration rates.	Mainland; Outer Banks
Permeable Pavement 	Suitable for parking areas or low traffic roadways (less than 100 vehicles per day) and pedestrian walkways. Ideal for small drainage areas that are flat and highly impervious. Best suited for in-situ soils have high permeability (hydraulic conductivity = 0.52 in/hr or greater)	Mainland *; Outer Banks
Riparian Buffers 	Ideal for small areas adjacent to perennial or intermittent streams and developments where natural areas and trails are planned. Function well in conjunction with other BMPs.	Mainland
Sand Filters 	Ideal for small, flat sites with a lot of impervious area and less than 5 acres of contributing drainage area. [3]	Mainland *; Outer Banks

TABLE 3-1: AUTHORIZED STORMWATER MANAGEMENT CONTROLS (NCSU, 2010)		
DEVICE TYPE	**PERFORMANCE / APPLICATIONS [1]**	**Preferred Stormwater Management Zone [2]**
Stormwater Wetlands 	Ideal for large commercial or residential developments with adequate space and reliable water source. Good for flat sites and sites with a high water table [4]. Soils must be sufficiently impermeable so wetland does not "dry out"; NRCS soil types C & D	Mainland; Outer Banks
Grassed Swales 	Ideal for residential and commercial developments, as well as highway medians as an alternative to traditional curb and gutter stormwater conveyance. Good for parking lots and other urban areas where sizing requirements are a concern.	Mainland*; Outer Banks
Vegetated Filter Strip 	Ideal for areas where dense vegetation can be established and most effective for flat sites with small drainage areas. Also good for sites with high water table. Natural vegetation is best for removing TSS; however, larger amounts of runoff will infiltrate in graded filter strips	Mainland; Outer Banks
Wet Detention Basin / Pond 	Ideal in low-density developments with adequate space & reliable water source and a minimum drainage area of ten square acres. In-situ soil permeability is 0.01 in/hr [5]	Mainland
NOTES: [1] TSS = Total Suspended Solids; TN = Total Nitrogen; TP = Total Phosphorus		

TABLE 3-1: AUTHORIZED STORMWATER MANAGEMENT CONTROLS (NCSU, 2010)		
DEVICE TYPE	**PERFORMANCE / APPLICATIONS [1]**	**Preferred Stormwater Management Zone [2]**
[2] Any control or practice may be used to meet the stormwater management standards; some controls may be more effective than others, depending on the soil and water table conditions. The Currituck County Stormwater Manual includes detailed guidance on which control devices are appropriate for which zones [3] If soil permeability is less than two inches per hour, an underdrain is required [4] Stormwater Wetlands must be sized to meet full-build out volume requirements [5] If TN is target pollutant, depth must be between 2.5 – 4 feet *Successful application of these BMPs in the northwest portion of Currituck County (west of Tulls Creek) will most likely require installation of underdrains.		

Chapter 4: Low Impact Development

CHAPTER 4. LOW IMPACT DEVELOPMENT

Protection of water quality and the aquatic ecosystems that depend on it, particularly in Currituck Sound, is vitally important to sustaining the quality of life and the unique character of Currituck County. The Sound and its tributaries are central to Currituck County's tourism industry and continued economic growth, and Currituck County has exhibited an ongoing commitment to the protection of these valuable water resources through the Currituck County Goes Green Initiative.

One of the most important threats to the Sound is increased pollutant loads from stormwater runoff resulting from increased levels of urban development and the associated increases in impervious surface throughout Currituck County. Some stormwater pollution problems also stem from older communities in Currituck County that were developed prior to the advent of modern stormwater management requirements, so the infrastructure to address stormwater is often lacking or occasionally absent in these communities. Low impact development (LID) offers a potential range of techniques and best management practices (BMPs), both structural and non-structural, to prevent adverse stormwater impacts from new development and to address some stormwater problems in existing communities through retrofit opportunities.

4.1. CURRITUCK SOUND

In the past, Currituck Sound was boasted a substantial largemouth bass fishery, but gradually increasing salinity and losses of large areas of submerged aquatic vegetation have resulted in a decline in that fishery. A large portion of the Currituck Sound is a vast marsh that serves as a critical part of the Atlantic Flyway for migratory waterfowl. Thousands of wintering ducks, geese and swans contribute to the sound's consistent reputation for waterfowl hunting, but just as with the freshwater fisheries in the sound, declines in this resource have been documented.

Based on the mid-winter waterfowl surveys conducted from 1961 through 2006, the waterfowl population peaked in 1976, with 305,000 birds. Since then, the waterfowl population declined well below 50,000 birds, with an estimated average of 25,000 birds per year. Of the 21 fish species identified in 1961, only fifteen were identified in 2003. The declines in fish and waterfowl populations are attributed to significant loss of submerged aquatic vegetation (SAV), a major food source for water bird and marine mammals, and critical habitat for a host of vertebrate and invertebrate organisms. SAVs once grew in abundance, covering most of the shallow waters of Currituck Sound and Back Bay. Today, these areas retain only 35% and 5%, respectively, of the SAV distributions of 25 years ago (http://www.saw.usace.army.mil/Currituck/).

Throughout history, inlets from the ocean to Currituck Sound have been periodically carved by storms. In addition to severe storm over wash, current sources of salt water into the sound include the Albemarle Sound, Back Bay, North Landing River and the Intracoastal Waterway. Inputs of freshwater are provided by Tulls Creek and Jean Guite Creek. Salinities above several parts per thousand have caused problems in Currituck's once viable freshwater fishery. Populations of largemouth bass and other primarily freshwater fish along with native freshwater macrophytes were greatly reduced with increasing salinities. These changes in salinity were caused both naturally and artificially. Severe droughts in the mid 1980's and pumping of saltwater into Back Bay contributed to increased salinities in the sound. A memorandum from the Environmental Protection Agency (EPA) and Albemarle Pamlico Estuarine Study (Dec 2, 1991) reports a potential problem, that of saltwater encroachment introduced by the hydrologic link from the Lynnhaven River to the Chesapeake Bay to the North Landing River (NCDWQ, 1997)

Monitoring data have indicated that increased nutrient enrichment and algal productivity have also been contributing factors to the decline in the overall ecological health in Currituck Sound. Historical data from Currituck Sound demonstrate that nutrients are elevated in the upper portion of Currituck Sound, in the North Landing River near the state border, in the mouth of Tulls Bay and in Tulls Creek at SR 1222. A study conducted by DWQ in 1994 showed that Tulls Creek exhibited high levels of nitrogen and phosphorus and that Tulls Creek is the largest contributor of nutrients to the sound (NCDWQ 1997).

In the 1994 study, pulses of nutrients were also observed in Knotts Island Bay and in Coinjock Bay near the Intracoastal Waterway. However, in 1995 these nutrients were low throughout the sound and were mostly below the detection level which indicates uptake by phytoplankton.

With the exception of two samples collected (Tulls Bay, Tulls Creek) in 1995, the entire sound was found to be phosphorus limited with TN:TP ratios ranging from 11:1 to 40:1. Data from previous years also demonstrated that Currituck Sound is phosphorus limited (NCDWQ, 1997). This is to be expected since fresh waters are typically phosphorus limited while salt waters are generally nitrogen limited. If the trend toward increasing salinity in the sound continues, it is possible that a gradual shift toward nitrogen limitation may occur.

Blooms of blue-green algae (cyanophytes) occur throughout Currituck Sound and were confirmed during several growing seasons in the 1990s. Eighty-seven percent of samples collected by DWQ during a study conducted in the growing season of 1992-1993 contained bloom densities of algae. However, the algal assessment conducted by NCDWQ in 1999 found no evidence of algal bloom conditions in the sound (NCDWQ, 2002). The 2007 iteration of NCDWQ's report on water quality in Currituck Sound (included in the Pasquotank River Basinwide Water Quality Plan) contains no indication of further assessment of algal productivity.

Currituck Sound was nominated for the designation of Outstanding Resource Waters (ORW) in 1990. Subsequently, a special study was conducted in 1992-1993 to assess water quality conditions and to determine if the sound qualified for the supplemental classification of ORW. Because of the presence of chronic widespread blue-green algal blooms, Currituck Sound failed to qualify for ORW (NCDWQ, 1997). It should be noted that the current Coastal Stormwater Rule requirements for water quality protection in Currituck County are less stringent than they could be due to the fact that Currituck Sound is classified as SC waters (salt waters protected for aquatic life propagation and secondary recreation) and its tributaries are classified as C-

Swamp waters (fresh waters, with swamp characteristics, protected for aquatic life propagation and secondary recreation). If the Sound were classified SA (salt waters protected for the propagation and harvesting of shellfish) or ORW (Outstanding Resource Waters), then developments would be required to achieve runoff rates no greater than the runoff predicted from the predevelopment condition for a one year, 24-hour storm event. This requirement would be triggered when the proposed built-upon area exceeded 12%, and the rules would cap the density of developments impacting SA and ORW waters at a maximum built-upon area of 25%.

Collectively, the past monitoring efforts conducted by NCDWQ in conjunction with their basin wide assessment and planning efforts have indicated that significant contributing factors to the ecological decline in Currituck Sound include increasing salinity and the subsequent loss of substantial areas of SAV. Water quality data have also indicated that increased nutrient loading has contributed to periods of higher levels of eutrophication and the associated algal turbidity has likely been an aggravating factor in the decline of SAV. Qualitative assessments conducted by the US Army Corps of Engineers in conjunction with their ongoing study of the sound have also indicated that nutrient and sediment loads from nonpoint sources continue to be problems. When other factors are considered equal, development project designers and stormwater managers/engineers shall target the implementation of stormwater BMPs that will maximize treatment of these pollutants.

4.2. INTRODUCTION TO LID

Low impact development (LID) describes an innovative approach to site development and stormwater management that aims to minimize impacts to land, water, and air resources, while reducing infrastructure and maintenance costs and increasing marketability. LID techniques (also known as sustainable sites, better site design, and "green" infrastructure) promote public health by providing greater protection and conservation of water resources, ecological processes, environmental quality, and community character (NCSU, 2009). The North Carolina Division of Water Quality (NCDWQ) encourages use of LID practices whenever feasible.

The ultimate goal of LID is to maintain and restore a watershed's hydrologic regime by changing conventional site design to create an environmentally and hydrologically functional landscape that mimics natural hydrologic functions. This is accomplished through the cumulative effects of various LID techniques and practices. The more techniques applied, the closer one can come to replicating the natural infiltration capacity of the landscape and its ability to capture and cycle pollutants. The uniform distribution of LID controls throughout a site increases runoff time of travel, thus dramatically reducing site discharge flow. All components of the urban environment have the potential to serve as an LID practice. This includes rooftops, streetscapes, parking lots, driveways, sidewalks, medians and the open spaces of residential, commercial, industrial, civic, and municipal land uses.

LID includes the following basic strategies, with multiple techniques for each strategy:

- **Conserve natural resources.** At the watershed level, the development tract levels, and the individual lot level, try to conserve natural resources (trees, water, wetlands and special areas), drainage patterns, topography, and soils whenever possible.
- **Minimize impact.** At all levels, attempt to minimize the impact of construction and development on natural hydrologic cycles and ecological systems by saving existing vegetation and reducing grading, soil compaction, clearing, impervious surfaces, and pipes.
- **Optimize water infiltration.** To the maximum extent practicable, slow down runoff and encourage more infiltration and contact time with the landscape by saving natural drainage patterns and by maintaining sheet flow using vegetative swales, lengthened flow paths, and flattened slopes. Infiltration can also be increased by disconnecting impervious surfaces. The runoff characteristics of a site are fundamentally changed when impervious surfaces are disconnected and drained to landscape features or LID practices.
- **Create multifunctional and multipurpose landscapes.** Many features of the urban landscape can be designed in a way to provide more functionality and reduce impacts. Every landscape feature shall be designed with some beneficial hydrologic or water quality to store, retain detain or treat runoff.
- **Think small scale and create areas for local storage and treatment.** Rather than centralizing stormwater storage, integrate multiple, small systems into numerous aspects of the site. The most efficient use of the landscape is to incorporate smaller more numerous techniques. With several LID techniques, the overall stormwater system is far less likely to fail due to its distributed nature. The disconnection of one or two rain gardens will only have a minor impact on the effectiveness of the entire system. Contrast this with systems that utilize one large stormwater pond, such that, if that fails, the entire system fails.
- **Build capacity for maintenance.** Develop reliable, long-term maintenance programs with clear and enforceable guidelines. Educate homeowners, management companies, and local government staff on the operation and maintenance of all practices, and about protecting water quality.

The creation of LID's wide array of micro-scale stormwater management principles and practices has led to the creation of new tools to retrofit existing urban development. Newer micro-scale practices that filter, retain, and detain runoff can be easily integrated into existing green space, streetscapes, and parking lots as part of the routine maintenance and repair of urban infrastructure. As Currituck County's urban areas are redeveloped and rebuilt using integrated LID techniques, it may be possible to reduce pollutant loads to receiving waters, increase the availability of local clean water, reduce problems with flooding during peak rain events, and reduce our dependency on expensive centralized stormwater systems.

Figure 4-1and Figure 4-2 illustrate the hypothetical redesign of a conventional residential development using LID techniques. The conventional design in Figure 4-2 has curb and gutters to collect runoff throughout and relies on a stormwater pond to detain and treat the runoff. The LID design eliminates the curb and gutter, and replaces the pond with linear bioretention cells (bioretention swales) along roadways and some bioretention cells on individual lots where necessary. The LID design also has narrower streets and a smaller envelope of grading and disturbance, resulting in a greater portion of the native forest vegetation left intact. Note that there is minimal change to the overall form of the development between the two design cases.

At the smaller scale, lots might look like the example shown in Figure 4-3when LID principles are applied.

Figure 4-1. Residential Subdivision with Conventional Design and Central Stormwater System

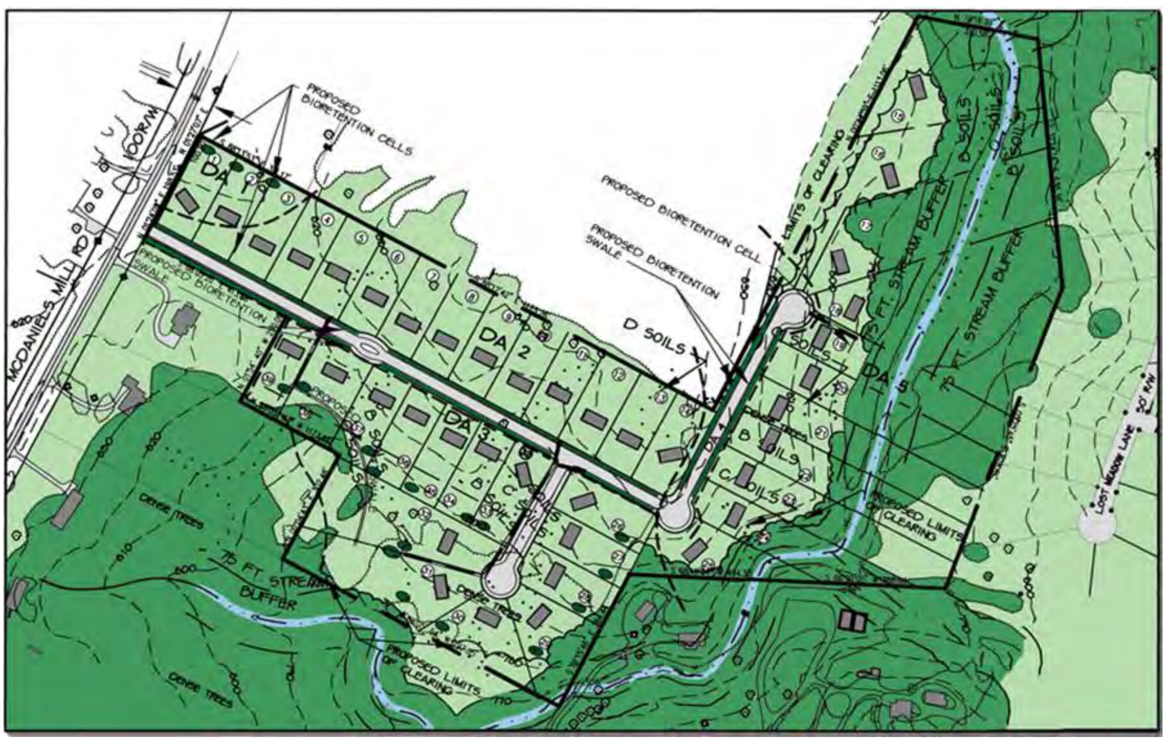


Figure 4-2. Hypothetical Redesign of Subdivision with LID Techniques

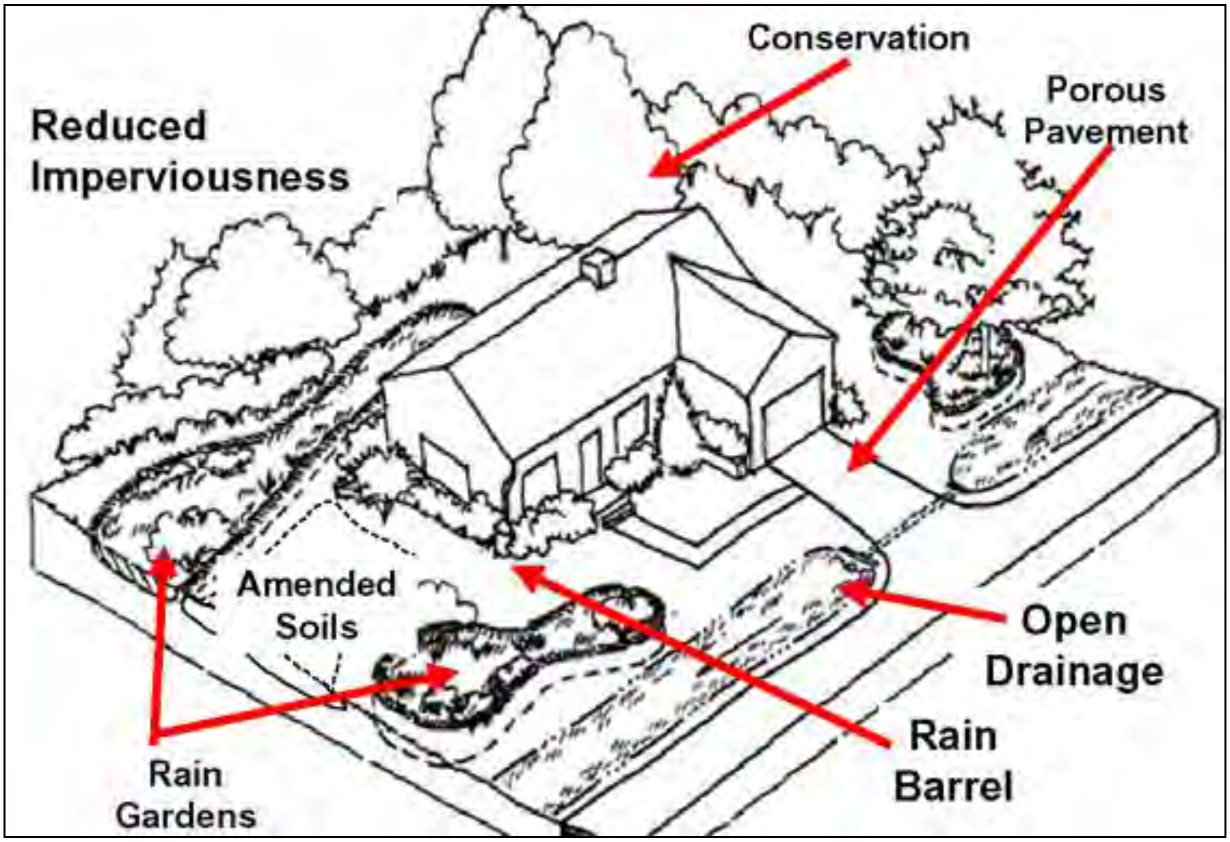


Figure 4-3. LID Principles Applied at the Individual Lot Scale

4.3. BENEFITS OF LID

One of the main responsibilities for state and local governments under the Clean Water Act is to protect and sustain the environmental integrity of its water resources. As urbanization has increased, conventional development and stormwater treatment methods have not always been adequate to prevent the degradation of water quality, nor has it prevented the adverse impacts to the ecological integrity to Currituck Sound and its tributaries. LID practices offer additional methodologies to protect water quality by optimizing the urban landscape to reduce and treat stormwater runoff. In addition, several studies have shown that LID may reduce the cost of infrastructure associated with new development or redevelopment projects, which can reduce strains on public budgets or increase profitability to private developers. The following subsections, which were adapted from the Low Impact Development: *A Guidebook for North Carolina*(NCSU, 2009), provide details on the full range of benefits that may be realized from the implementation of LID practices. Table 4-1lists the benefits that may accrue to various stakeholders from LID.

Table 4-1. LID Benefits to Stakeholders (Adapted from US Department of Housing & Urban Development and NAHB Research Center, 2003; with additions from MacMullan and Reich, 2007)

Developers
• Reduces land clearing and grading costs • Reduces infrastructure costs (streets, curbs, gutters, sidewalks) • Reduces stormwater management costs • Increases lot yields and reduces impact fees • Increases lot and community marketability
Municipalities
• Protects regional flora and fauna • Balances growth needs with environmental protection • Reduces municipal infrastructure (streets, curbs, gutters, sidewalks, storm sewers) • Reduces system-wide operations and maintenance costs of infrastructure • Reduces costs of combined sewer overflows (CSOs) • Increases groundwater recharge • Fosters public/private partnerships
Home Buyer/Homeowner
• Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies • Preserves and protects amenities that can translate into better resale potential and increased property values • Provides shading for homes, which decreases monthly energy bills for cooling • Reduces flooding • Saves money through water conservation
Environment
• Preserves integrity of ecological and biological systems • Reduces demands on water supply and encourages natural groundwater recharge • Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies • Reduces impact on local terrestrial and aquatic plants and animals • Preserves trees and natural vegetation

4.3.1. Economic Benefits

The economic benefits of LID have been demonstrated and documented through various research projects, case studies, and practical experience (MacMullan and Reich, 2007; France, 2002; Natural Resources Defense Council, 1999; U.S. Department of Housing and Urban Development in partnership with the National Association of Home Builders, 2003; USEPA, 2007; and many others).

The United States Environmental Protection Agency (USEPA) evaluated 17 LID case studies across North America for cost savings over conventional development (USEPA, 2007). In the majority of cases, LID practices were shown to be both economically and environmentally beneficial to communities, with capital cost savings ranging from 15 to 80 percent, due to reduced costs for site grading and preparation, paving and landscaping, and stormwater infrastructure (ponds, pipes, inlet structures, curbs, and gutters). Benefits to environmental goods and services include improved aesthetics, expanded recreational opportunities, increased property values due to desirability of the lots and their proximity to open space, increased total number of units developed, increased marketing potential, and faster sales.

The effective use of LID site design techniques can significantly reduce the cost of providing stormwater management. Savings are achieved by reducing or eliminating stormwater management ponds; reducing pipes, inlet structures, curbs and gutters; reducing roadway paving; and reducing the amount of land moved during the clearing and grading stages of construction. Where LID techniques are applied, and depending on the type of development and site constraints, stormwater and site development design, construction, and maintenance costs can be reduced by 25 to 30 percent compared to conventional approaches (Clar, 2000). The hypothetical redesign of the residential development illustrated in Figure 4-1 and Figure 4-2 resulted in significant cost based on opinions of probable cost due to significantly reduced infrastructure costs. The reduced infrastructure costs in that example stemmed from lower pavement costs, elimination of curb and gutter, and the elimination of stormwater piping and the stormwater pond required in the conventional design.

The growing number of LID evaluations across the U.S. provides strong evidence that the practice of LID is sound and offers many economic and environmental benefits over conventional approaches. Table 4-1 illustrates the potential benefits of LID and shows who receives those benefits. Economic evaluations of LID often focus on cost comparisons using initial construction costs, as this is the simplest evaluation to perform. However, this incomplete assessment neglects operation and maintenance costs, and it does not consider the increased values of environmental goods and services such as healthy fish populations and cleaner drinking water. When discussing the costs of LID, communities should discuss the full range of benefits and costs, including those benefits that are not easily monetized but are important to quality of life. A recent North Carolina Cooperative Extension fact sheet, *Low Impact Development—An Economic Fact Sheet*, provides a framework for discussing economics and includes examples of several economic studies (WECO, 2009).

4.3.2. Hydrologic Benefits

The hydrologic cycle describes the movement of water from the atmosphere to the earth's surface and subsurface layers, and back to the atmosphere again. It includes the ecological processes of rainfall (precipitation), infiltration (shallow subsurface flow and deep seepage), surface runoff, evaporation, and evapotranspiration. With each rainfall event, the water infiltrates into the ground, runs off the surface, evaporates, or is transpired by vegetation back to the atmosphere. With undeveloped conditions, the majority of precipitation either infiltrates or evapotranspires; there is typically very little or no surface runoff (Figure 4-4).

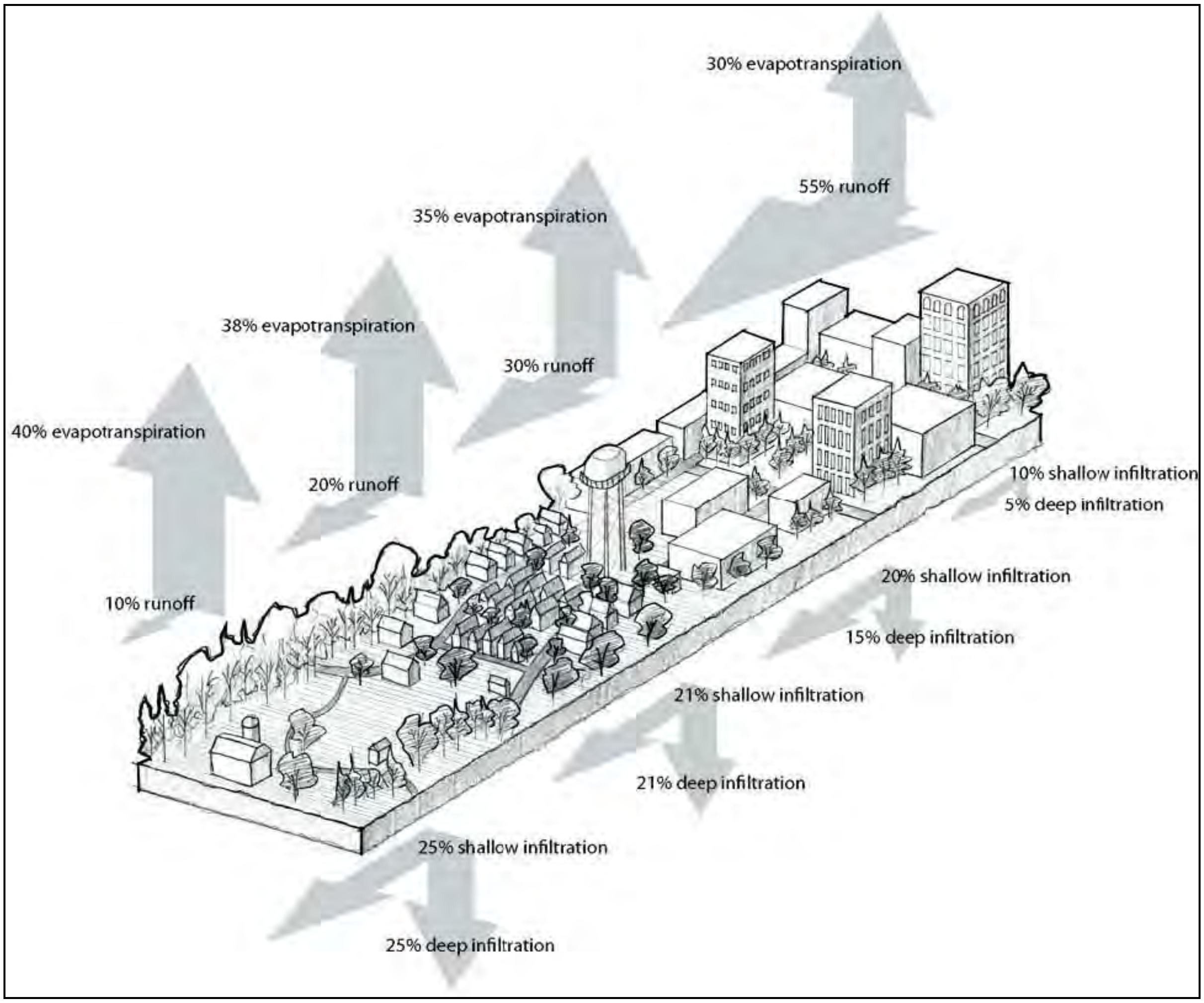


Figure 4-4. Runoff Increases Dramatically with Percent Urbanization (NCSU, 2009)

With conventional land development practices, the hydrologic cycle is disturbed as vegetation is removed, soil compacted, ground paved over, and buildings erected, which leads to less infiltration and evapotranspiration and more surface runoff. Conventional development and stormwater management methods—especially the typical stormwater collection and conveyance system—alter the hydrology and, consequently, may affect the physical, chemical, and biological condition of streams and other receiving waters.

The health of Currituck County's groundwater, streams, and estuaries and the aquatic life they support depend upon the undeveloped hydrologic cycle, where the majority of rainfall infiltrates and evapotranspires with minimal runoff. Continued economic growth and prosperity also depend on promoting a healthy hydrologic cycle, as wells, public drinking water supplies, tourism, recreational and commercial fishing, and shellfish harvesting all require reliable water quantities as well as high-quality water resources and the ability of groundwater to recharge.

The core environmental benefit of LID is that it offers the means to maintain a developed watershed's hydrologic and hydraulic systems by creating a site that mimics natural functions of runoff, infiltration, and evapotranspiration. This is accomplished by site planning and stormwater treatment techniques that manage runoff volume and water quality. The more LID is effectively integrated into the natural landscape, the greater capability of the site to replicate the natural functions of the watershed to capture stormwater and treat pollutants.

4.4. LID DESIGN APPROACH

4.4.1. LID Considerations in Currituck County

Due to its coastal setting, Currituck County has very limited topographic relief and a regular potential for heavy rainfall events associated with tropical and seasonal storms. In addition, development projects in Currituck County, by necessity, often occur in close proximity to environmentally sensitive amenities such as dunes, wetlands and surface waters. These conditions present challenges for conventional development projects, but in the right conditions, they can present opportunities for the implementation of LID.

One of the key attributes that will render sites either conducive or challenging to LID in Currituck County will be the soils for a given site. For projects taking place along the sandy ridgelines that trend north-south in Currituck County or on the Outer Banks in areas where some separation from the seasonal high water table is available, opportunities to capitalize on relatively high rates of infiltration can be realized and LID will be highly applicable. For projects occurring in the mucky soils prevalent in the northwest portion of Currituck County, where infiltration rates are low and water tables remain near the surface, application of LID techniques will be more challenging, if not prohibitive.

Many areas of Currituck County, typically areas at lower elevations, are dominated by poorly drained soils and shallow depths to seasonal high water tables. In areas with such high groundwater tables, incorporating LID may be more challenging and may require additional site engineering and creative grading to take advantage of swales, bioretention, sand filters, and infiltration devices for filtration of pollutants. For instance, practices such as routing roof drains to raised beds with bioretention systems may be applicable. In such areas conventional stormwater ponds and other BMPs that do not rely on infiltrations, such as constructed stormwater wetlands may be more desirable.

For development sites with poorly draining soils, or shallow SHWTs, it may be more feasible to rely on preventative conservation to the greatest extent possible. This approach will also reduce both quantity of runoff and the amount of pollutants generated. In the case of large scale development projects it will be desirable to condense the built-upon areas of the development and the associated diffuse stormwater treatments on the more suitable portions of the site with higher elevation and greater separation from SHWT, leaving the low lying portions of the site in some state of conservation.

If vegetative LID practices are to be used, they shall be at least 2 feet above seasonal high ground water levels. The top two feet is the biologically active zone of a plant and soil complex and is where most of the physical, chemical, and biological pollutant removal occurs.

Additionally, plants that tolerate wet conditions shall be installed with these LID practices. While infiltration may not be practical in these areas, bioretention systems designed for water filtration are still viable options. Soils and groundwater challenges may make it more attractive to rely on conservation of natural vegetation and use of conservation areas to filter runoff prior to discharging to sensitive waters.

Discussion of some additional implications of using LID techniques in each of Currituck County's Stormwater Management Zones is included below.

A. Outer Banks

The portions of the Currituck Outer Banks considered most suitable for development are dominated by very sandy soils (Figure 4-5) with relatively high capacity for infiltration of stormwater runoff. Such soils, in natural conditions, generate very little runoff themselves, so runoff volumes originate almost entirely from the impervious surfaces built on a given site. Areas which have deep, sandy soils such as those present in many areas of the Outer Banks will present the greatest opportunity to infiltrate runoff close to the source though the use of diffuse LID practices. However, while sandy soils drain quickly, this short duration drainage decreases the filtering capacity of the soil. Before runoff is allowed to be infiltrated in these areas, to the extent possible, it shall be routed through vegetated areas such as grassed swales, bioretention areas, filter strips and buffers in order to aid in pollutant removal.

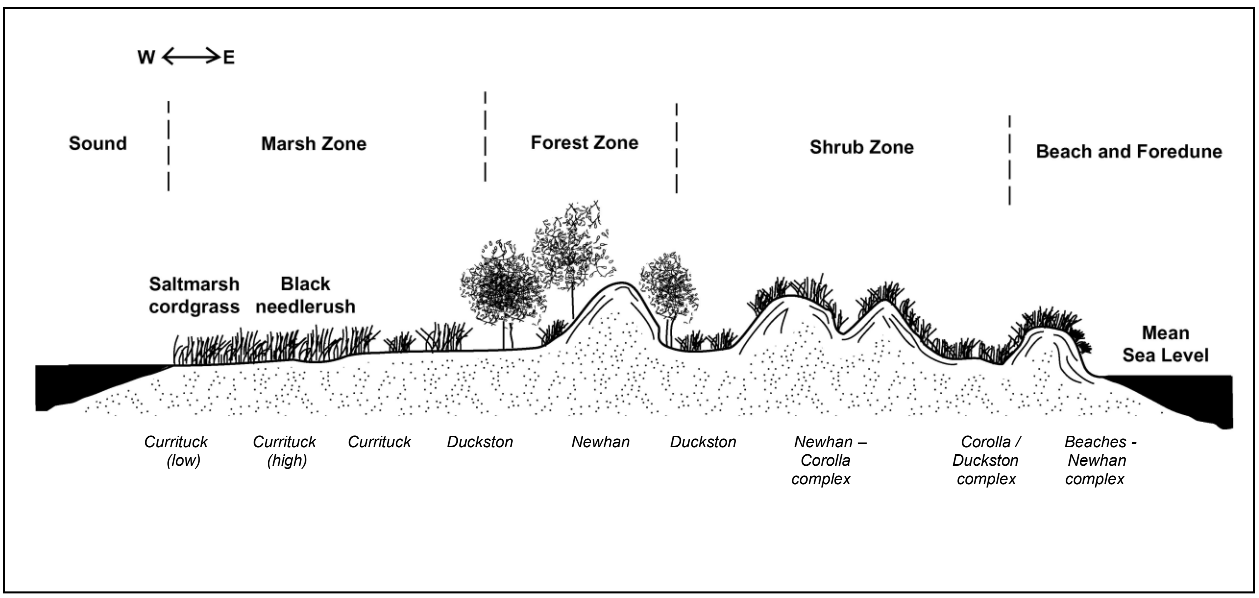


Figure 4-5. Typical Topographic and Soils Profile for the Outer Banks

B. Mainland

Both soils and topography can be highly variable on the Mainland. Effective site design and BMP implementation for LID (or stormwater management in general) will depend on analyses of soils for conductivity, which measures the capacity of the soil to infiltrate water, and for depth to seasonal high water table, which reflects the available soil storage space for runoff. Detailed soils analyses will be required, not just at the site-level, but at a sufficient numbers of locations within the site to adequately reflect the variability of soils condition throughout the entire area of a project. Efforts shall be made to restrict the project areas with the highest percentages of impervious surfaces to those portions of the site with the best draining and thus, most suitable soils. This practice will allow the smaller and diffuse BMPs associated with LID to be incorporated within the built environment where they can take advantage of the most suitable soils, resulting in greater infiltration of stormwater runoff near its sources. Conversely, to the extent practicable, those low-lying and poorly drained portions of the site should be devoted to natural areas and open space. More information on fitting the development design to the existing natural features of the site is presented in the LID Site Planning Process steps below.

The mucky, peaty soils and the consistently high water tables that dominate the northwest portion of Currituck County will present the greatest challenge to implementation of LID in Currituck County, which is unfortunate, because this is an area of Currituck County subject to significant growth pressure. As with low lying areas in the rest of Currituck County, it may be more feasible to rely on preventative conservation to the greatest extent possible in this zone. However, the conditions in the northwest are not entirely prohibitive to LID and many of the site planning and design practices will still be applicable. That said, the selection of stormwater BMPs that are appropriate to the site conditions will be of great importance, and it is likely that BMPs that rely heavily on infiltration, such as bioretention cells, will be less feasible in this zone. It is likely that small diffuse detention BMPs will be more practical in the northwest. Constructed stormwater wetlands and smaller pocket wetlands will be more applicable.

One of the ridges of sandy and loamy soils present in Currituck County trends northwest to southeast through the middle of Shawboro, so development projects in that vicinity may be able to take advantage of soils with greater capacity for infiltration. However, even in areas with poor soils may be able to utilize infiltration BMPs with the addition of soil amendments and under-drain systems, provided sufficient elevation above the SHWT exists.

4.4.2. Basic Site Planning Principles for LID

The most important goal of LID is to mimic the predevelopment hydrology. Therefore, the most effective LID projects require a thorough understanding of the site's soils, drainage patterns, and natural features. To optimize an LID design, it is important to consider a number of site planning principles and follow a systematic design process from the very beginning. Each site has a unique set of characteristics and will require the use of a unique blend of site-specific LID planning and treatment techniques. The integration of LID techniques into every facet of the project will require an interdisciplinary approach.

There are several basic LID planning principles that must be followed throughout the site planning and design process. These principles require a different way of thinking about site design. For example, detaining and retaining water on the site and using the landscape to treat runoff without causing flooding problems or interfering with the typical use of the property is in contrast to the current practice of grading plumbing a site to quickly remove water (Wilmington, 2008).

4.4.3. LID Site Planning Process

The following is a step-by-step site planning process, adapted from *Low Impact Development: A Guidebook for North Carolina* (NCSU, 2009), that factors in the basic LID site design principles and works to allow the landscape to remain a vital, functioning part of the ecosystem. To minimize the runoff potential of the development, hydrology is employed as a design element, and a hydrologic evaluation would be an ongoing part of the design process. It is important to note that an understanding of site drainage can suggest locations both for green areas and for potential building sites. In addition, an open drainage system can help integrate the site with its natural features, creating a more aesthetically pleasing landscape.

Step 1 Determine preliminary project goals (principles and values) and objectives (set project parameters and program).

Answer the following questions:

- What are the goals of the project, in priority order?
- What type of development is desired and what key elements are necessary to produce the desired result? What do we need to put on the site? What is optional?
- What are the available resources and expertise that can be applied to the project?

The project goals and objectives shall consider not only development characteristics and stormwater goals, but also human considerations (what character qualities does this place need to have?). This must include requirements for built structures and wastewater and stormwater treatment.

Step 2 Perform a site inventory and assessment (look closely at the site).

Identify the key physical and cultural factors that are required by the program. Analyze and map the key factors (see Figure 4-2). These shall include:

- topography
- drainage patterns and systems including existing waterways and stormwater facilities
- soils
- ground cover and vegetation
- existing development and land uses, including adjacent areas
- required protection areas such as wells

Natural and cultural features, which need to be identified and mapped, include:

- wetlands
- critical wildlife habitat areas
- boundaries of wooded areas or areas of sensitive or important vegetation
- important historic, archeological, or cultural resources
- floodplain boundaries
- site topography including steep slopes
- required buffers from waterbodies and/or adjacent or on-site land uses

- stream systems and other water areas

Note that the natural features of distinction here follow very closely with the list of primary and secondary conservation areas denoted in Section 6.4.5 of the Currituck County UDO, which could also be used as a guiding list for those areas that need to be considered in an LID site inventory and assessment, and avoided, to the extent possible, in the site layout.
Analyze site features and characteristics in light of the project goals and parameters. These goals will determine what takes precedence in the site assessment. Generally, for LID projects, the priorities are:

1. topography
2. soils
3. hydrology
4. vegetation and habitat
5. surrounding land uses
6. zoning
7. access
8. utility availability

Ensure natural resources are evaluated for rarity; diversity and pattern; size and shape; location; and relationship to other resources. Watch for potential problems such as low infiltration soils (particularly the mucky, peaty soils in the northwest portion of Currituck County, and poorly drained soils in low lying areas throughout Currituck County), seasonal high water table, and steep slopes.

Step 3 Site analysis (matching the program to the site).

Identify the opportunities and constraints inherent in the natural and cultural characteristics of the site (see Figure 4-6). Match the project form and key elements to the site assessment: are there better places for some things than others? Are there unique site opportunities that shall be maximized or at least considered (such as views or historic structures)?

The site analysis shall:

- Result in a map that establishes the proposed limits of disturbance and delineates resource protection areas;
- Involve the project team walking the property to ensure that all the key participants agree on project priorities and their implications for development, including site constraints and features to be preserved; and,
- Analyze the site for its capacity to handle the program—can it do what is needed without major reshaping?

Note that in the example in Figure 4-6, the envelope of disturbance and the built upon portions of the development are restricted to avoid adverse impacts to the buffers, wetlands, waterbodies, and other valuable resource areas identified in the site inventory stage.

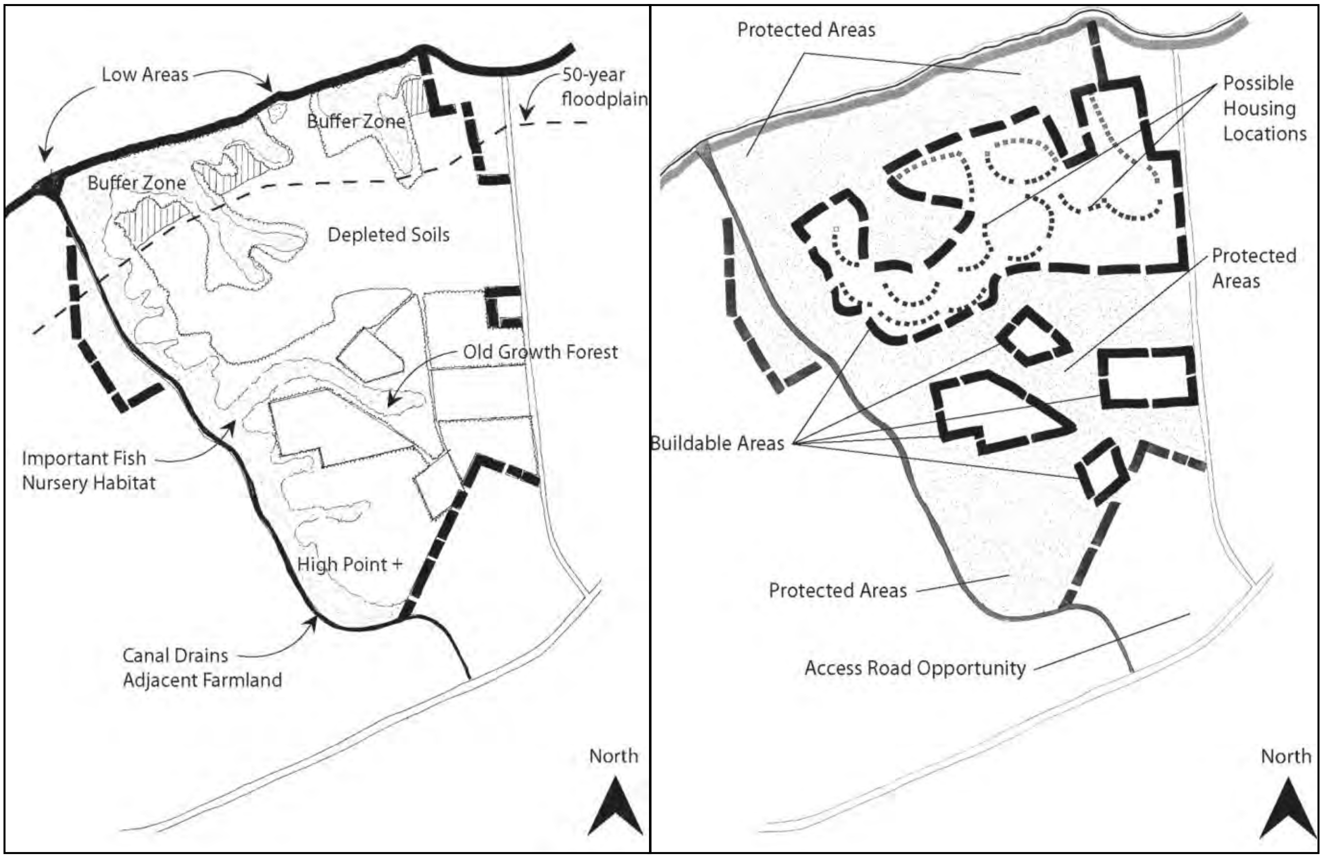


Figure 4-6. Site Inventory and Analyses to Match the Program to the Site (NCSU, 2009)

Step 4 Reassess project goals and objectives (how should the program change in light of the site constraints and opportunities?)

The site inventory, assessment, and analysis may have identified a development envelope that is too small to support the scope of the program initially proposed because of environmental or cultural conditions.
Opportunities to support additional density on a site shall be explored.

Step 5 Develop alternative design scenarios (schematics).

Multiple design scenarios (such as in Figure 4-7) shall be developed to account for the range of factors that can influence LID in a flexible fashion. For example, study different development layouts that emphasize different considerations, such as minimizing impervious areas, preserving existing vegetation, and preserving existing site topography.

Step 6 Evaluate the alternatives based on the site analysis and project goals and objectives.

Identify which design best meets the project goals and the design guidelines. This will be a matter of balancing conflicting demands and will require prioritization of some objectives over others. For example, you may be able to reduce impervious surface, but it may require significant cutting and filling, resulting in the loss of more existing vegetation, whereas with a little more impervious surface, you could save the vegetation. Which alternative do you pick? Return to your analysis and program and make the best decision based on long-term implications and community benefits.

Figure 4-7. Example of Multiple Design Scenarios

Step 7 Apply specific construction and ordinance requirements

Resolve the key details of your design. Match these to regulatory requirements, or identify preferred or recommended characteristics that are worth discussing with state and local approval bodies to identify opportunities for variances. Identify which ordinances to conform to, and which to challenge.

Step 8 Design a draft set stormwater management practices to treat runoff and maintain the hydrologic regime and model their effectiveness

See *Chapter 2* for the process for modeling your preliminary design to determine the required stormwater storage requirements. Have Currituck County staff and other permitting agencies review your initial designs for compliance and achievement of best practices. Stormwater BMPs typically associated with LID include, but are not limited to: bioretention cells (including bioretention swales and smaller cells, typically referred to as rain gardens), constructed wetlands, vegetated filter strips, infiltration basins and swales, permeable pavements, and green roofs. Detailed design guidance for each of these BMPs, as well as others is included in Section IV of this manual.

Step 9 Modify the design to develop final plan

The process of design, modeling and refinement will highlight areas or aspects that are causing problems with stormwater management. Modify the design to address these issues, and perform the modeling analyses again. When you are getting close to resolving the issues, check with Currituck County to review your designs for compliance and achievement of best management practices. Figure 4-8 illustrates the final development plan for the Village of Woodsong in Brunswick County, NC.

In addition to the steps outlined above, the following LID Site Design Checklist (Table 4-2) was also adapted from *Low Impact Development: A Guidebook for North Carolina* (NCSU, 2009).

Figure 4-8. Modify Design and Develop a Final Site Plan (image courtesy of The Milliken Company)

Table 4-2. LID Site Design Checklist (NCSU, 2009)

LID SITE DESIGN CHECKLIST	
Start big! Consider the entire site and surroundings and guiding principles, and then work your way down to the lot level. Finish with materials and design specifications.	
1.	**All impervious areas are designed with the minimum required paved area length and width needed to support their intended uses.** • Road widths are matched to traffic volumes. • Reduced parking standards are adopted if possible. • Emergency and service vehicle access are designed to reduce duplication. • Alternative street layouts are used to reduce road length. • Number of homes per unit of paved area is maximized. • Parking space size is minimized, including stall sizes. Alternative (permeable) materials for overflow parking areas are used where possible.
2.	**Alternative practices are used where possible to address street, sidewalk, and driveway stormwater.** • Bioretention areas are located in public rights-of-way or immediately adjacent to roadways. • Bike lanes are made of permeable pavement. • Vegetated swales replace curb and gutter.
3.	**Non-traditional lot layouts are used where possible to reduce road frontages and driveway lengths.**
4.	**Sidewalks are located and designed to accrue maximum benefits from the impervious surface.** • Sidewalks are located to address primary destinations. • Opportunities for single-sided sidewalk provision are identified, supportable, and implemented. • Permeable pavement is considered.
5.	**Pervious materials are used where possible.**
6.	**Rooftop runoff is captured and directed away from impervious areas or conveyance systems and onto surface pervious areas such as turf or vegetated areas (including rain gardens) or captured in cisterns or rain barrels for reuse.**
7.	**Site disturbance, clearing, and grading are limited to the smallest areas necessary.** • Development is planned to use roadways, future impervious areas, and building footprints for construction access and parking. • Best soils and most densely vegetated areas are preserved for infiltration. • Roads and driveways are sited so they follow the natural contours of the land, reducing the amount of cut and fill required.

LID SITE DESIGN CHECKLIST	
8.	**Natural systems are used to minimize development impacts.** • Existing waterways, vegetated areas, and amenable soils are used to direct, absorb, clean, recharge, or store water. • Opportunities to reduce air pollution, provide wildlife habitat, and add natural amenity value to a development have been recognized and adopted. • Low areas are used to provide retention. • Cut and fill is minimized and opportunities provided by existing topography are maximized. • Relatively high areas on the site (areas of higher topography such as hills or ridges) are identified. Use them as the starting point for infiltration by locating features relatively high and allowing space for infiltration (both structural and non-structural BMPs) at lower elevations. These areas of higher elevation will promote infiltration and begin the treatment train process. • Areas of established high-quality vegetation are preserved.
9.	**Opportunities to preserve site resources are maximized.** • Natural resources such as vegetated areas, waterways, topography, and cultural resources are preserved. • Opportunities to create areas for recreation and alternative forms of locomotion (such as walking and cycling) are recognized.
10.	**The design is easy to maintain and minimizes maintenance complexity, frequency, and cost.** • Information on future maintenance responsibilities is provided. • Information on appropriate maintenance protocols and intervals is provided. • The level of maintenance and equipment that will be available is accommodated. • Potential maintenance complications such as invasive or fruiting species are recognized and solutions are provided. • Plants require minimal pruning, but provide sufficient coverage to reduce weeding needs. • Native and well-adapted vegetation are used when appropriate. • Maintenance matches landscape needs.
11.	**Hydrologic opportunities are maximized.** • Sensitive areas that contribute to effective hydrological cycling (such as areas of quality soils or mature vegetation) are identified and preserved. • Existing areas of hydrologic function such as local streams, creeks, and wetlands are maintained. • Paths of flow, such as natural draws, swales, or ditches, which direct water to outflows are preserved. • Water is dispersed rather than concentrated to promote infiltration.

LID SITE DESIGN CHECKLIST	
	• The use of water as a desirable landscape component is recognized. • Impervious surfaces are disconnected by directing runoff to vegetated areas or cisterns.
12.	**Design features and systems address multiple functions.** • Areas with primary cultural function are maximized for environmental benefit. • Areas with primary environmental function are maximized for cultural and economic benefits. • All areas are maximized for recreational benefits, to enhance walkability, and for aesthetic character. • Vegetated areas address wildlife habitat, infiltration, pollution removal, and stormwater storage. • Stormwater capture and treatment areas provide sources of water for other purposes when possible.
13.	**Development impacts are managed at the source (or as close to it as possible).** • The use of engineered conveyance systems is limited. • Discrete, very large, or underground systems are avoided to the greatest extent possible. • Cut and fill is limited. • The site is revegetated to replicate pre-development vegetation levels.
14.	**Impervious areas are disconnected.** • Rainwater is directed from impervious areas to pervious areas. • Avoid linking multiple impervious areas together.
15.	**Site soil conditions are treated as a key factor in design.** • Clearing and grading and impervious areas are located in areas of less permeable soils. • Areas of permeable soils are preserved from construction and development.
16.	**Open space areas are consolidated and connected to create open space systems rather than unconnected islands.**
17.	**Alternative architectural designs are used to reduce building footprints or to adapt layout to site conditions such as topography.**

4.4.4. LID Site Design for Commercial and High Density Developments

The same basic site planning considerations detailed in the steps above can also apply to high density and commercial development. With high density and commercial development, it remains important to conserve natural resources and soils and minimize impacts internal to the site. Grading shall be conducted in a manner that ensures runoff will be dispersed and directed to the LID features as opposed to inlets and pipes. In most instances, LID techniques can be incorporated into the site design without significant alterations of traffic flow, parking capacity or building footprint / capacity potential. Not only are the LID techniques effective in meeting stormwater management objectives there are other ancillary benefits, such as heat island reduction, water conservation, and aesthetics.

The multifunctional use of landscape for stormwater control does not increase maintenance burdens. Bioretention islands and tree box filters require no more maintenance than typical landscape features. The selection and sizing of LID techniques depends upon a wide range of factors, including unique site constraints (soils, high ground) and water quality treatment objective. The typical LID techniques used for high-density developments include perimeter buffers, swales and bioretention systems; parking lot bioretention/detention islands, planter boxes, green roofs, porous pavers/pavement, and infiltration devices. Runoff can also be stored, detained, and / or infiltrated under the parking lot using porous pavement with subsurface gravel storage areas (New Hanover County & City of Wilmington, 2008).

Figure 4-9 demonstrates how LID can be incorporated into a site developed for an office or retail use. The use of several engineered LID practices can be designed to meet both water quality and water quantity requirements. LID features such as buffers, swales, and bioretention areas are incorporated on site. Proper grading is required to ensure that runoff is dispersed and directed to the various LID landscape features. This design is in contrast to typical site grading where runoff is concentrated and directed to inlets, pipes and a detention pond.

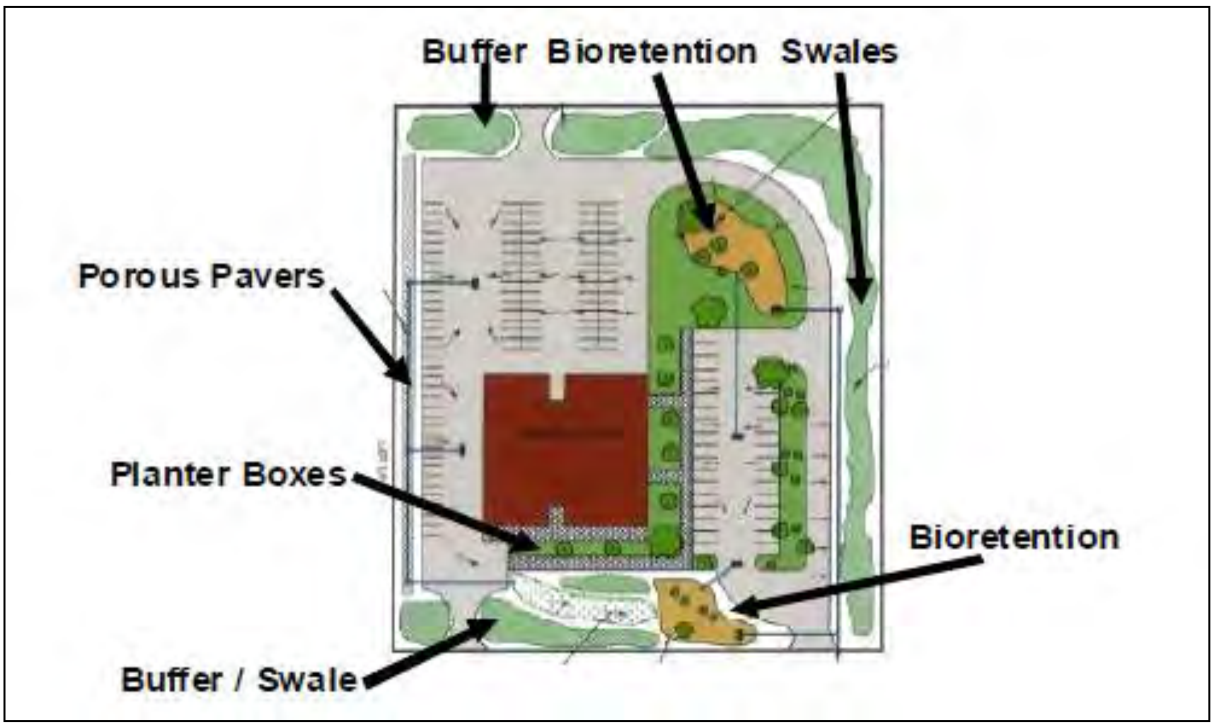


Figure 4-9. LID Design for an Office/Retail Project (New Hanover County & City of Wilmington, 2008)

The next figure, Figure 4-10, demonstrates how a "big-box" retail store could incorporate LID into the site. Swales, bioretention, buffers, and infiltration practices are incorporated throughout the site. The LID devices are incorporated into the landscape islands and used for filtration, infiltration, and water volume storage. The selection and sizing of the LID techniques that are ultimately chosen will depend upon a wide range of factors, including high ground water tables, soil consistency, and proximity of sensitive water bodies.

Lastly, Figure 4-11demonstrates a residential townhouse development where LID has been incorporated into the parking area and perimeter buffer areas.

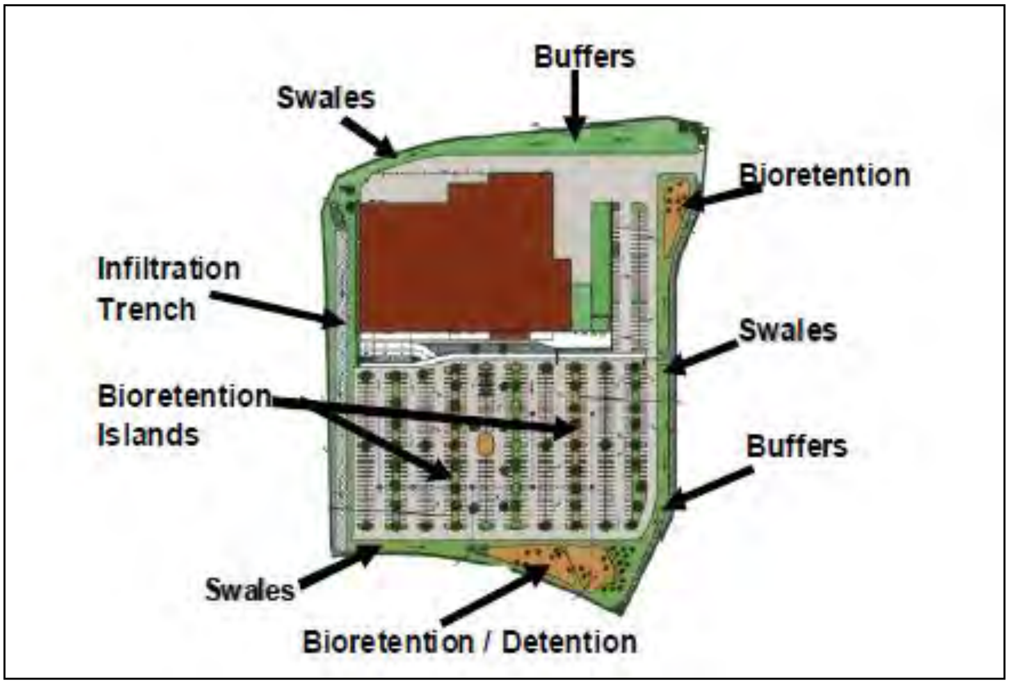


Figure 4-10. LID Design for a Big Box Retail Project (New Hanover County & City of Wilmington, 2008)

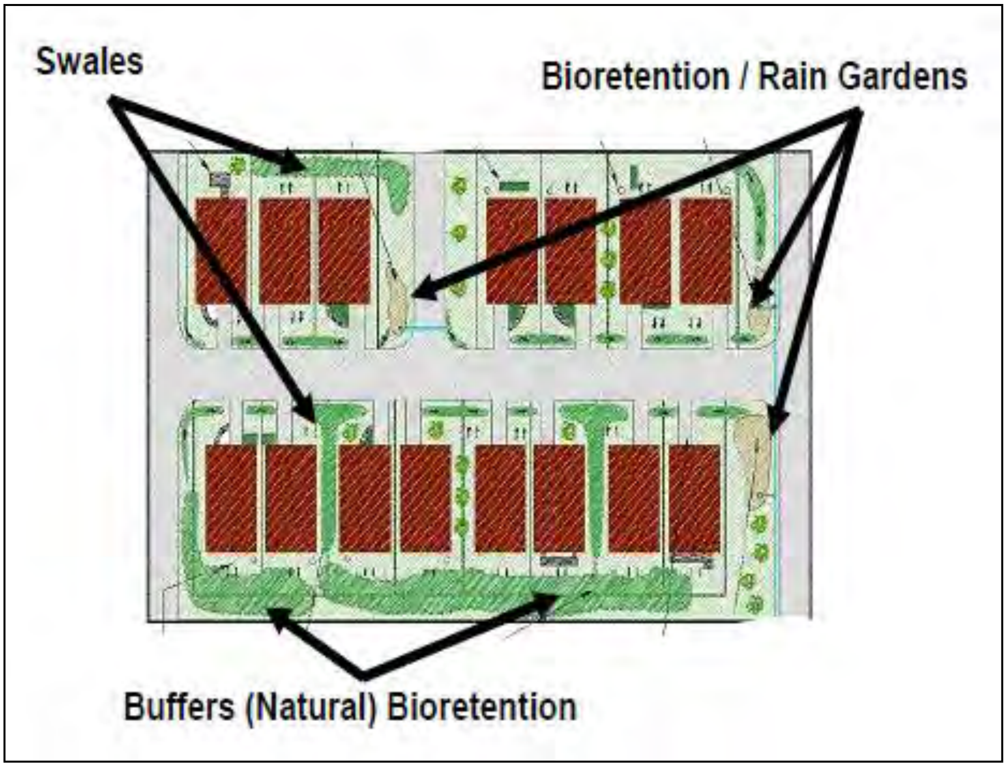


Figure 4-11. LID Design for a Residential Townhouse Project Constructing LID Projects (New Hanover County & City of Wilmington, 2008)

4.4.5. Training

It is very important that contractors, vendors, and inspectors be properly trained in the design specification and construction requirements for all LID practices employed. The success of many of the LID techniques depends on accurately following the grading plan; the use of proper materials and the appropriate location of practices. Due to the complexities of the practice, it may be necessary for vendors, contractors, and permitters to participate in certification training. For example, the design and construction of bioretention cells requires the knowledge of several disciplines including engineering, landscape architecture, and soil science to ensure the proper design and construction of the project.

North Carolina Cooperative Extension, through the N.C. State Biological and Agricultural Engineering Program, offers a stormwater BMP inspection and maintenance certification program. The purpose of the workshop is to offer instruction of BMP construction and maintenance activities. Professional development hours are offered for professional engineers and surveyors. More information about the certification program may be found at http://www.bae.ncsu.edu/stormwater or by contacting the N.C. State Biological and Agricultural Engineering Stormwater Program.

4.4.6. Communication

LID uses innovative techniques, unique strategies and various combinations of practices. Consequently, each development results in a unique design with its own set of issues and challenges. It is vital that everyone involved in the LID project (contractors, vendors, design engineers, and inspectors) understands the unique details of the LID project. A pre-construction meeting is the most useful approach to ensure that the project goals and issues are effectively communicated. Ideally the permit reviewer, contractor, vendor, design engineer, and inspector shall hold a meeting to go over the plans and discuss all aspects of the project. During the pre-construction meeting, the inspector may evaluate the proposed sequence of construction, sediment control requirements, and indicate when inspection points during construction of the LID practices are required as identified in the design manual. Throughout the construction process, there must be effective communication. No construction project takes place without unforeseen problems and the need to make some field adjustments. Proper lines of communication must be in place throughout the construction phase between the general contractor, site engineer, inspector, and permit staff to address required changes. After construction, a final inspection and walk-through of each LID practice is necessary to ensure its proper function.

4.4.7. Erosion and Sediment Control

One of the major advantages to an LID design is that it allows for clearing and grading in stages. Since LID can be a lot-specific approach to stormwater management, it is not necessary to completely clear-cut and re-grade the site to establish the drainage system. A development can be constructed on a lot-by-lot basis. This can greatly reduce the amount of sediment generated, thus reducing possible damage to LID designated areas.

Proper erosion and sediment control during construction is vital for LID practices. If existing vegetation is to be used for treatment, (bioretention, swales or buffers) then these areas must be protected from sedimentation. A thin layer of sediment over the root system is enough to suffocate a plant or tree. Additionally, areas that may be used for infiltration must be protected to prevent sediment from clogging soils with silts and clays. Preventing damage from sedimentation is less expensive than cleaning or rehabilitating an area.

4.4.8. Tree Protection

Care must be taken to protect tree conservation areas during construction. Tree conservation areas are ineffective if the trees die shortly after the project is completed. Trees can be damaged in a number of ways during the construction process; therefore it is recommended that a certified arborist be employed during the construction process.

In order to effectively protect trees, it is important to consider the following during any construction process:

A. All types of construction equipment can cause mechanical injury to roots, trunks, or branches. This can weaken a tree's resistance to a number of diseases and insect infestation. Trees shall be clearly marked and given wide clearance. Excavation around trees shall not be within the drip line of the tree.

B. Soil compaction squeezes the air and water out of the soil making it difficult for a tree to absorb oxygen and water. No construction equipment shall be allowed to run over the roots within the drip line of the tree.

C. Grading practices that deposit soil over the roots of trees eventually suffocates those roots. More than an inch or two of soil over the roots is enough to potentially suffocate the roots of trees and compromise the health of the tree. Measures can be taken to improve soil aeration around tree roots if it is necessary to add fill within the critical root zone.

D. Grading practices that divert too much runoff to a mature stand of trees can result in damage. As a tree matures its ability to adapt to changes decreases. Additionally, if a stand of trees is located in a normally dry area that suddenly becomes very wet, the additional water may kill the trees. An arborist may be consulted in these situations to determine the trees' tolerance to a change in hydrology.

E. A tree protection plan with written recommendations for the health and long-term welfare of the trees during the pre-construction, demolition, construction, and post-construction development phases, shall be developed. The tree protection plan shall include specifics about avoiding injury, information about treatment for damage and specifics about required inspections of protected trees. The tree protection plan shall also provide information about caring for damaged trees.

F. Tree protection zones shall be sized adequately, relative to the size of the trees, to achieve effective results (see Figure 4-12)

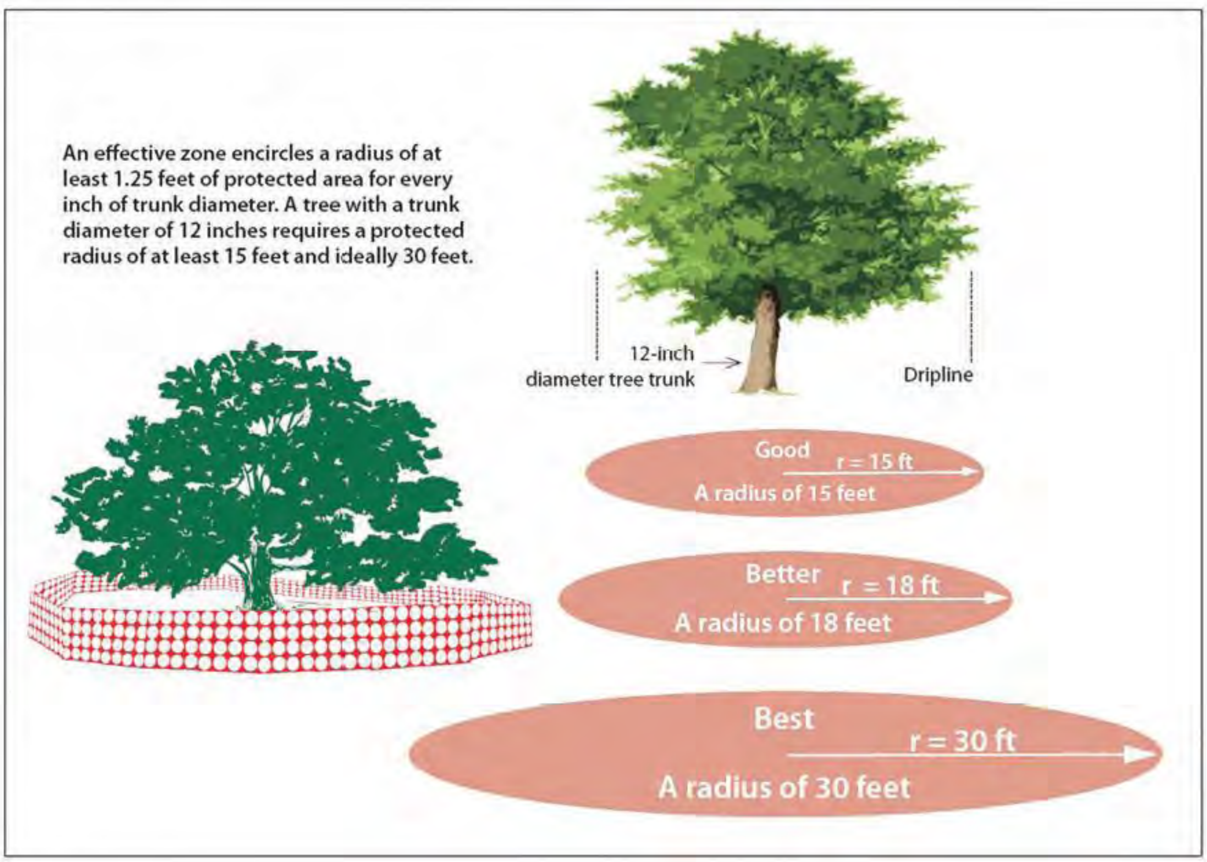


Figure 4-12. Effective Tree Protection Zones (NCDENR, 2009)

4.4.9. Construction Sequence

Construction sequencing is important to avoid problems while constructing LID projects. Proper sequencing decreases the likelihood of damage to the BMP during construction and helps to ensure optimal performance of the BMP. Each LID practice is somewhat different, therefore information should be provided to the contractor on the proper sequencing.

Conservation areas must be identified and protected before any major site grading takes place. Most of the engineered LID practices (bioretention, infiltration trenches, and infiltration swales) should be constructed at the end of the site development process, and preferably when most of the site is stabilized. Any LID practice that relies on filtration or infiltration must be protected throughout the construction phase from sedimentation and should not be activated until the contributing drainage area is stabilized. For example, bioretention areas should be constructed at the time of final grading and landscaping, and these areas should be protected from sedimentation until the drainage routes to the facility are stabilized.

4.4.10. Construction Administration

Proper oversight is important to the success of an LID design. Each engineered LID practice should be inspected at the time of installation. The general contractor should have their engineer on site during critical periods during the construction process, and the site manager should follow up with the engineer to ensure proper installation.

Inspectors not only need to be well informed about design and construction speciation of all LID techniques, they also need adequate enforcement tools. Occasionally, it is necessary to stop work and force contractors and vendors to remove and replace improper materials or install practices. It may not be possible to have the project manager on site at all times to make field adjustments. Therefore, it may be necessary to empower inspectors with the ability to make minor field adjustments in order to prevent unnecessary construction delays.

4.4.11. Maintenance

As with any stormwater management technique, maintenance is essential with LID BMPs to ensure that the designed stormwater benefits continue. Post-construction inspections and maintenance are important to ensure that each technique is functioning effectively. Annual inspections are recommended, with more frequent inspections during the first year to ensure that vegetation is thriving.

Inspection and maintenance of structural LID practices such as cisterns, vegetated roofs, permeable pavements, infiltration structures, and manufactured proprietary devices should follow local health department, state or local stormwater minimum standards, as well as manufacturer's recommendations for maintenance or repair. Any under-drains or outfall structures should be inspected on a regular basis and cleaned out or repaired as necessary.

The primary maintenance requirement for vegetative LID structural and non-structural practices is inspection and periodic repair or replacement of the treatment area's components. This often includes the maintenance of the vegetative cover (pruning), replacing mulch, removing weeds, and possibly removing sediment to preserve the practice's hydraulic properties. For many LID practices, this generally involves little more than the routine periodic landscape type maintenance. Maintenance requirements are further discussed in Chapter IV with each associated LID technique. To ensure continued long-term maintenance, all affected landowners should be made aware of their individual or collective maintenance responsibilities through legal instruments such as maintenance agreements and maintenance easements that convey with the property. Outreach materials, such as LID brochures or facts sheets that explain the function of practices and the anticipated maintenance responsibilities for homeowners, should be included in settlement or homeowner association documents. The developer should prepare a maintenance plan that provides clear guidance and instructions to the property owner property manager or property owners association about the annual maintenance needs of each LID technique.

4.5. ADDITIONAL LID INFORMATION

A great deal of valuable information and design guidance exists in the public space with regard to LID. The North Carolina State Government, N.C. State University, the USEPA, and numerous non-profit organizations and local jurisdictions have researched and developed detailed LID guidebooks and educational programs. The LID section of this manual, presented here, is merely intended as a condensed cross-section of that wealth of information, focused on the most important elements for Currituck County, and the implications of LID implementation specific to Currituck. The reader is urged to pursue the more detailed guidance and information present in the other sources listed below. Much of the material in this section has been drawn or adapted from these sources:

- Low Impact Development, A Guidebook for North Carolina (June, 2009)
  http://www.ces.ncsu.edu/depts/agecon/WECO/lidguidebook/
- *NCDWQ Stormwater Best Management Practices Manual* (July, 2007)
  http://portal.ncdenr.org/web/wq/ws/su/bmp-manual
- *North Carolina Erosion and Sediment Control Planning and Design Manual* (2006)
  http://portal.ncdenr.org/web/lr/publications
- *NCDWQ Stormwater Management Site Planning Handbook* (February, 1998)
  http://h2o.enr.state.nc.us/su/PDF_Files/SW_ Documents/Site_Planning_Document.pdf
- *City of Wilmington Low Impact Development Guidance Manual*
  http://www.wilmingtonnc.gov/development_services/historic_environmental/environmental_planning.aspx
- *Low Impact Development Design Strategies, An Integrated Design Approach (1999)*
  http://www.lowimpactdevelopment.org/pubs/LID_National_Manual.pdf
- Better Site Design Publications, Center for Watershed Protection (Various)
  http://www.cwp.org/documents/cat_view/77-better-site-design-publications.html

CHAPTER 5. REFERENCES

Brown, R. A. (2009). *Urban Waterways: Designing Bioretention with an Internal Water Storage (IWS) Layer.* NCSU.

Driscoll, E. (1986). *Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality. EPA440/5-87-001*. Washington DC: EPA.

Hunt, W. F. (1999). *Urban Waterways.* North Carolina Cooperative Extension Service.

Hunt, W. F., & Collins, K. A. (2008). *Urban Waterways - Permeable Pavement: Research Update and Design Implications.*

Hunt, W. F., & Lord, B. (2006). *Urban Waterways: Maintenance of Stormwater Wetlands and Wet Ponds.* NSCU BAE.

Hunt, W. F., & Szpir, L. L. (2006). *Urban Waterways - Permeable Pavements, Green Roofs, and Cisterns: Stormwater Treatment Practices for Low-Impact Development.*

Hunt, W. F., Burchell, M. R., Wright, J. D., & Bass, K. L. (2007). Urban Waterways: Stormwater Wetland Desgin Update.

Hunt, W. (2011, April). *Green Stormwater BMPs: Perfomance and their Metrics*. Retrieved from http://watercenter.unl.edu/SpringSeminars/Presentations2011/2011-04-13-hunt.pdf

Kurz, R. C. (1999). Removal of Microbial Indicators from Stormwater Using Sand Filtration, Wet Detention, and Alum Treatment Best Management Practices. *Sixth Biennel Stormwater Research & Watershed Management Conference.*

Lake Co. SMC. (2010). *Filtering Practices.* Retrieved from Lake County, Illinois Web Site: http://www.lakecountyil.gov/Stormwater/LakeCountyWatersheds/BMPs/FilteringPractices.htm

Moffatt & Nichol. (2011). *Technical Memorandum of Currituck County Stormwater Recommendations.* Raleigh: Moffatt & Nichol.

NC DENR, D. o. (2006). *North Carolina Erosion and Sediment Control Planning and Design Manual.*

NCDENR. (2009). *NC Erosion and Sediment Control Manual.*

NCDWQ. (2007). *Stormwater Best Management Practices Manual.* NCDENR.

NCSU BAE. (2011). *North Carolina State University Department of Biological and Agricultural Engineering.*

NCSU BAE. (2007). *Pathogen Transport and Removal in Urban Watersheds.*

NCSU. (2010). *BAE Stormwater Engineering*. Retrieved from Pathogen Transport and Removal in Urban Watersheds: http://www.bae.ncsu.edu/topic/swpathogens/index.html

NCSU. (2009). *Low Impact Development: A Guidebook for North Carolina.* Raleigh: North Carolina Cooperative Extension.

New Hanover County & City of Wilmington. (2008). *Low Impact Development Guidance Manual.*

NOAA. (2011). *Point Precipitation Frequency Estimates*. Retrieved from http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nc

NRCS. (1985). *National Engineering Handbook Technical Release 20.* USDA.

NRCS. (1986). *Urban Hydrology for Small Watersheds (Technical Release 55).* USDA.

Reich, D. M. (2007).

Schueler, T. (1992). *A Current Assessment of Urban Best Management Practices.* Metropolitan Washington Council of Governments.

Service, N. R. (2011). *Web Soil Survey*. Retrieved from http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

SMRC. (2011). *Stormwater Manager's Resource Center*. Retrieved from http://www.stormwatercenter.net/

UCONN. (2012). *University of Connecticut - NEMO*. Retrieved from http://nemo.uconn.edu/tools/stormwater/swales.htm

UDFCD. (1992). *Criteria Manual - Volume 3 - Best Management Practices.* Denver, CO: Urban Drainage and Flood Control District.

United States Environmental Protection Agency. (1999). *EPA 832-F-99-012: Storm Water Technology Fact Sheet - Bioretention.*

United States Environmental Protection Agency. (2010). *Vegetated Filter Strip Fact Sheet.* Retrieved from USEPA Website: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=76

United States Environmetal Protection Agency. (1999). *EPA 832-F-99-007: Storm Water Technology Fact Sheet - Sand Filters.* EPA.

United States Environmetal Protection Agency. (1999). *EPA 832-F-99-025: Storm Water Technology Fact Sheet - Storm Water Wetlands.*

US Department of Housing & Urban Development. (2003).

USACE. (2010). *HEC-RAS Hydraulic Reference Manual, Version 4.1*. USACE.

Wossink, A. a. (2003). *An Evaluation of Cost and Benefits of Structural Stormwater Best Management Practices.* North Carolina Cooperative Extension Service.

Appendix A: Required Forms

APPENDIX A. REQUIRED FORMS

To ensure compliance with the requirements of this Manual and the Unified Development Ordinance, a stormwater plan demonstrating how stormwater will be managed on a development site, including all required forms and calculations, shall be included with any application for site plan, subdivision, or zoning compliance permit, as appropriate. The required forms included in this section are intended to provide a standardized procedure for reviewing and approving stormwater plans.

The Currituck County Unified Development Ordinance includes additional standards for persons submitting applications for development review.

Minor Stormwater Plan Form SW-001

Review Process

Contact Information

Currituck County
Planning and Community Development
153 Courthouse Road, Suite 110
Currituck, NC 27929

Phone: 252.232.3055
Fax: 252.232.3026

Website: http://www.co.currituck.nc.us/planning-community-development.cfm

Currituck County
Engineering Department
153 Courthouse Road, Suite 302
Currituck, NC 27929

Phone: 252.232.6035

General

Minor stormwater plan approval is required for:

- Residential development that:
  - Exceeds the maximum allowed lot coverage by no more than 15%;
  - Proposes fill to achieve elevations higher than the highest adjacent grade; or,
  - Results in 10,000 square feet or more of total impervious cover within the Outer Banks Stormwater Management Zone.
- Nonresidential development that proposes fill to achieve elevations higher than the highest adjacent grade.
- A minor subdivision that:
  - Is located within the Outer Banks Stormwater Management Zone or,
  - Proposes fill to achieve elevations higher than the highest adjacent grade.

Step 1: Application Submittal

The applicant must submit a complete application packet consisting of the following:

- Completed Currituck County Minor Stormwater Plan Form SW-001 (unless submitting a building permit)
- Stormwater management plan drawn to scale. The plan shall include the items listed in the minor stormwater plan design standards checklist.
- Alternative stormwater runoff analysis, if applicable.
- Number of Copies Submitted:
  - 3 Copies of required plans
  - 3 Hard copies of ALL documents
  - 1 PDF digital copy (ex. Compact Disk – e-mail not acceptable) of all plans AND documents.

On receiving an application, staff shall determine whether the application is complete or incomplete. A complete application contains all the information and materials listed above, and is in sufficient detail to evaluate and determine whether it complies with appropriate review standards. An application for minor stormwater plan must be submitted and approved prior altering an existing drainage system, performing any land disturbing activity or, issuing a building permit.

Step 2: Staff Review and Action

Once an application is determined complete staff shall approve, approve subject to conditions or disapprove the application.

OFFICIAL USE ONLY:
Permit Number: ____________
Date Filed: ____________
Date Approved: ____________

Minor Stormwater Plan
Form SW-001

Contact Information

APPLICANT:		PROPERTY OWNER:	
Name:	____________	Name:	____________
Address:	____________	Address:	____________
	____________		____________
Telephone:	____________	Telephone:	____________
E-Mail Address:	____________	E-Mail Address:	____________

Property Information

Physical Street Address: ____________

Parcel Identification Number(s): ____________

FEMA Flood Zone Designation: ____________

Request

Project Description: ____________

Total land disturbance activity: ____________ sf   Calculated volume of BMP: ____________ sf

Maximum lot coverage: ____________ sf   Proposed lot coverage: ____________ sf

TYPE OF REQUEST

- ☐ Lot coverage (Must be designed and sealed by a registered engineer)
- ☐ Fill higher that highest adjacent grade
- ☐ Outer Banks Stormwater Management Zone -10,000 square feet or more of impervious cover
- ☐ Outer Banks Stormwater Management Zone - minor subdivision

TYPE OF PROPOSED BMP
(designed to infiltrate or detain runoff generated from impervious areas during a 4-inch rain event)

- ☐ Rain Garden (See Stormwater Manual for design standards)
- ☐ Swale (See Stormwater Manual for design standards)
- ☐ Alternative BMP (Must be designed and sealed by a registered engineer)

I hereby authorize county officials to enter my property for purposes of determining compliance. All information submitted and required as part of this process shall become public record.

____________________   ____________________
Property Owner(s)/Applicant   Date

Minor Stormwater Plan SW-001
Page 2 of 4

Minor Stormwater Plan Design Standards Checklist

The table below depicts the design standards of the minor stormwater plan application. Please make sure to include all applicable listed items to ensure all appropriate standards are reviewed.

Minor Stormwater Plan

Design Standards Checklist

Date Received: ____________________

Project Name: ____________________

Applicant/Property Owner: ____________________

Minor Stormwater Plan Design Standards Checklist		
	General	
1	Property owner name and address.	
2	Site address and parcel identification number.	
3	North arrow and scale to be 1" = 100' or larger.	
	Site Features	
4	Scaled drawing showing existing and proposed site features: Property lines with dimensions, acreage, streets, easements, structures (dimensions and square footage), fences, bulkheads, septic area (active and repair), utilities, driveways, and sidewalks.	
5	Approximate location of all designated Areas of Environmental Concern (AEC) or other such areas which are environmentally sensitive on the property, such as Maritime Forest, CAMA, 404, or 401 wetlands as defined by the appropriate agency.	
6	Square footage of all impervious areas (structures, sidewalks, walkways, vehicular use areas regardless of surface material).	
7	Description of surface materials.	
8	Stormwater storage volume calculations using the following formula: $\text{Volume} = \text{Impervious Area (ft}^2) * 4\text{" rainfall} * \frac{1 \text{ foot}}{12 \text{ inches}}$	
9	Existing and proposed drainage patterns.	
10	Location and capacity of existing and proposed stormwater management features.	
11	Plant selection	
12	Alternative stormwater runoff storage analysis, if applicable	
	Fill	
13	Purpose of proposed fill.	
14	Existing and proposed ground elevations shown in one foot intervals. All elevation changes within the past six months shall be shown on the plan. The toe of the fill slope shall be indicated on the plan.	
	Certificate	
15	The minor stormwater plan shall contain the following certificate: I, ________________, owner/agent hereby certify the information included on this and attached pages is true and correct to the best of my knowledge. On the site plan entitled ________________, stormwater drainage improvements shall be installed according to these plans and specifications and approved by Currituck County. Yearly inspections are required as part of the stormwater plan. The owner is responsible for all maintenance required. Currituck County assumes no responsibility for the design, maintenance, or performance of the stormwater improvements. Date:______________ Owner/Agent:________________	

Minor Stormwater Plan Submittal Checklist

Staff will use the following checklist to determine the completeness of your application. Please make sure all of the listed items are included. Staff shall not process an application for further review until it is determined to be complete.

Minor Stormwater Plan Form SW-001

Submittal Checklist

Date Received: ____________

Project Name: ____________

Applicant/Property Owner: ____________

Minor Stormwater Plan Form SW-001 Submittal Checklist		
1	Completed Minor Stormwater Plan Form SW-001	
2	Stormwater plan	
3	Alternative stormwater runoff storage analysis, if applicable	
4	3 copies of plans	
5	3 hard copies of ALL documents	
6	**1 PDF digital copy of all plans AND documents (ex. Compact Disk – e-mail not acceptable)**	

Comments

____

____

____

Major Stormwater Plan Form SW-002

Review Process

Contact Information

Currituck County
Planning and Community Development
153 Courthouse Road, Suite 110
Currituck, NC 27929

Phone: 252.232.3055
Fax: 252.232.3026

Website: http://www.co.currituck.nc.us/planning-community-development.cfm

Currituck County
Engineering Department
153 Courthouse Road, Suite 302
Currituck, NC 27929

Phone: 252.232.6035

General

Major stormwater plan approval is required for:

- Major subdivisions.
- Major site plans - development or expansion on a nonresidential, multi-family, or mixed use lot by 5,000 square feet or more of impervious coverage or resulting in 10% or more total impervious coverage.

Step 1: Application Submittal

The applicant must submit a complete application packet consisting of the following:

- Completed Currituck County Minor Stormwater Plan Form SW-002 (unless submitting a major subdivision or major site plan).
- Completed Rational Method Form SW-003 or NRCS Method Form SW-004.
- Stormwater management plan drawn to scale. The plan shall include the items listed in the major stormwater plan design standards checklist.
- Alternative stormwater runoff storage analysis and/or downstream drainage capacity analysis, if applicable.
- NCDENR permit applications, if applicable.
- Number of Copies Submitted:
  - 3 Copies of required plans
  - 3 Hard copies of ALL documents
  - 1 PDF digital copy (ex. Compact Disk – e-mail not acceptable) of all plans AND documents.

On receiving an application, staff shall determine whether the application is complete or incomplete. A complete application contains all the information and materials listed above, and is in sufficient detail to evaluate and determine whether it complies with appropriate review standards. An application for major stormwater plan must be submitted and approved prior altering an existing drainage system, performing any land disturbing activity or, before construction documents are approved.

Step 2: Staff Review and Action

Once an application is determined complete staff shall approve, approve subject to conditions or disapprove the application.

OFFICIAL USE ONLY:
Permit Number: ____________
Date Filed: ____________
Date Approved: ____________

Major Stormwater Plan
Form SW-002

Contact Information

APPLICANT:		PROPERTY OWNER:	
Name:	____________	Name:	____________
Address:	____________	Address:	____________
	____________		____________
Telephone:	____________	Telephone:	____________
E-Mail Address:	____________	E-Mail Address:	____________

Property Information

Physical Street Address: ____________

Parcel Identification Number(s): ____________

FEMA Flood Zone Designation: ____________

Request

Project Description: ____________

Total land disturbance activity: ____________ sf

Calculated volume of BMPs: ____________ sf

Maximum lot coverage: ____________ sf

Proposed lot coverage: ____________ sf

TYPE OF REQUEST

- ☐ Major subdivision (10-year, 24-hour rate)
- ☐ Major site plan (5-year, 24-hour rate)

METHOD USED TO CALCULATE PEAK DISCHARGE

- ☐ Rational Method
- ☐ NRCS Method (TR-55 and TR-20)
- ☐ Simple volume calculation for small sites (less than 10 acres)
- ☐ Alternative stormwater runoff storage analysis
- ☐ Downstream drainage capacity analysis

I hereby authorize county officials to enter my property for purposes of determining compliance. All information submitted and required as part of this process shall become public record.

____________ ____________
Property Owner(s)/Applicant Date

Major Stormwater Plan SW-002
Page 2 of 4

Major Stormwater Plan Design Standards Checklist

The table below depicts the design standards of the major stormwater plan application. Please make sure to include all applicable listed items to ensure all appropriate standards are reviewed.

Major Stormwater Plan

Design Standards Checklist

Date Received: ________________

Project Name: ____

Applicant/Property Owner: ________________________________

Minor Stormwater Plan Design Standards Checklist		
	General	
1	Property owner name and address.	
2	Site address and parcel identification number.	
3	North arrow and scale to be 1" = 100' or larger.	
	Site Features	
4	Scaled drawing showing existing and proposed site features: Property lines with dimensions, acreage, streets, easements, structures (dimensions and square footage), fences, bulkheads, septic area (active and repair), utilities, vehicular use areas, driveways, and sidewalks.	
5	Approximate location of all designated Areas of Environmental Concern (AEC) or other such areas which are environmentally sensitive on the property, such as Maritime Forest, CAMA, 404, or 401 wetlands as defined by the appropriate agency.	
6	Existing and proposed ground elevations shown in one foot intervals. All elevation changes within the past six months shall be shown on the plan.	
8	Limits of all proposed fill, including the toe of fill slope and purpose of fill.	
9	Square footage of all existing and proposed impervious areas (structures, sidewalks, walkways, vehicular use areas regardless of surface material), including a description of surface materials.	
10	Existing and proposed drainage patterns, including direction of flow.	
11	Location, capacity, design plans (detention, retention, infiltration), and design discharge of existing and proposed stormwater management features.	
12	Elevation of the seasonal high water level as determined by a licensed soil scientist.	
13	Plant selection.	
	Permits and Other Documentation	
14	NCDENR stormwater permit application (if 10,000sf or more of built upon area).	
15	NCDENR erosion and sedimentation control permit application (if one acre or more of land disturbance).	
16	NCDENR coastal area management act permit application, if applicable.	
17	Stormwater management narrative with supporting calculations.	
18	Rational Method Form SW-003 or NRCS Method Form SW-004	
19	Alternative stormwater runoff storage analysis and/or downstream drainage capacity analysis, if applicable	
20	Design spreadsheets for all BMPs (*Appendix F – Currituck County Stormwater Manual*).	
21	Detailed maintenance plan for all proposed BMPs.	

Major Stormwater Plan SW-002
Page 3 of 4

Certificate		
22	The major stormwater plan shall contain the following certificate: I, ______________, owner/agent hereby certify the information included on this and attached pages is true and correct to the best of my knowledge. On the plan entitled ____________________, stormwater drainage improvements shall be installed according to these plans and specifications and approved by Currituck County. Yearly inspections are required as part of the stormwater plan. The owner is responsible for all maintenance required. Currituck County assumes no responsibility for the design, maintenance, or performance of the stormwater improvements. Date:______________ Owner/Agent:__________________	

Major Stormwater Plan Submittal Checklist

Staff will use the following checklist to determine the completeness of your application. Please make sure all of the listed items are included. Staff shall not process an application for further review until it is determined to be complete.

Major Stormwater Plan Form SW-002

Submittal Checklist

Date Received: ______________

Project Name: ____

Applicant/Property Owner: ______________________________________

Major Stormwater Plan Form SW-002 Submittal Checklist		
1	Completed Major Stormwater Plan Form SW-002	
2	Completed Rational Method Form SW-003 or NRCS Method Form SW-004	
3	Stormwater plan	
4	NCDENR permit applications, if applicable	
5	3 copies of plans	
6	3 hard copies of ALL documents	
7	**1 PDF digital copy of all plans AND documents (ex. Compact Disk – e-mail not acceptable)**	

Comments

____

____

____

Rational Method Peak Flow

Form SW-003

Project Information

Project Location: ____

Parcel Identification Number(s): ______________________________________

Drainage area: ______________________ ac

Average Slope: ______________________ %

Maximum Slope Length: ________________ ft

Calculations

*The Rational Method may only be used where development will impact less than 10 acres

Time of Concentration (Tc) (Use additional sheets if necessary)			
	Pre-	**Post-**	
Sheet Flow			
Manning's roughness, n (Table 2-4)			
2-year, 24-hour Rainfall, P	4.0	6.0	in
Slope, S			ft/ft
Length of Sheet Flow, L (<=300 feet)			ft
Total Time for Sheet Flow			**min**
Shallow Concentrated Flow			
Surface Paved (P) or Unpaved (U)			
Length of flow, L			ft
Slope, S			ft/ft
Average Velocity, V (Table 2-3)			ft/min
Total Time for Shallow Concentrated Flow			**min**
Channel Flow			
Pipe (P) or Channel (C)			
If pipe: Diameter, D			in
If channel: Bottom Width, w			ft
If channel: side slope 1 (___:1)			
If channel: side slope 2 (___:1)			
Cross sectional flow area, A			sq ft
Wetted perimeter, Wp			ft
Hydraulic radius, R = A/Wp			ft

Rational Method Peak Flow SW-003
Page 1 of 2

Time of Concentration (Tc) (Use additional sheets if necessary)			
	Pre-	**Post-**	
Channel slope, S			ft/ft
Manning's roughness, n (Table 2-4)			
Channel velocity			ft/sec
Length of Flow, L			ft/sec
Total Time for Channel Flow			**min**
Total Time of Concentration, Tc			**min**

Pre-development Conditions			
Land Use Description	C	Area (acres)	C*A
Woods	0.2		
Total			

Intensity for 2-year, 24-hour storm (Table 2-5) ______________ in/hr

Pre-development peak flow, Q = CiA ______________ cfs

Post-development Conditions			
Land Use Description	C	Area (acres)	C*A
Totals			

Area-weighted C ______________

Intensity for 10-year, 24-hour storm (Table 2-5) ______________ in/hr

Post-development peak flow, Q = CiA ______________ cfs

Minimum Storage Volume Required – Refer to *Section 2.4.4* for Volume Calculations

Storage Volume, V_s ______________ ft^3

______________________________ ______________________
Applicant Date

Rational Method Peak Flow SW-003
Page 2 of 2

A.3.1 Rational Method Sample Calculations

The Rational Method may only be used for developments where the final build-out will impact less than 10 acres. Use the blank form (SW-003) for calculating the Rational Method peak runoff discharges.

Given: A 5.0 acre watershed located in Moyock, North Carolina will be developed into single-family residential housing, approximately 25% impervious. There will be 1.5 acres of open space for soccer fields. The proposed development will use trapezoidal ditches to convey stormwater to the BMP. Ditches will have 3-foot base widths and 3:1 side slopes. The average slope is 0.5 percent. The maximum flow length is 1,300 feet.

Find: Compute the design peak discharges for the pre- and post-development storms.

Step 1: Determine the drainage area, A, in acres:
5.0 acres

Step 2: Determine the runoff coefficient for the drainage area under wooded conditions (see Table 2-2):
Under wooded conditions: C = 0.2

Step 3: Determine the time of concentration, T_c, for the drainage area using the segmental method:

Sheet Flow

*Manning's n (*Table 2-4*) = 0.1 for woods*
Rainfall depth, P = 4.0 inches for the 2-year, 24-hour storm
Slope, S = 0.005
Flow Length, L = maximum of 300 feet

$$T_{c1} = \frac{0.42\,(nL)^{0.8}}{P^{0.5}S^{0.4}} = \frac{0.42\,(0.1 * 300)^{0.8}}{4.0^{0.5}0.005^{0.4}}$$

T_{c1} = 26.6 min

Shallow Concentrated Flow

Flow Length, L = 1,300 – 300 = 1,000 feet (For pre-development, usually assume shallow concentrated flow unless surveyed channel, stormwater system, or blue-line stream, as shown on USGS Quad map, is present)

$$V = 972S^{0.53} = 972 * 0.005^{0.53}$$

V = 58.6 ft/min

$$T_{c2} = \frac{L}{V} = \frac{1000}{58.6}$$

T_{c2} = 17.1 min

$T_c = T_{c1} + T_{c2}$ = 26.6 + 17.1 = 43.7 min = 0.7 hours

Step 4: Determine the peak rainfall intensity, i, using Table 2-5:
When using Table 2-5, always be conservative. Use Tc = 30 min. From Table 2-5 i = 2.80 in/hr for the 2-year, 24-hour storm

Step 5: Determine the peak discharge, $Q_{2\text{-}Pre}$:

C = 0.2 for woods
i = 2.8 in/hr
A = 5.0 acres

$Q_{2\text{-}Pre}$ = *CiA = 0.2*2.80*5.0*

$Q_{2\text{-}Pre}$ = *2.80 cfs*

Step 6: Determine the weighted runoff coefficient, C_w, for the post-development condition using Table 2-2:

Post-development Conditions			
Land Use Description	C	Area (acres)	C*A
Single-family Residential	0.40	3.5	1.4
Open Space	0.25	1.5	0.375
Totals			1.775

$$C_W = \frac{C * A}{A} = \frac{1.775}{5.0} = 0.36$$

Step 7: Determine the time of concentration, T_c, for the drainage area using the segmental method:

<u>Sheet Flow</u>

Manning's n (Table 2-4) = 0.035 for grassed lawns
Rainfall depth, P = 6.0 inches for the 10-year, 24-hour storm
Slope, S = 0.005
Flow Length, L = maximum of 300 feet

$$T_{c1} = \frac{0.42\,(nL)^{0.8}}{P^{0.5}S^{0.4}} = \frac{0.42\,(0.035 * 300)^{0.8}}{6.0^{0.5}0.005^{0.4}}$$

T_{c1}= 9.4 min

<u>Channel Flow</u>

Flow Length, L = 1300 – 300 = 1300 feet
Cross-sectional area, A = 90.0 sq ft

Wetted Perimeter = 34.6 ft
Hydraulic Radius, R = 2.6 ft
Slope = 0.005
*Manning's n (*Table 2-4*) = 0.035*

$$V = \frac{1.49 * R^{0.67} S^{0.5}}{n} = \frac{1.49 * 2.6^{0.67} 0.005^{0.5}}{0.035}$$

V = 5.7 ft/sec

$$T_{c3} = \frac{L}{60V} = \frac{1000}{(60 * 5.7)}$$

T_{c3}= *2.9 min*

$T_c = T_{c1} + T_{c3} = 9.4 + 2.9 = 12.3$ *min*

Step 8: Determine the peak rainfall intensity, i, using Table 2-5:
To be conservative, use Tc = 10 min. From Table 2-5 i = 6.26 in/hr for the 10-year, 24-hour storm

Step 9: Determine the peak discharge, $Q_{10\text{-Post}}$:

C_w *= 0.36 weight runoff coefficient*
i = 6.26 in/hr
A = 5.0 acres

$Q_{10\text{-Post}}$ *= CiA = 0.36*6.26*5.0*

$Q_{10\text{-Post}}$ *= 11.3 cfs*

Step 10: Determine minimum storage volume required (based on acreage)
Since the drainage area is 5 acres, the Simplified Method can be used.

Determine the weighted curve number, CN, for the post-development conditions using Table 2-6:

Post-development Conditions			
Land Use Description	CN	Area (acres)	CN*A
Residential – 1/2 acre lots	85	3.5	297.5
Open Space	84	1.5	126
Totals			423.5

$$CN_W = \frac{CN * A}{A} = \frac{423.5}{5.0} = 84.7$$

Step 11: *Select 10-year post-development design storm and determine the runoff depth, Q*

Weighted Curve Number, CN_w = 84.7
Rainfall depth, P (Table 2-7) = 6.0 for the 10-year, 24-hour storm

$$S = \frac{1000}{CN} - 10 = \frac{1000}{84.7} - 10 = 1.8$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} = \frac{(6.0 - 0.2 * 1.8)^2}{(6.0 - 0.8 * 1.8)} = 7.0\ inches$$

Step 12: *Determine the Runoff Volume, V_r*

$$V_r = \frac{Q}{12} * A = \frac{7.0}{12} * 5.0 = 2.9\ acre - feet$$

Step 13: *Determine the Required Storage Volume, V_s*

$$V_s = 1613.33 * V_r * \left(1 - \frac{Q_{2-pre}}{Q_{10-post}}\right) = 1613.33 * 2.9 * \left(1 - \frac{2.8}{11.3}\right)$$

V_S = 4680 CY

NRCS Method Peak Flow
Form SW-004

Project Information

Project Location: ______________________________

Parcel Identification Number(s): ______________________________

Check One: ☐ Pre-Development ☐ Post-Development

Calculations

Runoff Curve Number and Runoff

1. Runoff Curve Number (CN)

Soil Type	Cover Description	CN (Table 2-6)	Area (acres)	CN*A
		Totals		

$CN_{Weighted} = \frac{SCN*A}{SA} =$ ______

Use CN = ______

2. Runoff

	Storm #1	Storm #2	Storm #3
Frequency.............................Yr			
Rainfall, P (24-hour) (Use Table 2-7).........In			
Runoff, Q.............................In			

NRCS Peak Flow SW-004
Page 1 of 3

Time of Concentration (Tc)

NOTES: Space for as many as two segments per flow type can be used for each worksheet.
Include a map, schematic, or description of flow segments

Sheet flow **(Applicable to T_c only)**

			Pre		Post		
	Segment ID						
1.	Surface description						
2.	Manning's roughness coeff., n (Table 2-9)						
3.	Flow Length, L (total L<= 300 ft)	ft					
4.	24-hr rainfall, P	in	4.0		6.0		
5.	Land Slope, s	ft / ft					
6.	$T_t = 0.42(nL)^{0.8} / P_2^{0.5} s^{0.4}$	min		+		=	

Shallow concentrated flow

	Segment ID						
7.	Surface Description: paved (P) or unpaved (U)?						
8.	Flow Length, L	ft					
9.	Watercourse slope, s	ft / ft					
10.	Average velocity, V (Table 2-8)	ft / sec					
11.	$T_t = L / V$	min		+		=	

Channel flow

	Segment ID						
	Pipe (P) or Channel (C)?						
	If pipe, enter D (in):						
	If channel, enter bottom width:						
	If channel, enter side slopes (_:1):						
12.	Cross sectional flow area, a	sq ft					
13.	Wetted perimeter, w_p	ft					
14.	Hydraulic radius, $r = a / w_p$	ft					
15.	Channel slope, s	ft / ft					
16.	Manning's roughness coeff., n						
17.	$V = 1.49\ r^{0.67} s^{0.5} / n$	ft / sec					
18.	Flow length, L	ft					
19.	$T_t = L / 60V$	min		+		=	
20.	Watershed or subarea T_c or T_t (add T_t in steps 6, 11, 19)					min	

NRCS Peak Flow SW-004
Page 2 of 3

Graphical Peak Discharge

1. Data:

Drainage Area, Am	=	______	sq mi (acres/640)
Runoff Curve Number, CN	=	______	(From Runoff Curve Number Worksheet)
Time of Concentration, Tc	=	______	hr (From Time of Concentration Worksheet)
Rainfall Distribution	=	Type III	
Pond and swamp areas spread throughout watershed	=	______	% of A_m (______ acres covered)

			Storm #1	Storm #2	Storm #3
2.	Frequency	yr			
3.	Rainfall, P (24-hour)	in			
4.	Initial abstraction, I_a . . . . (Use CN)	in			
5.	Compute I_a/P				
6.	Unit peak discharge, q_u . . . . (use T_c and I_a/P with Figure 2-9)	csm/in			
7.	Runoff, Q . . . . (From Runoff Curve Number Worksheet)	in			
8.	Pond and swamp adjustment factor, F_p . . . . . . (Use Table 2-10)				
9.	Peak discharge, Q_p . . . . (Where $Q_p = q_u A_m Q F_p$)	cfs			

______________________ Applicant

______________________ Date

NRCS Peak Flow SW-004
Page 3 of 3

A.4.1 NRCS Method Sample Calculations

The NRCS Method may be used to calculate peak discharges for any development. Use the blank form (SW-004) for calculating the NRCS Method peak runoff discharges.

Given: A 5.0 acre watershed located in Moyock, North Carolina will be developed into single-family residential housing with 1/2-acre lots (approximately 25% impervious). There will be 1.5 acres of open space for soccer fields. The hydrologic soil type is D. The proposed development will use trapezoidal ditches to convey stormwater to the BMP. Ditches will have 3-foot base widths and 3:1 side slopes. The average slope is 0.5 percent. The maximum flow length is 1,300 feet.

Find: Compute the design peak discharges for the pre- and post-development storms.

Step 1: Determine the drainage area, A, in acres:
5.0 acres

Step 2: Determine the curve number for the drainage area under wooded conditions (see Table 2-6):
Under wooded conditions on D soils: CN = 77

Step 3: Select design storm and determine the runoff depth, Q

Curve Number, CN = 77 for wooded conditions on D soils
Rainfall depth, P (Table 2-7) = 4.0 for the 2-year, 24-hour storm

$$S = \frac{1000}{CN} - 10 = \frac{1000}{77} - 10 = 3.0$$

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} = \frac{(4.0-0.2*3.0)^2}{(4.0-0.8*3.0)} = 1.8\ inches$$

Step 4: Determine the time of concentration, T_c, for the drainage area using the segmental method:

<u>*Sheet Flow*</u>

Manning's n (Table 2-9) = 0.1 for woods
Rainfall depth, P = 4.0 inches for the 2-year, 24-hour storm
Slope, S = 0.005
Flow Length, L = maximum of 300 feet

$$T_{c1} = \frac{0.42\ (nL)^{0.8}}{P^{0.5}S^{0.4}} = \frac{0.42\ (0.1*300)^{0.8}}{4.0^{0.5}0.005^{0.4}}$$

T_{c1} = 26.6 min

Shallow Concentrated Flow

Flow Length, L = 1,300 – 300 = 1,000 feet (For pre-development, usually assume shallow concentrated flow unless surveyed channel, stormwater system, or blue-line stream, as shown on USGS Quad map, is present)

$$V = 972S^{0.53} = 972 * 0.005^{0.53}$$

V = 58.6 ft/min

$$T_{c2} = \frac{L}{V} = \frac{1000}{58.6}$$

T_{c2}= 17.1 min

$T_c = T_{c1} + T_{c2}$ = 26.6 + 17.1 = 43.7 min = 0.7 hours

Step 5: Determine the pond / swamp adjustment factor, F_p, using Table 2-10:
Default value equals 1.0 if no ponds or swamps are present

Step 6: Compute the initial abstraction, I_a:
Curve number, CN = 77

$$I_a = 0.2\left(\frac{1000}{CN} - 10\right) = 0.2\left(\frac{1000}{77} - 10\right) = 0.60$$

Step 7: Compute I_a/P:
I_a = 0.6
Rainfall, P = 4.0 for 2-year, 24-hour depth (see Table 2-7)
I_a/P = 0.15

Step 8: Compute the unit peak discharge, q_u, using Figure 2-9:
T_c = 0.7 hours, from Figure 2-9, q_u = 340 csm/in

Step 9: Determine the peak discharge, Q_{pre}:

Unit peak discharge, q_u = 340 csm/in
Drainage area = 5.0 acres = 0.0078 sq mi
Runoff Depth, Q = 1.8 inches
Pond adjustment factor, F_p = 1.0

$$Q_{pre} = q_u A Q F_p = 340 * 0.0078 * 1.8 * 1.0 = 4.8\ cfs$$

Step 10: Determine the weighted curve number, CN, for the post-development conditions using Table 2-6:

Post-development Conditions			
Land Use Description	CN	Area (acres)	CN*A
Residential – 1/2 acre lots	85	3.5	297.5
Open Space	84	1.5	126
Totals			423.5

$$CN_W = \frac{CN * A}{A} = \frac{423.5}{5.0} = 84.7$$

Step 11: Select design storm and determine the runoff depth, Q

Weighted Curve Number, CN_w = 84.7
Rainfall depth, P (Table 2-7) = 6.0 for the 10-year, 24-hour storm

$$S = \frac{1000}{CN} - 10 = \frac{1000}{84.7} - 10 = 1.8$$

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} = \frac{(6.0-0.2*1.8)^2}{(6.0-0.8*1.8)} = 7.0\ inches$$

Step 12: Determine the time of concentration, T_c, for the drainage area using the segmental method:

<u>Sheet Flow</u>

Manning's n (Table 2-9) = 0.035 for grassed lawns
Rainfall depth, P = 6.0 inches for the 10-year, 24-hour storm
Slope, S = 0.005
Flow Length, L = maximum of 300 feet

$$T_{c1} = \frac{0.42\ (nL)^{0.8}}{P^{0.5}S^{0.4}} = \frac{0.42\ (0.035 * 300)^{0.8}}{4.0^{0.5}0.005^{0.4}}$$

T_{c1} = 9.4 min

<u>Channel Flow</u>

Flow Length, L = 1300 – 300 = 1000 feet
Cross-sectional area, A = 90.0 sq ft
Wetted Perimeter = 34.6 ft
Hydraulic Radius, R = 2.6 ft
Slope = 0.005
Manning's n (Table 2-9) = 0.035

$$V = \frac{1.49 *\ R^{0.67}S^{0.5}}{n} = \frac{1.49 * 2.6^{0.67}0.005^{0.5}}{0.035}$$

V = 5.7 ft/sec

$$T_{c3} = \frac{L}{60V} = \frac{1000}{(60 * 5.7)}$$

T_{c3}= 2.9 min

$T_c = T_{c1} + T_{c3}$ = 11.5 + 2.9 = 12.3 min = 0.2 hours

Step 13: Determine the pond / swamp adjustment factor, F_p, using Table 2-10:
Default value equals 1.0 if no ponds or swamps are present

Step 14: Compute the initial abstraction, I_a:
Weighted Curve number, CN_w = 84.7

$$I_a = 0.2\left(\frac{1000}{CN} - 10\right) = 0.2\left(\frac{1000}{84.7} - 10\right) = 0.36$$

Step 15: Compute I_a/P:
I_a = 0.36
Rainfall, P = 6.0 for 10-year, 24-hour depth (see Table 2-7)
I_a/P = 0.06

Step 16: Compute the unit peak discharge, q_u, using Figure 2-9:
T_c = 12.3 min, from Figure 2-9, q_u = 550 csm/in

Step 17: Determine the peak discharge, Q_{post}:

Unit peak discharge, q_u = 550 csm/in
Drainage area = 5.0 acres = 0.0078 sq mi
Runoff Depth, Q = 7.0 inches
Pond adjustment factor, F_p = 1.0

$$Q_{post} = q_u A Q F_p = 550 * 0.0078 * 7.0 * 1.0 = 30.0\, cfs$$

Step 18: Determine minimum storage volume required (based on acreage)
Since the drainage area is 5 acres, the Simplified Method can be used.

Determine the Runoff Volume, V_r

$$V_r = \frac{Q}{12} * A = \frac{7.0}{12} * 5.0 = 2.9\, acre - feet$$

Determine the Required Storage Volume, V_s

$$V_s = 1613.33 * V_r * \left(1 - \frac{Q_{2-pre}}{Q_{10-post}}\right) = 1613.33 * 2.9 * \left(1 - \frac{4.8}{30.0}\right)$$

V_s = 3930 CY

Appendix B: Best Management Practices

APPENDIX B. BEST MANAGEMENT PRACTICES

B.1. GUIDANCE FOR COMMON BMP ELEMENTS

There are many common design elements for most BMPs. These elements are taken from the NCDENR Division of Water Quality *Stormwater Best Management Practices Manual* (NCDWQ, 2007). The elements are presented here rather than repeated in the individual BMP design guidance in *Section B.2*. The design elements presented are not intended to be comprehensive, nor a complete list of all design elements. The design professional is relied upon to make the correct design choices when selecting the appropriate BMP for a specific site.

B.1.1. Flow Splitter

For most BMPs, it is advantageous to install a flow splitter prior to the BMP to bypass stormwater in excess of the design flow around the BMP. Flow splitters help minimize the re-suspension of sediment, hydraulic overload, and erosion of the BMP. BMPs can be placed on-line or off-line. An on-line BMP will receive all stormwater flow regardless of intensity, with larger flows typically passing to an overflow structure. An off-line BMP typically has a flow splitter, which diverts the design volume flow to the BMP and bypasses excess flows around the BMP.

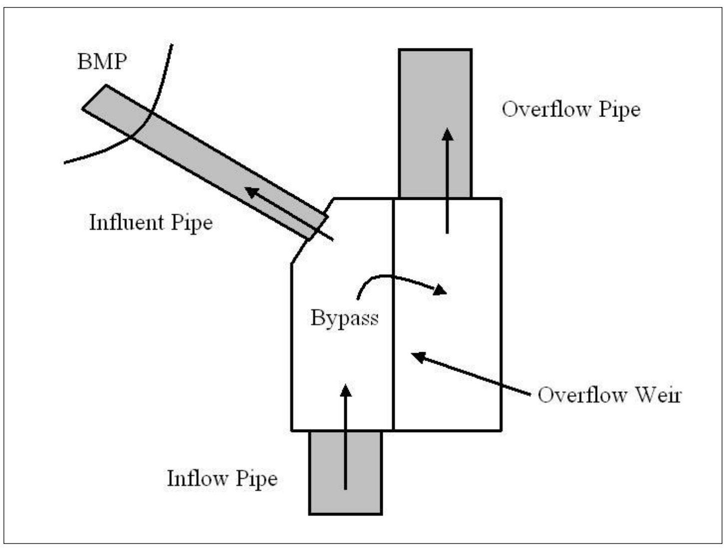


Figure B-1: Flow Splitter in a Vault (NCDWQ, 2007)

Flow splitters must be designed to send all flow from every rainfall event into the BMP until the BMP design volume has been reached, at which point, the flow splitter may start diverting a portion or all the additional flow around the BMP. The diverted flow may be routed to an additional BMP (if necessary), or it may be discharged to the receiving waters.

While many types of flow splitters designs are available, many of which involve various piping arrangements utilizing upturned overflow pipes and orifices, they may not meet the runoff requirement, or mitigate peak flows that are required. If a flow splitting device other than the one discussed below is proposed, the designer must prove that the flow splitting scenarios for all stormwater situations will properly meet stormwater requirements.

Flow splitters are most often designed as weir overflow devices placed in a manhole or vault. The elevation of the overflow weir is often set to 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 flows over the design volume to bypass the BMP.

The recommended design of the flow splitter will cause water levels in the BMP to exceed the design volume elevation. This must be accounted for in the BMP design. The height of the water level increase in a 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; however this would increase the size of the bypass structure. A balance must be struck between flow splitter design and BMP storage to best fit a specific situation.

Flow splitters can also cause a flow reversal and drain a certain volume of the BMP. This occurs when the influent flows drops the water level in the flow splitter faster than the outlet drops the water level in the BMP. This is best avoided by designing a wide weir and minimizing head over the weir.

The outfall pipe to the BMP must be sized so that it will not hydraulically limit the larger flows into the BMP and cause stormwater to prematurely overflow into the bypass before the stormwater capture or peak flow volumes have been sent to the BMP. Additionally, the flow splitter weir and outfall for the bypass must be able to handle the entire design flow capacity of the upstream conveyance system, not just the design storm for the BMP.

Materials for flow splitters must be corrosion resistant, such as concrete, aluminum, stainless steel, or plastic. Painted, zinc-coated, and galvanized metal materials are not permitted due to their corrosion potential and possible toxicity to aquatic life.

B.1.2. Forebays

According to the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007), a forebay is a settling basin near an inlet of a BMP designed to dissipate energy from the incoming stormwater and to settle out larger sediment particles. With larger sediment particles confined to the forebay area, maintenance is simpler and most cost-effective. Forebays also extend the life of the BMP. 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. If the BMP has a permanent water volume that is required as part of the design, a 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 BMP may be included in the overall storage volume as well.

Figure B-2: Example of a Forebay (NCSU, 2009)

Forebay volumes shall be approximately 20% of the total required storage volume (unless noted otherwise in specific BMP design). Multiple inlets may require additional forebay volume (or additional forebays). The forebay depth shall be approximately 3 feet, with a deeper section at the inlet to dissipate energy entering the forebay.

The main benefit of a forebay is to collect the majority of sediment volume in a small area that is specifically designed for easy removal. Sediment removal will likely be every 3-5 years for BMPs without forebays, as opposed to 15-25 years for BMPs with forebays. Due to the easy removal of sediment from the forebay, the overall cost should be less over the same period by installation of a forebay.

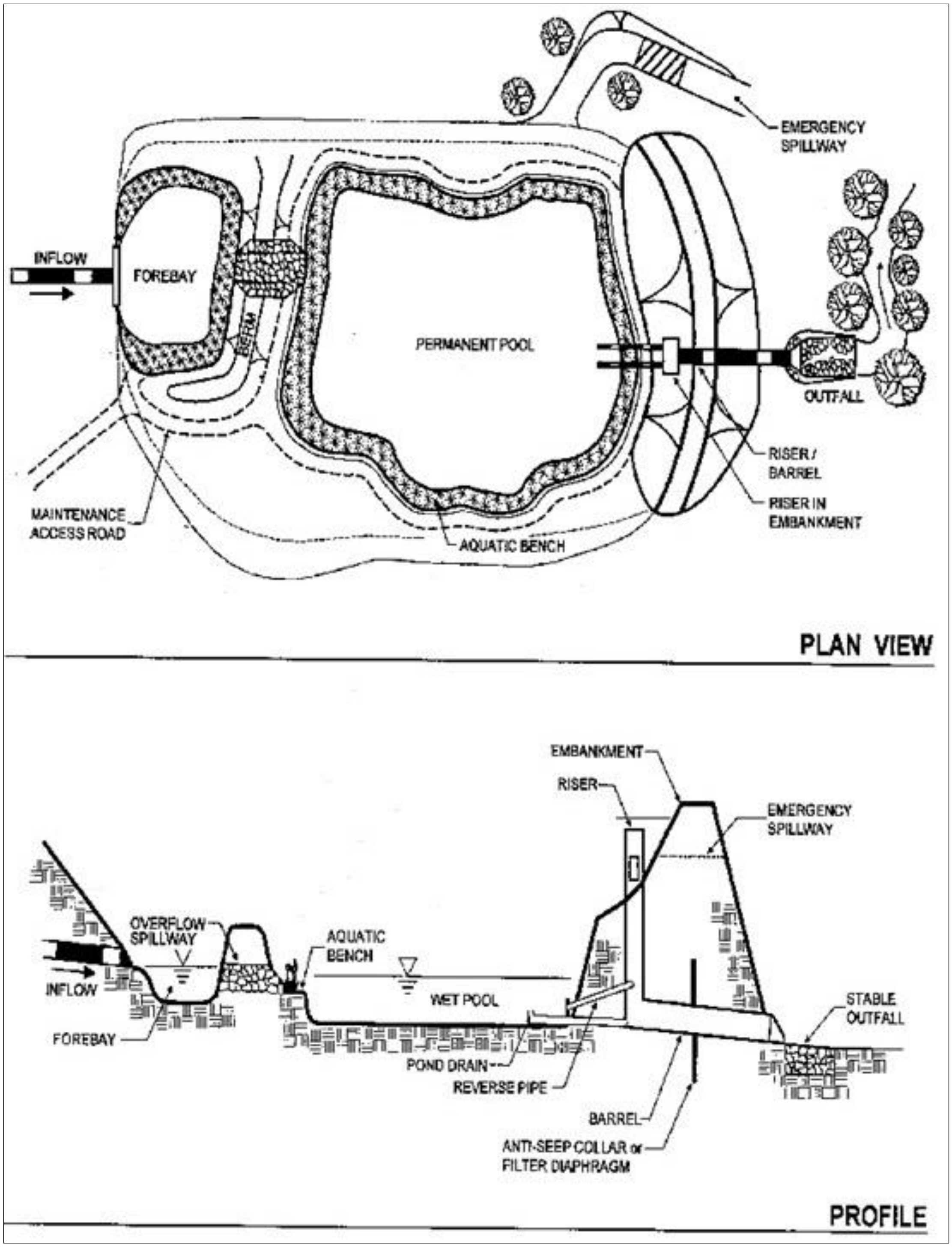


Figure B-3: Example of a Forebay Used in a Wet Pond (SMRC, 2011)

Forebays must have direct access provided for proper maintenance equipment. The BMP designer shall consider if hardened surfaces (gravel, open concrete pavers, etc.) need to be incorporated into the aesthetics. Hardened surfaces reduce erosion and vegetation disturbance during sediment removal. In addition, the bottom of the forebay shall be made of hardened material, if compatible with the design.

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. In wet pond forebay specifications, sediment shall be removed when the one foot depth of sediment storage is exhausted.

The forebay must be separated from the main body of the BMP. This separation can be an earthen or rip-rap berm, concrete wall, or gabion system wall. Another alternative is to set the forebay elevation higher than the main BMP and the separation structure could be several feet above the design stormwater level of the BMP and operate as an overflow structure. The elevation should be no more than 1 foot below the design stormwater elevation. Regardless of the relative elevation of the separation structure, the water flowing over (and possibly through) it must be a non-erosive velocity, preferably by designing the entire overflow structure at a single elevation to act as one large weir.

Vegetated shelves are recommended, especially if vegetated shelves are used in the main BMP. These shelves will increase safety, benefit water quality, and discourage non-migratory Canadian geese.

B.1.3. Underdrain Systems

Figure B-4: Example of an Underdrain System (NCSU BAE, 2011)

Underdrain systems should have a minimum of 0.5% slope and shall be constructed of Schedule-40 or SDR 35 smooth wall PVC pipe. Underdrains should be designed to carry 2 – 10 times the maximum flow exiting the BMP. The maximum flow is computed from Darcy's law and assumes maximum ponding and complete saturation along the depth of the medium.

$$D = \frac{(16 * Q * n)^{\frac{3}{8}}}{S^{0.5}}$$

Where:

D = Diameter of a single pipe in inches
n = roughness factor (0.011 for reinforced concrete pipe)
S = internal slope
Q = design flow in cubic feet per second

Manning's formula should be used to size the pipe, with the minimum pipe diameter allowed of 4 inches. The spacing of collection laterals should be no greater than 10 feet center to center, and a minimum of two pipes should be installed to allow for redundancy. A minimum of 4 rows of perforations should be provided around the diameter of the pipe (more for pipes 10 inches in diameter and larger). The perforations should be placed 6 inches on center within each row for the entire length of the drainage lateral. Perforations should be 3/8-inch diameter.

Underdrain pipes should have a minimum of 3 inches of washed #57 stone above and on each side of the pipe. Above the stone, either filter fabric or two inches of choking stone is required to prevent clogging. Avoid filter fabric if there is uncertainty about the stability of the drainage area. Refer to the NCDENR *Stormwater Best Management Practices Manual* for specific design criteria for underdrain systems (NCDWQ, 2007).

B.1.4. Level Spreaders

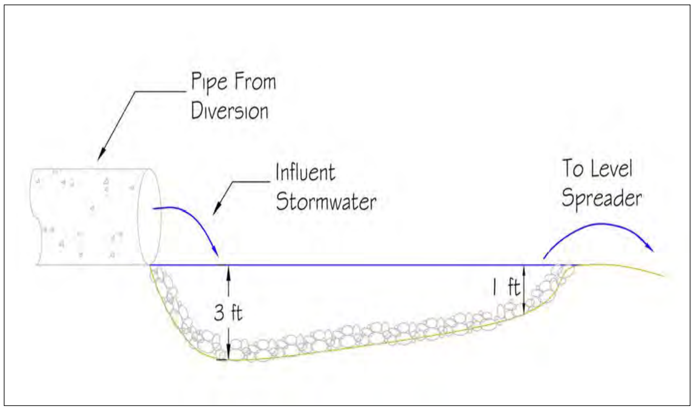


Figure B-5: Forebay Schematic with Level Spreader (NCSU, 2009)

A level spreader consists of a concrete linear structure constructed on a zero slope. The main purpose of a level spreader is to disperse concentrated stormwater over a wide enough area to prevent erosion of the BMP to which it outlets. If the level spreader is not outleting to a bioretention cell or other infiltration system, it will outlet to a vegetated filter strip.

Another purpose of a level spreader is to increase the interaction between the stormwater and vegetation and soils in the BMP. The vegetation and soils will aide in pollutant removal via filtration, infiltration, adsorption, absorption, and volatilization.
A level spreader consists of four components:

- *Flow Bypass System:* For level spreaders that divert outflow from an upstream BMP to a vegetated filter strip, a diverter box or flow splitter should bypass all flow above the 2-year wooded storm to a swale designed to pass the higher storm events. A bypass system is not needed if the level spreader lip is constructed to be long enough to handle these higher storm events. For level spreaders that outlet into a bioretention cell, the bypass system must be designed to bypass the higher storm event flows.

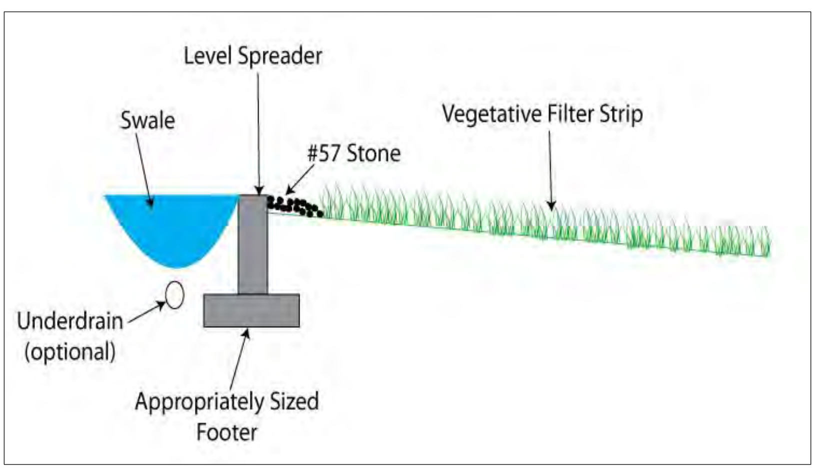


Figure B-6: Cross-section of Concrete Level Spreader (Hunt W. , 2011)

- *Forebay:* Forebays slow stormwater runoff and settle sediment and debris that could otherwise clog the BMP. If the level spreader is receiving flow from another BMP, such as a wet detention basin, then a forebay is not needed.

Horizontal angle of entry of 30° is recommended; armor may be needed to prevent scour. The forebay should have a surface area of 0.2% of the contributing impervious area. The recommended depth is 1 foot at the back end, sloping to 3 feet on the front side (the side closest to the inlet). The forebay can be lined with Class B rip-rap to dissipate energy.

- *Level Spreader Lip:* The portion of the level spreader that receives water from the forebay (or another BMP). The concrete lip is constructed so that it is level along its entire length. A swale is constructed immediately upslope of the lip, so stormwater can rise and fall evenly over the lip. The lip should be installed at a grade between 0 – 0.05%. The level spreader must be between 13 – 130 feet in length. The appropriate length is determined based on the type of vegetated filter strip and the design flow. Longer level spreaders are necessary for forested filter strips, because they are more susceptible to erosion.

Table B-1: Level Spreader Lengths (NCDWQ, 2007)

Grass or thick ground cover filter strip	Forested filter strip
13 feet of level spreader lip per 1 cfs of flow for slopes from 0 – 8%	65 feet of level spreader lip per 1 cfs of flow for slope from 0 – 6 %

The design flow will be based on the following:

- The peak flow resulting from the 2-year storm from wooded site conditions (which a high flow bypass and forebay is required)
- The drawdown rate from an upslope BMP
- The level spreader must be constructed of concrete

The lip of the level spreader should be higher than the existing ground by 3 to 6 inches. To prevent erosion downstream, a layer of filter fabric should extend 3 feet beyond the lip towards the buffer zone. Stone, such as No. 57 aggregate, should be placed on top of the filter fabric 3 – 4 inches deep to also reduce erosion. A 3-foot wide strip of erosion control matting can take the place of the filter fabric / stone combination; however, the area must be stable and have established vegetation before receiving stormwater (NCSU, 2009).

- *Vegetated Filter Strip:* A densely vegetated area that receives flow from the level spreader. See *Chapter B.2.11-Vegetated Filter Strip* for further design.

B.1.5. Outlets

BMP outlets are devices that control the flow of stormwater out of the BMP to the conveyance system. While most water quality treatment takes place within the BMP, the outlet is often integral to the treatment efficiency, as well as being a critical component in stormwater volume control.

Figure B-7: Example of an Outlet Box (NCDWQ, 2007)

Water quality is affected by how quickly the water is removed from the BMP, thereby affecting the sedimentation time and possibly causing re-suspension of particles. The depth from which the water is drawn also affects water quality, since water is typically cleaner higher in the water column. The outlet design is also the main factor in controlling peak flow volumes and rates. Design professionals should refer to the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007) for specific design criteria.

The outlet should be designed to retain the 1.5" of rainfall water quality volume (WQV) required by DWQ and release it over a period of time outlined in the NCDENR manual. Typically, the WQV is handled by a small, protected outlet structures such as a screen orifice or weirs. Larger discharges associated with the peak flows are typically handled with a riser with different sized openings (perforated riser), an overflow structure (outlet box or drop inlet), or a broad-crested weir or spillway.

A. Outlet Boxes

Outlet boxes are typically cast-in-place or precast concrete structures, with a free-flowing weir. They are generally used for smaller BMPs with low-flow volumes. Weirs can be made of various materials, and different weir shapes (rectangular and v-notch are 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. There are also "compound" weir designs, which incorporate different aspects of weir designs to achieve specific results. For instance, a compound weir might have a small-v-notch in the lower portion to provide lower release rates for the water quality event and a larger rectangular weir to provide larger release rates for large storm events.

B. Drop Inlets

The purpose of drop inlets is to allow rapid release of water once the lip of the outlet is reached. Drop inlets are not effective at providing peak runoff attenuation. Drop inlets are common for wet and dry detention basins, stormwater wetlands, and bioretention facilities. In general, BMPs with drop inlets also incorporate a lower level outlet to achieve specific attenuation objectives.

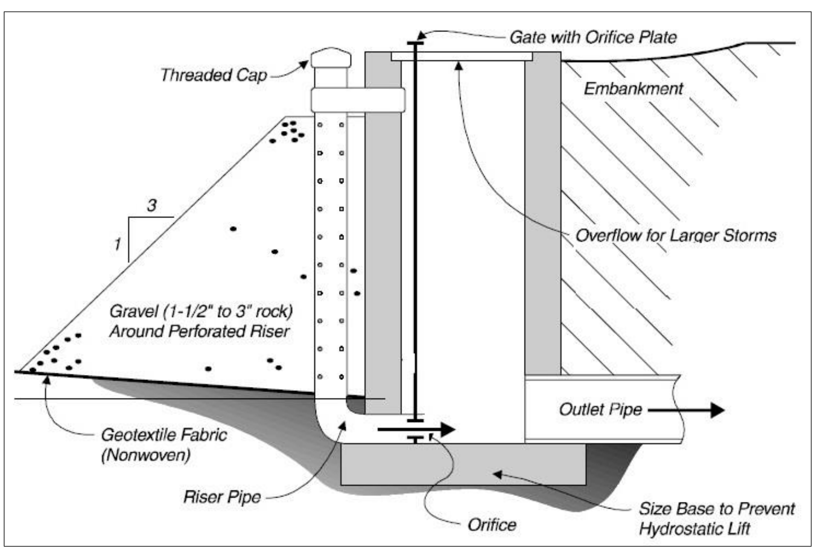


Figure B-8: Example of a Perforated Riser (UDFCD, 1992)

Drop inlets usually consist of a riser in the reservoir area connected to a pipe that extends through the embankment. Drop inlets should be designed to operate as weirs. The head over the inlet should not exceed 33% of the riser diameter. At greater heads, the flow becomes unstable, leading to surging, noise, vibration, or vortex action. In addition, downstream conditions, full flow conditions in the pipe, or other factors can result in complex hydraulics. **A full hydraulic analysis of the entire drop inlet system showing the controlling factors at all flow regimes is required.**

C. Perforated Riser

These are generally used for small BMPs with one or more columns of perforations in a vertical riser. It is typically constructed out of plastic pipe (PVC, HDPE, etc.). The main objective is to reduce the velocity near the outlet. Perforations should be smaller than 1-inch diameter.

Disadvantages of perforated risers include outlet rates that are greatest early in a storm event when most of the sediment is still suspended, and they draw most of the water from the deepest portions of the basin where the highest concentration of suspended sediments are located.

D. Multiple Outlets

In general, multiple outlets are used to achieve runoff peak attenuation goals. Outlets are arranged to provide the require attenuation while minimizing the overall size of the basin required. Multiple outlets frequently combine a number of different control devices, including orifices, various weirs, and drop inlets.

Figure B-9: Example of a Multiple Opening Outlet (NCSU BAE, 2011)

There are generally two types of multiple outlets: *shared outlet control structures* and *separate outlet control structures.* Shared outlets are typically a number of individual openings (orifices) and weirs at different elevations on a rise pipe or outlet box which all flow to a common larger outlet pipe or channel. Separate outlets are less common and consist of several pipes or culvert outlets at different levels that are either discharged separately or are combined to discharge at a single point.

Multiple outlets are useful when trying to achieve Currituck County's peak discharge requirements, while meeting the DWQ water quality volume requirement. A stage-discharge curve should be developed for the full range of flows that the BMP would experience. Outlet computations showing the different outfalls for each storm event should be included in the Stormwater plan.

E. Skimmers

Skimmers provide constant volume release rates regardless of water level, and collect water from the surface of a ponded area. Water near the surface has the lowest concentration of suspended sediment. Furthermore, the discharge rate for skimmers compared to perforated risers is significantly lower during the critical time when turbulence is greatest and sediment particles are suspended.

Tests reveal reductions of up to 45% in sediment mass discharged from sediment basis with skimmers compared to perforated risers. However, skimmers require frequent inspection and maintenance to operate properly.

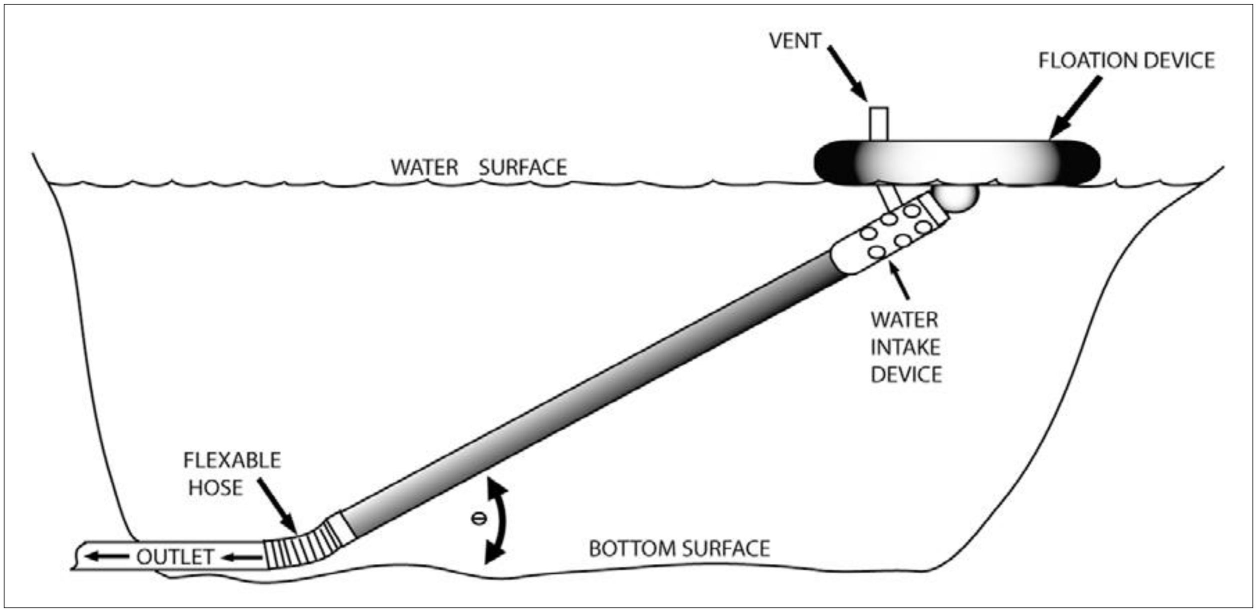


Figure B-10: Skimmer Schematic (NCDWQ, 2007)

F. Spillways and Emergency Overflows

Spillways are sections of the embankment designed to allow water exiting the BMP to spill over that portion of the embankment. Spillways can be lined with rip-rap, grass, concrete, or other materials. Manning's coefficients should be selected to accurately depict the spillway material. Uniform flow may be assumed in the exit channel when the flow is subcritical; however, the assumption is less accurate when the slope exceeds 10%. Turf-reinforcing geotextiles can be used for grass spillways if exit velocities exceed permissible velocity criteria. Both unit tractive forces and permissible velocities must be obtained from the geotextile vendor. Rip-rap spillways should be considered when design velocities exceed those acceptable for vegetated spillways. A tractive force analysis should be used when designing rip-rap spillways. Rip-rap spillways are recommended on berms constructed of fill material.

All BMPs that incorporate impoundment of water are required to have an emergency overflow for large storm events and/or primary outlet failure so that the embankment will not be compromised by high water levels. An emergency overflow separate from the principal outlet is advisable. In situations when this is impractical, a combined principal-emergency outlet may be considered. A combined principal-emergency outlet is a single outlet structure that conveys both low flows and extreme flows. The primary design consideration is protection against clogging. Trash-racks should be designed as described below. The emergency outlet should be designed as if no additional storage is available and if the principal outlet is inoperative or clogged.

G. Trash Racks

Outlets generally are subjected to trash and debris from incoming flows. Before a debris control structure is designed, the anticipated debris problem should be analyzed. The type and quantity of debris are determined from upland land use, soil erodibility, watershed size, and type of stormwater management facility.

Figure B-11: Example of a Trash Rack (Hunt, Burchell, Wright, & Bass, 2007)

Trash racks designed for drop inlets should provide protection against clogging under any operating level. The average velocity through a clean trash rack should not exceed 2.5 ft/sec during the peak design flow. Velocity is computed on the basis of the net area of opening through the part of the rack receiving flow. The same criteria should apply to ports or openings along the side of a riser. The clear distance between bars should not be less than 2 inches, with the exception of the apex of the trash rack. Bar spacing should be no greater than one-half the minimum conduit dimension in the drop inlet, with a maximum of 5.5 inches for safety.

H. Anti-Vortex Devices

All closed-conduit outlets designed for pressure flow should have adequate anti-vortex devices. Anti-vortex devices may be a baffle or a plate set on top of a riser, to a headwall set to one side of a riser.

I. Basin Drains

Basins that have permanent pools must have provision for draining the permanent pool. This will ease maintenance and sediment removal. The drain usually consists of some type of valve or gate attached to the spillway. Basin drains should be designed with enough capacity so that maintenance can be performed without risk of inundation from frequent rainfall events. The drains should be sized to pass a 1-year return period interval with limited ponding in the reservoir. In most cases, the drain should be no smaller than 8 inches in diameter.

Sluice gates are preferred over “inline” type valves (knife gate valves, plug valves, etc.). Sluice gates are generally able to pass debris-laden flow, less prone to clogging, and easier to maintain. The basin drain should be able to drain the basin in 24 hours. An uncontrolled or rapid drawdown could cause slides or sloughing of the saturated upstream slope embankment. In general, the drawdown rate should not exceed 6 inches per day. For embankments with slopes of clay or silt, drawdown rates as low as 1 foot per week may be required to maintain slope stability. For basins that cannot be drained by gravity, pumping is required for maintenance. Pump discharges may need to be filtered prior to discharge to receiving waterbodies.

B.2. GUIDANCE FOR SPECIFIC STORMWATER BMPS

This section will provide guidance for BMPs applicable to Currituck County. General information on BMPs has been taken from the following references: NCDENR Division of Water Quality – *Stormwater Best Management Practices Manual* (July 2007), EPA Stormwater Technology Fact Sheets (September 1999), *North Carolina Guidebook to Low Impact Development* (June 2009), North Carolina State University Department of Biological and Agricultural Engineering Fact Sheets, and USDOT Federal Highway Administration – *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring* (May 2002). Stormwater permit applicants should refer to the latest version of the NCDENR *Stormwater Best Management Practices Manual* for design criteria and the information below to design structural BMPs. Applicants must include the appropriate design spreadsheet for all proposed BMPs with the stormwater permit application. Design spreadsheets can be downloaded from Currituck County's website.

It should be noted that neither the Currituck County UDO nor the North Carolina Coastal Stormwater Rules include provisions requiring specific levels of water quality pollutant removal in Currituck County. However, when the BMP design guidance in this section was adapted from various sources, information on the pollutant removal rates credited to each stormwater BMP according to the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007) was retained. The information on removal rates is conveyed herein so designers can make an informed decision with regard to BMP selection and their expected water quality benefits. A large study on the water quality and ecological health of Currituck Sound is currently being undertaken by the U.S. Army Corps of Engineers (USACE). To date, no water quality modeling has been performed in that study to support the need for specific pollutant reduction regulations. However, qualitative assessment conducted thus far have indicated that sediment loading and re-suspension, as well as algal turbidity stemming from nutrient enrichment and increased eutrophication, are significant problems in the Sound. As a result, when other selection factors are considered equal, designers and developers are encouraged to utilize the information provided to select and implement BMPs that maximize the removal of sediment and nutrients.

B.2.1. Wet Detention Basin / Pond

A. Description

Wet detention basins are excavated areas or natural depressions designed to detain stormwater runoff. They help to reduce peak discharges by storing runoff and releasing the stored volume at a reduced rate, resulting in reduced erosion and improved water quality downstream. Wet detention basins maintain a permanent pool and a water quality pool that is released over a long period of time, allowing sufficient time for particulates to settle out. These basins also remove other pollutants through physical and biological processes in the permanent pool.

B. Performance

According to the NCDWQ *Stormwater Best Management Practices Manual*, wet detention basins have an assumed TSS removal rate of 85% if designed according to specifications found in the manual. The following pollutant removal efficiencies for conventional wet detention ponds are reported in the EPA Stormwater Technology Fact Sheet: TSS 50-90%, Total Phosphorous 30-90%, soluble nutrients 40-80%, Lead 70-80%, Zinc 40-50% and BOD/COD 20-40% (Schueler, 1992). Varying hydraulic residence times are the cause for the wide range in removal efficiencies. By extending the detention time in the permanent pool with the construction of a sediment forebay or peripheral ledges, the pond's treatment efficiencies can be improved. The following fecal coliform removal rates were experienced at two 0.15 acre experimental wet detention ponds (varying residence times and depths noted) at the Southwest Florida Water Management District's Tampa Service Office: 5-day shallow (3.3 ft) wet detention pond – 98.2%, 5-day deep (9 ft) wet detention pond – 88.5%, 14-day shallow (3.3 ft) wet detention pond – 76.4% and 14-day deep (9 ft) wet detention pond – 69.2%. (Kurz, 1999) This case demonstrates that a shallow wet detention pond allows for more exposure to sunlight, causing increased degradation of organisms.

Figure B-12: Example of a Wet Detention Basin with Vegetated Shelf (NCSU BAE, 2011)

C. Design Guidance

Although wet detention basins have been found to remove a significant amount of pollutants, the main problem with using them as a BMP is land constraints. Wet detention basins must have ample space for installation that may not be available at the project site. Permanent retaining walls may be used to obtain the required design volumes, while reducing the footprint that would otherwise be required for earthen construction.

Wet detention basins may not be constructed on intermittent or perennial streams, or in jurisdictional wetlands. Wet detention basins also cannot adversely affect adjacent wetlands. To limit groundwater contamination, they also require soil permeability between 10^{-5} and 10^{-6} cm/sec to be effective. Water quality control requirements for the permanent and temporary water quality pools are listed below:

Permanent Water Quality Pool

- Average permanent water quality pool depths should be between 3 to 6 feet with a minimum requirement of 3 feet.
- The surface area required can be determined once the required storage volume is determined. Refer to *2.3.5* - Alternative Stormwater Runoff Storage Analysis

The sandy soils of the Outer Banks can have significant capacity to store stormwater runoff naturally within the existing soil profile. An applicant may submit and alternative analysis demonstrating and accounting for the natural storage capacity of the soils on their site. The natural soil storage capacity may be counted toward increased amounts of impervious surface, reduction in the size of the required stormwater BMP, or elimination of the BMP altogether, if sufficient natural soil storage capacity is present. Stormwater plans which include and account for the natural soil storage capacity are **required to be sealed by a professional engineer,** and should include the following elements in addition to those enumerated in Chapter 2 in conjunction with SW-002:

- Site Plan indicating topographic contours of the finished site at 1-foot intervals or less with arrows indicating flow directions and paths of stormwater runoff and how the impervious surfaces of the site drain to pervious areas
- A site soils analysis performed by a licensed soil scientist indication the depth to seasonal high water table and the soil porosity.

In order to receive credit for the natural soil storage available on the site, the site must be graded such that the portions of the site counted for natural storage are fully accessed by runoff emanating from the impervious surfaces. Storage within pervious portions of the site that do not receive runoff cannot be credited.

- Impervious areas used for sizing should be those that are expected in the final build-out of the development and should include any offsite runoff draining to the basin.
- Enough volume should be included in the pool to store the sediment that will accumulate between cleanout periods.
- The minimum surface area of the permanent pool should follow the surface to drainage area ratio outlined in Table B-2.

Table B-2: Surface to Drainage Area Ratio for Permanent Pool Sizing (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

10%	0.9	0.8	0.7	0.6	0.5	0	0	0	0
20%	1.7	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6
30%	2.5	2.2	1.9	1.8	1.6	1.5	1.3	1.2	1.0
40%	3.4	3.0	2.6	2.4	2.1	1.9	1.6	1.4	1.1
50%	4.2	3.7	3.3	3.0	2.7	2.4	2.1	1.8	1.5
60%	5.0	4.5	3.8	3.5	3.2	2.9	2.6	2.3	2.0
70%	6.0	5.2	4.5	4.1	3.7	3.3	2.9	2.5	2.1
80%	6.8	6.0	5.2	4.7	4.2	3.7	3.2	2.7	2.2
90%	7.5	6.5	5.8	5.3	4.8	4.3	3.8	3.3	2.8
100%	8.2	7.4	6.8	6.2	5.6	5.0	4.4	3.8	3.2

- A sediment forebay should be included to encourage early settling. The volume of the forebay should be equal to 20% of the total basin volume.
- The site must have adequate base flow from the groundwater or from the drainage area to maintain the permanent pool. Underlying soils with permeability between 10^{-5} and 10^{-6} cm/sec will be adequate.
- A minimum 10-foot wide vegetated shelf shall be installed around the perimeter. The inside edge of the shelf should be 6" below the permanent pool elevation; the outside edge of the shelf should be 6" above the permanent pool elevation.

Temporary Water Quality Pool

- The temporary pool must be located above the permanent pool and is sized to detain the difference between the 10-year, 24-hour post-development runoff peak flow and the 2-year, 24-hour wooded runoff peak flow.
- The outlet device should be sized to release the 1.5" DWQ water quality runoff volume over a drawdown period of 2 to 5 days.
- The outlet device should discharge to a vegetative filter strip though a level spreader that ensures even, non-erosive distribution of flow. Wet detention basins designed for 85% TSS removal are required to discharge through a 30-foot vegetated filter strip to minimize erosion and provide additional pollutant removal. For sites that cannot provide the necessary 30 feet, additional storage must be provided for 90% TSS removal.

In addition to the permanent and temporary water quality pools, pond contours and layout are also important design considerations. Slopes should be 3:1 or greater, allowing for easy maintenance access and establishment of vegetated wetland shelves at the edges. Enhanced sedimentation within the permanent pool can be achieved by designing the wet pond with a length to width ratio of 2:1. Baffles and islands can also be added in the permanent pool to increase the flow times. The following figures illustrate a typical wet detention basin layout.
Wet detention basins should incorporate a diverse selection of native shallow water vegetative species on the vegetated shelf. Diversity in species increases the hardiness of the shelf by increasing the chances of survival due to minor changes in permanent pool elevation. Vegetative shelves increase pollutant removal, protect the banks from erosion, and increase safety by discouraging people from entering the basin. They have also been shown to reduce the occurrence of waterfowl usage of the impoundments. Vegetated shelves should be 10 feet

wide, with the inside edge no deeper than 6" below the permanent pool level. Side slopes on the vegetated shelf are 10:1.

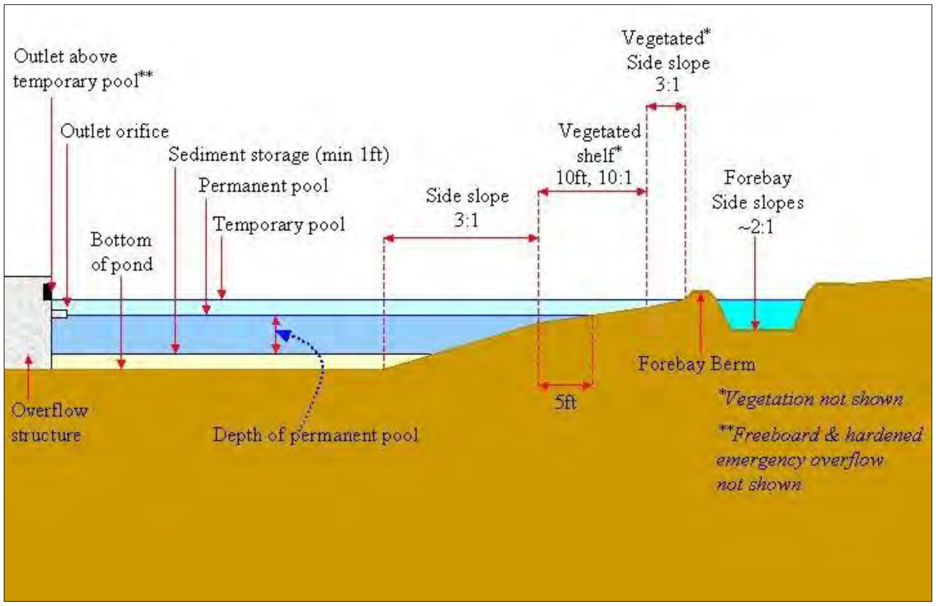


Figure B-13: Wet Detention Basin Cross Section (NCDWQ, 2007)

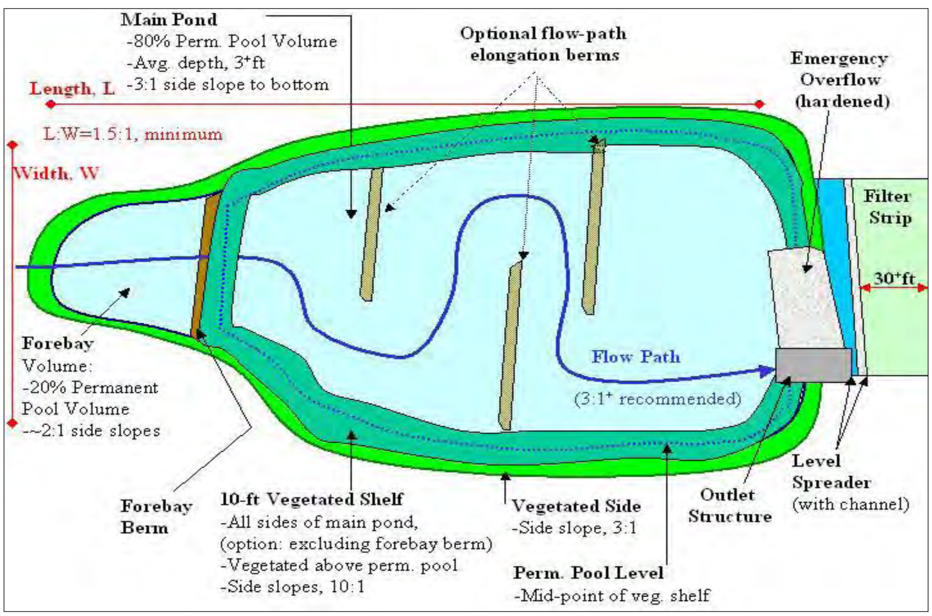


Figure B-14: Wet Detention Basin Plan View (NCDWQ, 2007)

On top of berms and exterior side slopes, maintain turf grass in access areas. Well-maintained grass stabilizes the embankments, enhances access, and makes maintenance easier. Wildflowers, native grasses, and ground covers can be utilized to reduce mowing. Trees and shrubs should maximize shading. They reduce thermal heating of the water and help maintain aesthetics by reducing algal blooms and possible anaerobic conditions. Full size trees and very large shrubs should not be planted along the embankments, as they may reduce the structural integrity. All trees and shrubs should be set back so that branches will not extend over the basin. Appendix D has a list applicable for Currituck County.

D. Applications

Wet detention basins are applicable in residential, industrial, and commercial developments where adequate space and a reliable source of water are available. Wet detention basins should have a minimum contributing drainage area of 10 acres. Basins can be adapted for smaller drainage areas, especially if groundwater is the primary water source. Wet detention basins are sized to provide significant removal of pollutants from the incoming stormwater runoff. They decrease downstream flooding and erosion for smaller storms by retaining runoff and release it over an extended period of time.

Wet detention basins can be aesthetically pleasing and can be sited in both low- and high-visibility areas. They provide a wildlife habitat and have the potential for recreation. Care should be taken to prevent safety hazards. Trash racks and other debris-control structures should be sized to prevent entry by children. Other safety considerations include using fences, using shallow, heavily vegetated benches around the basin, and posting warning signs. Riser openings must not allow unauthorized access. End walls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent falls.

E. Limitations

Due to the large storage volumes needed to achieve the appropriate detention times, wet detention basins require a large amount of area. Small project sites or highly developed areas may restrict the necessary area required for a wet detention basin. However, it should be noted that wet detention basins require less land area than constructed stormwater wetlands and may be suited to applications where land area is insufficient for a constructed wetland.

Wet detention basins require a permanent pool to be effective. Therefore, they should not be constructed in areas with insufficient precipitation or highly permeable soils. They can also have an adverse effect on water quality if they are not properly designed. Wet detention ponds are not designed for flood storage. In general they provide minimal reduction in runoff volume; however, when meeting the Currituck County stormwater requirements, they can provide some flood control.

If wet detention ponds are not properly maintained, they can create problems such as nuisance odors, algae blooms, and rotting debris. They may also attract excessive waterfowl, which can also be a nuisance and potentially raise fecal coliform levels. Wet detention ponds may also raise thermal pollution, so they should not be used in sensitive aquatic species habitats.

F. Inspection and Maintenance

The vegetation located on the vegetated shelf must be properly maintained in order to achieve additional pollutant removal and prevent bank erosion. Weeds, invasive species, and bare spots should be corrected as soon as possible to prevent larger issues. Periodic weeding will be necessary. Mowing of the non-marsh grasses may be required based on the location and surrounding land uses.

The periodic removal of sediment deposits from the forebay and permanent pool is required to maintain the pollutant removal efficiencies for conventional wet detention ponds. Sediment accumulation should be monitored through visual inspection of the basin bottom and the sediment accumulation depth marker. When the specified depth has been reached in the forebay or main basin, the sediment should be removed and the forebay or main basin repaired (NCDWQ, 2007). Disposal of the sediment removed from these ponds must be handled based on the types of pollutants present in the pond. Twenty year maintenance costs are estimated to be a total of 6% to 17% of the original construction cost based on the size of the watershed. (Wossink, 2003)

Routine maintenance includes (NCDWQ, 2007):

- Immediately after the wet detention basin is established, plantings on the vegetated shelf and perimeter should be watered twice weekly if needed, until plants become established.
- No portion of the wet detention basin should be fertilized after the first initial fertilization that is required to establish vegetated shelf plantings.
- Stable ground cover should be maintained in the drainage area to reduce sediment loads into the basin.
- Removal of sediment from the forebay and main treatment area once sediment has accumulated to reduce the depth to 75% of the design depth.
- Routine mowing to keep vegetation around the basin maintained to a height of approximately 6 inches. Cold season grasses should be no shorter than 4 inches; warm season grasses no shorter than 3 inches.
- If the basin must be drained for an emergency or to perform maintenance, the flushing of sediment through the emergency drain should be minimized.
- Remove weeds and noxious vegetation by hand or by wiping herbicide. Do not spray.

Inspection routines include:

- The basin should be inspected once a month after the wet detention pond is established, and within 24 hours after every storm event greater than 1.5 inches. Records should be kept and made available upon request.
- Check sediment accumulation in the forebay and main treatment areas. If sediment accumulation has reduced the depth to 75% of the design depth, remove sediment and dispose of it off-site.
- Check for weeds and other noxious plants which may choke out desirable vegetation.
- Once a year, a dam safety expert should inspect the embankment.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.2. Stormwater Wetlands

A. Description

Wetlands and shallow marsh systems are areas designed to mitigate the impacts of stormwater runoff that occur during urbanization. Wetlands temporarily store stormwater runoff and use biological and naturally occurring chemical processes in water and plants to remove pollutants. There are two basic wetland designs used in North Carolina: extended detention wetlands and pocket wetlands. Extended detention wetlands are similar to wet detention basins, only with a larger vegetated shelf and deeper inundation zones. Pocket wetlands tend to serve smaller sites and thus have a smaller permanent pool of water. Pocket wetlands are also less effective in removing pollutants and are therefore required to be used in combination with other BMPs to achieve the desired pollutant removal. Design of pocket wetlands differs slightly from extended detention wetlands in regard to the pond area depth distribution of high marsh, low marsh and open water.

Figure B-15: Example of a Stormwater Wetland (NCSU, 2010)

B. Performance

According to the NCDENR *Stormwater Best Management Practices Manual*, extended detention wetlands have an assumed TSS removal rate of 85% if designed according to specifications found in the manual. Pocket wetlands, when used in combination with other BMPs, can also achieve the desired 85% TSS removal rate. The following pollutant removal efficiencies for constructed wetlands as a whole are reported in the EPA Stormwater Technology Fact Sheet: TSS 67%, Total Phosphorous 49%, Total Nitrogen 28%, Organic Carbon 34%, Petroleum Hydrocarbons 87%, Cadmium 36%, Copper 41%, Lead 62%, Zinc 45%, and Bacteria 77% (United States Environmetal Protection Agency, 1999)
Recent research performed by NC State's Department of Biological and Agricultural Engineering Department and Cooperative Extension has shown that stormwater wetlands can remove as much as 80% of the total nitrogen and phosphorus (Hunt, Burchell, Wright, & Bass,

2007). Efficiency of the wetland increases as the systems ages and as the vegetation becomes more established.

C. Design Guidance

The design of wetlands and shallow marsh systems is similar to that of the wet detention pond. The permanent pool depth should be kept to a minimum of 3 feet. The storage required must detain the difference between the 10-year, 24-hour post-development peak flow and the 2-year, 24-hour wooded peak flow. The outlet should be sized to release the 1.5" DWQ runoff volume over a period of 2 to 5 days. A forebay must be included upstream of the wetland area. The forebay should be between 10 – 15% of the total surface area. Side slopes should be 3:1 or greater. Sizing of the wetland is based on full-build out storage volume requirements. The minimum length to width ratio should be 1.5:1; however, 3:1 is preferred. Based on NCDENR requirements one of two criteria must be met: 1) The deep pools shall be at least six inches below the seasonal low water table, or 2) A clay liner shall be installed such that the minimum infiltration rate is 0.01 in/hr. Topsoil should be added to the clay liner to support plant growth (NCDWQ, 2007). The suggested thickness of topsoil is 3 – 6 inches.

Sites that cannot provide enough area for the required volume storage may need to utilize a runoff bypass. When an undersized wetland does not use a bypass, too much flow can enter the wetland, risking damage to the vegetation and high pollutant loading downstream. If the available space is less than 67% of the design surface area required, a bypass should be considered.

The NCDENR *Stormwater Best Management Practices Manual* illustrates how to find the required surface area of a wetland (NCDWQ, 2007). There are two factors are necessary to determine the required surface area needed for a stormwater wetland: the water-quality volume required and the depth of water that the plants can sustain for several days. The total surface area of the wetland is:

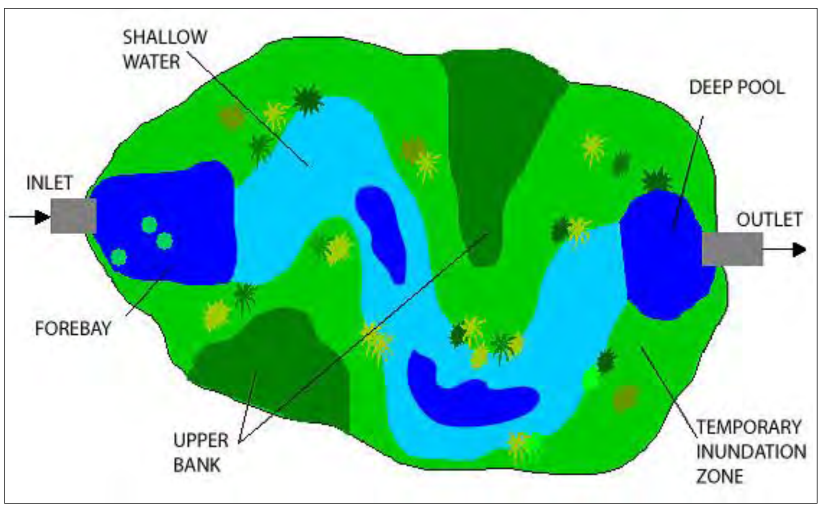


Figure B-16: Plan View of a Stormwater Wetland (Hunt, Burchell, Wright, & Bass, 2007)

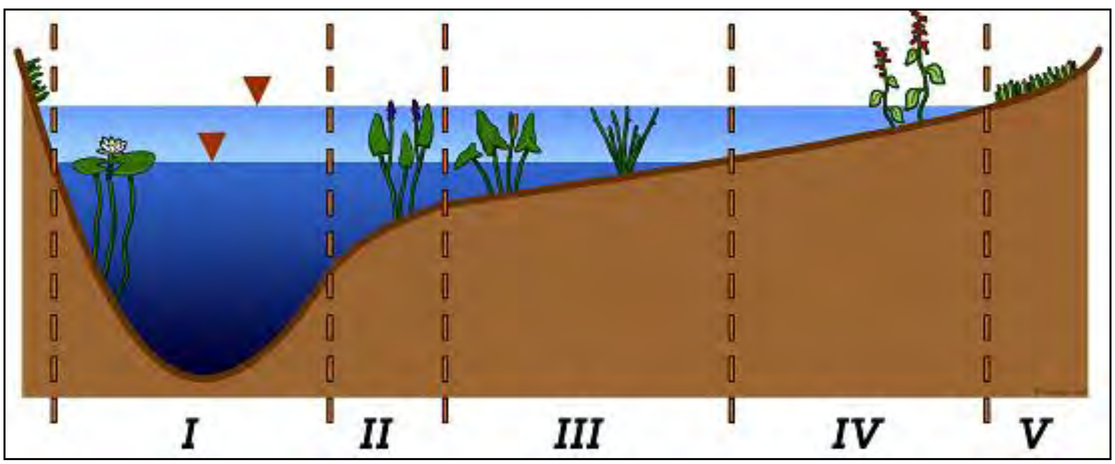
$$Surface\ Area\ (ft^2) = \frac{Q_{volume}\ (ft^3)}{D_{plants}\ (ft)}$$

The total surface area can be divided into the five (5) various wetland zones: deep pools, transitions zones between deep and shallow water, shallow water, temporary inundation areas, and the upper banks which tie back into existing ground (Hunt, Burchell, Wright, & Bass, 2007). Figure B-16 and Figure B-17 illustrate an example of a stormwater wetland. Each zone will support different vegetation. By incorporating the different zones, the system can dissipate energy by distributing flow over the entire wetland, create multiple areas for pollutant removal, and create an aesthetically pleasing diverse ecosystem for plants and animals.

Zone I – Deep Pools

Deep pools dissipate energy, trap sediments, and provide enhanced nitrate removal by providing an anaerobic environment. They also provide storage to reduce runoff volume during larger storm events. Deep pools provide a year-round habitat for mosquito predators, such as the mosquito-eating fish, *Gambousia*. Multiple deep pools should be considered in the design of a stormwater wetland to allow these predators to access all parts of the wetland during runoff events. Most aquatic plants cannot live in the deep pools. Water lilies and other floating plants can be utilized in deep pools, except at the outlet device to prevent clogging.

The forebay is a deep pool that collects sediment and other materials from the inlet structure. The entrance to the forebay should be deeper than the exit of the forebay. This will help to dissipate energy before entering the wetland. The forebay should be 10 – 15% of the wetland surface area.
The bottom elevation of the deep pool should be at least 18 inches deeper than the designed normal pool water elevation, ideally at least 30 inches deep. Deep pools should be a minimum of 5 ft^2 to provide sufficient habitat for wildlife. Non-forebay pools should be between 5 – 10% of the wetland surface area.



Interior Wetland Zones: (I) Deep Pool, (II) Transition, (III) Shallow Water, (IV) Temporary Inundation, and (V) Upper Bank

Figure B-17: Cross Section View of a Stormwater Wetland (Hunt, Burchell, Wright, & Bass, 2007)

Zone II – Transition Zones

The transition zones consist of gentle slopes between the deep pools and the shallow water zones. The difference between the deep pools and the shallow water can be anywhere between 16 – 26 inches. These zones should be connected with a maximum slope of 1.5:1. Steeper slopes may cause soil instability within the wetland. The water depth in a transition zone should be between 6 – 9 inches at normal pool.

Zone III – Shallow Water

Shallow water zones provide the majority of pollutant removal in the wetland. They are better oxygenated than the deep pools and are able to sustain a wide range of plant life. During runoff events, the water entering the wetland will follow the shallow water zone course. During extended drought periods, these areas will dry out. Therefore it is necessary to select plants that can withstand both wet and dry conditions. The average water depth at normal pool should be between 2 – 4 inches. The transition and shallow water zones should be approximately 40% of the wetland surface area.

Zone IV – Temporary Inundation Zones

Also known as *shallow land*, these zones act as an internal floodplain. It is designed to inundate during a storm event larger than the design water quality event. The temporary inundation zone contains the treatment volume after a rain event. The wetland should be sized to ensure that this zone can accommodate the required volume. This zone should have no standing water several days after a storm. At normal pool, the depth of water ranges between 0 – 12 inches; the actual depth varies based on the storage requirement. The temporary inundation zones should be between 30 – 40% of the total wetland surface area. This percentage should be maximized if pathogens are the target pollutant.

Figure B-18: Traditional Flashboard Riser (Hunt, Burchell, Wright, & Bass, 2007)

Zone V – Upper Bank

The upper bank consists of the area surrounding the wetland. It ties the wetland contours to the existing ground elevations. A wide variety of vegetation can survive in this zone, provided that it can grow on slopes. The dam face should be free of trees and large shrubs as they might interfere with structural integrity. The upper bank should have 3:1 slopes or greater, especially in sandy soils. This is considered an optional design feature and should not be used when calculating the required surface area for the wetland.

Wetland outlet structures should be designed to retain stormwater for a minimum of 48 hours after the design water quality event. However, they must also safely bypass larger events. To achieve this, the outlet structure consists of a small orifice sized to retain the 1.5” DWQ water quality volume, with a larger outlet designed to pass the 2-year wooded peak flow rate.

To prevent clogging, a trash rack should be placed around the orifice. Other ways to prevent clogging include submerging the orifice in the deep pool, or incorporating a flashboard riser. A flashboard riser is traditionally a corrugated aluminum pipe cut in half with sleeves at either end into which wooden boards are placed. The boards can be either added or removed to adjust water elevation within the wetland. High flow will overtop the riser, allowing the riser to act as the overflow for larger storm events. An example of a flashboard riser is shown in Figure B-18. Flashboard risers can also drain all wetland zones, except the deep pools, for maintenance purposes.

Wetlands must be stabilized within 14 days of construction. The denser the initial planting, the more quickly the vegetation will become established. Specification and installation of wetland plants is a very important design consideration. The recommended planting is one plant on 24-inch centers (or one plant every 4 square feet). Herbaceous plants should be planted on 36-inch centers (one plant per 9 square feet). Unlike naturally occurring wetlands, stormwater wetlands can experience frequent and dramatic changes in water surface elevation. Most naturally occurring wetland plants cannot tolerate these extreme variations (Hunt, Burchell, Wright, & Bass, 2007). A list of plants that should be used in stormwater wetlands can be found in Appendix D.

Cattails should be avoided in wetlands, as they provide shelter for mosquitoes. If cattails colonize more than 15% of a stormwater wetland that is near a population center, the majority, if not all, should be removed. For rural wetlands, it is reasonable to allow cattail growth.

D. Applications

Stormwater wetlands provide an efficient method for removing a variety of pollutants, including heavy metals, toxic organic pollutants, and suspended solids. They can also reduce high levels of fecal coliform and other pathogens. They provide some stormwater runoff storage in shallow pools that can support a diverse aquatic habitat for a number of species. Thus they are ideal for large commercial or residential sites that have enough space for the required storage volume.

The two primary factors for selecting the appropriate site for a stormwater wetland are the availability of water to "feed" the wetland and site topography. In sandy soils, it is important to verify the water table depth, as the base of the wetland should be approximately 6 inches lower than the seasonably low water table. This will guarantee that water will be in the wetland for the majority of the year, with exceptions in cases of extreme drought. In clayey soils, the wetland may be "perched" above the water table; however, the soils must have sufficient permeability so the wetland does not dry out.

E. Limitations

Stormwater wetlands require a large area to provide the necessary pollutant removal. Smaller sites may have to utilize a bypass structure to reduce the necessary surface area for a wetland. Also, wetlands need a constant water source, either a stream or a high water table. If the water table is deep, constructing a wetland could be cost prohibitive. In general, wetlands are appropriate for NRCS type C and D soils. A soil analysis should be conducted to determine if the soils on site will promote healthy vegetation growth and adequate infiltration rates.

Flat sites are better suited for stormwater wetlands. Excavation and hauling costs may limit stormwater wetlands in excessively hilly sites. Like wet detention ponds, public safety concerns may prohibit the construction of stormwater wetlands.

Poorly maintained wetlands can become a mosquito habitat. Sites that are close to population centers may not be ideal for stormwater wetlands if there is not a clear maintenance plan in place. Regular maintenance includes removing cattails and other debris that can encourage mosquito breeding.

F. Inspection and Maintenance

Due to the variety of different species that promotes a healthy wetland, a landscape professional should understand the biological requirements for each species and maintain water levels necessary to ensure survival. Though wetland plants need water for growth and reproduction, excessive water can drown vegetation. The plant environment is most critical during seed germination and early establishment. Initial growth is best with transplanted plants in wet, well-aerated soils. After the second growing season, a minimum 70% coverage is required, with optimal 90 – 95% coverage. If a wetland has less than 70% coverage, supplemental plantings are needed.

The vegetation can indicate improvements or problems. For example, light is required for submergent aquatic plants. The disappearance of these plants may indicate inadequate water clarity. The appearance of cattails or other invasive species can indicate there are problems with the aquatic / soil / vegetative requirements. Cattails should be removed as soon as possible by wiping an aquatic glyphosate, a systemic herbicide, on them.

Unlike wet or dry detention ponds, sediment removal should only be done selectively from wetlands. Sediment removal disturbs a stable ecosystem and disrupts flowpaths through the wetlands. Before sediment removal, the top few inches of sediment should be stockpiled so that it can be replaced to re-establish vegetation using its own seed bank. Accumulated sediment should be removed from around inlet and outlet structures (NCDWQ, 2007). An annual inspection of the embankment should be done by an appropriate professional.

Routine maintenance includes (NCDWQ, 2007):

- Immediately after the wetland is constructed, the wetland plants should be watered twice weekly if needed until the plants are established (approximately 6 weeks).
- Fertilizer should not be used beyond the first initial use for establishment of plants.
- Stable ground cover should be maintained throughout the drainage area to prevent excessive sediment accumulation.
- Pruning is shown to optimize plant health. Regular pruning should be done according to best professional practices.
- Invasive species, such as cattails, should be removed by wiping herbicide (do not spray) on the plants.

Routine inspection includes (NCDWQ, 2007):

- An annual inspection of the embankment by a dam safety expert
- The wetland should be inspected once a month and within 24 hours of a storm event greater than 1.5 inches. Records should be kept and made available upon request.

- Check for algal growth. Algal growth over 50% should be controlled. Consult a professional to remove and control algal growth
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.3. Sand Filters

A. Description

A sand filter is a device that allows stormwater to infiltrate through sand layers, where TSS and to varying degrees, other pollutants are filtered out. Sand filters are a two-tiered system, where stormwater enters a sedimentation chamber (or forebay) where debris settles out. The water then flows to a sand chamber where it passes through a column of sand. The sand most often used is concrete sand. Sand filters can be open or buried trench (closed basin). A variation of the open sand filter, the open organic filter is used when maximum nutrient or trace metal removals are desired. Sand filters will typically have an underdrain system to collect the stormwater for discharge from the BMP; however, if the in-situ soils have appropriate permeability, sand filters can also be designed as infiltration systems. The in-situ soils in many areas of Currituck County, specifically along the Outer Banks have adequate permeability; therefore a sand filter can be considered an infiltration system for many project sites.

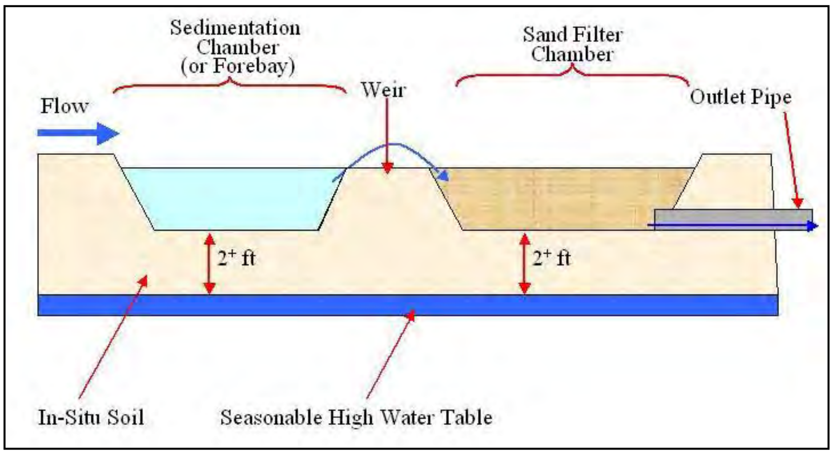


Figure B-19: Open Basin Sand Filter (NCDWQ, 2007)

Sand filters, as opposed to infiltration systems, require that the stormwater pass through a specific depth of specific media prior to leaving the device. Infiltration systems generally do not have a media requirement other than providing adequate void storage space. Sand filters are primarily designed for water quality improvement; flow volume control is typically a secondary consideration.

B. Performance

According to the NCDENR *Stormwater Best Management Practices Manual*, sand filters have

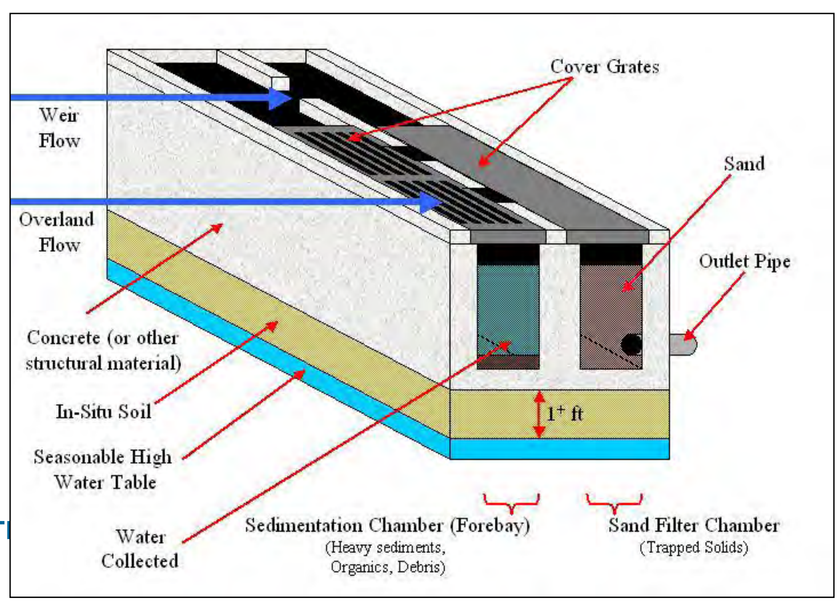


Figure B-20: Buried Trench (Closed Basin) Sand Filter (NCDWQ, 2007) an assumed TSS removal rate of 85% if designed according to the specifications found in the manual. Sand filters also have a removal rate of 35% for Total Nitrogen and 45% for Total Phosphorous. Construction of an open basin sand filter also passively lowers nutrient loading since it is counted as a pervious surface when calculating nutrient loading. Buried trench (closed basin) sand filters receive whatever runoff values the surface above is assigned.

Research performed by NC State's Department of Biological and Agricultural Engineering Department and Cooperative Extension has shown that sand filters can remove as much as 80% of the total nitrogen and 60% phosphorus. Sand filters, however, are nitrate creators. They tend to trap other forms of nitrogen, such as organic nitrogen, which under an aerobic environment can become nitrate. So while total nitrogen removal rates are positive, nitrate-nitrogen levels can increase (Hunt, 1999).

Sand filters can be designed with enough storage to provide some active volume capture; however, special provisions must be made at the outlet to provide peak flow attenuation. Open basin sand filters provide some passive volume control capabilities by providing pervious surface, therefore reducing the total runoff volume to be controlled; however, buried trench sand filters may not.

The performance and longevity of sand filters benefit greatly from pre-treatment that reduces the amount of suspended solids entering the BMP. Filter strips and grassed swales can be deployed upstream of sand filters for this purpose.

C. Design Guidance

Erosive velocities and high sediment loads are a concern with sand filters, as sediment will quickly bind to filter media and cause premature failure. Flow over the design flow can overload the hydraulic capacity of a sand filter, causing erosion in open basin sand filters, and delivering higher sediment loads to the filter than is necessary. Due to these issues, NCDENR requires that all sand filters be designed "off-line", meaning only the design volume of the stormwater flow is sent from the conveyance system into the treatment filter, and the excess is diverted. Use of flow splitters and forebays will help reduce erosive velocities and high sediment loads through the sand filter.

If the proposed sand filter is a stand-alone BMP, it must be designed to capture the difference between the 10-year, 24-hour post-development and the 2-year, 24-hour wooded runoff peak flows. If the sand filter is used as part of a series of BMPs (i.e. a treatment train), then the series should be designed to reduce the peak flow difference. The sand filter must also be able to treat the first 1.5" rainfall volume as required by DWQ.

A forebay or sedimentation chamber is required on all sand filters to protect filter from clogging due to sediment, and reduce the energy of influent flow. The forebay can be in the form or an open basin (typical with open basin sand filters), or a subsurface concrete chamber (typical with buried trench sand filters). Forebay volume should be approximately 20% of the total required storage volume. The depth of the forebay shall be approximately 3 feet, with a deeper section on the inlet site in order to dissipate hydraulic energy entering the forebay. For open basins, the forebay will have a maximum of 3:1 side slopes. The minimum width (measurement parallel to the flow direction) of the forebay should be 1.5 feet. The forebay must contain ponded water (not to be drained down with the sand filter). When located in areas with gravelly sands, or fractured bedrock, a liner may be needed to sustain a permanent pool for water. If a subsurface concrete chamber is used, appropriate means of removing accumulated sediment must be included in design.

After the forebay, the stormwater flow can be distributed over the surface of the sand filter in a variety of ways. For an open channel sand filter, it could flow as sheet flow via a level spreader; however level spreaders generally do not provide even enough flow distribution to prevent clogging at the leading edge of the sand filter. The most common way to distribute flow across a sand filter is through the use of a pipe distribution or weir system. Design of the pipe distribution system can mimic the design of an underdrain system (see *Chapter B.1.3 - Underdrain Systems* for design parameters).

Sand filters must be completely drained within 40 hours; therefore 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 filter media, since the influent can come at such a rate that all the volume would need to be stored above the media since essentially no infiltration will have taken place yet. Refer to the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007) for specific calculations when designing a sand filter.

Design Guidelines:

Forebay or Sediment Chamber

- Volume = 20% of total required storage volume
- Depth = 3 feet with deeper portion at inlet to dissipate energy
- 3:1 side slopes
- Minimum width = 1.5 feet
- Permanent pool must not be drawn down by filter

Sand Filter Chamber

- The design must reduce the 10-year post-development peak storm flow to the 2-year wooded peak flow
- Time required to drain the design flow through the sand filter = 40 hours
- Depth of sand = 18 inches minimum; with 12 inches minimum over the drainage pipe
- Sand media should be cleaned, washed, course masonry sand such as ASTM C33 and have particles less than 2 mm average diameter
- Surface area is determined by Darcy's Law:

$$A_f = \frac{(V_{Design})(d_f)}{(k)(t)(h_a + d_f)}$$

Where:

A_f = Surface area of the sand filter (ft^2)

d_f = Depth of the sand filter bed (ft); Minimum of 1.5 feet

k = Coefficient of permeability for the sand filter bed (3.5 ft/day)

t = Time required to drain the design volume through the sand filter (days) = 40 hours (1.66 days)
h_a = Average head (ft).

- For underground sand filters, provide at least 5 feet of clearance between the surface of the sand filter and the ceiling of the underground structure to facilitate maintenance.
- No single outlet pipe greater than 6 inches in diameter.

D. Applications

Sand filters are intended for water quality treatment. In general, sand filters are preferred over infiltration practices when contamination of groundwater is a concern. In most cases, sand filters can be constructed with impermeable bottoms, which collect and treat stormwater with no contact between contaminated runoff and groundwater (United States Environmetal Protection Agency, 1999). They are best suited for small sites with flat terrain or high water tables. Due to the tendency for sand filter to clog, they are primarily used to treat runoff from highly impervious areas, such as parking lots. Sand filters do not require as much surface area as ponds or wetlands; therefore they are a viable alternative where space is a premium.

A basin used for construction sediment and erosion control can be converted into an open basin 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 sand filters are typically constructed after site construction and not placed in modified site construction sediment and erosion control basins.

The maximum contributing drainage area to an individual sand filter should 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.

E. Limitations

Sand filters are not designed to control peak discharges, therefore are generally not recommended for large sites, or sites will generate a great deal of sediment runoff as it will tend to clog the filter. They are expensive and may be of limited use for sites that require high nutrient and heavy metal removal. In these areas, other BMPs that would be less costly and possibly more effective should be considered.
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 open basin design. For buried trench filter designs, the seasonal high water table is less than 1 foot below the bottom of the filter.
- Exceptions to the one-foot seasonal high water table separation will be made if for buried trench sand filters that do not drain the water table and do not float. Special care should be used when proposing structures such as concrete due to joint failure over time, causing the water table to leak into the sand filter.
- If site restrictions such as bedrock or hydraulics prevent the facility from being constructed to a depth that would allow the required media thickness, ponding depth, and other appurtenances.

- The sand filter will be located less than 30 feet from surface waters and 50 feet from Class SA waters.
- The sand filter will be located less than 100 feet from a water supply well.

F. Inspection and Maintenance

Sand filters should be inspected at least once a month, and within 24 hours after every storm event with 1.5 inches of rainfall or greater. Visible surface sediment accumulation, trash, debris, and leaf litter need to be removed to prevent clogging. The forebay should be cleaned out when sediment has accumulated to a depth of 6 inches. All structures should be checked annually for damage or degradation.

When the filtering capacity diminishes substantially (i.e. when the water ponds on the surface for more than 40 hours), remedial action must be taken. A potential problem is that the collector pipe system is clogged. Annual flushing though the pipe cleanouts is recommended to facilitate unclogging without disturbing filter media. 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. If issues still exist, more extensive rebuilding may be required.

Routine maintenance includes (NCDWQ, 2007):

- Regular street sweeping and careful monitoring of erosion within the drainage area to reduce sediment accumulation in the sand filter.
- Annual flushing to unclog pipe cleanouts without disturbing filter media.
- Removal of any visible trash or debris to prevent clogging.
- Annually skim the filter media.
- Replace the filter media whenever it fails to function properly after regular maintenance.

Routine inspection includes (NCDWQ, 2007):

- Sand filters should be inspected once a month and within 24 hours after a storm event (1.5 inches of rainfall)
- Note if water ponds on the surface for more than 24 hours after a storm. Check for clogging and flush if necessary.
- Annual inspections of the embankment (if applicable) should be completed by a dam safety expert
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.4. Bioretention

A. Description

Bioretention is a process by which pollutants are removed stormwater runoff via infiltration through a vegetated soil media. Bioretention effectively removes TSS, heavy metals, nutrients and pathogens through a combination of adsorption, filtration and sedimentation. A bioretention cell is typically a depression in ground filled water-tolerant vegetation and a supporting soil media. Polluted runoff enters the device from stormwater pipes and/or surface drainage, filters through the soil media and exits the device by a combination of an underdrain system, soil exfiltration and evapotranspiration. The primary function of the bioretention cell is to provide pollutant removal. However, if the in-situ soils have appropriate soil permeability (as the case in many locations through Currituck County, specifically along the Outer Banks), the bioretention cells can be utilized for peak runoff attenuation, reduction of runoff volumes and groundwater recharge. Bioretention cells can also serve the role of providing additional landscaping for helping to meet regulatory requirements or for aesthetic enhancement.

B. Performance

According to the NCDENR *Stormwater Best Management Practices Manual*, bioretention devices designed according to the specifications in the manual can receive regulatory credits for removal rates of: TSS 85%, total nitrogen 35% and total phosphorous 45%. If properly demonstrated through stormwater flow modeling, bioretention areas can receive credit for peak runoff attenuation. In cases with infiltration, bioretention cells may receive credit for reduction of the overall runoff volume (NCDWQ, 2007).

Figure B-21: Bioretention Cell in Parking Lot Island (NCDWQ, 2007)

The EPA Stormwater Technology Fact Sheet estimates the removal efficiencies for the following pollutants as: TSS 90%, TKN 68-80%, total phosphorous 70-83%, metals (Cu, Zn, Pb) 93-98%, organics 90% and bacteria 90% (United States Environmental Protection Agency, 1999)

C. Design Guidance

The most important design criterion for bioretention cells to ensure the device is sited in a location appropriate for proper functioning. According to the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007), bioretention devices shall *not* be utilized when:

- The seasonal high water table is less than 2 feet below the bottom of the cell. There must be adequate space to allow for infiltration for the BMP to properly function. Since Currituck County has a seasonal high water table less than 2 feet in various areas throughout Currituck County, this BMP may not be appropriate for many project sites.
- Slopes are greater than 20%.
- Further construction is planned within the device's contributing drainage area.
- Cell is inaccessible for maintenance.
- Cell will not comply with local landscape ordinances.

All drainage must enter bioretention cells as sheet flow or by way of energy dissipating devices to prevent erosion within the cell. Site conditions and space limitations will determine whether drainage is conveyed as sheet flow by gradual slopes, level spreaders and/or filter strips or as concentrated flow by diversion structures, grass swales and/or underground piping networks. Pretreatment areas are devices utilized to dissipate energy and/or remove sediment prior to flow entering the effective bioretention area. Inclusion of a pretreatment device such as a grass/gravel strip, grassed water quality swale or forebay is required as a component of the bioretention cell.

Individual bioretention cells should be design to capture the difference between the 10-year, 24-hour post-development and the 2-year, 24-hour wooded runoff peak flows. Cells should also retain the first 1.5" rainfall associated with the WQV with a ponding depth no greater than 12 inches (less than 9 inches is recommended). The required surface area for a cell can be determined by dividing the calculated design volume by the design ponding depth. When determining the geometry of the cell, ensure that no dimension is less than ten feet to allow adequate space for vegetation and for maintenance access. Cell geometry should also be such that heavy equipment can be used to maintain the device without driving on or over the any part of the bioretention surface. Vegetated side slopes within the cell shall be no steeper than 3:1.

The selection of design factors for the soil media (composition and depth) is critical to the proper performance of the cell and achievement of the desired pollutant removal efficiencies. The target pollutant is the driving factor for determining the appropriate choices for the soil media. TSS and pathogens are primarily removed in pretreatment and at the cell surface. Heavy metals are removed in the first 1-2 inches of mulch and in the top 8 inches of soil. Soil depth and composition have little impact on the removal efficiencies of these pollutants. When TN and phosphorous are the target pollutants, careful choices must be made to determine the appropriate design. All soil media chosen for a bioretention cell should be a clean (free of debris), homogeneous mix of 85-88% by weight sand, 8-12% fines, and 3-5% organic matter. When TN is the target pollutant, the higher percentage range of fines (12%) should be chosen. When phosphorous is the target, the lower end of the range for fines (8%) should be used. All soils should have a P-Index of 10-30 to prevent phosphorous export. Soil pH should be within 5.5-6.5 and have a maximum 500ppm concentration of soluble salts to facilitate pollutant uptake and promote microbial decomposition (United States Environmental Protection Agency, 1999). Soils should be sent to the NC Dept. of Agriculture labs for analysis and determination of suitability.

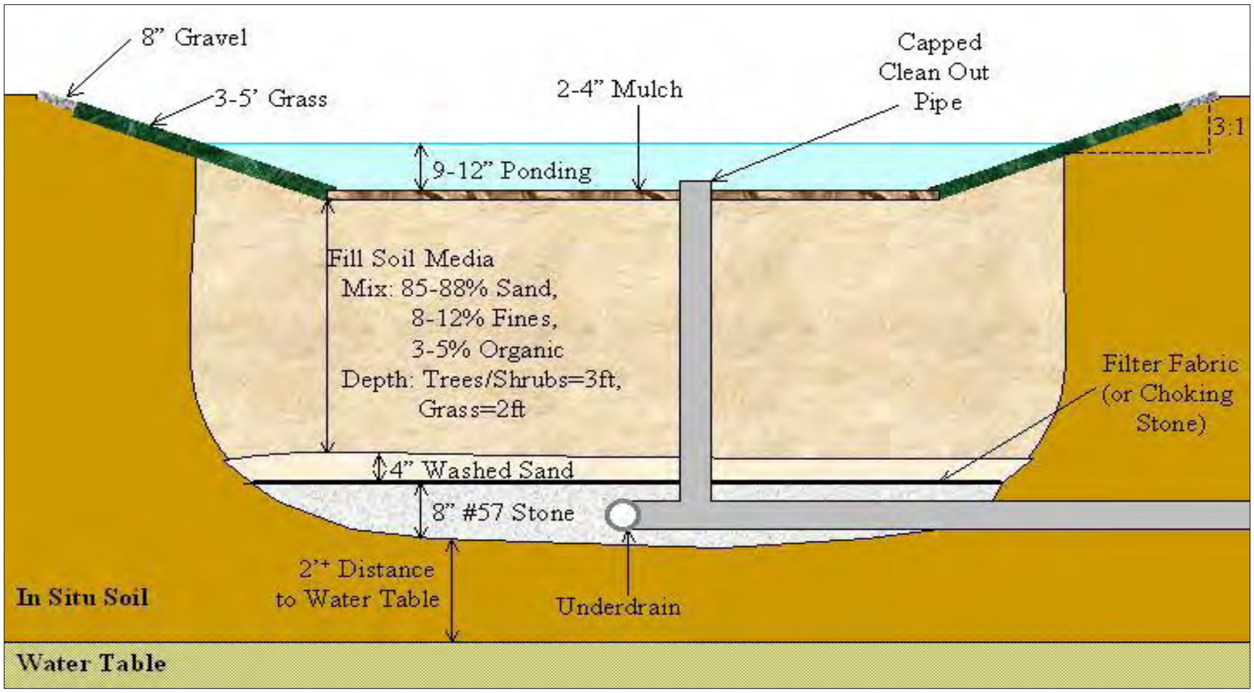


Figure B-22: Bioretention Conceptual Layout: Cross Section (NCDWQ, 2007)

The required depth of the soil media is between 2.0-4.0 feet. Most pollutants are removed within the first 2.0 feet of soil media, with the exception of nitrogen. If TN is the target pollutant, the media depth should be between 2.5-4.0 feet, as nitrogen removal occurs at least 30 inches below the surface of the cell. All backfilled soil media must have an in-situ permeability of 0.52-6.0 inches per hour in order to ensure the duration of ponding is less than the maximum 12 hours and that the ponded water drains to a level 24 inches below the surface within 48 hours. A soil media permeability of 1.0-2.0 inches per hour is preferred to meet the design criteria of the device. The vegetation chosen for the cell is dependent on media depth, with grasses suitable for shallower design depths (2-3ft) and trees/shrubs suitable for deeper media depths (3-4ft).

In-situ soil permeability is the driving factor for determining the necessity of an underdrain system. If the in-situ soil permeability is less than 2.0 inches/hour, a bioretention cell will typically require an underdrain system that connects to another BMP or the stormwater conveyance network. The underdrain shall be sized (with minimum 4" diameter pipes) to convey the flow volume out of the cell at a rate 10 times that of the flow rate through the soil media. Capped cleanout pipes will be provided for every 1000 square feet of surface area (NCDWQ, 2007).

Bioretention devices are typically designed as either "online" or "offline" structures. Online devices receive all the flow from the contributing drainage basin and will typically utilize an overflow structure within the bioretention area to convey the additional flows from rainfall volumes in excess of the first flush. The overflow structure is typically a riser device with the weir crest elevation set at the design ponding depth. The overflow shall be designed to convey the higher runoff volumes with enough freeboard to the top of cell that the risk of flooding in adjacent areas in not a concern. "Offline" structures utilize an upstream flow diversion device that allows the design flow to be routed to the cell and all flows greater than the design flow to bypass to a level spreader, another BMP or the stormwater conveyance network. Offline systems typically will result in higher pollutant removal efficiencies, as the higher flow draining to online cells can have the potential to wash out the pollutants from the water quality volume through the overflow device.

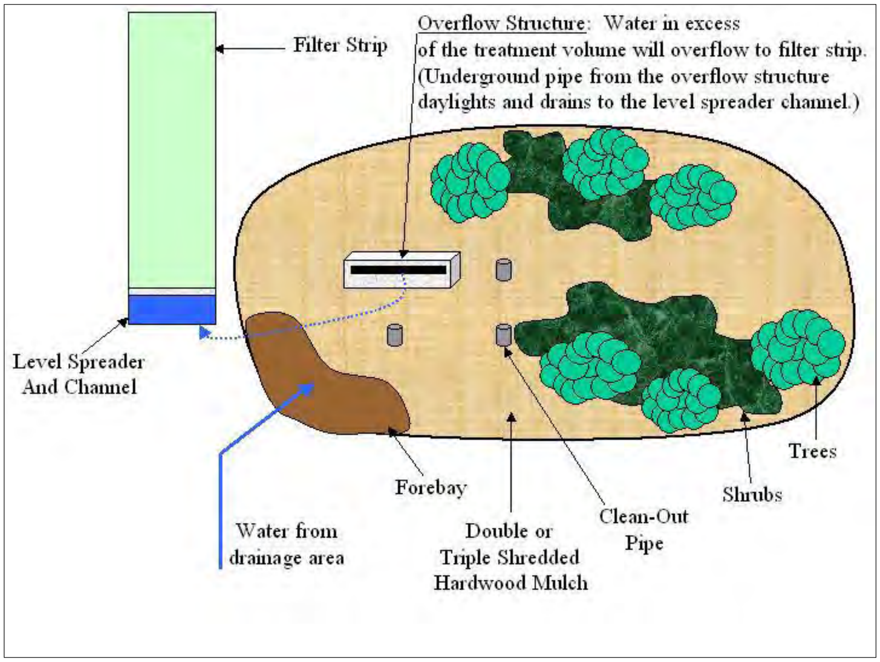


Figure B-23: Typical Bioretention Cell Utilizing an Overflow Structure (NCDWQ, 2007)

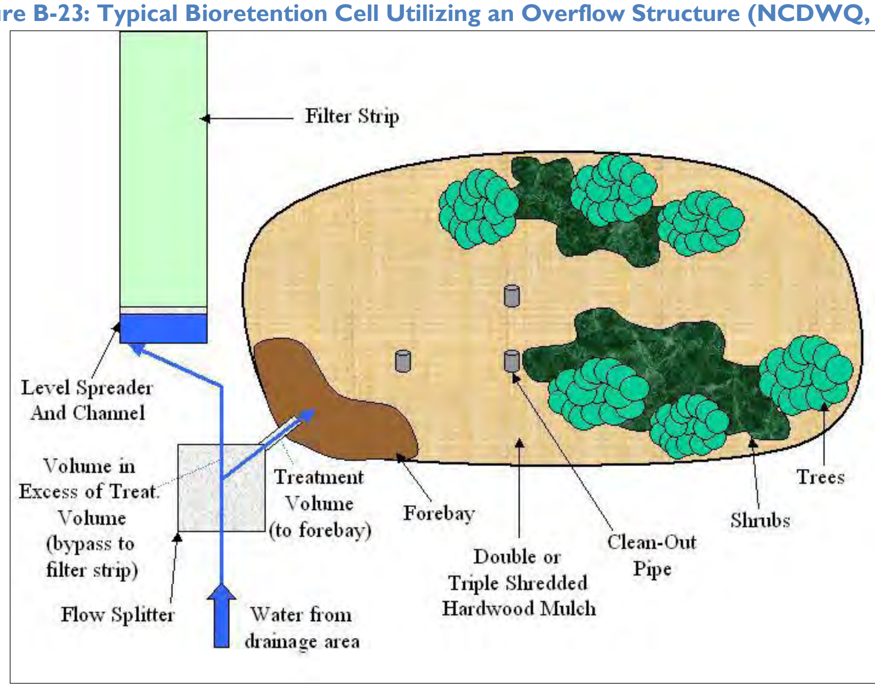


Figure B-24: Typical Bioretention Cell Utilizing a Flow Splitting Structure (NCDWQ, 2007)

Vegetative plantings and mulch are the last critical components that contribute to the overall pollutant removal capability of a bioretention device. A minimum of three tree, three shrubs and three herbaceous species should be incorporated into non-grassed cells to increase bio-diversity and reduce susceptibility to insects and disease. Plant size shall be a minimum 2.5” diameter breast height (DBH) for trees, 3-gallon for shrubs and 1-quart for herbaceous plants. Refer to Appendix D for a list of suitable plants. Vegetation should also be selected based on the following criteria:

- Tolerance of variable soil moisture conditions and temporary submergence.
- Pollutant tolerance and phytoremediation capabilities.
- Potential for encroachment on existing infrastructure (above and below ground).
- Compatibility with adjacent, native vegetative species.
- Visual buffering and aesthetics compliance.

A clean, 3-4 inch (settled) layer of double or triple-shredded hardwood mulch shall be maintained on the bioretention surface to reduce weeds, reduce soil compaction, prevent erosion, and reduce likelihood of soil-borne diseases within the cell.

The design of a bioretention cell can be summarized in the following 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 and design the appropriate overflow bypass/diversion structure.
8. Select plants and mulch.

D. Applications

Bioretention devices provide an efficient method for removal of a variety of stormwater pollutants, including TSS, TN, phosphorous, heavy metals, and pathogens. Bioretention with infiltration (dependent on soil conditions) can be also utilized for peak runoff attenuation and runoff volume reduction of relatively frequent storms. In the areas of Currituck County with highly permeable soils (specifically along the Outer Banks), bioretention cells are ideal BMPs as they can utilize infiltration of stormwater to reduce runoff volumes.

Bioretention devices are a favorable option when physical site constraints prevent a developer or designer from utilizing conventional, "centralized" BMP's. Bioretention is applicable to highly urbanized/highly impervious sites, smaller sites that cannot incorporate the hydrology of "wet" BMP's or larger BMP footprints, redevelopment projects with limited useable land area, or in an areas with poorly drained soils. Bioretention treatment can be achieved by employing the use of multiple cells across a particular site to reach the target pollutant removal efficiencies. This "decentralized" aggregate treatment approach is viable as cells can be located within almost any open space area including, but not limited to medians, parking lot islands, and traffic circles. Bioretention should also be considered when aesthetic quality is a deciding factor, as devices easily integrate into and enhance existing landscaping features.

E. Limitations

While bioretention is an effective means for managing stormwater quality, it is not the most cost efficient practice for stormwater quantity control. Bioretention is not meant to treat large drainage basins, and is not a good BMP choice when there are no limitations or concerns regarding space, steep slopes (greater than 20%), hydrology, and/or soil conditions on a site. Bioretention is not suitable in drainage basins that are not fully built out and subject to future development, as cells can be ruined by heavy sediment loading from construction sites.

Bioretention cells have a more intensive maintenance regimen than most other BMP's. The surface soil layer is susceptible to clogging, the mulch layer is susceptible to washing out and the plant materials require upkeep. Poorly maintained bioretention cells are not effective in removing pollutants and clogged devices can potentially be a flood hazard.

F. Inspection and Maintenance

Since vegetative cover is such a critical component of bioretention, the maintenance requirements are much like that of any landscape care/upkeep program. Proper maintenance not only ensures the device retains its vital function, but that it also stays aesthetically pleasing. Special care is required in selection of soil material and vegetative species so that plants can become established within the bioretention cell. Plant growth shall be established without the use of fertilizers and pesticides, as these may degrade the pollutant removal capacity of the device. Cell vegetation should be watered twice weekly for the first 5-6 weeks after planting. As soil media permeability and over-compaction is a primary concern, it is important to ensure that no heavy load is experienced by the cell during installation, maintenance or repair. Bulk material such as soil, mulch or snow shall never be piled or stored on the cell. Heavy machinery or vehicles shall never be driven over or on top of the bioretention surface.

Routine maintenance includes (NCDWQ, 2007):

- Watering is required twice a week until plants become established (approximately 6 weeks). Afterwards, watering should only be necessary during prolonged dry periods.
- Pruning is shown to optimize plant health. Regular pruning should be done according to best professional practices.
- Replace mulch annually and whenever voids form. Mulch depth should be between 2 – 3 inches.
- Annual flushing of pipe cleanouts is recommended to prevent clogging and diminished capacity.
- Annual soil tests to determine pH and heavy metal levels.
- Remove weeds and noxious vegetation by hand or by wiping herbicide. Do not spray.

Routine inspection includes (NCDWQ, 2007):

- Bioretention cells should be inspected once a month and within 24 hours after every storm event (1.5 inches of rainfall or more). Records of inspection and maintenance should be kept in a set location and be available upon request.
- Inspect inflow devices, ponding areas, and surface overflow area for signs of erosion. Erosion problems should only occur during extreme storm events. If problems do occur, several factors should be assessed: flow volumes, flow velocities, dissipation, and erosion protection measures within the pre-treatment area.
- Note if water ponds on the surface for more than 12 hours after a storm. Check for clogging and flush if necessary.

- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.5. Infiltration Devices

A. Description

Infiltration devices are trenches or basins that fill with stormwater and allow the water to exit the device by infiltrating the soil. Infiltration devices reduce runoff volume, recharge groundwater, and have high removal efficiencies for sediment and pollutants. Given the high permeability of the in-situ soils in various areas around Currituck County, infiltration devices are ideal BMPs if a given site's characteristics will permit.

B. Performance

According to the NCDENR *Stormwater Best Management Practices Manual*(NCDWQ, 2007), infiltration devices have an assumed TSS removal rate of 85% if designed according to the specifications detailed in the manual. Infiltration devices also have the following removal efficiencies: 30% Total Nitrogen (TN) and 35% Total Phosphorus (TP).

C. Design Guidance

There are typically two types of infiltration devices: infiltration trenches and infiltration basins. Infiltration trenches are filled with large crushed stone or another media to create storage between the voids in the media. Other versions use precast concrete vaults with open bottoms to provide large storage volume to hold stormwater for infiltration. Trenches are typically used to manage runoff from parking lots and buildings.

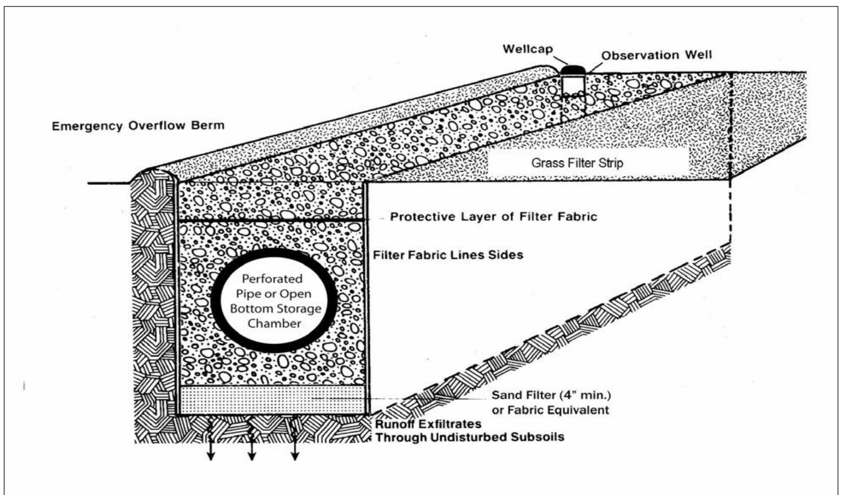


Figure B-25: Example Infiltration Trench (NCDWQ, 2007)

Infiltration basins are normally dry, much like an extended dry detention basin; however stormwater infiltrates into the ground rather than existing to a receiving stream. Pre-treatment devices such as filter strips, grassed swales, and forebays must be used to protect infiltration devices from clogging. Often, the same basin can be used during construction as a sediment control device and later converted to an infiltration basin.

The size of an infiltration device depends on the dewatering requirements. Infiltration devices must be completely drained in 2 to 5 days. The time to dewater is estimated as the runoff capture volume divided by the product of the hydraulic conductivity and the effective infiltrating area:

$$A = \frac{V_{Design}}{2 * K * T}$$

Where:

A = effective infiltrating area (ft^2)

V_{Design} = volume of water requiring infiltration (difference between the 10-year post-development and the 2-year wooded storm events) (ft^3)

K = hydraulic conductivity of soil (in/hr)

T = dewatering time (days)

If the infiltration device is not designed to meet the volume control requirements, it is the volume of water that is diverted and stored for infiltration. The value of A is actually the larger value between either the bottom surface area, or one-half the total wetted wall area. The calculations for length, width, and depth is an iterative process using the effective area, the correction factor for true surface areas of in-situ soil interface, and typical length, width, and depth recommendations. Flow splitters should be utilized to divert flows greater than the 10-year post-development design flow around the infiltration basin.

To prevent falling within the regulatory definition of "injection well", infiltration trenches must be constructed such that their depth is less than the greatest surface dimension. Trench depths must be between 3 and 8 feet. The recommended width (perpendicular to influent flow direction) is less than 25 feet. Infiltration basins can be many different configurations, but require 3:1 side slopes.

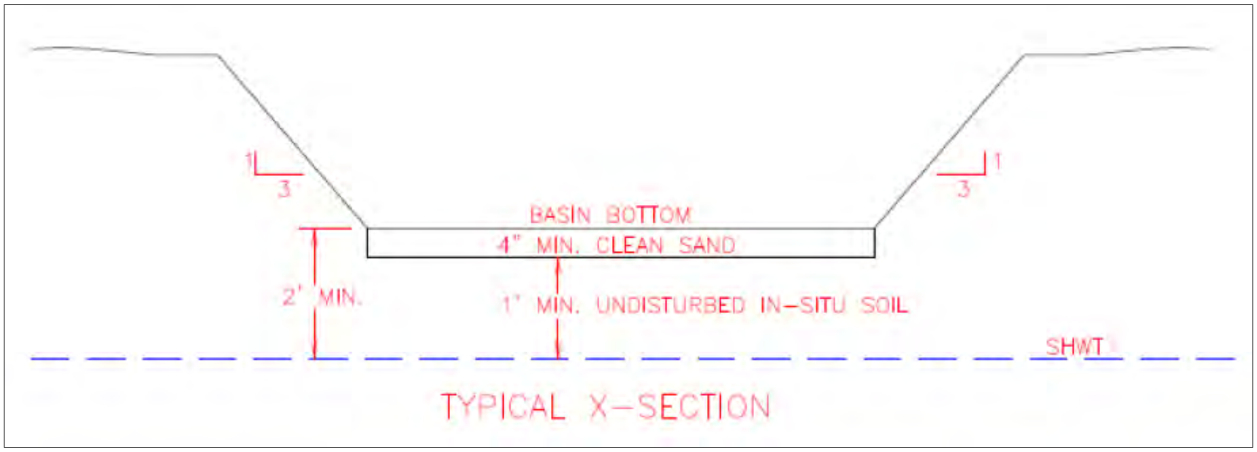


Figure B-26: Example Cross-section for Infiltration Basin (NCDWQ, 2007)

Uniform sand, gravel, or crushed stone (uniformity coefficient of 2 or smaller) should be used as the drainage medium, as they have high porosities and large storage capacities. The porosity of the medium should be determined by laboratory tests and certified by the suppler. Drainage medias should be hard, durable, inert particles, free from slate, shale, clay, silt, and organic matter. It is recommended that the material be double-washed. Drainage media should be enclosed on all sides by geotextile fabric. The top surface of the geotextile should be 6 – 12 inches below the upper surface of the drainage media. The bottom of infiltration basins and trenches should be lined with a 4 inch (or greater) layer of clean sand, unless in-situ soils are equivalent (1 – 2% fines or less).

Infiltration systems do not have regular outlet devices; however, they should be designed with dewatering provisions to facilitate maintenance or repair. This can be done with underdrain systems that can be pumped out or gravity drained to the surface.

D. Applications

Infiltration devices transfer more stormwater to the soil than any other type of BMP. They work best with relatively small drainage areas or drainage areas that are completely impervious or stable (to minimize the amount of sediment going to the BMP). Individual infiltration devices should not receive more than 2 acres-inches of runoff, and less than 1 acre-inch is recommended. The contributing drainage area should be 5 acres or less. Infiltration devices must be "off-line", meaning that excess runoff must be diverted around the BMP.

Infiltration devices must be constructed level (grades between 0 – 0.05%). They should not be located in fill soils. New legislation requires at least 1 foot of naturally occurring soils above the seasonal high-water table. Infiltration devices should not be placed in locations with less than 2 feet (4 feet is recommended) between the bottom of the infiltration device and the seasonal high water table, underlying impervious soil layers, or bedrock.

The in-situ soils have to have high permeability and a low enough groundwater table to allow for infiltration. For this reason, acceptable infiltration device locations may be limited to the Central and Outer Banks Stormwater Zones. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inches per hour or greater, as determined by NRCS soil classification and subsequent field tests. The minimum testing is one test hole per 5,000 ft^2 of infiltrating area, with a minimum of two borings per facility. The highest measurement should be discarded when computing the hydraulic conductivity.

E. Limitations

Infiltration devices tend to fail more quickly than other BMPs. A common cause of failure among infiltration devices is clogging due to excessive sediment loads. For this reason, infiltration devices should not be used until the contributing drainage area has been fully stabilized. Infiltration devices should not be placed in locations that cause water problems to down gradient properties. They must be a minimum of 15 feet down gradient from structures and a minimum 100 feet horizontally from water supply wells, 50 feet from Class SA waters, and 30 feet from surface waters.

Infiltration basins may potentially contaminate the groundwater. For this reason, runoff from industrial sites and contaminated land uses or activities cannot be infiltrated without proper pretreatment to remove hydrocarbons, trace metals, and other hazardous substances.

F. Inspection and Maintenance

Routine maintenance is very important for infiltration devices. Especially important is the maintenance of areas that drain to the infiltration systems, as clogging is typical problem with these BMPs. Areas that are allowed to erode will contribute excessive sediment into the infiltration system and reduce its effectiveness.

The surface of infiltration trenches must be kept in good condition. Grasses and other plants should be removed since this can lead to reduced infiltration rates. Concrete grid pavers or similar permeable paving systems that are easily removed help prevent excessive plant growth.

Routine maintenance includes (NCDWQ, 2007):

- Annual removal of sediment in the pre-treatment area
- Annual replacement of the top several inches of filter media and filter cloth, or whenever the dewatering time is longer than 5 days.
- Regular sweeping or vacuuming of pavers or permeable pavement (if applicable)
- Vegetation in and around the infiltration basin is maintained to a height of approximately 6 inches (if applicable).
- Remove weeds and noxious vegetation by hand or by wiping herbicide. Do not spray.

Routine inspections include (NCDWQ, 2007):

- Infiltration systems should be inspected quarterly, and within 24 hours after any storm event of 1.5 inches of rainfall or more. Records of inspection and maintenance should be kept in a known location and made available upon request.
- For an infiltration trench: Check for ponded water 24 hours after a storm. Also check that the depth in trench is greater than 75% of the design depth.
- Check observation well for standing water.
- For an infiltration basin: Check sediment accumulation in the forebay and main treatment areas. If sediment accumulation has reduced the depth to 75% of the design depth, remove sediment and dispose of it off-site. Also check for standing water in the main treatment area. Water should not be standing more than 5 days after a storm event.
- Annual inspection of the embankment should be completed by a dam safety expert.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.6. Extended Dry Detention Basins

A. Description

Between storm events, dry detention basins (DDB) are typically dry. A low-flow outlet slowly releases stormwater detained over a period of days. The main purpose of dry detention basins is to attenuate and delay stormwater runoff peaks. When water quality is the desired purpose, DDBs need to be modified to provide longer detention times and sediment trapping and removal. DDBs tend to be less expensive to construct and maintain than Wet Detention Basins and Stormwater Wetlands.

B. Performance

When designed according to the specifications outlined in the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007), DDBs are able to removed 50% total suspended solids (TSS). The removal efficiencies for both Total Nitrogen (TN) and Total Phosphorus (TP) are 10%.

Figure B-27: Example of Extended Dry Detention Basin (NCSU BAE, 2007)

C. Design Guidance

Forebays are recommended for all DDBs as they trap excessive sediment and extend the life of the BMP. A forebay is required to trap incoming sediment if the design flow is over 10 acre-inches. The forebay must contain ponded water and be designed as described above in *Chapter B.1.2 - Forebays* and the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007).

The volume of a DDB is driven by the volume of stormwater that is required to be captured. The design volume required is WQV that is associated with the first 1.5" of rainfall. The DDB must also reduce the 10-year, 24-hour post-development peak flow to a 2-year, 24-hour wooded peak flow. Once the design volume is calculated, the dimensions are based on the individual site characteristics. Dimension requirements are listed below:

- The maximum depth is 10 feet. Since Currituck County has high groundwater levels, generally the maximum depth to the seasonal high water table is the limiting factor.
- There must be at least a 2-foot separation between the bottom of the basin and the seasonal high water table
- A minimum 1 foot of freeboard between the design flow pool elevation and the emergency overflow invert is required
- The minimum flow length to width ration is 1.5:1; however, 3:1 is recommended. Larger length to width ratios should be considered if sedimentation of particles during low flows is desirable. If site characteristics prevent long, narrow DDBs, baffles can be used to lengthen the flowpath.
- Side slopes are no steeper than 3:1 and stabilized by vegetation.
- The DDB must provide sediment storage equal to 25% of the detention volume, in addition to the detention volume. Consideration should be given to upstream activities that may contribute to the sediment loading and the DDB should be sized accordingly.
- A sinuous low-flow channel should be constructed through the basin. The channel should be grass-lined and sloped at approximately 2% to promote drainage. The entire bottom of the basin should drain to the low-flow channel.
- The riser should be placed in or at the face of the embankment for easier maintenance. A small permanent pool near the outlet should be included to prevent debris from clogging the outlet.

- Basin drains must be included for maintenance.
- Durable materials such as reinforced concrete or plastic materials are preferable to corrugated metal for the outlet
- There should be a low-flow orifice at least 2 inches in diameter.
- Erosion protection measures should be used at the discharge point.
- To prevent piping and internal erosion problems around the spillway, a filter diaphragm and drainage system is recommended.

A sediment depth indicator must be provided in the DDB and forebay (when applicable). Sediment will accumulate more quickly in basins without a forebay or for contributing areas that are not stabilized. Sediment should be removed when the depth indicator shows that sediment accumulation has reached the design sediment depth.

Vegetation selections need to consider the environment of a DDB. Frequent inundations, warm and cold seasons, salt and oil loadings are all design considerations that should be accounted for when selecting vegetation. Plants should only be fertilized once after seeding. Mowing should be kept to a minimum. Research has shown that a mixture of wet meadow mix or Bermuda grass performs well. DDB must be stabilized within 14 days after the end of construction.

D. Applications

Dry extended detention basins are useful when the primary site goal is to manage peak runoff rates and water quality issues are secondary, as the removal efficiencies are low. This BMP is applicable in residential, industrial, and commercial developments. They can be used for very large sites (25 acres or more) where sufficient space is available.

The seasonal high water table must be at least 2 feet below the bottom of the basin. Less separation can make the bottom vulnerable to developing ephemeral pools during wet-weather periods.

E. Limitations

Extended dry detention basins do not have high removal pollutant efficiencies when compared to other BMPs; therefore they have limited use when water quality is the primary goal. Generally if DDBs are not maintained properly, they can become an eyesore. They can also develop "soggy" bottoms or standing water, which hinders maintenance and can become potential mosquito-breeding grounds.

F. Inspection and Maintenance

After the DDB is established, it should be inspected once a quarter and within 24 hours after a storm event greater than 1.5 inches. DDB should also be inspected annually to verify the device is operating properly. If possible, inspections should occur during wet weather to verify retention times. Maintaining turf grass on the tops of berms and exterior slopes is necessary to facilitate access and inspection. The frequency of mowing is dependent on the individual site and visibility requirements. However, the cold season grasses should be maintained no shorter than 4 inches and warm season grasses no shorter than 3 inches. Shorter mowing can lead to the turf dying off and requiring a higher level of maintenance.

When the sediment depth indicator shows that the sediment accumulation has reached the design depth, the sediment and debris must be cleaned out with earth-moving equipment and disposed of properly. Once the sediment has been removed, the disturbed areas should be stabilized and revegetated immediately. Freshly seeded areas should be protected to prevent erosion until established.

Routine maintenance includes (NCDWQ, 2007):

- Water should occur twice weekly after construction until vegetation is established (approximately 6 weeks). After establishment, watering should only be needed during periods of extended drought.
- Removal of sediment from the forebay and main treatment area once sediment has accumulated to reduce the depth to 75% of the design depth.
- Routine mowing to keep vegetation in and around the basin maintained to a height of approximately 6 inches. Cold season grasses should be no shorter than 4 inches; warm season grasses no shorter than 3 inches.
- Remove weeds and noxious vegetation by hand or by wiping herbicide. Do not spray.

Routine inspections include (NCDWQ, 2007):

- Dry detention basins should be inspected quarterly, and within 24 hours after any storm event of 1.5 inches of rainfall or more. Records of inspection and maintenance should be kept in a known location and made available upon request.
- Check for ponded water. Water should not be standing for more than 5 days after a storm event; check the outlet device for clogging. If outlet device is clear, the problem may be a design issue.
- Check sediment accumulation in the forebay and main treatment areas. If sediment accumulation has reduced the depth to 75% of the design depth, remove sediment and dispose of it off-site.
- Annual inspection of the embankment should be completed by a dam safety expert.
- Check for weeds and other noxious plants which may choke out desirable vegetation. Wipe weeds with herbicide to remove.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.7. Permeable Pavement

A. Description

Permeable pavement systems allow for infiltration of stormwater into a storage area, with void spaces that provide temporary storage. Permeable pavement has openings that allow water to pass through, rather than run off. Depending on rainfall intensity, rainfall volume, and in-situ soil infiltration rates, water will exit the bottom of the permeable pavement via soil infiltration or an underdrain pipe. Intense rainfall can produce runoff, especially on concrete paver systems filled with sand. Permeable pavement systems reduce peak runoff attenuation and peak stormwater volume by lowering the impervious area for runoff calculations. They also reduce pollutant loads and can recharge groundwater.

B. Performance

Currently, North Carolina does not provide pollutant removal credits for permeable pavement systems. North Carolina does provide credits for peak runoff attenuation and volume reduction by lowering the percent impervious.

Table B-3: Credit Received for Various Permeable Pavement Systems (NCDWQ, 2007)

Permeable Pavement System	Credit as % 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%

However, research has shown that permeable pavement removes metals, sediment, and motor oil from runoff, as well as reduces pH and temperature. Nutrient removal rates are not as thoroughly understood. Some studies have shown that permeable pavements remove total phosphorus (TP), often due to adsorption to the sand and gravel-base layers. Other studies have shown little to no reduction in TP. Similar studies have shown a decrease in concentrations of all measured nitrogen species (NH4-N, TKN, and NO3N), but several studies have also shown little to no reduction of certain forms of nitrogen.

In general, North Carolina does not offer nutrient removal credits to all types of permeable pavement systems. However, some pavement types may be eligible to receive "special" consideration. Concrete pavers (CGP) filled with sand are able to reduce total nitrogen, in part because this type of permeable pavement resembles a low-head, limited-media, depth sand filter. Therefore, this type of permeable pavement is the "preferable" option for nitrogen removal (Hunt & Collins, 2008).

C. Design Guidance

For the purposes of stormwater runoff volume reduction, Currituck County allows designers and engineers to account for permeable pavements by lowering the post-development equivalent curve numbers on areas that would otherwise be deemed impervious. Areas of permeable pavement should be clearly marked on site plans and justification of selected curve numbers should be provided as part of the Stormwater plan.

There are five types of permeable pavements: permeable asphalt (PA), permeable concrete (PC), permeable interlocking concrete pavers (PICP), concrete grid pavers (CGP), and plastic grid pavers (PG). Examples of each are shown in Figure B-28. The designer is referred to the AASHTO Flexible Pavement Method for specific design requirements to the structural design of permeable pavements. Permeable pavement is similar to traditional asphalt and concrete in regards that the materials and construction techniques are the same. Design differs with regard to the depth of aggregate sub-grade, the thickness of the pavement to achieve the design depth, and use of geotextile fabric below the sub-grade.

The aggregate sub-grade consists of uniformly-graded, 57-size stone. The stone should be crushed and clean washed. Fine particles from standard "crusher run" will clog the pores and will not be allowed. The sub-grade is typically divided into upper and lower filter courses, comprised of fine and larger aggregate, respectively. Geotextile fabric is placed beneath the sub-grade to separate the aggregate from the in-situ soils. Perforated pipes may be placed in the sub-grade to allow runoff from adjacent impervious areas to enter the stone bed directly.

Figure B-28: Types of Permeable Pavement (Hunt & Collins, 2008)

Permeable pavement should be placed on non-compacted soil, and great care should be taken to ensure that soils are not compacted during construction. Erosion control techniques should remain in place around the permeable pavement area until the site has become fully stabilized to avoid excessive sediment onto the permeable surface. Overland runoff should be diverted from the permeable pavement to decrease sediment loading, reduce maintenance, and maximize the lifespan of the pavement. Effective grading or installation of perimeter berms or filter strips can accomplish this.

Additional design guidelines are as follows (New Hanover County & City of Wilmington, 2008):

- Registered professional engineers should design the permeable pavement system
- The storage capacity of the stone reservoir should be able to contain the volume associated with the first 1.5" of rainfall.
- Sub-base layers should be capable of bearing the appropriate design load without deforming. When designing the base course, select the appropriate porosity value for the material used.
- Strength and durability under saturated conditions should be considered in the design.
- A bedding layer should be laid over the base course as level bedding for the blocks consisting of small open-graded aggregate meeting criteria for a filter layer.

- An overflow, possibly with an inlet to a stormwater system, should be installed 2 inches above the level of the permeable pavement surface.
- Filter fabric should be placed on the bottom and sides of the sub-base layer. To prevent clogging, filter fabric should be woven geotextile such as SI Corporation Geotex 17F or approved equivalent.
- An impermeable liner should be installed under the base course to inhibit infiltration when installing over expansive soils, or if runoff will contain fertilizers, chemicals, or petroleum products.
- Open-celled block pavers must be vibrated into place within the bedding layer.
- During construction, heavy construction equipment or vehicles should not traverse the excavated recharge beds or areas of completed permeable pavement.
- Edge restraints should be installed on compacted sub-grade or base material, not bedding. A concrete perimeter wall should be installed to confine the edges of the block installation. The perimeter wall should be 6" thick and extend 6" deeper than the base course.
- For aggregate fill in the open-celled block pavers, material should be open-graded sand and be the same as the bedding material.
- Do not use concrete sand, which is traditionally used for interlocking concrete pavement bedding layer construction. It is shown to have low permeability.
- Do not sweep sand into the joints after the pavers have been installed.
- Lateral flow cut-off barriers should be installed using a 16-millimeter or thicker PE or PVC impermeable membrane liner or concrete walls installed normal to flow. This prevents flow of water downstream from disrupting block installation.
- The distance between cut-off barriers should not exceed: $L_{Max} = \frac{D}{(1.5 * S_0)}$

  Where:

  L_{MAX} = Maximum distance between cut-off barriers

  D = Depth of aggregate base course

  S_0 = Slope of base course

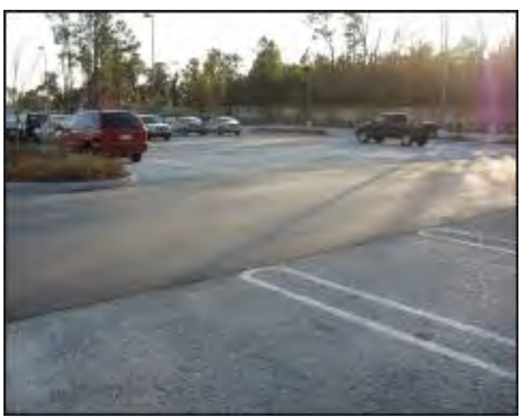


Figure B-29: Example of Permeable Concrete Parking Stalls (New Hanover County & City of Wilmington, 2008)

- For sites where the in-situ soils allow for adequate infiltration, underdrains will not be required. A detailed soils analysis must be supplied for all instances where in-situ soils will be considered for infiltration.
- An underdrain is required where impermeable liners or in-situ soils prevent proper infiltration rates. Locate each underdrain upstream of the lateral flow cut-off barrier.
- For vegetation between pavers, the planting medium should be sandy and open-graded. In bedding and base course, a limited amount of planting medium can be mixed into the aggregate to deepen roots. Plant grass as plugs or broadcast seed at a reduced rate to account for concrete grids.

- Cut pavers with a paver splitter or masonry saw. Pavers should be no smaller than 1/3 of the full unit size along the edges subject to vehicular traffic.

D. Applications

Permeable pavement can be used as a substitute for conventional pavement, but it should be limited to parking areas or low-traffic roadways where little to no truck traffic is anticipated (less than 100 vehicles per day). Example applications include: parking stalls in commercial parking lots, overflow parking areas, residential street parking lanes, driveways, pedestrian walkways, emergency vehicles or fire access lanes, and equipment storage areas (New Hanover County & City of Wilmington, 2008).

Permeable pavement should be installed in flat areas (i.e. less than 0.5% slope). If designed to infiltrate into underlying soils, appropriate screening, infiltration testing, water table separation, and setback standards required for infiltration systems should be applied to permeable pavement. The seasonal high water table must be at least 2 feet below the base of the permeable pavement or gravel storage layer.

The in-situ soils beneath the permeable pavement must have sufficient infiltration capacity to drain the pavement. According to the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007), the following conditions must be met:

- The footprint of the permeable pavement installation must have a vertical saturated hydraulic conductivity of 0.52 in/hr, or greater (as determined by a soil analysis) for the soil horizon located beneath the base of the pavement system to a total depth of 3 feet.
- The soil beneath the pavement system (to a total depth of 3 feet) must also have no finer texture than Loamy Very Fine Sand as defined by the USDA-NRCS and soil analyses.
- Only 2 ac-ft of soil per acre disturbed can be moved for the footprint of permeable pavement. Mass grading can significantly alter the site's applicability for permeable pavement. If mass grading occurs and the conditions above are still met, then an exception for this requirement can be given. However, a soil analysis will be required after grading is complete.

Figure B-30: Example of Open-celled Block Pavers in Overflow Parking Lot (New Hanover County & City of Wilmington, 2008)

E. Limitations

Permeable pavement systems have a tendency to clog. Therefore, permeable pavement systems are not suitable for high-traffic areas. They should not be placed in areas where upland land disturbance will occur, where excessive sediment loads may result in frequent pavement clogging. Nor should they be placed in areas where high winds can blow sediment across the pavement systems. Overhanging trees should be pruned back away from the pavement system, as leave debris can also clog the pavement. Permeable pavement systems are not allowed in areas where impervious surfaces are not permitted, such as buffers. Permeable pavements may cause uneven driving surfaces, and may be problematic in pedestrian areas for high-heeled shoes and wheelchairs.

Permeable pavement systems tend to cost between 25 – 100% more than traditional asphalt (Hunt & Szpir, 2006). However, implementing permeable pavement systems may reduce the need for other stormwater BMPs or reduce the required size for other BMPs. The overall cost therefore, is site specific.

F. Inspection and Maintenance

Maintenance is imperative for the success of permeable pavement. Even with proper design and installation, there is still potential for permeable pavement to clog with sediment and debris. Important maintenance procedures include (NCDWQ, 2007):

- Stable groundcover should be maintained within the drainage area to reduce excessive sediment loadings.
- The area around the perimeter should be stabilized and mowed, with the clippings removed. Maintain vegetation to a height of 3 to 6 inches.
- Any weeds that grow in the permeable pavement should be sprayed with herbicide immediately. Do not pull weeds, as this may damage the fill media.
- Annually, the pavement system should be vacuum swept. Vacuum sweeping should also occur whenever pavement appears to be clogged. Hand held pressure washers can be used in small areas on porous asphalt or concrete and should follow vacuum sweeping. It should not be used in open-celled block pavers as it will dislodge the media between the pavers.

Routine inspections include (NCDWQ, 2007):

- Permeable pavement should be inspected quarterly, and within 24 hours after any storm event of 1.5 inches of rainfall or more. Records of inspection and maintenance should be kept in a known location and made available upon request.
- Check for ponded water. If there is ponded water on the surface, vacuum sweep the pavement. If water still ponds, consult a professional.
- Check sediment accumulation on the surface of the pavement.
- Check for weeds; spray with herbicide. Do not pull.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.8. Green Roofs

A. Description

Green roofs include vegetated roof covers and roof gardens. Green roofs are used extensively throughout Europe and are now gaining popularity in the US. They consist of waterproofing

Figure B-31: Example of Extensive Green Roof (New Hanover County & City of Wilmington, 2008)

and drainage mats, a special growing media, and plants able to withstand extreme climates. There are two types of green roofs: Extensive and Intensive.

Extensive green roof are a low-lying vegetated carpet, with soil media typically 3 – 5 inches deep. They a generally less expensive than the intensive green roof as they require little maintenance and are not designed to support large groups of people.

Intensive green roofs are more like roof gardens. They can be designed to support trees and shrubs because of their deep soil layer. They can also carry large amounts of pedestrian traffic and can be used as additional living space. They tend to be very expensive to construct and maintain as irrigation and fertilization is often required.

B. Performance

To date, North Carolina does not provide pollution credits for any rooftop runoff management activities. Green roofs can receive peak attenuation and volume reduction credits by reducing the percent impervious for a site. Research done by NC State University has shown that green roofs can retain over 50% of rainfall annually, and reduced the peak flows and stormwater volume for large storms. However, outflow from green roofs has more nitrogen and phosphorus than rainfall due to the soil media, which is a concern for nutrient sensitive waters. Ongoing research examines how changes in media can help reduce the nutrients in outflow (Hunt & Szpir, 2006).

Recent research has shown that green roofs provide additional secondary benefits as well. Green roofs increase evapotranspiration, prolong the roof life, reduce roof temperatures, and decrease energy costs. They also provide an aesthetic aspect to the site design.

C. Design Guidance

Green roofs can be incorporated into new construction or as a retrofit to existing buildings (additional structural support may be needed). There are several factors that should be considered in green roof design: position of the roof, the microclimate of the site, prevailing winds, building function, etc. Green roofs consist of several layers, as shown in Figure B-32.

The design should reduce the 10-year, 24-hour post-development peak flow to the 2-year, 24-hour wooded peak flow. The minimum storage volume required is the volume generated by the first 1.5" of rainfall. If the green roof is part of a treatment train, then the system must retain the design volume.

The drainage layer may not be necessary for sloped roofs. The drainage layer should be capable of conveying the discharge associated with the design storm without ponding water of top of the roof cover. It should have good hydraulic conductivity with roof gutters, drains, and downspouts.

Material for the growing media should be weed seed free and the proper material and depth for the particular roof style. Low-density substrate materials with good water-retention (i.e. mixtures containing expanded slate, shale, clay, and terra cotta) capacity is required. Media should retain 40 – 60% water by weight and have bulk dry densities between 35 and 50 lb/ft^3. Care should be taken when specifying compost because it will eventually break down over time and the depth of the media will decrease (NCDWQ, 2007).

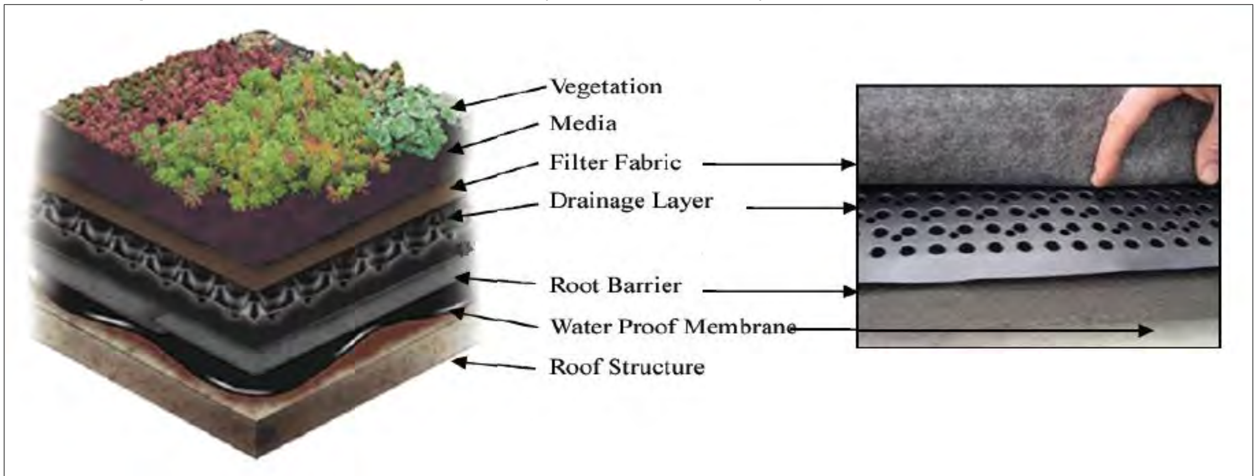


Figure B-32: Layers for a Green Roof (NCSU, 2009)

A limited number of plants can thrive on rooftop environments. Effective plant species must tolerate mildly acidic conditions and poor soil. They should prefer very well-drained conditions and full sun. Studies have shown that succulents are preferred to grasses.

At a minimum, any green roof must meet the major design elements indicated in the North Carolina Building Code. A structural engineer must be consulted and verify roof and structure strength. Generally a building's structure must be able to support an additional 10-25 lbs per square foot of weight for an extensive green roof, depending on the growth media and vegetation used. On roof slopes greater than 20 degrees, horizontal strapping or other support systems must be installed to avoid slippage and slumping of growing media and plants. A vegetation plan prepared by a horticulturalist versed in green roof vegetation is also required.

D. Applications

Generally, green roofs are useful in urban situations. However, green roofs can provide numerous environmental, economic, and social benefits. They improve building insulation, thereby reducing energy costs. They increase wildlife habitats, absorbs noise pollution, reduce glare that affects adjacent buildings. They also improve air quality by reducing air temperatures, filtering smog and dust particles, and converting carbon dioxide to oxygen.

Green roofs have been shown to double the life span of a roof, by protecting the roof's structural components from UV rays, wind, and temperature fluctuations. They also can provide additional living space or help blend a structure into the natural surroundings.

E. Limitations

The main drawback of green roofs is the construction cost, which ranges $12 - $25 per square foot more than traditional roofs. Costs are high due to the materials used, difficulty transporting materials to the roof, and the additional structural reinforcement required. However, when compared over the building life cycle, a green roof can be cost-competitive. Maintenance is also a concern that should be factored into a cost analysis.
If nutrient removal is a concern, green roofs should not be considered, as they can actually contribute to nutrient runoff. Also, unconventional designs may prolong the permitting process.

High winds may prevent green roofs from being an effective BMP, especially for intensive green roofs. Sites along the Outer Banks should consider extensive green roofs with low, salt-tolerant vegetation if considering this BMP.

F. Inspection and Maintenance

Access to the roof for inspection and maintenance is required. For the first year, the green roof should be inspected monthly and after each large storm event for erosion, plant survival, proper drainage, and waterproofing. Once established, inspection should occur every quarter and within 24 hours after every storm event greater than 1.5 inches. Soil levels should be inspected semi-annually to ensure plant survival and rainfall absorption.

Irrigation should be done in short bursts (3 – 5 minutes) to prevent runoff. Irrigation frequencies should be established by the designer using an automated system. If vegetation is flammable during the dry season, it should be mowed or watered a needed to prevent a fire hazard (New Hanover County & City of Wilmington, 2008).

Routine maintenance procedures include (NCDWQ, 2007):

- Irrigation is important for plant survival. Irrigation frequency depends on the type of vegetation used; generally it is needed twice weekly until vegetation is established, then only during periods of extended dryness.
- Routine weeding is necessary to maintain the health of the green roof.
- Fertilizers should be applied annually, unless the green roof is used for water quality improvement.
- Clean out gutters, drains, spouts, and other components of the drainage system.

Routine inspections include (NCDWQ, 2007):

- During first year, green roofs should be inspected monthly and after each large rainfall event. Once established, inspections should occur every quarter and within 24 hours after every storm event with 1.5 inches of rainfall or greater. Records of inspection and maintenance should be kept in a known location and made available upon request.
- Check for weeds, diseased, or dying plants.
- Check gutters, drains, and spouts for clogging.

- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

Figure B-33: Cistern for Rainwater Harvesting in Dare County, NC

B.2.9. Cisterns

A. Description

Cisterns, or rain barrels, are a method of collecting and storing rainwater from roof runoff for future use. Cisterns reduce the runoff volume and peak flows for small, frequently occurring storms. Irrigation, vehicle washing, toilet flushing, and laundry operations are just some of the uses.

B. Performance

Cisterns reduce the runoff volume by an amount equal to the available volume of the cistern. The peak discharge rate may be attenuated depending on the captured volume. For a residence, a cistern probably needs to exceed 500 gallons for it to have an effect on runoff reduction (NCSU, 2009). With a dedicated water use regime and frequent use, cisterns capture between 30 to 70% of stormwater.

C. Design Guidance

Cisterns can be constructed from raw materials; however, prefabricated tanks are readily available and affordable. Cistern sizing depends on the water demand and collection volume. To meet Currituck County stormwater requirements, a stand-alone cistern must be sized to capture the volume associated with the first 1.5" of rainfall. It must also reduce the peak flow generated by the 10-year, 24-hour post-development to the 2-year, 24-hour wooded peak. Cisterns that are part of a treatment train can be smaller, as long as the treatment train meets the storage requirements. Additional storage also may be needed if the cistern is not emptied between storms. Per-capita use of cistern water can be used to calculate the demand or outflow rate. The size, shape, and placement of the tanks will depend also on the impervious surfaces, soil composition, and site slopes.

The higher above ground tanks are located, the more gravity-feed pressure is available. If a building's structure can support it, cisterns can be placed on rooftops and drained by gravity. Water can also be distributed by booster pumps, irrigation systems, channels, or perforated pipes. Tanks can also be constructed in series with the overflow of one tank, filling another; or all tanks connected at the bottom to maintain a constant water level in all tanks.

A basic cistern system should consist of the following (New Hanover County & City of Wilmington, 2008):

- Impervious surfaces to collect runoff
- Devices to collect and convey runoff. Downspouts and other inlets should be screened to prevent mosquito breeding, other animals, and debris from entering the tank.

- Debris screen
- Pipes located at least 10 feet from the building foundation to carry water to the tank
- A locking, removable lid or access point for maintenance
- An overflow pipe that is of equal or greater capacity than the fill pipe. Overflow pipes must operate passively (without the assistance of a pump). Overflow should be diverted away from buildings.
- An exit port to distribute stored runoff (e.g. a hose bib), located several inches from the bottom of the tank to allow sediment to settle to the bottom.
- A booster pump if gravity cannot deliver the necessary pressure
- Opaque tanks that prevent evaporation, mosquito breeding, and algae growth. All tank openings should be locked for safety.
- Avoid placing vegetation with intrusive roots near or on top of below-ground tanks.

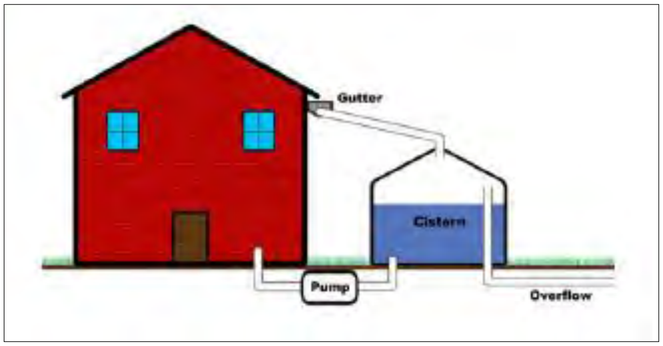


Figure B-34: Example of a Cistern System (NCSU, 2009)

D. Applicability

Cisterns are useful in areas where domestic water is at a premium and where high real estate prices, poor soil infiltration capacity, or little available open space preclude the use of other infiltration techniques. Cisterns can serve as a secondary source of water for applications that do not require potable water.

Landscaping irrigation can account for as much as 40% of domestic water consumption (New Hanover County & City of Wilmington, 2008). Roof runoff is relatively clean, and can provide a source of chemically untreated "soft water", free of most sediment and dissolved salts. Cisterns are a viable option in areas that use a great deal of water for irrigation.

Cistern tanks should be placed on level pads in areas not vulnerable to erosion or settling. Underground tanks should be placed at least 10 feet from a building to avoid foundation damage if leakage occurs. If a tank is located in a basement, a case pumping system is required.

E. Limitations

Cisterns can either be located above or below ground. Above-ground tanks are substantially cheaper; however, occupy a good deal of space. Below-ground systems are more expensive, and require pumping to deliver storage water for the desired purpose. The storage capacity needs to be available to catch the next storm's flow. Development of a water budget should be conducted prior to permitting. Also, water standing for more than 72 hours can provide mosquito breeding grounds. To prevent mosquitoes, cisterns should be tightly sealed and screened.

F. Inspection and Maintenance

Regular maintenance is important to any cistern system. The following inspection and maintenance practices are recommended (New Hanover County & City of Wilmington, 2008):

- Cleanout gutters, inflow, and outflow pipes as needed
- Gutters and downspouts should be free of debris prior to rainy season.
- Remove sediment that may interfere with the outlet.

Routine inspections include (New Hanover County & City of Wilmington, 2008):

- Inspect the tanks to insure the system is functioning properly. Inspections should occur quarterly and after heavy rainfall events (1.5 inches of rainfall or greater within a 24 hour period).
- Inspect the inlet and outlet pipes for mosquitoes. No opening should be greater than 1/16 inch in diameter where water is retained for more than 72 hours.
- Cap and lock tanks for safety. Caps should have access ports for interior inspection and maintenance.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.10. Grassed Swales

A. Description

Grassed swales are long open channels that are lined with grass or other vegetation. They are often used in residential or commercial developments and highway medians to convey stormwater to other BMPs or drainage systems. Grassed swales can filter pollutants and reduce flow velocities and runoff peaks. They can incorporate check dams or depression storage to promote infiltration. There are three types of grassed swales addressed in the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007):

Figure B-35: Example of a Grassed Swale (NCSU, 2009)

- *Curb Outlet Systems for Low Density Projects*: Swales designed to convey stormwater through low-density projects
- *Water Quality Swales Seeking Pollutant Credit:* Swales intended for pollutant removal. They may include roadside swales, lot line swales, and primary outlet swales.
- *Swales Not Seeking Pollutant Credit:* Swales not intended for pollutant removal. Water in swales meeting the requirements for this design is allowed to travel at higher velocities and steeper side slopes are allowed.

B. Performance

The effectiveness of a swale in reducing the flow rate and volume of runoff is a function of the size and composition of the contributing drainage area, the slope and cross section of the channel, the soil permeability, the type of vegetation in the swale, and the swale dimensions.

- *Curb Outlet Systems for Low Density Projects*: Current North Carolina does not provide any pollutant removal credits for these swales
- *Water Quality Swales Seeking Pollutant Credit:* If designed according to the specifications outlined in the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007), these swales can remove 35% TSS, 20% TN, and 20% TP
- *Swales Not Seeking Pollutant Credit:* Current North Carolina does not provide any pollutant removal credits for these swales

C. Design Guidance

The location of swales should be based on topography and unique site characteristics. Whenever possible, natural drainage ways should be maintained. Steep slopes can be difficult to design swales with non-erosive velocities. Generally, Currituck County will not provide stormwater volume reduction credit for swales; unless a detailed soils analysis shows significant infiltration capacity. This exemption will be handled on a case-by-case basis. It is expected that these systems will be used as part of an overall stormwater plan with other BMPs for a given site.

A swale should be designed as either a curb and gutter system for a low-density development, or as a water treatment swale. Swales typically have a parabolic or trapezoidal cross section. These shapes are ideal for ease of construction, maintenance, and reducing scour. Generally, shallow swales with at least 2-foot bases are ideal. V-shaped swales are acceptable for curb outlet systems for low-density projects. Table B-4 show specific design requirements for the three different types of swales:

Table B-4. Swale Design Requirements (NCDWQ, 2007)

	Curb Outlet for Low-Density	Water Quality Swale Seeking Credit	Swale Not Seeking Credit
Sizing should take into account all runoff at full build-out, including off-site drainage	X	X	X
BMP should be located in a recorded drainage easement with access easement to a public ROW The design must non-erosively pass the 10-year, 24-hour post-development peak runoff rate	X	X	X
Where practicable, the maximum longitudinal slope should be 0.5%	X	X	X
Swales should convey the design discharge while maintaining a 0.5-foot of freeboard	X	X	X
Swales cannot exceed the maximum permissible velocity for the design storm	X	X	X
Maximum allowable ponding time = 48 hours	X	X	X
1-foot separation from bottom of swale to SHWT	X	X	
Maintenance agreement required	X	X	
Maximum allowable velocity as outlined in NCDENR *Erosion and Sediment Control Manual*	X		X
Maximum allowable velocity = 1 ft/sec for the 10-year, 24-hour storm		X	
Side slopes = 3:1 or greater			X
Sides slopes = 5:1 or greater	X	X	
Swale length should be a minimum 100 feet	X		
Swale length should be a minimum 150 feet		X	

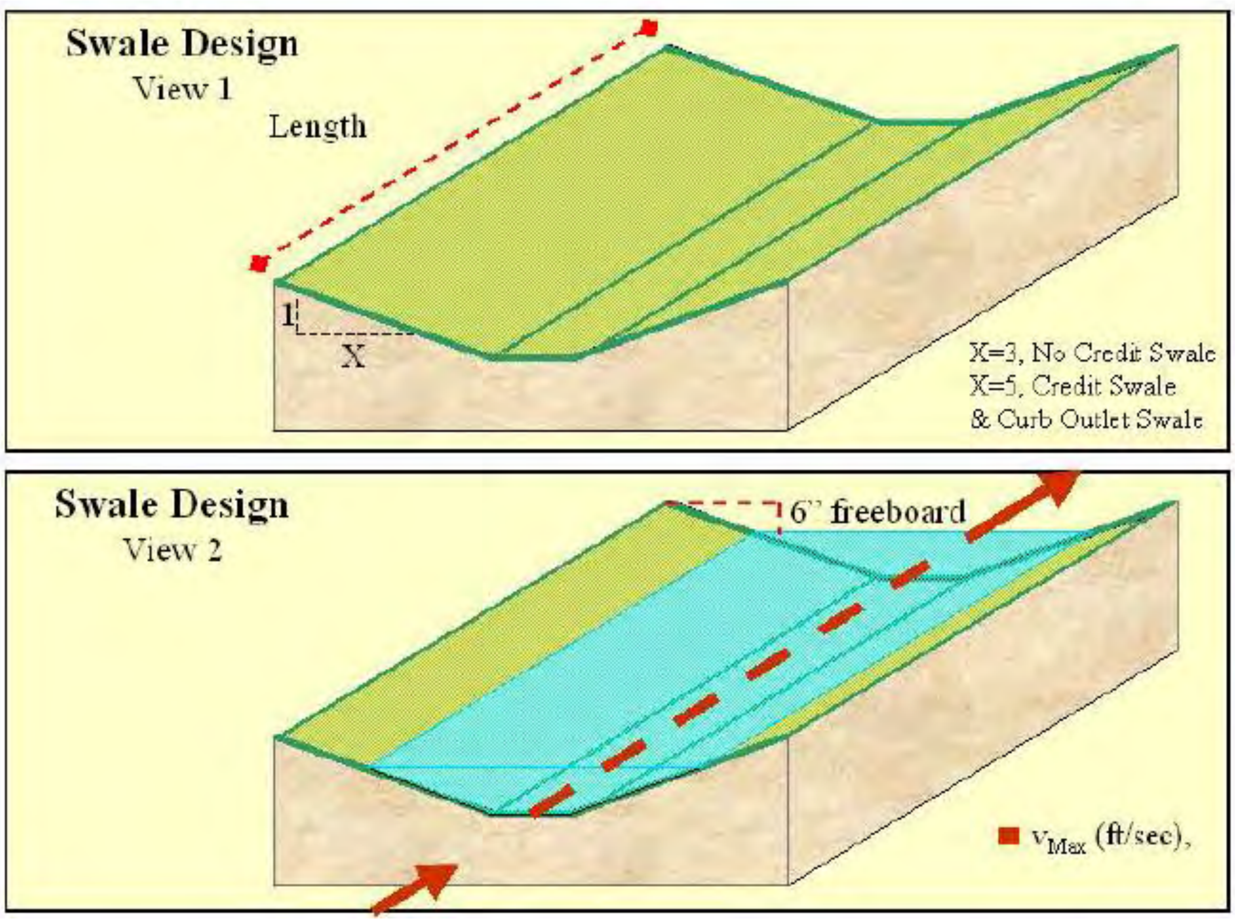


Figure B-36: Grassed Swale Design Elements (NCDWQ, 2007)

A dense grass cover is the ideal vegetation to maximize the performance of a grassed swale. Standard turf grasses may be used if a lawn appearance is desired. A list of recommended grass mixtures can be found in *Appendix D - Recommended Plantings*. Topsoil should be suitable for healthy growth. Whenever in situ soils are unsuitable, applying a loamy or sandy soil to the top 12 inches is beneficial.

Temporary retention of small amount of water may facilitate the treatment of stormwater and provide ecological and visual diversity. Retained water will infiltrate, be lost through evapotranspiration, or slowly released over time. The maximum allowable retention is 48 hours. An underdrain system should be installed if retention times are longer.

(1) Check Dams

A check dam is a small obstruction within the swale, typically made of earth, stone, or timber 3 to 6 inches high. These are designed to retain stormwater runoff from routine rainfall events. Shorter check dams can act as level spreaders to help diffuse flow along the swale cross section.

(2) Elevated Drop Inlets

An elevated drop inlet can be used when a combination of swales and storm sewers are being used within a site. The swales would serve as collector systems, and the inlet to the storm sewer would be raised slightly to retain stormwater during routine storm events. The height of the drop inlet would depend on soils, slope of swales, and the desired amount of ponding. Pocket wetlands can be designed in ponded areas if allowable.

(3) Elevated Culverts

Elevated culverts are similar to elevated drop inlets, in that they are designed to retain routine runoff events. As with drop inlets, wetland vegetation can develop in ponded areas.

(4) Depression storage

Small depressions along the bottom of the swale can retain stormwater for infiltration if in situ soils are favorable. These depressions will likely accumulate sediment at a quicker rate than the rest of the swale.

(5) Underdrains

Underdrains can enhance the performance of a swale by providing additional filtration through soils similar to a bioretention cell. These swales have a layer of engineered soils underlain by a gravel layer surrounding a perforated pipe. No additional removal credits are given for the addition of underdrains. Refer to *Chapter B.1.3 - Underdrain Systems* for design specifications.

D. Applicability

Grassed swales are ideal for residential and commercial developments, as well as highway medians as an alternative to storm sewers. Due to their small sizing requirements, swales are also ideal for parking lots and other urban areas where sizing conventional BMPs is a concern.
Generally, swales are used for the conveyance of stormwater to other BMPs. Swales can be designed to retain runoff to help minimize the peak flows for larger BMPs by increasing the time of concentration and limiting the need for curb and gutter systems. They can also be designed to infiltrate stormwater and removal pollutants. Generally, Currituck County will not provide stormwater runoff credit for swales; unless a detailed soils analysis shows significant infiltration capacity. This exemption will be handled on a case-by-case basis.

E. Limitations

Grassed swales generally cannot meet regulatory requirements alone. They almost always need a companion BMP to achieve necessary design goals. They provide no peak runoff attenuation and very little stormwater volume reduction by themselves. They also provide very little pollutant removal. They can develop "soggy" bottoms or standing water, which hinders maintenance and can become potential mosquito-breeding grounds.

F. Inspection and Maintenance

Maintenance of grassed swales involves grooming the vegetation and trash and debris removal. If native vegetation is used, vegetation should be mowed seasonally. Excessive sediment should not accumulate if erosion is adequately controlled upstream.

Routine maintenance procedures include (NCDWQ, 2007):

- Irrigation is important for plant survival. Irrigation frequency depends on the type of vegetation used; generally it is needed twice weekly until vegetation is established, then only during periods of extended dryness.
- Routine mowing if turf grass is used. Grass should be cut no lower than 5 inches. Swales populated with wetland vegetation do not require mowing.
- Periodic sediment removal (no less than once annually). Sediment should be removed when it reaches a depth of 4 inches.
- Repair erosion and regrade swale as needed
- Revegetate swale to maintain dense growth as needed.
- Routine weeding is necessary

Routine inspections include (NCDWQ, 2007):

- Inspections should occur every quarter and within 24 hours after every storm event with 1.5 inches of rainfall or greater. Records of inspection and maintenance should be kept in a known location and made available upon request.
- Check for weeds, diseased, or dying plants.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.11. Vegetated Filter Strip

A. Description

A vegetated filter strip (VFS) is a gently sloping area covered in grasses or other vegetation that receives sheet flow runoff from up-gradient development. A VFS works to slow runoff velocities and is effective in removing suspended solids, nitrogen and phosphorous from stormwater runoff. A VFS also works to promote infiltration of runoff; however NCDENR does not recognize these as devices capable of attaining credits for stormwater quantity control. Regulatory credits may only be attained for the partial removal of the aforementioned pollutants. Polluted runoff enters the VFS as sheet flow surface drainage, or when flow is concentrated upstream, it enters the VFS as sheet flow from a level spreader device. Filter strips utilized in conjunction with developed will most always require a level spreader to un-concentrate stormwater flows. A VFS is not effective at all if sheet flow is allowed re-concentrate at any point within the effective filter area.

Figure B-37: Grass Filter Strip with Upstream Level Spreader (NCSU BAE, 2011)

Filter strips can be utilized to serve a variety of purposes for stormwater management. A VFS is often used as a sediment pretreatment device for bioretention and infiltration trenches, as a downstream "companion" BMP to stormwater wetlands and wet basins, or as simply as a primary treatment device for upstream impervious areas in commercial and residential areas. Natural filter strips, (such as the outer zone of a riparian stream buffer) can be utilized as a VFS if sheet flow can be demonstrated and maintained throughout the buffer area.

B. Performance

According to the NCDENR *Stormwater Best Management Practices Manual*, filter strips designed according to the specifications in the manual (or a natural VFS demonstrated as suitable) can receive regulatory credits for removal rates of: TSS 25-40% (25% for grass cover, 30% for planted wooded vegetation, 40% for natural wooded vegetation) total nitrogen (TN) 20% and total phosphorous (TP) 35%.(NCDWQ, 2007).

C. Design Guidance

Filter strips will not require modeling to determine flow reduction characteristics, as no credit will be allowed for stormwater quantity reduction. Variances will be granted on a case-by-case basis for small sites with highly permeable soils. A detailed soils analysis will be required to receive stormwater reduction credit for VFS.

The design flow limitations as specified in the NCDENR *Stormwater Best Management Practices Manual* (NCDWQ, 2007) are directly related to type of vegetative cover, width and slope of the filter strip. To achieve the benefits of reduced runoff rates, pollutant removal, and increased infiltration, sheet flow is required through the filter strip. A level spreader is required for all filter strips unless proven that the inflow is evenly disturbed without the use of a level spreader. A filter strip should be located such that it receives flow from a relatively small drainage basin, as there are limitations on the flows allowed to drain to a level spreader - vegetated filter strip (LS-VFS) system. The VFS must be located in areas that can maintain dense stands of the selected vegetation. Grasses and other vegetative species selected for filter strips should be specifically tolerant to saturation and drought, chemicals, salts and metals. A VFS must not be located in any area with a slope greater than 15%, though the recommended slope is less than 5%. Steeper slopes make the VFS more prone to re-concentrating flows and thus more susceptible to erosion.

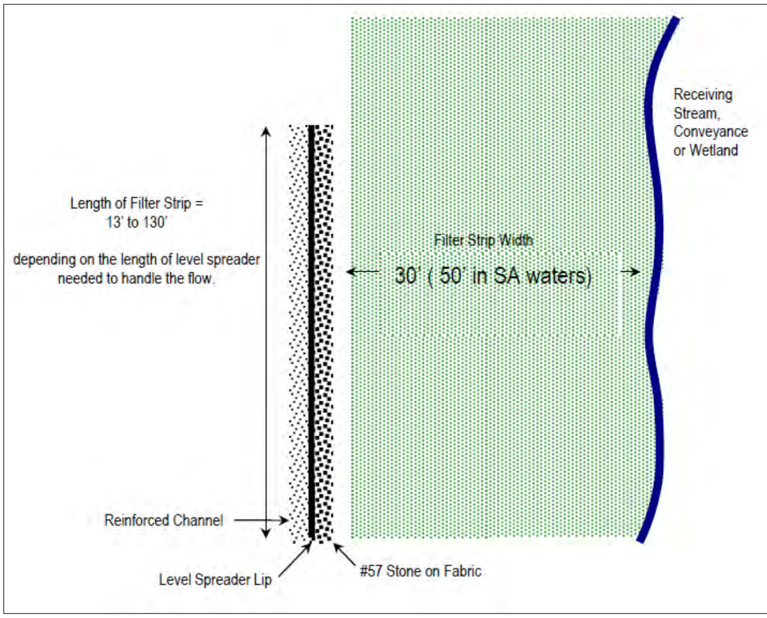


Figure B-38: Filter Strip Schematic as a Companion BMP (NCDWQ, 2007)

The top edge of the filter strip should follow an elevation contour. If a section of the top edge dips below the contour, runoff eventually will 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 to prevent runoff from bypassing any portion of the filter strip.

The length (perpendicular to flow) must be between 13 – 130 feet. The length is calculated as follows:

- For grass or thick ground cover: 13 feet of length per 1 cfs of flow on slopes 0 – 8%
- For forested vegetation: 65 feet of length per 1 cfs of flow on slopes 0 – 6%
- If forest vegetation is 100 – 150 feet wide, length can be reduced to 50 feet of filter strip per cfs of flow
- If forest vegetation is more than 150 feet wide, length can be reduced to 40 feet of filter strip per cfs of flow
- For filter strips with grass / ground cover and forested areas, the length is determined by calculating the weighted average of the lengths required for each vegetation type
- The width (parallel to flow) of a filter strip should be a minimum of 50 feet
- Non-erosive velocities are required; typically ranging from 4 ft/sec for grass, less than 2 ft/sec for wooded filter strips

For some BMPs, a VFS is required to meet North Carolina's State Stormwater Management Program rules. No specific pollutant removal is assigned for the companion filter strip, but the filter strip must be included in the stormwater control system. The slope and length of the filter strip should be designed to provide a non-erosive velocity through the filter strip for the 10-year, 24-hour post-development storm. The slope shall be 5% or less where applicable. The slope shall not exceed 15% under any circumstances.

The width should be 50 feet when installed on the discharge from another BMP when draining to SA waters. The width of the filter strip should be 30 feet when installed on the discharge from a wet detention basin or another BMP.

The type of vegetation is an essential element to filter strip design. For forested filter strips, vegetation should be deep-rooted, have well-branched top growth, and resistant to damage from saturation and drought. VFS that receive street and parking lot runoff must be resistant to chemicals, salts, and heavy metals. A grading and vegetation plan must be prepared by an appropriately licensed design professional for all filter strips.

D. Applications

Filter strips perform well in areas where dense, vegetative growth can be established. Whenever possible, natural forested areas provide good long-term removal of pollutants and priority should be given to protect existing forested areas. However, studies have shown that designed filter strips will infiltrate larger quantities of runoff when graded, ensuring their "levelness". Water will remain in sheet flow for longer periods than those travelling through a naturally occurring buffer (NCSU, 2009).

In general, filter strips are most effective for relatively flat sites with small contributing drainage areas. They are most appropriate in locations with a seasonal high water table near the surface. Slopes less than 5% are preferred; however, slopes cannot exceed 15%. Filter strips cannot handle large sediment accumulation; therefore filter strips would not be installed until the contributing drainage area is stabilized. Filter strips can be used for larger areas when they are used in series, or interspersed between impervious surfaces.

For the purposes of stormwater runoff reduction, only filter strips located on small sites with highly porous soils will be considered on a case-by-case basis. It is expected that these devices will be used at the end of a treatment train of upstream BMPs as a water quality "finishing" device.

E. Limitations

As they do not provide adequate storage of runoff to reduce the peak discharge or storm runoff volume, VFS are often used in conjunction with additional BMPs. In most instances, a forebay is required prior to the level spreader to capture sediment prior to entering the filter strip. Also, while a level spreader does not require much area, a VFS does require a substantial amount of surface area.

VFS are not resistant to high velocities; therefore should not be used in areas with intense development or steep slopes. High dune areas are too dry to support dense vegetative cover and are not appropriate for filter strips.

F. Inspection and Maintenance

VFS that are not properly maintained can quickly become deficient. Routine maintenance includes mowing, trimming, and replanting when necessary. Excessive sediment loading may require periodic regarding and reseeding, as sediment can kill grass and cause erosion.

For the first two years after construction, VFS should be inspected for proper distribution of flows and signs of erosion during and after storm events. After the first couple of years, VFS can be inspected annually. If erosion exists, gullies should be filled and reseeded. The cause of erosion should be investigated and remedied if possible.

Routine maintenance includes (NCDWQ, 2007):

- Twice weekly watering is required after construction until VFS is established (approximately 6 weeks).
- Annual reseeding to maintain dense growth
- Annual soil testing for pH

- Soil aeration should occur annually
- Mowing grass as needed. Turf grass should not be cut shorter than 3 inches; however, grass can grow up to 1 foot, depending on aesthetic requirements.

Routine inspection includes (NCDWQ, 2007):

- VFS should be inspected quarterly and within 24 hours after every storm event 1.5 inches of rainfall or greater. Records of inspection and maintenance should be kept in a known location and made available upon request.
- Check the level lip for cracks, settling, undercutting, erosion, or other damage. Repair or replace as needed.
- Check for erosion around the end of the level spreader if stormwater has bypassed it.
- Check the bypass channel erosion control measures for damage or if riprap (if applicable) remains in place. If not, assess the drainage area flows to determine if a larger bypass channel is needed.
- Check plants for any signs of disease or death. Remove invasive species as needed.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

B.2.12. Restored Riparian Buffers

A. Description

Restored riparian buffers are natural (or constructed) low-maintenance ecosystems adjacent to surface water bodies. Vegetation functions as a filter to remove pollutants from surface stormwater flow and shallow groundwater flow prior to discharging to receiving waters.

B. Performance

According to the NCDENR *Stormwater Best Management Practices Manual*, riparian buffers designed according to the specifications in the manual can receive regulatory credits for removal rates of: TSS - 60%, total nitrogen (TN) - 30%, and total phosphorous (TP) - 35%. (NCDWQ, 2007).

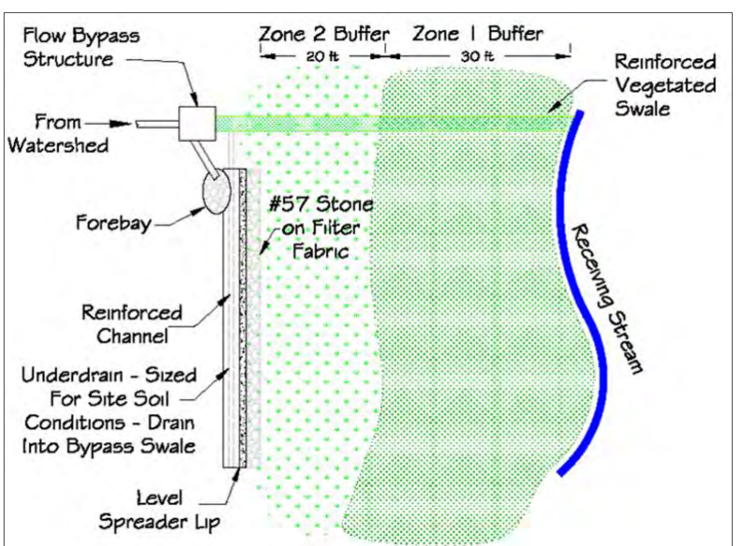


Figure B-39: Typical Layout of Level Spreader System to a Riparian Buffer (NCSU, 2009)

C. Design Guidance

The restored riparian buffer must be a total of 50 feet wide and is comprised of two zones: Zone 1 is a minimum 30-foot wide forested zone; Zone 2 is a minimum 20-foot wide grassed zone. Level spreaders are required unless the design professional can prove that water will sheet flow through the buffer. Refer to *Chapter B.1.4 - Level*

Spreaders for proper level spreader design. Buffers are a minimum of 13 feet and a maximum 130 feet in length, as set by the level spreader requirements.

Designers have the option of placing two or more restored riparian buffers adjacent to one another along a stream in order to treat higher stormwater flows. Riparian buffers can also be used downstream of other BMPs, which will attenuate larger flows and allow the drawdown flow to receive additional treatment.

Based on the site assessment, the designer should choose between 10 – 12 different species of native trees and shrubs for Zone 1. Typically, there should be at least 3 – 4 understory trees for every canopy tree to provide diversity similar to mature forests. Where shrub species are incorporated, they should be distributed more densely at the outer edge to reduce light penetration and re-colonization by invasive species.

Trees should be planted at an approximate density of 320 trees per acre. Trees should be planted with spacing between 8X8 to 10X10 feet. Shrubs should be planted at to provide approximately 1,200 shrubs per acre, between 3X3 to 5X5 feet of spacing. The minimum size for trees is 2.5 inches dbh (diameter breast height). Trees should be bare root or balled and burlapped. The minimum shrub size is 1-gallon containers. Refer to Appendix D for a list of acceptable plants.

Zone 2 should be planted with a dense cover of grass. Fescue and bluegrass are not recommended as they are invasive and will compete with native vegetation. Do not work under frozen, muddy, or saturated conditions. Centipede and Zoysia grasses should be planted in mid-May until late-August.

D. Applications

Riparian buffers must be constructed in areas directly adjacent to perennial or intermittent surface waters (as shown in the most recent NRCS Soil Survey or USGS 1:24,000 scale quadrangle topographic map). The existing buffer must be defined as "impaired", which includes: pastures that have been actively used within the last 3 years, wooded buffers that have been cutover within the last 5 years, or where wooded vegetation is sparse or absent (less than 100 stems per acre that are greater than 5 inches in diameter at breast height).

The slope of a riparian buffer should be less than 6%. The flow to the riparian buffer must be less than 3 cfs. If the flow is greater, an upland storage device or another BMP should be used to reduce the flow to the required 3 cfs.

All restored riparian buffers must be placed in the permanent easement so it will not be disturbed in the future. However, natural areas and trails through the riparian buffer can provide a nice feature for residents.

It is expected that these devices will be used at the end of a treatment train of upstream BMPs as a water quality "finishing" device. Generally, riparian buffers do not provide any reduction in stormwater runoff volumes. For the purposes of stormwater runoff reduction credits, only riparian buffers located on small sites with highly porous soils will be considered on a case-by-case basis.

E. Limitations

Riparian buffers require a large amount of surface area, yet provide almost no volume capture or peak flow rate attenuation. They are generally useful for smaller sites with little runoff. For larger sites, they are often used in conjunction with other BMPs like wet or dry detention ponds, which also require a large amount of space. Riparian buffers can also been seen as undeveloped areas, and may be used abused for places to dump trash and litter.

F. Inspection and Maintenance

Riparian buffers require maintenance to fill gullies, repair streambank erosion, remove invasive species, and protect against wildlife damage. Removal of natural leaf litter is discouraged. Where natural material is not present, organic mulch should be maintained to a minimum depth of 2 inches.

Watering is necessary during the initial planting year, and other times during drought. Immediately after planting, vegetation should be watered twice weekly until the plants become established. Replanting may be necessary to maintained required plant densities. After trees are established, period thinning and harvesting mature trees is recommended to promote growth. The required density must be maintained and no trees larger than 2-inch diameter are removed unless dead or diseased. Thinning of vines and thick underbrush is encouraged.

In the early stages of riparian buffer establishment, weed control is important. Design plans should incorporate control of the herbaceous layer. Optional weed control includes 4 – 6 inches of well-aged hardwood mulch, weed control fabrics, or pre-emergent herbicide. Weed control should be continued for 3 years from time of planting, after which it should be self-controlling.

Once a year, Zone 2 should be reseeded to maintain a dense growth of vegetation and the soil aerated. Two or three times a year, Zone 2 should be mowed and the clippings harvested to promote thick growth. Grass should not be cut shorter than 3 – 5 inches, and allowed to grow as tall as 12 inches, depending on aesthetic requirements.

Routine maintenance includes (NCDWQ, 2007):

- Immediately after construction, twice weekly watering is necessary until plants become established (approximately 6 weeks).
- Annually, Zone 2 should be reseeded to maintain dense growth.
- Annually, Zone 2 soils should be aerated.
- Zone 2 should be mowed and clipping removed as needed. Turf grass should not be cut shorter than 3 inches; however, it can grow up to 1 foot depending on aesthetic requirements.
- Annual soil tests should be conducted.

Routine inspections include (NCDWQ, 2007):

- Riparian buffers should be inspected quarterly and within 24 hours after every storm event 1.5 inches of rainfall or greater. Records of inspection and maintenance should be kept in a known location and made available upon request.
- Check flow splitter device for signs of clogging or damage.
- Check the level lip for cracks, settling, undercutting, erosion, or other damage. Repair or replace as needed.
- Check for erosion around the end of the level spreader if stormwater has bypassed it.
- Check the bypass channel erosion control measures for damage or if riprap (if applicable) remains in place. If not, assess the drainage area flows to determine if a larger bypass channel is needed.
- Check plants for any signs of disease or death. Remove invasive species as needed.
- Refer to Appendix C for a sample inspection checklist. Inspection activities should be performed as recommended in the checklist. Any problems found should be repaired immediately.

Appendix C: Maintenance Requirements

APPENDIX C. MAINTENANCE REQUIREMENTS

C.1. INSPECTING AND MAINTAINING STORMWATER DEVICES

Regular inspection and maintenance is an ongoing requirement after construction for any BMP. The BMP system will not function efficiently without proper maintenance. Inspections should be completed at regular intervals throughout the year. Currituck County requires that a BMP inspection record log be maintained by the owner. Inspection and maintenance records must be made available at Currituck County's request.

Stormwater management devices that receive runoff from less than five acres shall be inspected at least once every three years; stormwater management devices that receive runoff from more than five acres shall be inspected annually by a registered engineer, licensed surveyor or landscape architect. It is advised that routine inspections also occur within 24 hours after every storm event with 1.5 inches of rainfall or more within 24 hours. Routine maintenance should occur yearly for all BMPs, or sooner if the inspection requires immediate action. Damage may occur during large storm events; therefore, additional maintenance may be required due to high flows or large sediment accumulation from localized erosion. Any deficient BMP elements in the inspection should be corrected, repaired, or replaced immediately, as these issues can affect the performance of the BMP. Repairs should be made by appropriate professionals. Major repairs or maintenance work should include the same level of inspection and documentation as the original installation. Should issues arise, Currituck County may require additional maintenance be performed at the owner's expense.

The following pages include inspection checklists for different BMPs. The checklists are not meant to be all-inclusive; however, inspectors should document the condition of each individual component of the BMP and note deficient areas that are in need of repair.

Stormwater BMP Inspection Checklist
Bioretention Cells

Development Name: ____________________

Address: ____________________

Inspector Name: ____________________

Signature: ____________________ Date: __________

BMP Feature	Potential Problem	Maintenance Needed	✓
The bioretention cell	Tree stakes/wires are present six months after planting	Remove tree stakes/wires, as they can kill a tree if not removed.	☐
	Mulch is breaking down or has floated away	Spot mulch if there are only random voids. Replace whole mulch layer if necessary. Remove the remaining mulch and replace with triple shredded hard wood mulch at a maximum depth of 3 inches.	☐
	Soils and/or mulch is 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 3 inches. Search for source of sediment and remedy the problem if possible.	☐
	Soil tests shows that pH has dropped or heavy metals have accumulated in the soil media	Dolomitic lime should be applied as recommended per the soil test and toxic soils should be removed, disposed of properly, and replaced with new planting media.	☐
	Plants are dead, diseased, or dying	Try to determine the cause of the problem (may need to consult an expert). Correct the problem and replace the plants.	☐
The drop inlet, vaults, or other underground structure (if applicable)	Any portion of the structure is cracked or damaged	Repair or replace the structure. An appropriate professional should inspect the structure after the repairs or replacements are made.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Bioretention Cells
Page 1 of 1

Stormwater BMP Inspection Checklist
Cisterns

Development Name: ______________________________

Address: ______________________________

Inspector Name: ______________________________

Signature: ______________________________ Date: ______________

BMP Feature	Potential Problem	Maintenance Needed	✓
Gutters, drains, and spouts	Clogging has occurred	Remove leaves, debris, and other foreign matter and dispose in a manner that will not impact the BMP.	☐
Gutters, drains, and spouts	Any portion of the gutter, drain, or spout is crushed or damaged	Repair or replace as needed.	☐
The tank	Any portion of the structure is cracked or damaged	Repair or replace the structure. An appropriate professional should inspect the structure after the repairs or replacements are made.	☐
Inlet and Outlet pipes	Cracks and other openings greater than 1/16 inch wide	Repair or replace the pipes to prevent mosquitoes.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Cisterns
Page 1 of 1

Stormwater BMP Inspection Checklist
Dry Detention Basin

Development Name: ______________________________

Address: ______________________________

Inspector Name: ______________________________

Signature: ______________________ Date: ______________

BMP Feature	Potential Problem	Maintenance Needed	✓
The main treatment area	Water is standing for more than 5 days after a storm event	Check outlet structure for clogging. If it is a design issue, consult an appropriate professional.	☐
	Vegetation is less than 4 inches or greater than 8 inches	Mow vegetation to height of approximately 6 inches.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Dry Detention Basin
Page 1 of 1

Stormwater BMP Inspection Checklist

Grassed Swales

Development Name: ______________________________

Address: ______________________________

Inspector Name: ______________________________

Signature: ______________________________ Date: ____________

BMP Feature	Potential Problem	Maintenance Needed	✓
The entire swale	Trash or debris is present	Remove trash/debris.	☐
	Exposed soil and/or gullies are present	Regrade soil if necessary to remove gully, then plant ground cover and water until established. Provide lime and one-time fertilizer application.	☐
	Sediment accumulation 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 less than 4 inches or greater than 8 inches	Mow vegetation to height of approximately 6 inches.	☐
The receiving water	Erosion or other signs of damage have occurred at the outlet	Consult a professional.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Grassed Swales
Page 1 of 1

Stormwater BMP Inspection Checklist
Green Roofs

Development Name: ______________________

Address: ______________________

Inspector Name: ______________________

Signature: ______________________ Date: ______________

BMP Feature	Potential Problem	Maintenance Needed	✓
The plants	Weeds are present	Remove weeds by hand.	☐
	Plants are dead, diseased, or dying	Try to determine the cause of the problem (may need to consult an expert). Correct the problem and replace the plants.	☐
Gutters, drains, and spouts	Clogging has occurred	Remove leaves, debris, and other foreign matter and dispose in a manner that will not impact the BMP.	☐
	Any portion of the gutter, drain, or spout is crushed or damaged	Repair or replace as needed.	☐
	Weeds and noxious plants are growing in the main treatment area	Remove plants, preferably by hand. If herbicide is used, wipe it on rather than spraying.	☐
	Pipe has become full with sediment and/or debris	Unclog the affected area and remove sediment and/or debris off-site.	☐
	Any portion of the pipe is crushed or damaged	Make any necessary repairs or replace if the damage is too large for repair.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Green Roofs
Page 1 of 1

Stormwater BMP Inspection Checklist
Infiltration Basin/Trench

Development Name: ____________________

Address: ____________________

Inspector Name: ____________________

Signature: ____________________ Date: ____________

BMP Feature	Potential Problem	Maintenance Needed	✓
The basin	A visible layer of sediment has accumulated	Search for the sediment source and correct problem if possible. Remove accumulated sediment and dispose of it in a location where it will not impact 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 problem. If not, then consult a professional for a more extensive repair.	☐
	Weeds and noxious plants are growing in the main treatment area	Remove plants, preferably by hand. If herbicide is used, wipe it on rather than spraying.	☐
The trench	Water is standing on the surface for more than 24 hours after a storm	Remove accumulated sediment from the infiltration system and dispose in a location that will not impact the BMP.	☐
	The depth in the trench has been reduced to 75% of the original design depth	Remove accumulated sediment from the infiltration system and dispose in a location that will not impact the BMP.	☐
	Grass or other plants are growing on the surface of the trench	Remove plants, preferably by hand. If herbicide is used, wipe it on rather than spraying.	☐
The observation well	The water table is within one foot of the bottom of the system for a period of 3 consecutive months	Consult a professional.	☐
	Pipe has become full with sediment and/or debris	Unclog the affected area and remove sediment and/or debris off-site.	☐
	Any portion of the pipe is crushed or damaged	Make any necessary repairs or replace if the damage is too large for repair.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Infiltration Basin/Trench
Page 1 of 1

Stormwater BMP Inspection Checklist
Permeable Pavement

Development Name: ______________________________

Address: ______________________________

Inspector Name: ______________________________

Signature: ______________________ Date: __________

BMP Feature	Potential Problem	Maintenance Needed	✓
The pavement	Trash or debris is present	Remove trash/debris.	☐
	Weeds are growing on the surface of the permeable pavement	Do not pull weeds (may pull out media as well). Spray with herbicide.	☐
	Sediment is present on the surface	Vacuum sweep the pavement.	☐
	Pavement does not dewater between storms	Vacuum sweep the pavement. If pavement still does not dewater, consult a professional.	☐
	The pavement is damaged or deteriorating	Consult a professional.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist

Sand Filter

Development Name: ______________________________

Address: ______________________________

Inspector Name: ______________________________

Signature: ______________________ Date: ______________

BMP Feature	Potential Problem	Maintenance Needed	✓
The adjacent pavement	Sediment is present of the pavement surface	Sweep or vacuum the sediment as soon as possible.	☐
The filter bed and underdrain collection system	Water ponds on the surface for more than 24 hours after a storm event	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 and expert.	☐
The drop inlet, vaults, or other underground structure (if applicable)	Any portion of the structure is cracked or damaged	Repair or replace the structure. An appropriate professional should inspect the structure after the repairs or replacements are made.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Sand Filter
Page 1 of 1

Stormwater BMP Inspection Checklist

Wet Detention Basin

Development Name: ______________________________

Address: ______________________________

Inspector Name: ______________________________

Signature: ______________________________ Date: ____________

BMP Feature	Potential Problem	Maintenance Needed	✓
The entire BMP	Trash or debris is present	Remove trash/debris.	☐
The perimeter of the BMP	Exposed soil and/or gullies are present	Regrade soil if necessary to remove gully, then plant ground cover and water until established. Provide lime and one-time fertilizer application.	☐
	Vegetation is less than 4 inches or greater than 8 inches	Mow vegetation to height of approximately 6 inches.	☐
The inlet device (pipe or swale)	Sediment accumulation exceeds 6 inches	Search for the sediment source and correct problem if possible. Remove accumulated sediment and dispose of it in a location where it will not impact the BMP.	☐
	Pipe has become full with sediment and/or debris	Unclog the affected area and remove sediment and/ or debris off-site.	☐
	Any portion of the pipe is crushed or damaged	Make any necessary repairs or replace if the damage is too large for repair.	☐
	Erosive gullies have formed	Regrade swale if necessary to smooth it over and provide erosion control devices such as reinforced turf matting or riprap to avoid future problems.	☐
	Stone verge is clogged or covered in sediment	Remove sediment and clogged stone and replace with clean stone.	☐
	The flow splitter device is clogged	Unclog the conveyance and dispose of any sediment off-site.	☐
	The flow splitter is damaged	Make any necessary repairs or replace if damage is too large to repair.	☐
	Turf reinforcement is damaged or riprap is rolling downhill	Study the site to see if a larger bypass channel is needed (enlarge if necessary). After this, replace the erosion control material.	☐
	The level lip is cracked, settled, undercut, eroded, or otherwise damaged	Repair or replace the level 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 established. Provide lime and a one-time fertilizer application.	☐
The pretreatment area or forebay (if applicable)	Sediment has accumulated to a depth greater than the original design sediment storage depth	Search for the sediment source and correct problem if possible. Remove accumulated sediment and dispose of it in a location where it will not impact the BMP.	☐
	Erosive gullies have formed and/or flow is bypassing pretreatment area	Regrade if necessary to smooth over and provide erosion control devices such as reinforced turf matting or riprap to avoid future problems.	☐

Stormwater BMP Inspection Checklist – Wet Detention Basin
Page 1 of 2

	Weeds are present	Remove weeds, preferably by hand. If an herbicide is used, wipe it on 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 sediment source and correct problem if possible. Remove accumulated sediment and dispose of it in a location where it will not impact the BMP.	☐
	Algal growth covers over 50% of the area	Consult a professional to remove and control algal growth.	☐
	Cattails, phragmites, and other invasive plants cover 50% of the area	Remove plants by wiping them with an herbicide (do not spray).	☐
	Plants are dead, diseased, or dying	Determine the source of the problem: soils, hydrology, disease, etc. Remedy the problem and replace the plants. Provide a one-time fertilizer application to establish the plants if soil tests indicate it is necessary.	☐
	Weeds are present	Remove weeds, preferably by hand. If an herbicide is used, wipe it on plants rather than spraying.	☐
	Plants need regular pruning to maintain optimal plant health	Prune according to best professional practices.	☐
The embankment (if applicable)	Shrubs have started to grow on the embankment	Remove shrubs immediately.	☐
	Evidence of beaver or muskrat activity is present	Use traps to remove muskrats and consult a professional to remove beavers.	☐
	Trees have started to grow on the embankment	Consult a dam safety specialist to remove trees.	☐
The outlet device (pipe or swale)	Pipe has become full with sediment and/or debris	Unclog the affected area and remove sediment and/ or debris off-site.	☐
	Any portion of the pipe is crushed or damaged	Make any necessary repairs or replace if the damage is too large for repair.	☐
	Erosive gullies have formed	Regrade swale if necessary to smooth it over and provide erosion control devices such as reinforced turf matting or riprap to avoid future problems.	☐
	Grass is too short or too long	Maintain grass to height of approximately 3 - 6 inches.	☐
	Sediment is building up on the filter strip	Remove the sediment and restablize the soil with vegetation if necessary. Provide lime and 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 the plants. Provide a one-time fertilizer application to establish the plants if soil tests indicate it is necessary.	☐
	Nuisance vegetation is choking out desirable species	Remove vegetation by hand if possible. If herbicide is used, do not allow it to get into receiving waters.	☐
The receiving water	Erosion or other signs of damage have occurred at the outlet	Consult a professional.	☐

Comments

____

____

____

Stormwater BMP Inspection Checklist – Wet Detention Basin
Page 2 of 2

Stormwater BMP Inspection Checklist

Wetlands

Development Name: ______________________________

Address: ______________________________

Inspector Name: ______________________________

Signature: ______________________________ Date: ______________

BMP Feature	Potential Problem	Maintenance Needed	✓
Deep Pools & Temporary inundation zone	Temporary inundation zone remains flooded for more than 5 days after a storm event	Unclog the outlet device immediately.	☐
	Sediment has accumulated and reduced the original design sediment storage depth to 75%	Search for the sediment source and correct problem if possible. Remove accumulated sediment and dispose of it in a location where it will not impact the BMP.	☐
Plants	Cattails, phragmites, and other invasive plants cover 50% of the area	Remove plants by wiping them with an herbicide (do not spray).	☐
	Plants are dead, diseased, or dying	Try to determine the cause of the problem (may need to consult an expert). Correct the problem and replace the plants.	☐

Comments

____

____

____

Appendix D: Recommended Plantings

APPENDIX D. RECOMMENDED PLANTINGS

Wet Pond & Stormwater Wetland Plants – Tier 1 (Hunt, Burchell, Wright, & Bass, 2007)

Common Name	Scientific Name	Depth Range [inches, (-) below water surface, (+) above water surface]	Comments
Fragrant water lily	*Nymphaea odorata*	(-)24 to (-)12	Deepest fringe of Zone II only. Although this species is listed as native to North Carolina, some vegetation experts do not recommend its use
Spatterdock	*Nuphar lutea*	(-)24 to (-)12	Deepest fringe of Zone II only. Although this species is listed as native to North Carolina, some vegetation experts do not recommend its use
Softstem bulrush	*Schoenoplectus tabernaemontani (formerly Scirpus validus)*	(-)4 to (-)2	
Pickerelweed	*Pontederia cordata*	(-)4 to (-)2	Bright purple-blue flowers
Broadleaf Arrowhead	*Sagittaria latifolia*	(-)4 to (-)2	Broad leaves; white flowers in summer
Bulltongue Arrowhead	*Sagittaria lancifolia*	(-)4 to (-)2	White flowers in summer
Burreed or bur-reed	*Sparganium spamericanum*	(-)4 to (-)2	Tolerates flowing water zones near inlets and outlets
Lizard's tail	*Saururus cernuus*	(-)2 to (+)6	Can tolerate dryer years; thin white flowers
Woolgrass	*Scirpus cyperinus*	(-)2 to (+)6	Tall, brown seed heads in late summer; makes tall border
Sedge	*Carex* spp.	(-)2 to (+)6	Many different species available; good initial colonizer
Common rush	*Juncus* spp.	(-)2 to (+)6	Grows best at water's edge; nearly evergreen in coastal plain

Wet Pond & Stormwater Wetland Plants – Tier 2 (Hunt, Burchell, Wright, & Bass, 2007)

Common Name	Scientific Name	Depth Range [inches, (-) below water surface, (+) above water surface]	Comments
Water lotus (American lotus)	*Nelumbo lutea*	(-)24 to (-)12	Protrudes from deep pools. Some concern that this plant is too aggressive. Although this species is listed as native to North Carolina, some vegetation experts do not recommend its use
Arrow arrum	*Peltandra virginica*	(-)4 to (-)2	Similar appearance to Arrowhead
Swamp milkweed	*Asclepias incarnata*	(-)2 to (+)6	Orange flowers in fall
Blue flag iris	*Iris virginica* or *versicolor*	(-)2 to (+)3	Blue flowers in late spring; grows at water's edge
Cardinal flower	*Lobelia cardinalis*	0 to (+)6	Red flowers in late summer
Hibiscus (rose mallow)	*Hibiscus moscheutos* and *H. grandiflorus*	0 to (+)6	White and red flowers in mid- to late summer
Swamp rose	*Rosa palustris*	0 to (+)6	Off-white blooms in spring
Joe-pye weed	*Eupatorium purpureum*	(-)2 to (+)6	Purplish boom in the summer and fall

Bioretention and Dry Basin Plants – Trees (NCDWQ, 2007)

Species / Common Name	Exposure	Height / Spread	Comments
Amalanchier canadensis Shadberry / Serviceberry	Sun	35 – 50 ft 35 – 50 ft	Salt resistant; moist to average soils; high wildlife value
Betula nigra River Birch	Sun	50 – 75 ft 50 – 75 ft	Drought and heat resistant
Cercis canadensis Eastern Redbud	Sun / Part Shade	20 – 35 ft 20 – 35 ft	Moist soils but not too wet; drought tolerant; many good cultivars
Chionanthus virginicus Fringetree	Sun / Shade	20 – 35 ft 20 – 35 ft	Moist soils; excellent small urban tree
Fraxinus americana White Ash	Sun / Shade	75 – 100 ft 50 – 75 ft	Moist to average soils; urban light resistant
Fraxinus pennsylvanica Green Ash	Sun	50 – 75 ft 35 – 50 ft	Moist to average soils; light and drought resistant
Pinus palustris Longleaf Pine	Sun	75 – 100 ft 25 – 35 ft	Wet to average soils; drought resistant
Pinus taeda Loblolly Pine	Sun	75 – 100 ft 25 – 35 ft	Wet to average soils; drought resistant
Plantanus occidentalis American Sycamore	Sun / Part Shade	75 – 100 ft 75 – 100 ft	Wet to average soils; drought resistant
Populus deltoides Eastern Poplar	Sun	75 – 100 ft 75 – 100 ft	Wet to average soils; drought and salt resistant
Quercus bicolor Swamp White Oak	Sun / Shade	75 – 100 ft 50 – 75 ft	Wet to moist soils; drought and salt resistant
Quercus phellos Willow Oak	Sun	50 – 75 ft 50 – 75 ft	Wet soils; drought and salt resistant
Taxodium distichum Bald Cypress	Sun	50 – 75 ft 20 – 35 ft	Wet-moist soils; drought resistant; not salt tolerant
Ulmus americana American Elm	Sun / Part Shade	75 – 100 ft 75 – 100 ft	Moist to dry soils; drought resistant
Viburnum rufidulum Rusty Blackhaw Viburnum	Sun	20 – 35 ft 20 – 35 ft	Average to droughty soils

Bioretention and Dry Basin Plants – Shrubs (NCDWQ, 2007)

Species / Common Name	Exposure	Height / Spread	Comments
Amorpha fruticosa Indigobush Amorpha	Sun	6 – 12 ft 12 – 20 ft	Very flood tolerant; salt tolerant; very drought-heat resistant
Aronia arbutifolia Red Chokeberry	Sun / Shade	6 – 12 ft 3 – 6 ft	Very flood tolerant; salt tolerant; very drought-heat resistant
Betula lenta Cherry Birch	Sun	15 – 25 ft 6 – 12 ft	Flood tolerant; drought resistant
Callicarpa americana American Beautyberry	Sun / Shade	6 – 15 ft 12 – 20 ft	Average to droughty soils
Ceanothus americanus Jerseytea Ceanothus	Sun / Shade	3 ft 6 ft	Average to droughty soils; salt resistant
Clethra alnifolia Summersweet Clethra	Sun / Shade	6 – 12 ft 6 – 12 ft	Flood tolerant; salt, drought, and heat resistant
Cornus amomum Silky Dogwood	Sun	6 – 12 ft 6 – 12 ft	Flood tolerant; intermediate drought and heat resistant
Cornus sericea Red-ossier Dogwood	Sun / Shade	15 ft 6 – 12 ft	Prefers wet to moist soils; drought and heat resistant; red twigs
Corylus americana American Filbert	Sun	6 – 12 ft 6 – 12 ft	Prefers moist-dry soils; drought and heat resistant

Species / Common Name	Exposure	Height / Spread	Comments
Cyrilla racemiflora Swamp Cyrilla	Sun / Shade	12 – 20 ft 12 – 20 ft	Wet to moist soils; drought and salt resistant
Diospyros virginiana Persimmon	Sun / Shade	10 – 15 ft 6 – 10 ft	Wet to average soils; can be hard to transplant
Fothergilla gardeni Dwarf Fothergilla	Sun / Shade	3 ft 6 ft	Wet to average soils; multi-season landscape interest
Halesia carolina Carolina Siverbell	Sun / Shade	20 ft 12 ft	Moist, well-drained soils
Hammamelis spp. Witchhazel	Sun / Shade	15 – 20 ft 6 – 12 ft	Moist soils; does well in poorly-drained soils; many fine cultivars
Hypericum densiflorum Dense Hypericum	Sun	3 ft 6 ft	Does extremely well in dry soils; very flood and salt tolerant
Hypericum proloficum Shrubby St. Johnswort	Sun	3 ft 6 ft	Does extremely well in dry soils; very flood and salt tolerant
Ilex decidua Possumhaw	Sun / Shade	12 – 20 ft 12 – 20 ft	Very flood tolerant; very drought and salt resistant
Itea virginica Virginia Sweetspire	Sun / Shade	6 – 12 ft 6 – 12 ft	Very flood and drought tolerant; salt resistant; many fine cultivars
Kalmia angustifolia Lambkill Kalmia	Sun / Shade	3 ft 3 – 6 ft	Very flood and drought tolerant; lavender-purple flowers
Myrica cerifera Wax Myrtle	Sun	12 – 20 ft 6 – 12 ft	Very flood tolerant; excellent salt and drought resistance
Nerium oleander Oleander	Sun	6 – 12 ft	Very flood tolerant; excellent salt and drought resistance
Rhododendron nudiflorum Pinxter Azalea	Sun / Shade	6 – 12 ft 6 – 12 ft	Intermediate tolerance to street lighting and prolonged drought
Rhododendron viscosum Swamp Azalea	Sun / Shade	6 – 12 ft 6 – 12 ft	Intermediate tolerance to street lighting and prolonged drought
Rosa carolina Carolina Rose	Sun	3 ft 3 – 6 ft	Very drought resistant; deep pink flowers
Sabal minor Palmetto	Sun / Shade	6 – 12 ft 6 – 12 ft	Flood tolerant; some salt tolerance; drought and heat resistant
Vaccinium corymbosum Highbush blueberry	Sun / Shade	6 – 12 ft 6 – 12 ft	Very flood tolerant; intermediate drought tolerant; salt resistant
Viburnum dentatum Arrowwood Viburnum	Sun / Shade	6 – 12 ft 6 – 12 ft	Very flood tolerant; intermediate drought tolerant; salt resistant
Viburnum nudum Possumhaw Viburnum	Sun / Shade	6 – 12 ft 6 – 12 ft	Very flood tolerant; intermediate drought tolerant; salt resistant

Bioretention and Dry Basin Plants – Groundcover, Perennials, and Ornamental Grasses
(NCDWQ, 2007)

Species / Common Name	Exposure	Height / Spread	Comments
Achillea Yarrow	Sun	1.5 ft	Dry to moist soils; many cultivars available
Acorus calamus Sweet Flag	Sun	1 ft	Wet to moist soils; drought resistant
Amsonia ciliate Creeping Blue Star	Sun	6” 2 ft	Very drought and heat resistant; pale blue flowers

Species / Common Name	Exposure	Height / Spread	Comments
Amsonia hubrichtii Narrow Leaf Blue Star	Sun	36”	Very drought and heat resistant; Carolina blue flowers
Amsonia ludoviciana Louisiana Blue Star	Sun	24” 2 ft	Very drought and heat resistant; pale blue flowers
Asclepias tuberose Butterfly weed	Sun	20”	Very drought and 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	White flowers late summer
Carex spp. Sedge	Sun	6 – 12”	Tolerates a wide variety of conditions; many different cultivars
Coreopsis spp. Tickseed	Sun	1 – 3 ft	Tolerates a wide variety of conditions; many different cultivars
Echinacea purpurea Coneflower	Sun	1 – 2 ft	Drought tolerant; wide variety of cultivars
Gaillardia spp. Blanket Flower	Sun	1 – 2 ft	Drought tolerant; wide variety of species and hybrids
Gaura lindheimeri Gaura	Sun	2 – 4 ft	Thrives in hot, dry climate; many select cultivars
Geranium sanguineum Geranium	Sun	10 – 14”	Tolerates wide range of conditions including drought
Hemerocallis spp. Daylily	Sun	2 – 4 ft	Tolerates a wide variety of conditions; many different cultivars
Heuchera spp. Coral Bells	Sun	12 – 18”	Sun-tolerant; well-drained soils; many different cultivars
Muhlenbergia capillaris Purple Muhly Grass	Sun	1 – 3 ft	Tolerates a wide variety of soil conditions
Panicum virgatum Switchgrass	Sun	2 – 5 ft	Tolerates a wide variety of soil conditions; Can be invasive
Pennisetum spp. Fountain Grass	Sun	2 – 5 ft	Extremely tolerant of adverse conditions; many species and cultivars
Penstemon australis Beard’s Tongue	Sun	15”	Tolerant of heat and humidity; mauve flowers
Potentilla gracilis Cinquefoil	Sun	1 – 2 ft	Moist to dry soils; yellow flowers
Rudbeckia hirta Black-eyed Susan	Sun	2 – 4 ft	Moist to dry soils; other species and cultivars
Spartina patens Saltmeadow Cordgrass	Sun	1 – 3 ft	Tolerates wide range of conditions including drought
Solidago spp. Goldenrod	Sun	1 – 4 ft	Extremely tolerant of adverse conditions; many species and cultivars
Uniola paniculata Sea Oats	Sun	3 – 6 ft	Tolerates wide range of conditions including drought; salt resistant

Riparian Buffer Plants – Zone 1 (NCDWQ, 2007)

Species / Common Name	Exposure	Comments
Large to Medium Trees		

Species / Common Name	Exposure	Comments
Acer baratum Southern Sugar Maple	Shade / Part Shade	Moderate Moisture
Betula nigra River Birch	Sun / Part Shade	Moderate to High Moisture
Carya aquatic Water Hickory	Sun / Part Shade	High Moisture
Carya cordiformis Bitternut Hickory	Sun / Shade	Moderate to High Moisture
Carya glabra Pignut Hickory	Sun / Shade	Moderate Moisture
Carya ovate Shagbark Hickory	Sun / Shade	Moderate Moisture
Carya tomentosa Mockernut Hickory	Sun / Shade	Low to Moderate Moisture
Celtis laevigate Sugarberry, Hackberry	Sun / Part Shade	Moderate Moisture
Chamaecyparis thyoides Atlantic white cedar	Sun / Part Shade	Moderate to High Moisture
Diospyros virginiana Persimmon	Sun / Shade	Low to Moderate Moisture
Fagus grandifolia American Beech	Shade / Part Shade	Moderate Moisture
Fraxinus americana White Ash	Shade / Part Shade	Moderate Moisture
Fraxinus pennsylvanica Green Ash	Shade / Part Shade	Moderate to High Moisture
Fraxinus profunda Pumpkin Ash, Red Ash	Part Shade	High Moisture
Juglans nigra Black Walnut	Shade / Part Shade	Moderate Moisture
Liriodendron tulipifera Tulip Poplar, Yellow Poplar	Sun / Shade	Moderate Moisture
Nyssa aquatica Water Tupelo	Sun / Shade	High Moisture / Aquatic
Nyssa sylvatica Black Gum	Sun / Shade	Low to Moderate Moisture
Nyssa sylvatica var. biflora Swamp Black Gum	Sun / Shade	High Moisture
Oxydendrum arboreum Sourwood	Sun / Part Shade	Low to Moderate Moisture
Pinus echinata Shortleaf Pine	Sun / Part Shade	Low Moisture
Pinus palustris Longleaf Pine	Sun / Part Shade	Low to Moderate Moisture
Pinus serotina Pond Pine	Sun	Moderate to High Moisture
Plantanus occidentalis Sycamore	Sun / Part Shade	Moderate to High Moisture
Populus deltoides Eastern Cottonwood	Sun	High Moisture
Populus heterophylla Swamp Cottonwood	Sun / Part Shade	High Moisture
Prunus serotina Black Cherry	Sun / Shade	Low to Moderate Moisture
Quercus alba White Oak	Sun / Part Shade	Low to Moderate Moisture
Quercus falcata Southern Red Oak	Shade / Part Shade	Low to Moderate Moisture
Quercus pagoda Cherrybark Oak	Shade / Part Shade	Moderate to High Moisture

Species / Common Name	Exposure	Comments
Quercus laurifolia Laurel Oak	Sun / Shade	Moderate to High Moisture
Quercus lyrata Overcup Oak	Shade / Part Shade	High Moisture
Quercus margaretta Sand Post Oak	Sun / Part Shade	Low Moisture
Quercus marilandica Black Jack Oak	Shade / Part Shade	Low Moisture
Quercus michauxii Swamp Chestnut Oak	Sun / Shade	Moderate to High Moisture
Quercus nigra Water Oak	Sun / Shade	Low to Moderate Moisture
Quercus phellos Willow Oak	Sun / Shade	Moderate to High Moisture
Quercus shumardii Shumard Oak	Shade / Part Shade	Moderate to High Moisture
Quercus stellata Post Oak	Sun / Shade	Low Moisture
Quercus velutina Black Oak	Shade / Part Shade	Low Moisture
Quercus virginiana Live Oak	Sun / Part Shade	Low Moisture
Robinia pseudoacacia Black Locust	Sun / Part Shade	Moderate Moisture
Taxodium ascendens Pond Cypress	Sun / Part Shade	Aquatic
Taxodium distichum Bald Cypress	Sun / Part Shade	Aquatic
Ulmus alata Winged Elm	Sun / Shade	Low to Moderate Moisture
Ulmus americana American Elm	Shade / Part Shade	Moderate Moisture
Small Trees		
Amelanchier arborea Downy Serviceberry, Shadbush	Shade / Part Shade	Moderate Moisture
Amelanchier canadensis Canada Serviceberry	Sun	Moderate Moisture
Asimina triloba Pawpaw	Shade / Part Shade	Moderate Moisture
Carpinus caroliniana Ironwood, American Hornbeam	Shade / Part Shade	Moderate to High Moisture
Cercis canadensis Eastern Redbud	Shade / Part Shade	Moderate Moisture
Chionanthus virginicus White Fringetree, Old Man's Beard	Sun / Part Shade	Moderate Moisture
Cornus florida Flowering Dogwood	Shade / Part Shade	Low to Moderate Moisture
Crateagus crus-galli Cockspur Hawthorn	Sun / Part Shade	Low to Moderate Moisture
Crateagus flava October hawthorn	Sun / Part Shade	Moderate Moisture
Cyrilla racemiflora Titi	Sun / Part Shade	Moderate to High Moisture
Fraxinus caroliniana Water Ash	Shade / Part Shade	High Moisture
Gordonia lasianthus Loblolly Bay	Sun / Shade	Moderate to High Moisture
Ilex opaca American Holly	Shade / Part Shade	Low to High Moisture

Species / Common Name	Exposure	Comments
Juniperus virginiana Eastern Red Cedar	Sun / Part Shade	Low to Moderate Moisture
Magnolia virginiana Sweetbay Magnolia	Sun / Shade	Moderate to High Moisture
Morus rubra Red Mulberry	Shade / Part Shade	Moderate Moisture
Osmanthus americana Wild Olive, Devilwood	Shade / Part Shade	Moderate Moisture
Persea borbonia Red Bay	Sun / Shade	Low to Moderate Moisture
Persea palustris Swamp Bay	Sun / Shade	Moderate to High Moisture
Prunus caroliniana Carolina Laurel-cherry	Sun / Part Shade	Low to Moderate Moisture
Quercus incana Bluejack Oak	Sun / Part Shade	Low to Moderate Moisture
Quercus laevis Turkey Oak	Sun / Part Shade	Low to Moderate Moisture
Salix caroliniana Swamp Willow	Sun / Part Shade	Moderate to High Moisture
Salix nigra Black Willow	Sun / Part Shade	Moderate to High Moisture
Sassafras albidum Sassafras	Sun / Part Shade	Low to Moderate Moisture
Symplocos tinctoria Horse-sugar, Sweetleaf	Shade / Part Shade	Low to Moderate Moisture
Shrubs		
*Alnus serrulata** Common Alder	Sun / Shade	High Moisture / Aquatic
Aronia arbutifolia Red Chokeberry	Shade / Part Shade	Moderate to High Moisture
Baccharis halimifolia Silverling	Sun / Part Shade	Low to Moderate Moisture
Cailicarpa americana American Beautyberry	Sun / Shade	Moderate Moisture
Castanea pumila Allegheny Chinkapin	Sun / Shade	Low Moisture
Ceanothus americanus New Jersey Tea	Sun / Part Shade	Low Moisture
Cephalanthus occidentalis Buttonbush	Sun / Part Shade	Aquatic
Clethra alnifolia Sweet Pepperbush	Shade / Part Shade	Moderate to High Moisture
Cornus amomum Silky Dogwood	Shade / Part Shade	High Moisture / Aquatic
Cornus stricta Swamp Dogwood	Shade / Part Shade	High Moisture
Euonymus americanus Hearts-a-bustin', Strawberry Bush	Shade / Part Shade	Low to Moderate Moisture
Fothergilla gardenii Witch Alder	Part Shade	Moderate to High Moisture
Gaylussacia frondosa Dangleberry	Sun / Part Shade	Moderate to High Moisture
Hamamelis virginiana Witch Hazel	Shade / Part Shade	Low to Moderate Moisture
Ilex coriacea Gallberry	Shade / Part Shade	Moderate to High Moisture
Ilex deciduas Deciduous Holly, Possumhaw	Shade / Part Shade	Moderate Moisture

Species / Common Name	Exposure	Comments
Ilex gladbra Inkberry	Sun / Part Shade	Moderate to High Moisture
Ilex verticillata Winterberry	Sun / Shade	Moderate to High Moisture
Ilex vomitoria Yaupon Holly	Sun / Shade	Low Moisture
Itea virginica Virginia Willow	Shade / Part Shade	High Moisture
Kalmia angustifolia var. caroliniana Lamb-kill, Sheep-kill	Sun / Part Shade	Moderate to High Moisture
Leucothoe axillaris Coastal Dog-hobble	Shade / Part Shade	Moderate Moisture
Leucothoe racemosa Fetterbush	Shade / Part Shade	Moderate to High Moisture
Lyonia ligustrina Northern Maleberry	Part Shade	Moderate to High Moisture
Lyonia lucida Shining Fetterbush	Shade / Part Shade	Moderate Moisture
*Myrica cerifera** Southern Wax Myrtle	Sun / Shade	Low to High Moisture
*Myrica cerifera var. pumila** Dwarf Southern Wax Myrtle	Sun / Part Shade	Low to Moderate Moisture
Myrica heterophylla Bayberry, Evergreen Bayberry	Shade / Part Shade	Moderate Moisture
Rhododendron atlanticum Dwarf Azalea	Part Shade	Moderate Moisture
Rhododendron periclymenoides Pinxter Flower, Wild Azalea	Shade / Part Shade	Moderate Moisture
Rhododendron viscosum Swamp Azalea	Sun / Part Shade	Moderate to High Moisture
Rhus copallina Winged Sumac	Sun / Part Shade	Low to Moderate Moisture
Rosa carolina Pasture Rose, Carolina Rose	Sun / Part Shade	Low to Moderate Moisture
Rosa palustris Swamp Rose	Sun / Part Shade	Aquatic
Rubus cuneifolius Blackberry	Sun / Part Shade	Low to Moderate Moisture
Salix sericea Silky Willow	Sun / Part Shade	Aquatic
Sambucus canadensis Common Elderberry	Sun	Moderate to High Moisture
Spiraea tomentosa Meadowsweet	Sun / Part Shade	High Moisture
Stewartia malacondendron Silky Camellia	Shade / Part Shade	Moderate Moisture
Styrax grandifolia Biglead Snowbell	Shade / Part Shade	Moderate Moisture
Vaccinium arboreum Sparkleberry	Shade / Part Shade	Moderate to High Moisture
Vaccinium Corymbosum Highbush Blueberry	Sun / Shade	Low to High Moisture
Vaccinium crassifolium Creeping Blueberry	Part Shade	Moderate Moisture
Vaccinium elliottii Mayberry	Shade	Moderate Moisture
Vaccinium stamineum Deerberry, Gooseberry	Shade / Part Shade	Low Moisture
Viburnum dentatum Southern Arrowwood Viburnum	Sun / Shade	Moderate Moisture

Species / Common Name	Exposure	Comments
Viburnum nudum Possumhaw Viburnum	Shade / Part Shade	High Moisture
Viburnum prunifolium Blackhaw Viburnum	Shade / Part Shade	Moderate Moisture
Viburnum rufidulum Rusty Blackhaw	Shade / Part Shade	Low Moisture
Xanthorhiza simplicissima Yellowroot	Shade / Part Shade	Low to Moderate Moisture

*These are fixed nitrogen and should not be used adjacent to Nutrient Sensitive Waters.

Turf Grasses for Grassed Swales (NCDENR, 2009)

Species / Common Name	Season of growth	Height	Recommended Variety	Comments
Ammophila brevologulata American Beachgrass	Cool	20 – 60 in	Hatteras	Perennial grass; Good for dune building and excessively drained soils
Paspalum notatum Bahiagrass	Warm	15 – 30 in	Pensacola and Wilmington	Perennial grass; Fine turf, waterways and critical areas
Cynodon dactylon Bermudagrass	Warm	4 – 16 in	Coastal, Tifway, Tifway II, and Tifton-44	Perennial grass; Salt and drought tolerant; Common Bermudagrass is an aggressive invader
Eremochloa ophiuroides Centipedegrass	Warm	4 – 12 in		Perennial grass; Ideal for dry areas
Spartina cynosuroides Giant Cordgrass	Warm	Up to 9 feet		Perennial grass; Good for irregularly flooded estuarine areas of moderate salinity
Setaria italica German Millet	Warm	2 – 3 ft		Annual grass; Used for temporary seeding in spring and summer
Spartina patens Saltmeadow Cordgrass	Warm	1 – 4 ft		Perennial grass; Good for areas of poorly drained soils and high salinity
Spartina alterniflora Smooth Cordgrass	Warm	1 – 6 ft		Perennial grass; Good for marsh restoration
Festuca arundinacea Tall Fescue	Cool	3 – 4 ft	KY-31 for fine turf: Rebel, Falcon, and others	Perennial grass; Good for shade, traffic bearing, drought, and periodic flooding areas.
Secale cereale Rye	Cool	Up to 4 feet		Annual grass; Used for temporary seeding in fall and winter
Uniola paniculata Sea Oats	Warm	3 – 4 ft		Perennial grass; Good for dune building and excessively drained soils

Appendix E: Rain Garden Plantings

APPENDIX E. RAIN GARDEN PLANTINGS

Plants for Rain Gardens

Recommended for Southeastern North Carolina

Charlotte Glen, Urban Horticulture Agent,
North Carolina Cooperative Extension – New Hanover County Center

Soil conditions in rain gardens alternate between wet and dry, making them tough places for many plants to grow. The following plants are adapted to these conditions, though some plants will tolerate more moisture than others. Each plant is marked according to its flooding tolerance, with **3**'s being tolerant of longer flooding, **2**'s only tolerating brief flooding, and **1**'s indicate plants that tolerant extended drought once established.

All of these plants are native to the southeastern United States in wetland habitats and most are readily available at local nurseries. Wetland plants can generally grow well in moist or well-drained soils, whereas plants adapted to dry soils rarely survive in soggy conditions. How wet a rain garden stays will vary considerably depending on the site where it is installed. Rain gardens created on sandy soils will rarely hold water for more than a few hours. On these sites it is most important to choose plants for their drought tolerance. Rain gardens created on loamy or silty soils could pond water for 1-2 days (if your site ponds water for more than 3 days, you should consider creating a wetland). On these sites, choosing plants tolerant of extended flooding is critical to success.

Remember you are not limited to planting just within the excavated area! Extending plantings around this area will help the rain garden to blend in with the overall landscape. Any plants adapted to the site conditions can be used outside of the excavated area.

For more information on designing rain gardens and bioretention areas, refer to the following NCSU publication: Designing Rain Gardens (Bioretention Areas), available from your local NC Cooperative Extension office or online at: http://legacy.ncsu.edu/classes-a/bae/cont_ed/bioretention/lecture/design_rain.pdf

Large Trees (over 30` tall)

Deciduous

Red Maple (2) – *Acer rubrum*
River Birch (1,3) – *Betula nigra*
Green Ash (3) – *Fraxinux pennsylvanica*
Black Gum (2) – *Nyssa sylvatica*
Willow Oak (1,2) – *Quercus phellos*
Willows (3) – *Salix* species
Bald Cypress (1,3) – *Taxodium distichum*
Pond Cypress (1,3) - *Taxodium ascendens*
Nutall Oak (1,2) – *Quercus nuttalii*

Evergreen

Atlantic White Cedar (1,3) – *Chamaecyparis thyoides*
Southern Magnolia (1,2) – *Magnolia grandiflora*
Longleaf Pine (1,2) – *Pinus palustris*
Swamp Laurel Oak (3) – *Quercus laurifolia*

Small Trees (under 30' tall)

Deciduous

Red Buckeye (2) – *Aesculus pavia*
Ironwood (1,3) – *Carpinus caroliniana*
Redbud (1.2) – *Cercis canadensis*
Fringe Tree (2) – *Chionanthus virginicus*
Washington Hawthorn (3) – *Crataegus phaenopyrum*
Possumhaw (1,3) - *Ilex decidua*

Evergreen

Dahoon Holly (1,2) – *Ilex cassine*
American Holly (1,2) – *Ilex opaca*
Red Cedar (1,2) – *Juniperus virginiana*
Sweet Bay (3) – *Magnolia virginiana*
Devilwood (1,2) – *Osmanthus americanus*
Red Bay (1,2) – *Persea borbonia*

Evergreen shrubs that can be grown as small trees include Yaupon, Wax Myrtle, and Anise Shrub.

Shrubs

Deciduous

Chokeberry (1,3) – *Aronia arbutifolia*
Beautyberry (2) – *Callicarpa americana*
Sweet Shrub (2) – *Calycanthus floridus*
Buttonbush (3) – *Cephalanthus occidentalis*
Pepperbush (2) – *Clethra alnifolia*
Strawberry Bush (2) – *Euonymous americanus*
Fothergilla (2) – *Fothergilla gardenii*
Winterberry (3) – *Ilex verticillata*
Virginia Willow (3) – *Itea virginica*
Spicebush (2) – *Lindera benzion*
Possumhaw (3) – *Viburnum nudum*
Dusty Zenobia (2) – *Zenobia pulverulenta*

Shrubs continued. . . .

Evergreen

Florida Leucothoe (2) – *Agarista populifolia*
Inkberry (2) – *Ilex glabra*
Yaupon (1,2) – *Ilex vomitoria*
Florida Anise Shrub (3) – *Illicium floridanum*
Anise Shrub (1,2) – *Illicium parviflorum*
Coastal Leucothoe (2) *Leucothoe axillaris*
Wax Myrtle (1,2) *Myrica cerifera*
Dwarf Palmetto (3) – *Sabal minor*

Perennials

Blue Star (3) – *Amsonia tabernaemontana*
Lady Fern (2) – *Athyrium felix-femina*
Butterflyweed (1) – *Asclepias tuberosa*
Swamp Milkweed (3) – *Asclepias incarnata*
Climbing Aster (3) *Aster carolinianus*
False Indigo (1,2) – *Baptisia species*
Boltonia (3) – *Boltonia asteriodes*
Turtlehead (3) – *Chelone glabra*
Green and Gold (2) – *Chrysongonum virginianum*
Mouse Ear Coreopsis (2) *Coreopsis auriculata*
Tickseed (1,2) – *Coreopsis lanceolata*
Swamp Coreopsis (2) – *Coreopsis rosea*
Joe Pye Weed (3) *Eupatorium dubium*
Swamp Sunflower (3) – *Helianthus angustifolius*
Swamp Mallow (3) – *Hibiscus moscheutos*
Texas Star (3) – *Hibiscus coccineus*
Blue Flag Iris (3) – *Iris virginica*
Seashore Mallow (3) – *Kosteletskya virginica*
Gayfeather (2) – *Liatris spicata*
Cardinal Flower (3) – *Lobelia cardinalis*
Cinnamon Fern (3) – *Osmunda cinnamomea*
Royal Fern (3) – *Osmunda regalis*
Garden Phlox (2) – *Phlox paniculata*
Moss Pinks (1,2) *Phlox subulata*
Rudbeckia (1,2) – *Rudbeckia fulgida*
Green Headed Coneflower (3) – *Rudbeckia laciniata*
Goldenrod (3) *Solidago rugosa*
Stoke's Aster (2) – *Stokesia laevis*
Ironweed (3) – *Vernonia novaboracensis*
Verbena (1,2) – *Verbena canadensis*

Ornamental Grasses

River Oats (1,3) – *Chasmanthium latifolium*
Muhly Grass (1,2) – *Muhlenbergia capillaris*
Panic Grass (1,3) – *Panicum virgatum*
Indiangrass (1,2) – *Sorghastrum nutans*

Sedges and Rushes

Lurid Sedge (3) – *Carex lurida*
Fringed Sedge (3) – *Carex crinita*
Southern Waxy Sedge (3) – *Carex glaucescens*
White-topped Sedge (3) – *Rhynchospora latifolia*
Woolgrass (3) - *Scirpus cyperinus*

Non-native perennials and ornamental grasses suitable for rain gardens include: Liriope (1,2) (*Liriope muscarii* and *L. spicata*), Siberian Iris (2) (*Iris sibirica*), Daylily (1,2) (*Hemerocallis* hybrids), Rain Lilies (3) (*Zephyranthes* species), Crinum Lilies (3) (*Crinum* species), Japanese Painted Fern (2) (*Athyrium nipponicum*) and Maiden Grass (1,2) (*Miscanthus* cultivars).

1 Plants that, once established*, can withstand considerable drought (3-4 weeks without rainfall)

2 Plants that grow best in moist to average soils and will only tolerate short periods (1-2 days) of flooding.

3 Plants that will tolerate longer periods of flooding (3-5 days), but will also grow in moist to average soils.

*Establishment usually takes 1-2 years for trees and shrubs and 1 year for perennials.

For more detailed information and images of each plant, visit the Plant Fact Sheets available on NCSU's Urban Horticulture website: www.ncstate-plants.net

NC STATE UNIVERSITY
A&T STATE UNIVERSITY
COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

Appendix F: BMP Design Spreadsheets

APPENDIX F. BMP DESIGN SPREADSHEETS

Design Spreadsheets are required for any BMP shown on a stormwater management plan. BMP Design Spreadsheets are available online at:

Website: http://www.co.currituck.nc.us/unified-development-ordinance-new.cfm

Or by contacting:

Currituck County
Engineering Department
153 Courthouse Road, Suite 302
Currituck, NC 27929
Phone: 252.232.6035
Email: eric.weatherly@currituckcountync.gov or michelle.perry@currituckcountync.gov