Low Impact Development in Coastal South Carolina: A Planning and Design Guide

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1:

Introduction to Low Impact Development in Coastal South Carolina

1.1 Introduction to LID

What is LID?

Low Impact Development (LID) is an integrated, comprehensive approach to land development or redevelopment that works with nature to manage stormwater as close to its source as possible (US EPA, 2014). To achieve stormwater management, LID practices mimic the natural hydrologic regime through strategically integrated stormwater controls distributed throughout the landscape. The primary goal of LID is to recreate the predevelopment site hydrology through site design techniques that promote storage, infiltration, evaporation, and treatment of runoff. LID employs principles to create functional and appealing site drainage, such as preserving and recreating natural landscape features, that minimizes imperviousness and treats stormwater as a resource rather than a waste product (US EPA, 2014). These methods help reduce runoff and contribute to groundwater recharge and increase base flow.

The South Carolina Department of Health and Environmental Control's Bureau of Water (SCDHEC-BOW) states that "LID is designed to mimic, as close as possible, the naturally occurring hydrologic conditions of a site thereby reducing the adverse impacts created by increased runoff that is typically associated with traditional development laden with impervious areas. The fundamental principle behind ***Low Impact Development*** is to both reduce the volume of runoff and to divert stormwater flows away from a common collection point. There are various practices that can be used in conjunction with one another to accomplish this goal. Some examples of these practices include open space preservation, infiltration basins/trenches, rain gardens, rain barrels/cisterns, eliminating curbs/gutters, bioretention, vegetated swales and converting turf areas to trees and shrubs."

A related, but not interchangeable, term is ***green infrastructure (GI)***. The United States Environmental Protection Agency (US EPA) notes that green infrastructure is a relatively new and flexible term that has been used differently in different contexts. It defines the term green infrastructure as, "systems or practices that use or mimic natural processes to infiltrate, evapotranspirate, or reuse stormwater or runoff on the site where it is generated (US EPA, 2014). Green infrastructure can be used at a wide range of landscape scales in place of, or in addition to, more traditional stormwater control elements to support the principles of LID." In this manual, green infrastructure will refer to individual stormwater control elements that can be used to achieve low impact development goals.

More information can be found online at:

- http://water.epa.gov/polwaste/green/
- http://www.scdhec.gov/HomeAndEnvironment/Water/Stormwater/LowImpact-Development/

The Need for Coastal South Carolina LID Guidance

Since 2009, the Coastal Training Programs (CTPs) at the Ashepoo-Combahee-Edisto (ACE) Basin and North Inlet-Winyah Bay (NIWB) National Estuarine Research Reserves (NERRs) collaborated with partners at South Carolina Sea Grant and Clemson University along with engineers, researchers, developers, planners, and other coastal decision makers (CDMs) to identify barriers to LID implementation and the information that will help overcome these barriers. This feedback was generated using informal discussion with stakeholders and a formal needs assessment developed by the CTPs. Through workshops, facilitated meetings, and surveys, stakeholders identified the need for an LID guidance document that is specific to coastal South Carolina. Overwhelmingly, they requested an LID manual that addresses the needs of planners, landscape architects, developers, engineers, regulators, and home owners associations (Pollack and Szivak, 2007; Walker, 2011, Wood, 2012; Sutely, 2011). Furthermore, local research supports the need to use a comprehensive stormwater management approach that focuses on LID (Mallin, 2000; Mallin et al., 2001; Lewitus et al., 2003; Lewitus and Holland 2003; Brock, 2006; Drescher et al., 2007; Lewitus et al., 2008; Delorenzo and Fulton, 2009; Vandiver and Hernandez, 2009).

The need for a coastal LID manual for South Carolina is highlighted by a geographic gap in available resources. Neighboring states – Georgia and North Carolina – have coastal LID manuals that provide direction for improved stormwater management (CWP, 2009; NCCE, 2009). These two manuals, along with national guidance for coastal LID practices provided by research from UNH (2007), CWP (2010), and Schueler (2009), have helped develop the scope of information provided in this document, *Low Impact Development in Coastal South Carolina: A Planning and Design Guide*. In summary, the Coastal South Carolina LID manual need, research, policy, content, and application have been vetted over the years; research supports using LID to improve water quality and the need for a manual; and southeast and national LID resources and experts were used to support the manual.

This manual outlines the rationale for LID as a management tool to protect and restore coastal resources. LID is used collectively with planning, engineering, landscaping, education, and outreach strategies. The objectives of LID are accomplished using three basic principles (Prince Georges County, 1999):

1. Minimize stormwater impacts to the extent practicable. Highlighted techniques include reducing impervious cover, conserving natural resources and ecosystems, maintaining natural drainage courses, and minimizing clearing and grading.

2. Provide runoff storage measures placed throughout a site's landscape by using a variety of detention, retention, and infiltration practices.
3. Maintain predevelopment time of concentration by strategically routing flows to maintain travel time and control the discharge.

Low impact development can be part of the stormwater education and outreach programs in coastal South Carolina. While this manual focuses on better stormwater management for development, implementation of practices on public or private property, such as homeowner rain gardens or demonstration sites, is essential for a watershed-based approach to stormwater management and should also be considered. The public's involvement in LID implementation and maintenance is essential to support coastal water quality goals, and can be strengthened by education and outreach.

Manual Purpose and Application

The purpose of this manual is to remove barriers to Low Impact Development implementation by providing engineering tools, planning guidance, and case study examples that are relevant to the South Carolina coastal zone. The overall goal of this project is to provide local decision makers with the knowledge and resources to apply LID practices on the community, neighborhood, and site scale. The first chapter introduces LID terminology and coastal features pertinent to LID design. Chapter 2 provides a background on pertinent national, state, and local regulations and guidance related to stormwater and LID, in addition to strategies for how local governments can incorporate LID into ordinances. Chapter 3 focuses on the "big picture" of low impact development as a holistic process encompassing conservation, neighborhood site design, and landscaping practices. Chapter 4 provides specifications for stormwater best management practices that can be incorporated as part of a low impact design for a site. Chapter 5 includes additional LID case studies from the coastal region. Additional resources are provided in the Appendices, including strategies for climate change adaptations to LID stormwater designs, checklists for construction sequences and post-construction maintenance, and spreadsheet tools for runoff reduction crediting.

The information and references provided in this manual are the best available at the time of publication. Please be mindful that ordinances, regulations, and online references are subject to change after publication of this document.

The case studies included in this manual serve as general examples of successful low impact development projects in the South Carolina Coastal Plain. However, it is important to keep in mind that these examples were designed and built before this manual was written, so they may not align completely with the recommendations provided in the technical specifications or better site design guidance.

1.2 Benefits of LID

Overview

The benefits of LID can reach a wide spectrum of stakeholders, as summarized below (NCCE, 2009; US EPA, 2013):

- ✧ 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 native 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 Buyers and Residents
  - Preserves and protects amenities that can translate into more salable homes 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
  - Improves air quality through the addition of vegetation
  - Reduces urban heat stress
  - Lessens sewer overflows

- ✧ Social
  - Enhances aesthetics
  - Stimulates economic development
  - Creates green jobs
  - Encourages more urban greenways
  - Educates the public on their role in stormwater management
  - Reduces flooding

Environmental Benefits of LID

Coastal Plain communities face many environmental challenges when it comes to managing stormwater runoff. The unique resources affected include shellfish, nearshore fisheries, spawning grounds, and tourism revenue. The natural resources in South Carolina contribute roughly $30 billion and 230,000 jobs to the state's economy according to a 2009 study conducted by the University of South Carolina's Moore School of Business Division of Research.

Table 1.2-1. Overall Economic Impact of Natural Resources in South Carolina (USC, 2009)

2008	Direct	Indirect	Induced	Total
Labor Income	$4,700,082,548	$1,620,135,670	$1,460,706,160	$7,780,924,382
Employment	$150,531	$40,677	$44,885	$236,110
Total Impact	$18,472,375,564	$5,806,770,994	$4,803,232,321	$29,082,378,867

Protecting coastal waters from pollution provides cleaner water that supports recreation, tourism, and economics. Clean water allows residents and tourists to fish, swim, and safely enjoy coastal South Carolina. The Watershed Planning Needs Survey of Coastal Plain Communities conducted by Law et al. (2008) captured a snapshot of what coastal communities are doing to protect or restore local watersheds. The survey included 12 responses from South Carolina (16% of the total), and 45 responses from other southeast states including North Carolina, Georgia, and Florida (comprising 62% of total). According to the results of the survey, the top three stormwater pollutants identified as priorities in coastal watersheds are: sediment (65%), nitrogen (60%), and trash/debris (46%). Also, bacteria (43%) and phosphorus (38%) were noted as pollutants of concern, but by fewer communities. Of the communities surveyed, 47% reported problems with harmful algal blooms due to excessive nutrient pollution and tidal flushing of stormwater ponds.

In South Carolina, sediment and bacterial water pollution of tidal creeks has been correlated to urbanization of coastal uplands at large spatial scales (Van Dolah et al., 2008). In addition, the sediment contaminant classes considered in the study (PAHs, PCBs, pesticides, metals) increased significantly in concentration with increasing urban land cover. Findings indicate that upland urbanization can result in an increased risk of biological degradation, as well as reduction in safety of human contact with South Carolina's coastal resources (Holland & Sanger, 2008; Van Dolah et al., 2008).

Although a relatively recent addition to the coastal landscape, stormwater detention ponds are the most common Best Management Practices (BMPs) applied in South Carolina urban environments to treat stormwater runoff, with over 14,000 ponds exceeding 21,000 acres in total area identified along the SC coastal zone (Drescher et al., 2011; Smith, 2012). According to Vandiver and Hernandez (2009), this trend will continue in the future due to the ability of ponds to meet the regulatory requirements, enable development of low elevation flat property, and provide "fill" for low-lying areas within the development. However, recent studies have examined how they may affect nutrient and organic matter dynamics and the implications for managing and maintaining water quality in the coastal zone. Smith (2012) studied residential ponds located in Georgetown and Horry Counties and found that stormwater ponds have become the loci of nutrient-driven eutrophication; excess organic production from these ponds is exported to receiving coastal waters and promotes declines in dissolved oxygen conditions.

LID practices are promoted as a reasonable alternative to ponds and researchers (Vandiver and Hernandez, 2009 and Drescher et al., 2007) note that although the use of LID practices in the South Carolina coastal region is currently limited, with increased awareness, guidance, and training, increased LID implementation can be expected. Various studies have shown the benefits of different types of LID practices. Some, like green roofs, have well documented reduction in runoff. Bioretention, on the other hand, has documented reduction in both nutrients and metals (Ahiablame et al., 2012). In comparing traditional development methods to LID techniques, low impact developments retain significantly more stormwater on-site and have fewer pollutants exported from the site (Bedan and Clausen 2009). Traditional development practices like curb and gutter frequently produce stormwater discharge from the site, where low impact development techniques can produce little to no discharge for small rainfall events (Selbig and Bannerman, 2008). Compared to traditional development, LID reduces runoff depths and peak discharges, and produces a longer lag time to peak discharge. LID practices better mimic pre-development hydrology to help reduce stormwater pollution (Hood et al., 2007). Table 1.2-2 compares the annual estimates for pollutant removal for various LID and traditional stormwater management practices.

In addition, LID provides a host of "ecosystem services" that are typically not included in cost-benefit analysis. An *ecosystem* is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit, and *ecosystem services* are defined as benefits people obtain from ecosystems (Millennium Ecosystem Assessment, 2005). The human population is dependent on the essential flow of ecosystem services, including:

- ✧ Provisioning services:
  - Food
  - Water
  - Timber
  - Fiber
- ✧ Regulating services:
  - Climate
  - Floods
  - Disease
  - Wastes
  - Water quality

- ✧ Cultural services:
  - Recreational
  - Aesthetic
  - Spiritual
- ✧ Supporting services:
  - Soil formation
  - Photosynthesis
  - Nutrient cycling

Table 1.2-2. Stormwater Management Practice Performance

BMP	Pollutant Removal[1] (%)				
	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Metals	Pathogens
Bioretention	80-90	55-90	65-90	N/A	55-90
Permeable Pavement	80	60-80	60-80	N/A	45-75
Infiltration	80-95	65-95	55-90	N/A	65-95
Green Roofs	80	45-60	45-60	N/A	45-60
Rain Water Harvesting	Varies				
Disconnection	80	25-50	25-50	25-50	N/A
Open Channels	40	40-45[2]	20-35[3]	30	N/A[4]
Stormwater Filtering Systems	90	65	45	50	80
Dry Detention[5]	N/A	N/A	N/A	N/A	N/A
Wet Ponds	85	75	40	40	70
Wetlands	80	50	30	50	70

[1] *expected annual pollutant load removal*
[2] *range, with best removal for the wet or dry swales*
[3] *range, with best removal for grassed channels*
[4] *no data available, but expected poor pollutant removal*
[5] *available data suggest minimal pollutant removal*

Low impact development contributes to ecosystem services by reducing flooding, improving water quality, reducing ambient air temperatures, and improving air quality (ECONorthwest, 2007). LID also promotes infiltration with the benefit of sustaining stream baseflow; additionally, LID reduces runoff volumes and pollutant loadings to downstream waters and reduces incidences of combined sewer overflows. Current development practices can short circuit this process, and thus produce faster and larger volumes of stormwater runoff, which in turn leads to flashy stream flow conditions (Callahan et. al. 2011). Other LID benefits that are typically not considered include restoration of habitats and vegetation that are important to wildlife.

Economic Benefits of LID

Cost information is a key factor for LID implementation. The designer, engineer, developer, and construction teams need to know how much LID will cost because the price can drive decisions to use LID or to use conventional structural stormwater practices, such as stormwater ponds.

While expense is a very important consideration, the data is variable, is influenced by many factors, and changes over time and space. Additionally, there are few LID cost reports. Cost and value exist in many categories such as construction, maintenance, retrofits, do-nothing scenarios, property development opportunity lost, property value increase, and several others. Keeping this complexity in mind, the economics of LID are outlined here. This information should be used to inform stormwater professionals and builders as a general rule of thumb. The body of LID economic information will grow and will be refined as more LID practices are implemented on South Carolina's coast.

There are three major methods used to assess the economics of LID:

- Cost comparison – Includes initial construction costs only.
- Life-cycle cost analysis – Includes planning, design, installation, operation and maintenance, and decommissioning.
- Benefit-cost analysis – Includes a range of costs and benefits, encompassing long-term life cycle costs that contain the parameters in the life-cycle cost analysis method. The benefit-cost analysis incorporates the economic benefits of LID (Beggs and Perrin, 2008).

The US EPA found that developers, property owners, and communities save money and protect and restore water quality when well-chosen LID practices are implemented (US EPA, 2007). The following resources include case studies, research, recommendations, and site specific LID costs:

- "Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs" (US EPA, 2013)
- "Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices" (US EPA, 2007)
- "The Economics of Low-Impact Development: A Literature Review (ECONorthwest, 2007);
- "Low Impact Development Versus Conventional Development" (Shaver, 2009)
- "Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions" - See Chapter 3 from the Economics of LID (UNH, 2011)
- Coastal LID Case Studies include site specific information and cost information when available. These are online at http://www.cwp.org/case-studies-from-the-coastal-plain

For example, in Boulder Hills, NH, a design firm developing a 24-unit condominium community compared two development options – conventional and LID – for the project, and the LID development option saved money in most line items (Table 1.2-3). The final cost savings for this LID development was $49,000 and this represented a 6% savings in total cost of stormwater infrastructure for the zero stormwater discharge site. [See UNH (2011) for the entire case study].

Table 1.2-3. Comparison of unit costs for materials for Boulder Hills LID Subdivision (UNH, 2011). Note the road for this development was porous asphalt.

Item	Conventional	LID	Difference
Site Preparation	$23,200.00	$18,000.00	-$5,200.00
Temp. Erosion Control	$5,800.00	$3,800.00	-$2,000.00
Drainage	$92,400.00	$20,100.00	-$72,300.00
Roadway	$82,000.00	$128,000.00	$46,000.00
Driveways	$19,700.00	$30,100.00	$10,400.00
Curbing	$6,500.00	$0.00	-$6,500.00
Perm. Erosion Control	$70,000.00	$50,600.00	-$19,400.00
Additional Items	$489,700.00	$489,700.00	$0.00
Buildings	$3,600,000.00	$3,600,000.00	$0.00
Project Total	$4,389,300.00	$4,340,300.00	-$49,000.00

Regional LID cost examples include the following:

- There are several LID economic and general presentations on SCDHEC’s website at http://www.scdhec.gov/HomeAndEnvironment/Water/Stormwater/LowImpact-Development/Presentations/
- Nicole Saladin (2008), from the North Inlet-Winyah Bay NERR’s Coastal Training Program, gave a presentation “Stormwater & South Carolina: A Case for Low Impact Development” and cited the following reduced infrastructure costs:
  - $150 per linear foot road reduced
  - $25 to $50 per linear foot road narrowed
  - $10 per linear foot sidewalk eliminated
  - $1,100 construction cost per parking space eliminated
- The Berkeley-Charleston-Dorchester Council of Governments (BCDCOG) compared LID versus conventional stormwater designs in coastal Cane Bay Plantation in South Carolina. The study reported that LID design costs for single family residential homes were about $2,000 to $11,000 per acre more expensive than conventional design. However, the LID design costs for multi-family residential development were similar to conventional design (Fisher et al., 2007).
- Charlotte, NC’s Charlotte-Mecklenburg Storm Water Services used LID/GI to prevent more waterway degradation and protect the drinking water reservoir. This was a 526 square mile area with 890,000 people. The county conducted a cost-effectiveness analysis to determine the cost of sediment per pound removed using LID/GI. They found LID practices such as stream restoration cost far less than traditional, structural stormwater practices. Stream restoration cost $0.60 to $1.00 per pound of sediment removed compared to $45 to $69 per pound of sediment removed by a wet detention pond. See Exhibit A.8.1: Cost-effectiveness of program components in the McDowell Creek watershed for the suite of LID/GI cost comparisons (in $ per lb. of sediment saved) (US EPA, 2013).

- The Poplar Street Apartments in Aberdeen, North Carolina used bioretention, grass channels, swales, and stormwater basins in an apartment complex during the development. Using LID not only reduced stormwater runoff volume at the site but also saved an estimated $175,000 (US EPA, 2007).
- A case study from Brunswick, NC provided by NC State University demonstrated $45,900 cost savings using LID versus a stormwater pond (Hunt et al., 2007).
- Homeowner's willingness to pay more for LID value was $5,000 per home in the Shepards Vineyard housing development in Apex, NC (Beggs and Perrin, 2008).
- LID implementation in Lockwood Folly, NC, reduced the size of the required stormwater pond that allowed the addition of another home and increased the developer revenue by $90,000 (Beggs and Perrin, 2008).

EPA (2007) reviewed 17 case studies of developments that included LID practices and concluded that applying LID techniques could reduce project costs and improve environmental performance. In most cases, LID practices were shown to be both fiscally and environmentally beneficial to communities. In a few cases, LID project costs were higher than those for conventional stormwater management practices. However, in the vast majority of cases, significant savings were realized due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Implementation of individual LID devices at limited locations within a mostly conventional development plan does not reduce expense. Rather, the EPA study found that cost savings were realized through a holistic LID site design and planning process. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with a few exceptions in which LID project costs were higher than conventional stormwater management costs.

In 2011, the US EPA funded a project by Greenville County, SC, in conjunction with Upstate Forever and economists from Clemson University, to present information about the average construction costs of traditional and LID BMPs. The costs were determined through a combination of data from installed BMPs in Greenville County, component costs from regional sources, and national average costs for components (where regional data was unavailable). The construction requirements and specifications for both the traditional and LID BMPs were determined using the guidance in the Greenville County *Storm Water Management Design Manual* (2013), the North Carolina Department of Environment and Natural Resources *Stormwater Best Management Practices Manual* (2007), and the Maryland Department of the Environment *Stormwater Design Manual* (2000). The costs are summarized in Table 1.2-4.

Table 1.2-4. BMP Cost Summary*		
BMP Practice	**Standard Size**	**Standardized Cost**
Dry Pond	¼ Acre	$12,629
Wet Pond	¼ Acre	$16,271
Bioretention Cell	500 ft^2	$3,122
Bioswale	100 ft^2	$280
Buffer Strip	100 ft^2	$7
Constructed Wetland	1,000 ft^2	$8,016
Green Roof	100 ft^2	$1,732
Infiltration Trench	100 ft^2	$555
Porous Pavement	100 ft^2	$810
Interlocking Pervious Pavers	1,000 ft^2	$19,000
Rain Barrel (average)	55 gallons	$193
Sand Filter	100 ft^2	$3,490
**information excerpted from Greenville County Stormwater BMP Report*		

Another study at NC State University (Wossink and Hunt, 2003), found that the size of the watershed, the soil type, the imperviousness of the watershed, the pollutant of main concern, and the amount and price of land for the structure all influence the selection of a BMP. Table 1.2-5 summarizes the cost information from this study and shows that a bioretention area would be the least expensive BMP if it could be installed in sandy soil. Both the cost per treated acre and cost per percent of total nitrogen (TN) removed are less for this practice than if a wet pond or wetland were used. However, if clay soils were prevalent, a stormwater wetland would be the least expensive solution (based on annualized cost per acre of watershed). The study also found that maintenance for stormwater wetlands and bioretention units was less expensive than for wet ponds.

Table 1.2-5. Cost comparison of four BMPs for a 10-acre watershed (CN 80)*				
Practice	**Wet Pond**	**Wetland**	**Bioretention in clay soils**	**Bioretention in sandy soils**
Construction cost	$64,357	$11,740	$124,445	$7,843
Annual maintenance cost	$4,411	$752	$583	$583
Opportunity cost of land ($217,800/acre)	$43,560	$65,340	$65,340	$65,340
Present value of total cost	$146,474	$83,486	$194,751	$78,137
Annualized cost per acre watershed	$1,721	$981	$2,288	$918
Annualized cost per percent pollutant removed				
TSS	$26	$15	N/A	N/A
TN	$61	$45	$51	$20
**information excerpted from Wossink and Hunt (2003)*				

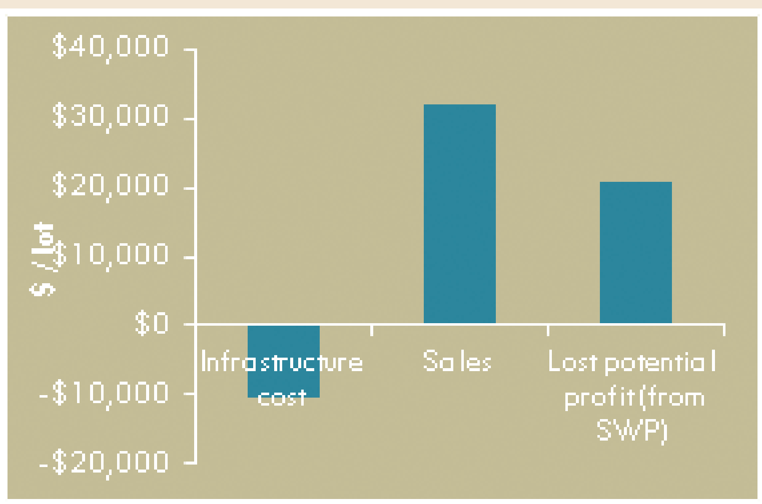
LID Cost Case Study:
Oak Terrace Preserve Cost Comparison

Oak Terrace Preserve (OTP) is a 55-acre sustainable redevelopment project located in Park Circle, North Charleston. In the construction of OTP, developers and engineers created a system of LID practices, including bioretention swales, pervious pavers, pocket parks, and a forebay, to restore pre-development hydrology and promote infiltration and retention of stormwater on site. In addition, the developers and engineers of OTP partnered with local scientists to evaluate the effectiveness of these systems, including a cost comparison of OTP's LID development to traditional stormwater pond developments.

Development costs and profits were compared between OTP (an LID development) and 3 traditional stormwater pond developments (Tupper, 2012). Both infrastructure costs (e.g., stormwater, engineering, roads, water and sewer lines) and indicators of potential profits (e.g., home sales price, sales minus infrastructure costs, lost potential profit from stormwater pond area) were used in the comparison of LID to stormwater pond developments. All values were standardized by either square footage of the homes and/or the number of lots within the development. Due to data limitations, the evaluations were not able to address potential variations in the cost of the land and/or home construction.

The study indicated that the infrastructure costs of the LID development, OTP, were over $10,000 more per lot when compared to traditional development costs. In addition to using LID stormwater practices, OTP incurred costs associated with the re-development of the land. Furthermore, the development of OTP was provided through a public-private partnership with the City of North Charleston; therefore, the costs of the OTP development also included the costs to upgrade the roads and stormwater infrastructure of an adjacent public school on the property. Subsequently, the costs directly associated with the LID stormwater practices versus the costs of re-development were difficult to determine.

A comparison of indicators of potential profit, however, suggest that the LID development, OTP, may be more profitable than traditional stormwater pond developments. Sales price minus the costs of infrastructure suggested that the LID development lots were potentially $32,000 more profitable than the lots in the traditional developments. In addition, the use of stormwater ponds in the traditional developments required additional area which resulted in an average loss of 19 lots per development. This lost land area equated to lost potential profit (or cost) of nearly $21,000 per lot when compared to the LID development. In summary, although the LID development had greater initial upfront costs, the higher sales price and the prevention of 'lost profit' from stormwater pond area, made the lots in the LID development over $42,000 more profitable than those in the traditional developments. In fact, an OTP homeowner, when discussing the appeal of the green features of Oak Terrace (e.g., LID), said "…that is why I spent a lot more money on this house than I expected or wanted to" (Vandiver and Hernandez, 2009). These study results support findings that the consumer plays an important role in providing financial incentives for LID in the immediate future (Vandiver, 2012).



Comparison of the cost and potential profit of Oak Terrace Preserve (an LID development) to 3 traditional stormwater pond developments. Based on these findings, infrastructure cost of LID was greater but potential profit was also greater; making the lots in Oak Terrace Preserve on average $42,000 more profitable than the lots in the traditional developments.

Case Study provided by Lisa Vandiver, NOAA Restoration Institute

Economic Benefits Case Study: Rivertowne Harris Teeter, Mt. Pleasant, SC

Fox Capital Partners, in collaboration with Harris Teeter, made the initial decision to build a new shopping center with Leadership in Energy and Environmental Design (LEED) certification. Part of that certification process involved stormwater management. Tom Fox, partner-in-charge at Fox Capital Partners, said that the decision to use low impact development techniques on this property was "a no-brainer – it's smart and saved us money on piping and grading."

Drainage presented a challenge on this site, due to flat topography and aligning with a fixed discharge point to an existing pond in the adjacent Planters Point development. The flat topography in the Coastal Plain, combined with the high groundwater table, limits the amount of vertical distance that pipes can be sloped and still provide adequate drainage. Stormwater pipes are designed to flow using gravity where possible. If the designers and developer had decided to use the typical "curb and gutters" that consist of parking lot inlet and pipes, the invert elevations for each subsequent pipe needs to be lower. Eventually, this would create a vertical space limitation. Furthermore, if traditional stormwater inlets and pipe networks were used to drain the site, the pipes would need to be a modified elliptical shape. Elliptical pipes carry more capacity than the usual round pipes, but also are significantly more expensive.

A creative LID solution used a central bioretention swale in the main parking lot, which drains through a series of bioretention areas, a stormwater pond, and finally a vortex separator (KRISTAR). The engineers designed the parking lot to drain using sheet flow into the central swale, eliminating the need for piping. Minimizing the amount of piping saved the client money and gave the engineers more flexibility to design the pipe network that connected the Rivertowne shopping center BMPs to the neighboring stormwater pond in Planters Pointe. Additionally, the parking lot utilizes pervious pavers in overflow parking and along the perimeter of the parking lot. Fox emphasized that even in a wet year, such as 2013, the system functioned properly and was successful. He plans to use LID stormwater practices again on future projects. Part of the success was credited to regular maintenance that included sweeping the parking lot three to four times weekly; and picking up trash two to three times weekly per the typical Harris Teeter business trash maintenance.

The bioretention cell (left) and swale (right) in grocery store parking lot intercept and treat stormwater runoff.

Other Nutrient Reduction Practices

Although they are not typical LID practices, two of the top-ranked BMPs (CWP, 2013) for nutrient reduction are pet waste programs and illicit discharge elimination. The CWP study calculated preliminary cost and performance estimates for these practices. Based on limited data, these practices have a high potential for a role in local urban stormwater strategies.

Behavioral programs, such as pet waste programs, are part of a watershed-based approach to better stormwater management. Although these programs and practices are not detailed in this manual, they can be effective pollution reduction and prevention measures. For more information, please see Clemson University's information for pet owners: http://www.clemson.edu/public/carolinaclear/what_you_can_do/pet_owner.html

Illicit discharge detection and elimination (IDDE) is one of the six minimum measures required for the Municipal Separate Storm Sewer (MS4) permit. Often the MS4 permit requirement for IDDE can be enhanced and improved at the local level. Recent work by Lilly et al. (2012) identified dry weather sewer leaks (i.e., IDDE) in Baltimore City, MD that if fixed would result in 217 lb/yr TN and 1,897 lb/yr TP pollutant load reduction in the coastal watershed. For more information, please see the Clemson University fact sheet about Illicit Discharge: http://www.clemson.edu/public/carolinaclear/water_quality/idde/

In summary, the LID economics in coastal SC will be refined as more LID projects are implemented and these findings are reported to the developers, engineers, architects, landscapers, researchers, and other groups that are interested in this topic. National and regional case studies demonstrate that the developments that use LID realize cost savings and increased value of the goods and services to the community (i.e., non-market valuation). However, not all developments will realize cost savings using LID. Careful consideration of the market, value of LID to the developer and subsequent market, and the appropriate method to assess the economics of LID should be conducted on a case-by-case basis to ensure LID meets the goal.

Evaluating Cost Effectiveness of LID

CWP (2013) evaluated a suite of urban stormwater practices to determine which procedures provide the greatest nutrient and sediment reductions for the lowest investment to help localities more cost-effectively achieve the pollutant load reductions to accomplish water quality goals. Cost-effectiveness is defined in this paper as an annual unit cost per unit of pollutant removed, and is calculated based on annualized life cycle costs divided by the pounds of pollutants removed per year. This metric is intended to be used by Virginia localities to compare the relative costs and pollutant removal effectiveness of 33 strategies to treat urban stormwater runoff (CWP, 2013)

The goal of the cost analysis was to calculate 20-year life cycle costs associated with BMP implementation, including design, construction, land values, financing, and operation and maintenance. A review of the published literature on BMP costs (e.g., King and Hagan, 2011) was conducted to compile the existing data. The study's key conclusions include:

- In general, cost effectiveness decreases when practices are installed as retrofits (compared to new), have underdrains (compared to none), or have poorly drained soils (compared to A/B soils).
- Permeable pavement, dry detention ponds and hydrodynamic structures consistently rank in the least cost-effec-

tive category, due to their low water quality benefit (dry detention ponds and hydrodynamic structures) or high cost (permeable pavement).

See Table 2 on page 13 in CWP (2013) for a full list of the urban stormwater BMPs and associated cost effectiveness ($/lb) for total nitrogen (TN), total phosphorus (TP), and total suspended solid removal (TSS). This is available online at http://www.jrava.org/what-we-do/cost-effective-stormwater-management

While the initial costs of adopting and designing newer technologies may be higher, there is ample evidence which demonstrates the use of LID development strategies can be cost effective in the long term. Land conservation, another key aspect of LID, can also have economic benefits. Conservation subdivisions have been shown to provide higher profits to developers because lots in conservation subdivisions carry a price premium, are less expensive to build, and sell more quickly than lots in conventional subdivisions (Rayman, 2006). A recently conducted graduate study evaluated the costs and potential profits at Oak Terrace Preserve and three comparable traditional developments in Charleston and Beaufort Counties. The findings from this study show that even though the costs of conservation and LID stormwater practices at Oak Terrace Preserve were slightly more expensive, their potential profit margins were significantly higher than all three of the traditional developments (Vandiver, 2012). Furthermore, the homes in Oak Terrace Preserve have maintained sales in a less than favorable real estate market (Tupper, 2012). Sometimes, as in the preceding case studies, LID techniques are the most cost-effective solution to drainage problems.

1.3 Coastal Features and LID

Most stormwater management practices were originally developed in the Piedmont physiographic region and have not been adapted for the distinct conditions in the Coastal Plain. Consequently, much of the available stormwater design guidance is strongly oriented toward the rolling terrain of the Piedmont with its defined headwater streams, minimal shallow groundwater flow, low wetland density, and well-drained soils. By contrast, both conventional and LID stormwater design in the Coastal Plain is strongly influenced by unique physical constraints, pollutants of concern, and resource sensitivity of the coastal waters. The significance of these constraints is described in this section. Further, stormwater management regulations and policies are often founded on Piedmont-based estimates of the volume and rate of stormwater runoff and efficiencies of control technologies that often do not apply to the coastal zone. This can result in inadequate stormwater control practices. Recent studies by Epps et al. (2013a and 2013b) suggest guidance for land-use and water resource management decisions, specifically with respect to stormwater management requirements for residential and commercial development, that consider not only surface water, but also groundwater. Low gradient topography and shallow water table characteristics of lower Coastal Plain watersheds allow for unique hydrologic conditions that must be assessed and managed differently than higher gradient watersheds.

LID can be applied effectively in the Coastal Plain with careful planning and design. Improper application of LID design, with little consideration for physical constraints, will reduce LID performance and efficiency. Physical factors in the Coastal Plain include flat terrain, high water table, altered drainage areas, extensive groundwater interactions, poorly-drained soils, and extensive

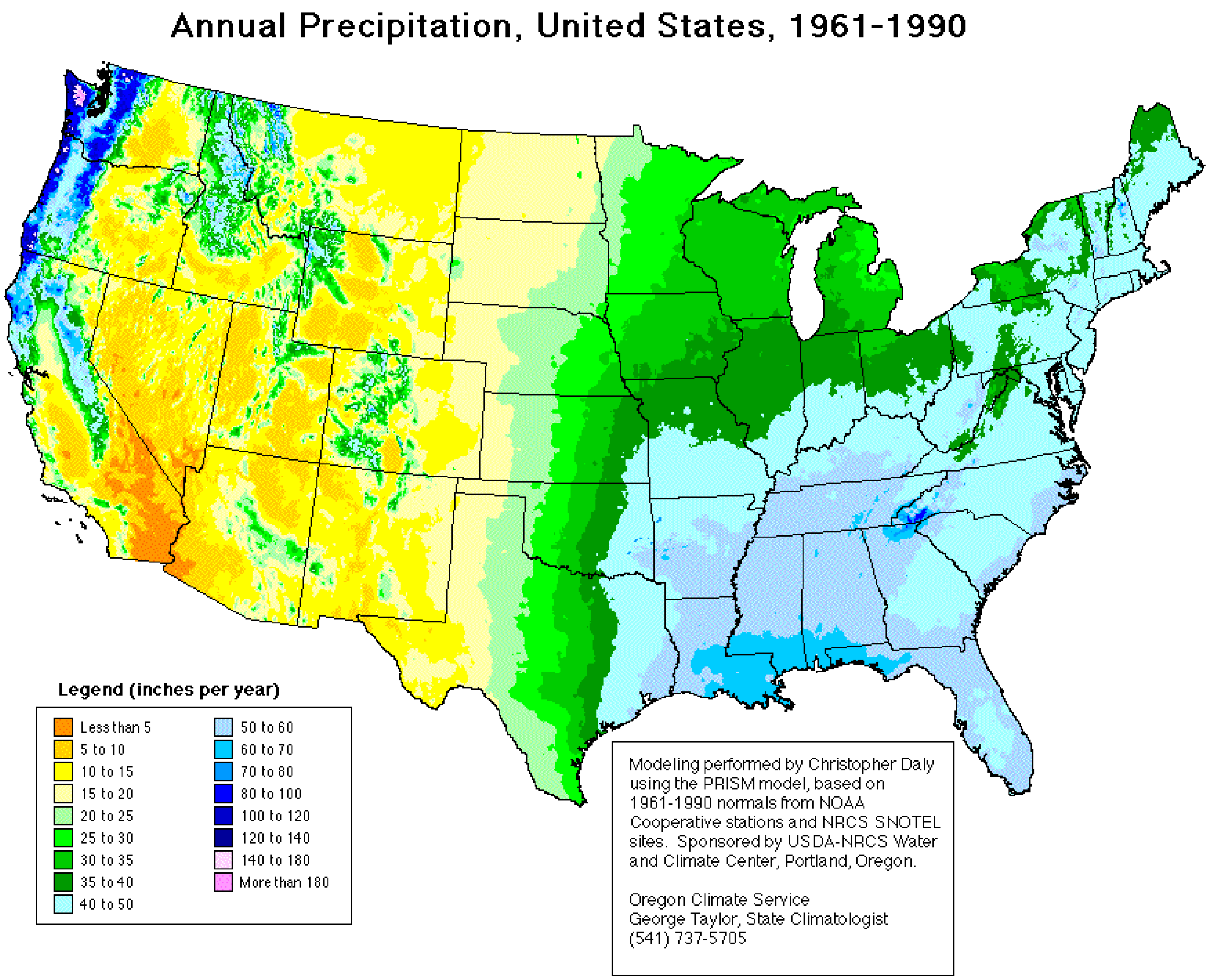


Figure 1.3-1. Annual Precipitation Map, United States, 1961-1990
(Source: http://hercules.gcsu.edu/~sdatta/home/teaching/hydro/slides/US_precip_map.gif*)*

wetland systems. The most notable feature of the Coastal Plain is its flat terrain, which in combination with its generally high and often tidally-influenced groundwater table, allows greater opportunity for non-point source (NPS) pollution to enter a coastal system when compared to inland systems. South Carolina's Coastal Plain has the highest average annual rainfall in the United States (see Figure 1.3-1), with the exception of the Pacific Northwest. The Coastal Plain in South Carolina averages 50 to 52 inches per year (SC State Climatology Office, accessed 2013). In addition, the region is subject to intense tropical storms and hurricanes, and generally has higher rainfall intensities than further inland. Recent studies related to the impacts of hurricanes on coastal forested wetlands have shown that Hurricane Hugo reduced carbon dioxide sequestration and significantly transformed the hydrology through two paired coastal watersheds (Dai et al., 2013; Jayakaran et al., 2013). The combination of high rainfall inputs, flat terrain, dense areas of impervious surfaces, and poorly drained soils (in some areas) can result in more frequent and even catastrophic flooding.

Flat Terrain

The most notable feature of the Coastal Plain is its uniformly flat terrain, which creates several watershed planning challenges. The low relief makes it possible to develop land without regard to topography. From a hydrologic standpoint, flat terrain increases surface water/groundwater interactions and reduces head available to treat the stormwater or move floodwaters through the watershed during the intense tropical storms and hurricanes. Work by Amatya et al. (2013) demonstrated a need for application of LIDAR-based digital elevation models together with field verification to improve the basis for assessments of hydrology, watershed drainage characteristics, and modeling in the flat lower Coastal Plain watersheds.

High Water Table

In much of the Coastal Plain, the water table exists within a few feet of the surface. This strong interaction increases the movement of pollutants through shallow groundwater and diminishes the feasibility or performance of many stormwater practices, including both LID and conventional BMPs. Additionally, the water table shows a strong relationship to tidal influences (Czwartacki, 2013), making it difficult to determine and design around the seasonal high water table. When the seasonally high water table is not accurately accounted for in design, it is not uncommon for LID and conventional best management practices to suffer performance deficiencies; for example, practices that were designed to infiltrate stormwater (e.g., bioretention) perform more similarly to stormwater wetlands.

Altered Drainage

The Coastal Plain stream network has been severely altered by 300 years of ditching, channelization, agricultural drainage, and mosquito control. The headwater stream network in many Coastal Plain watersheds no longer exists as a natural system because most first and second order streams have been replaced by ditches, canals, and road drainage networks (Van Dolah et al., 2008; O'Driscoll et al., 2010; Amatya et al., 2013; Jayakaran et al., 2013). These changes to the natural drainage patterns in the Coastal Plain are not reflected in existing LID models and regulations that may exist in other geographic regions, such as the Piedmont.

Poorly Drained Soils

Figure 1.3-2 depicts how portions of the Coastal Plain have soils that are poorly drained and frequently exhibit low permeability (Skaggs et al., 2011). As a result, the Coastal Plain watersheds contain extensive wetland complexes and have a greater density of wetlands than any other physiographic region in the country (see Figure 1.3-3). The South Atlantic Coastal Plain and Gulf Coastal Plain (excluding Texas) contained 29% of the total wetland acreage in the conterminous U.S. in 2004, while in many coastal watersheds, wetland cover alone often exceeds 25% of the total land cover, compared to the national average of 7% (Dahl, 2006). The prevalence of poorly-drained soils and wetlands may present certain challenges for implementing LID site design and practices which rely on infiltration.

Very Well-Drained Soils

In other parts of the Coastal Plain, particularly near the coast line, sandy soils with high permeability can have infiltration rates that exceed four inches per hour (Epps et al., 2013b). There is the possibility that runoff can move too rapidly through the soil profile without receiving full treatment.

Figure 1.3-2: Hydrologic Soil Group distribution, area, infiltration rates, and runoff potential for Coastal South Carolina

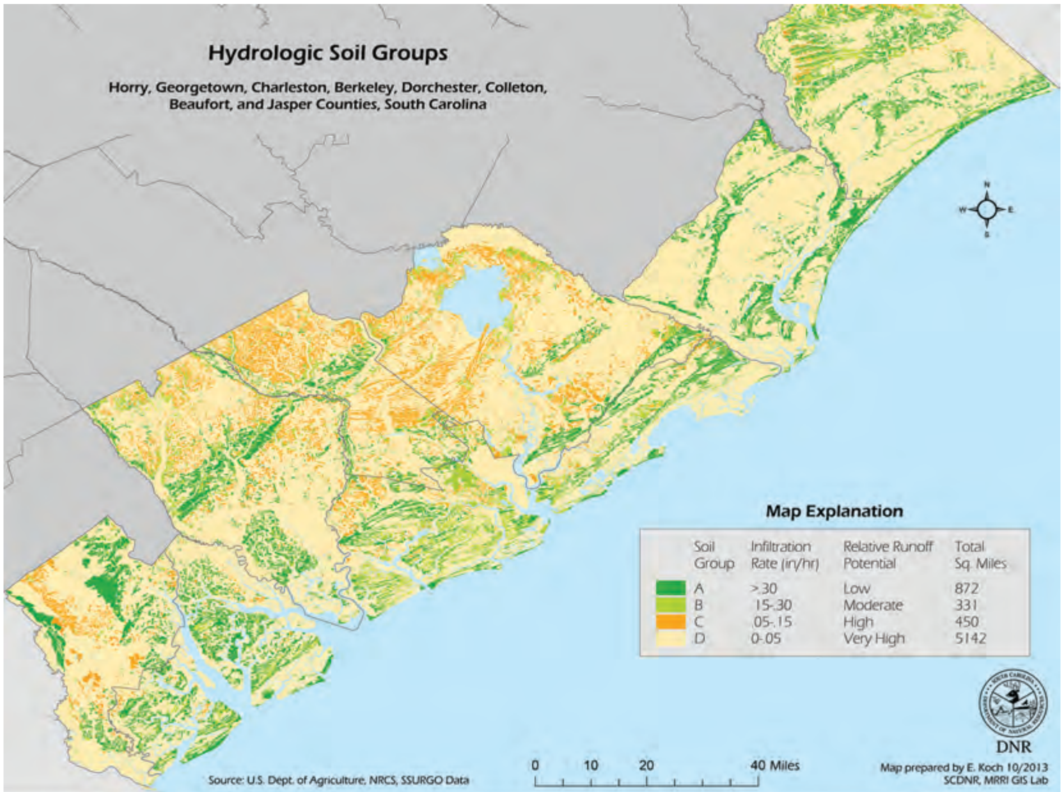
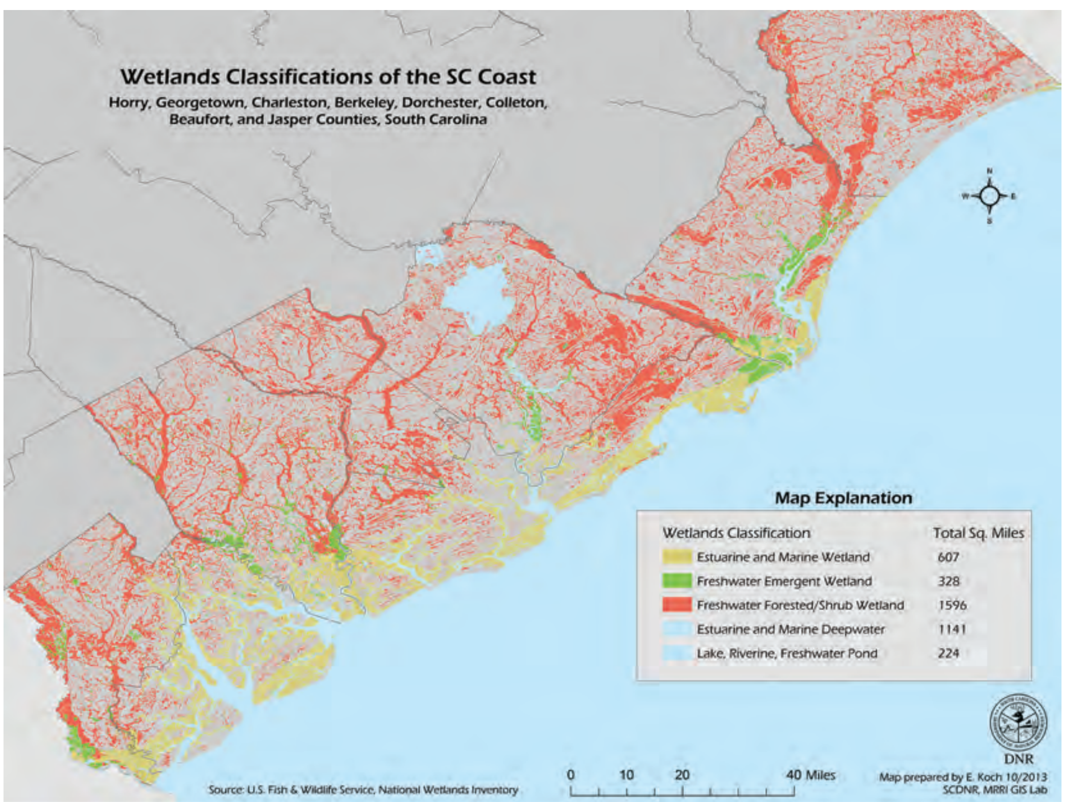


Figure 1.3-3: Extent and size of different types of wetlands along the South Carolina coast.



The risk is that these contaminated waters may be transported into nearby creeks and can pollute these waterbodies. At the same time, development in the Coastal Plain relies extensively on septic systems or land application to treat and dispose of domestic wastewater. Designers need to carefully consider how they design and locate stormwater so they do not impact adjacent septic systems.

Conversion of Croplands with Land Application

Land application of animal manure and domestic wastewater on croplands is a common practice across the Coastal Plain. When the land use of these areas changes (from agriculture to residential or commercial development), there may be concern that infiltration through these nutrient-enriched soils may actually increase nutrient export from the site. However, there are several regulations and permitting programs in place in South Carolina to prevent or limit these risks, including:

- SC R.61-43 *Standards for the Permitting of Agricultural Animal Facilities*;
- SC R.61-9.503 (Domestic Sewage Sludge) and SC R.61-9.504 (Industrial Sludge); and
- SC R.72-106 Erosion and Sediment Reduction and Stormwater Management.

Pollutants of Concern

Historically, watershed managers in the Piedmont have focused on phosphorus control, which is frequently a limiting nutrient for fresh waters but seldom for brackish coastal waters; however, given the naturally high phosphorus content in coastal soils and ubiquitous nature of freshwater stormwater ponds in the Coastal Plain, phosphorus is still considered a pollutant of concern. Phosphorus is a major indicator of algae in stormwater ponds and the presence of harmful algal blooms (HABs) in ponds has both human and ecosystem health impacts. The Ashley Cooper Stormwater Education Consortium identified phosphorus as a pollutant of concern to be addressed as part of a priority education strategy for both residential and commercial audiences in 2011 (Joyner and Counts, 2012).

Additional key pollutants of concern in Coastal Plain watersheds are sediment, nitrogen, bacteria, and metals. These pollutants have the ability to degrade the quality of unique Coastal Plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, aquatic vegetation, migratory bird habitat, and tidal wetlands. The design and engineering of stormwater practices may need to be modified to achieve greater reductions in nitrogen, bacteria, and metals to improve coastal water quality.

Unique Development Patterns

The development patterns of Coastal Plain watersheds are also unique, with development concentrated around waterfronts, water features, and golf courses rather than an urban core. The demand for vacation rentals, second homes, and retirement properties also contributes to sprawling development.

The Highway as the Receiving System

The highway system represents an opportunity to treat stormwater runoff from these impervious surfaces in the Coastal Plain. The stormwater conveyance system for much of the Coastal Plain is frequently tied to the highway ditch system, which is often the low point in the Coastal Plain drainage network. New upland developments usually need approval from highway authorities to discharge to their drainage system, which may already be at or over capacity with respect to handling additional stormwater runoff from larger events. The prominence of the highway drainage network in the Coastal Plain has several implications. For example, new and redevelopment projects should coordinate with the highway authorities to ensure that the site's stormwater runoff does not exceed the existing drainage system capacity. Also, when new development or redevelopment triggers stormwater treatment requirements, planners and designers should consider capturing and treating additional stormwater runoff from the highway with these new practices.

Hurricanes and Flooding

Communities face challenges when it comes to handling flooding events in the Coastal Plain (Amatya et al., 1998). First, their location on the coast subjects them to rainfall intensities that are 10 to 20% greater for the same design storm event compared to further inland. Second, the flat terrain lacks enough head to move water quickly out of the conveyance system (which may be further complicated by backwater effects due to tidal surges).

Future Conditions

Gradually, factors such as sea level rise and climate change will reshape the coastal features described in this section and potentially affect the ways stormwater will be generated and treated in the coastal region in the future, as described in Table 1.3-1. Climate change is anticipated to impact every aspect of the water cycle, and many of the underlying assumptions that stormwater managers use for runoff and storm system design might become outdated if these predictions become a reality. Changes in water elevation, storm intensity, and storm duration can impact the stormwater management program's LID placement, design hallmarks (such as the design storm, water quality volume, and stormwater conveyance), and other considerations needed to account for changing climate and associated impacts. Strategies to plan for these changes are provided in *Appendix G: Adapting Stormwater Management for Climate Change*.

Table 1.3-1. Climate Change Effects on Stormwater Design and Management

Climate Change Factors	Several Possible Effects on Stormwater Design & Management
♦ Increase temperature of atmosphere ♦ Increase temperature of runoff ♦ Change in rainfall depth, intensity, and frequency ♦ Change in drought frequency and severity ♦ Decrease soil moisture (antecedent soil moisture between storms) ♦ Increase variability in winds and drying conditions ♦ Sea level rise ♦ In northern climates, more winter precipitation and creating rain on snow events ♦ Erratic climate patterns resulting in flash flooding, tornadoes, snow/ice precipitation, and severe drought	♦ Exceedances of storm system capacity and safety ♦ Increase in peak flows ♦ Number of properties and structures subject to flooding ♦ Decrease in annual infiltration volume due to higher evaporation and proportionally more runoff from more intense storms ♦ Decrease in stream baseflow ♦ Wider range of storm events to manage in order to achieve same level of pollutant load reduction ♦ Increased demand for water supply storage and reliability ♦ Broader application and geographic coverage of drought-tolerant plants for vegetated stormwater practices ♦ Impacts to sensitive waters, wetlands, and cold water fisheries ♦ Need for more land-use planning, such as floodplain management, “freeboard” requirements for storm systems, etc.

Sources: Booth (2006), Hirschman et al. (2011), MWH (2009), Oberts (2007), and Shaw et al. (2005).

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Chapter 2:
Strategies for Local Governments

2.1 Getting Ready for Low Impact Development

Stormwater regulation and policy are the basis for coastal water protection. Stormwater management program regulation and planning strategies are major tenets that support successful LID implementation. This chapter outlines the current federal, state, and local stormwater regulations and presents planning and regulatory strategies needed for coastal SC LID implementation. At the local level, planning improvements, better development patterns, effective LID implementation, and accurate LID reporting support state policy goals.

2.2 Applicable Regulations and Requirements for LID

Federal and State Stormwater Regulations

The US Environmental Protection Agency (EPA)'s National Pollutant Discharge Elimination System (NPDES) permitting program is the result of laws enacted by Congress that are then developed and implemented under the law's regulations. The Clean Water Act establishes environmental programs, including the NPDES program, to protect the Nation's waters and directs EPA to develop, implement, and enforce regulations consistent with this law. The NPDES stormwater program regulates stormwater discharges from municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. The goal is to reduce pollution that enters the receiving waterways from point and non-point sources of pollution.

South Carolina is authorized to implement the NPDES Stormwater Program and administer its own stormwater permitting program. The SC Department of Health and Environmental Control (SCDHEC) manages the state stormwater program. It is important to note that South Carolina's Construction General Permit operates on a five-year cycle and this manual references the permit requirements that were reissued on January 1, 2013 (SCDHEC, 2013). More information is available in Appendix H and online at: http://www.scdhec.gov/HomeAndEnvironment/Water/Stormwater/

To protect water quality during construction and development, the state (or MS4 local government under Phase II NPDES requirements) generally requires a permit for projects within ½ mile of a receiving waterbody or those that disturb greater than one acre. Typically, projects within ½ mile of a receiving waterbody should capture and store onsite the first ½ inch of runoff from the site or the first one inch of runoff from the built upon area, whichever is greater. For certain land disturbance activities, state regulations require that peak post-development discharge rates from the site must be at or below pre-development rates for the 2- and 10-year, 24- hour storm events (approximately 4.5 and 6-inch rain events, respectively, but this varies regionally). During construction, a site-level stormwater management plan should demonstrate an 80% sediment trapping efficiency for the 10-year, 24-hour storm event if the project disturbs greater than 10 acres and drains to a common point (SCDHEC, 2002). The latest SCDHEC BOW stormwater BMP manual includes the best available information as of 2005 (SCDHEC, 2005; also check website for updates). Table 2.2-1 summarizes the applicable state regulatory requirements for pre- and post- land development in South Carolina.

Table 2.2-1. South Carolina Regulatory Requirements for Land Development

Extent of Land Disturbance (acres)	Applicable Regulatory Requirements
Automatic Permit Coverage, 0.1-0.5 acres (non-LCP*, within ½ mile of CRW**)	R.72-307H, SCR100000, Coastal Zone Stormwater Management Program Refinements
Less than one acre (non-LCP*, not within ½ mile of CRW**)	R.72-307H, permit coverage not required
One to two acres of disturbance (non-LCP*, not within ½ mile of CRW**)	R.72-307H, SCR100000
0.6-2.0 acres of disturbance (within ½ mile of CRW**)	R.72-307H, SCR100000, Coastal Zone Stormwater Management Program Refinements
More than two and less than five acres of disturbance	R.72-307I, SCR100000 When located within ½ mile of CRW** Coastal Zone Stormwater Management Program Refinements also apply
Five acres or more of disturbance	R.72-307, SCR100000 When located within ½ mile of CRW** Coastal Zone Stormwater Management Program Refinements also apply

** LCP – Larger Common Plan of Development*
*** CRW – Coastal Receiving Water*

From these regulations, the State has established minimum stormwater quality and quantity requirements for the local governments located within the eight coastal counties. Note, when infiltration is used to satisfy Coastal Zone Stormwater Management Program Refinements, design criteria established in R.720307.C(11) applies. Table 2.2-2 summarizes the requirements based on BMP and location. For the purposes of this Manual, most LID BMPs are considered as "infiltration" practices, thus providing an incentive for designers (only requiring the storage of one inch of runoff over the impervious area).

Table 2.2-2. SC Coastal Zone Management Program Stormwater Quality BMP Requirements			
BMP Facility Type	**Water Quality Volume Requirements***		
	5 acres or more of land disturbance	**Within 0.5 Miles of a Receiving Waterbody in the Coastal Zone****	**Within 1,000 Feet of Shellfish Beds**
Water quality facility with permanent pool of water (detention)	Storage volume above permanent pool of 0.5 inches of runoff from site based upon drainage area, required to release over a 24-hour period	Storage volume over permanent pool of 0.5 inches of runoff from entire site based upon drainage area or 1.0 inches of runoff from built upon portion of the site, whichever is greater	Not applicable
Water quality facility without permanent pool of water (detention)	Storage volume of 1.0 inches of runoff from site based upon drainage area, required to release over a 24-hour period	Storage volume of 0.5 inches of runoff from entire site based upon drainage area or 1.0 inches of runoff from built upon portion of the site, whichever is greater	Not applicable
Infiltration practices (including LID practices)	Storage volume of 1.0 inches of runoff from impervious surfaces, required to drain completely in 72 hours	Storage volume of 0.5 inches of runoff from entire site based upon drainage area or 1.0 inches of runoff from built upon portion of site, whichever is greater, required to drain completely in 72 hours	Storage volume of 1.5 inches of runoff from built upon portion of site, required to drain completely in 72 hours

** Projects which result in land disturbance less than 1 acre, but are part of a larger common plan of development (LCP) may also be subject to coverage under the NPDES Construction General Permit.*
*** Section III.C.3.XIIIA of the Coastal Zone Management Program Refinements also applies to projects less than 5 acres.*

This *Planning and Design Guide* allows innovative stormwater management that may be used to comply with state regulations and also uses the best available science and practical knowledge to implement LID. See the LID BMP Specifications in Chapter 4 for detailed information. In addition to the state-level stormwater requirements, many local governments have established additional or unique conditions in their local regulations.

Local Regulations and Ordinances

The Coastal Zone of South Carolina is currently organized into 8 counties (Beaufort, Berkeley, Charleston, Colleton, Dorchester, Georgetown, Horry and Jasper) and 51 municipalities. Within this group of individual counties and municipalities, there are two urbanized areas designated as Regulated Small Municipal Separate Storm Sewer Systems (MS4s): Charleston and Myrtle Beach (See Table 2.2-3). The designations are based on urbanized areas determined by the latest census, and it is anticipated that the Beaufort area will be designated as another MS4 in the near future.

Table 2.2-3. Regulated Small MS4s in the Coastal Zone

Urbanized Area	Municipality
Charleston – North Charleston (including Ladson, a CDP*)	Berkeley County Charleston Charleston County Dorchester County Folly Beach Goose Creek Hanahan Isle of Palms Lincolnville Mount Pleasant North Charleston Sullivan's Island Summerville
Myrtle Beach (including Forestbrook, Garden City, Little River, Murrells Inlet, Red Hill & Socastee CDPs)	Atlantic Beach Briarcliffe Acres Conway Georgetown County Horry County Myrtle Beach North Myrtle Beach Surfside Beach

** The US Census Bureau recognizes CDPs (Census-Designated Places) as the statistical counterpart to incorporated places such as cities, town, and villages. CDPs are areas that lack a formal government but are otherwise similar to incorporated places.*

The SC Department of Health and Environmental Control (SCDHEC) defines MS4s as "a system of conveyances that include, but are not limited to, catch basins, curbs, gutters, ditches, man-made channels, pipes, tunnels and/or storm drains that discharge into Waters of the State." These MS4s are required to obtain National Pollutant Discharge Elimination System (NPDES) Phase II permits in order to discharge stormwater into Waters of the State; the current NPDES General Permit for Storm Water Discharges from Regulated Small MS4s became effective January 1, 2014, and includes the urbanized areas listed in Table 2.2-3 (SCDHEC, 2013). Communities subject to the SMS4 Permit are required to develop new development and redevelopment standards for sites greater than 1 acre that "demonstrate the runoff reduction and pollutant removal necessary to approximate pre-development conditions to the Maximum Extent Practicable (MEP) and to protect water quality." Projects in an MS4 must design, construct, and maintain stormwater management practices that control rainfall on-site, and prevent the off-site discharge of 1" of runoff from the site's disturbed area.

In addition to the Regulated Small MS4s listed below, SCDOT has been designated as a large MS4 and has been issued its own NPDES General Permit for Stormwater Discharges.

Table 2.2-4 summarizes examples (as of September 2013) of coastal counties and municipalities which have requirements that are stricter than this state requirement for stormwater volume control. Information for the design manuals and local ordinances for these local governments is included in the References section at the end of this chapter.

Table 2.2-4. Unique Stormwater Volume Control Requirements

Municipality	Stormwater Volume Control
Beaufort County (*Including the City of Beaufort and Town of Port Royal*)	All stormwater from the 95^{th} percentile storm (1.94 inches) must be retained on site
Town of Bluffton	In areas of Hydrologic Soil Groups A&B, the development shall control and infiltrate the first one inch of stormwater runoff from the entire development or maintain the pre-development hydrology for the Water Quality Design Storm Event (95th percentile storm = 1.95 inches), whichever is greater
Horry County	Three Options: 1. Redevelopment projects must achieve a 10% reduction in runoff volume (from pre-redevelopment levels) 2. Reduce impervious cover on the site by at least 20% 3. Reduce the post-development peak discharge rates by 20% for the 10- and 25-year, 24-hour storms
Jasper County	The 85^{th} percentile storm (1.2 inches) must be retained on site
City of Myrtle Beach	As a minimum, the first inch of rainfall from each storm over the developed portion of the site shall be retained on site
City of North Myrtle Beach	Minimum storage volume shall be provided to retain on-site the first inch of runoff generated by any storm event over the developed or redeveloped portion of the site
Town of Hilton Head	The first flush runoff (0.5 to 1.0 inch) from paved streets and parking areas shall be filtered through vegetation, grass, gravel, sand or other filter mediums to remove oil, grease, gasoline, particulates and organic matter is required before the runoff leaves the site or enters any natural or manmade waterbody.
Town of Surfside Beach	As a minimum, adequate storage volume shall be provided to retain on-site the first inch of runoff generated by any storm event over the developed or redeveloped portion of the site.

The State requires the following minimum standards for water quantity management: post development peak discharge rates shall not exceed pre-development discharge rates for the 2- and 10-year frequency, 24-hour duration storm event. Implementing agencies may utilize a less frequent storm event (e.g. 25-year, 24-hour) to address existing or future stormwater quantity or quality problems. Hydraulic modeling is required for the 100-year, 24-hour storm to demonstrate that the discharge from a stormwater control structure will not cause downstream damage. Table 2.2-5 summarizes some of the local stormwater design criteria that exceed this minimum state standard, as of August 2013.

Table 2.2-5. Unique Stormwater Peak Discharge Control Requirements

Municipality	Peak Stormwater Control
Horry County	Projects greater than 5 acres or redevelopment projects must reduce post-development peak discharge by 20% for the 10-year and 25-year storms
City of Hardeeville	The post-development peak discharge shall not exceed the pre-development peak for developments from 0-299 acres (25-year storm); over 300 acres (50-year storm)
Beaufort County Berkeley County Charleston County Dorchester County Georgetown County Horry County Jasper County City of Beaufort City of Charleston City of Conway City of Georgetown City of Goose Creek City of Hanahan City of Myrtle Beach City of North Charleston City of North Myrtle Beach Town of Bluffton Town of Hilton Head Town of Port Royal Town of Summerville Town of Surfside Beach	Post-development peak discharge shall not exceed pre-development rate for 2, 10, and 25-year storm

2.3 Regional Planning Strategies

The past few decades of stormwater management have focused on using control and treatment strategies that are largely hard-infrastructure-engineered, end-of-pipe, and site-focused practices primarily concerned with peak flow rate and suspended solids concentration control. The collective experience of communities across the United States demonstrates that looking only at site-level practices will not repair damaged waterbodies and will likely put more streams on impaired lists over time (US EPA, 2013). Factors at the site, district/neighborhood, and regional scales can drive the creation of unnecessary impervious cover and other land cover conditions that produce excessive runoff. These factors are embedded in a community's land use codes and policies. Therefore, a comprehensive approach to stormwater management should include an examination of a locality's land development regulations, policies, and ordinances to align better with water quality goals.

Some common land use regulations, codes, and policies that can drive impervious cover include the following from Hirschman and Kosco (2008):

- Zoning ordinances
- Subdivision codes
- Street standards or road design guidelines
- Parking requirements
- Minimum setback requirements;
- Site coverage limits
- Height limitations

The conservation principles and neighborhood site design guidance for LID outlined in Chapter 3 are supported by codes and ordinance updates. The first step in this process is to review local codes and ordinances objectively. During this review, opportunities for updates and/or improvements are recorded. The codes and ordinance review team can share findings, make recommendations for improvements, and implement changes as appropriate. Each local jurisdiction is unique with respect to the specific policies, window of opportunity, time frame, and additional variables. Code and ordinance reviews, updates, and improvements are a key strategy to plan for future conditions that best meet the community needs.

Planning for Future Growth Conditions and Patterns

Proper planning can lead to more sustainable future growth patterns. For example, updating current codes and ordinances can support future development patterns that use the better site design development principles, protect trees, promote stormwater LID, reduce the impervious cover and urban footprint, and additional site assessment principles for LID discussed in this manual.

Land use development can occur in conjunction with better stormwater management and additional watershed goals. Future land development should be done under updated codes, ordinances, and policies that promote LID as much as possible. Planning for future growth conditions and patterns means promoting LID, reducing impervious cover, and preserving natural areas. Preserving natural areas can be accomplished by promoting growth in more suitable areas. For example, by directing and concentrating new development in areas targeted for growth, communities can reduce or remove development pressure on undeveloped parcels and protect sensitive natural lands and recharge areas. Coastal land use planners must weigh these options carefully before determining where to direct future growth. Table 2.3-1 provides tools to direct development in Coastal Plain watersheds. Because communities vary in their current state of buildout, proximity to the coast, legal authority to regulate land use and resources, and regulatory climate, a tailored approach using multiple tools, such as those suggested here, may be necessary to support planning for future growth conditions and patterns.

To protect important natural resources from development impacts while still accommodating growth, coastal communities should encourage redevelopment and infill over conversion of natural lands to development. Concentrating development in certain areas while limiting it in other areas reduces sprawl and may be the only way to maintain the pristine condition of undeveloped subwatersheds, since even low levels of impervious cover are associated with waterway degrada-

Table 2.3-1. Tools to Direct Development in Coastal Plain Watersheds

Tool	Description	Where Applicable	Advantages	Disadvantages
Real estate disclosures	Require notification of new or potential property owners about erosion or flood risk	Hazard areas	Ensures property owners are aware of risks on their own property	Does not prevent development or shoreline hardening; requires good data on location of hazard areas
Insurance incentives/ disincentives	Deny property or flood insurance for structures in high-risk erosion or flood areas; place a mandatory surcharge on flood insurance; provide insurance that is not subsidized to protect coastal flooding impacts (see Briggert-Waters Act); grant lower insurance premiums for implementing better site design (BSD)	Hazard areas	More accurately reflects costs of developing in hazard areas; promotes good development practice	May not be enough to discourage development or encourage use of BSD; requires good data on location of hazard areas; requires mechanism to enforce use of BSD
Limit/direct expansion of infrastructure	Fund/approve infrastructure expansions in planned growth areas only	Rural areas	Reduces sprawl and associated infrastructure costs	May encourage use of septic systems in areas with unsuitable soils
Urban growth boundaries	Defined area for urban and rural growth to occur	Anywhere, but probably most useful in rapidly urbanizing watersheds	Applies restrictive boundary on growth	Difficult to coordinate between multiple jurisdictions
Transfer or purchase of development rights	Exchanging or purchasing development rights from land with valuable natural resources to land in a more appropriate growth area.	Watersheds that have both pristine and urban/ urban areas	If done correctly, results in placement of development in areas with existing infrastructure and provides protection of rural lands	Challenging to establish the trading market
Watershed based zoning	Revise zoning to achieve targeted impervious cover goals on a watershed basis	Watersheds with very little development	Directly ties land use to stream conditions	Disconnection between watershed boundaries and jurisdictional boundaries

Table 2.3-1. Tools to Direct Development in Coastal Plain Watersheds				
Tool	**Description**	**Where Applicable**	**Advantages**	**Disadvantages**
Natural resource protection regulations (e.g. floodplains, wetlands)	Require protection of specific resources	Rural, suburban and urban areas	Directly protects resources from being developed	Requires legal authority to adopt local ordinances
Overlay zoning	Superimposes additional standards onto existing zoning provisions to protect natural resources or hazard areas	Rural, suburban and urban areas	Does not require changes to existing zoning	Requires legal authority to establish overlay districts
Managed retreat policy	Allows the shoreline to migrate inland unobstructed by demolishing or relocating structures inland	Shoreline areas	Less expensive than structural shoreline stabilization; maintains natural shoreline processes	May be politically unpopular and lower shoreline property values
Buy-back or relocation assistance program	Provides grants, loans or purchase of property located in retreat area or setback area so that property owners can relocate inland	Shoreline areas	Can avoid 'takings' claims; less expensive than structural shoreline stabilization; maintains natural shoreline processes	Can be costly and politically unpopular; may be difficult to identify land to relocate to.
Incentives for redevelopment infill, and brownfield/greyfield development	Provide financial incentives or reduced requirements to encourage redevelopment and infill	Highly urban areas	Reduces development pressure on greenfield areas; reduces need for infrastructure expansion; can improve water quality if done right	Can further degrade water quality if not done right or if environmental regulations are relaxed for these sites
Large lot zoning	Majority of land zoned 0.5 to 0.05 du*/acre	Rural or suburban communities often used for drinking water protection	Provides some measure of protection for sensitive subwatersheds; relatively easy to implement	Can contribute to regional sprawl
Watershed impervious cover caps	Used to limit IC and ultimately the amount and type of development in a given watershed	Watersheds with very little development	Directly ties land use to stream conditions	Difficult to measure change in IC over time
References: CWP, 1998; CSN, 2008; Schueler, 2000. ** du = density unit*				

Regional Planning Case Study: Coastal Waccamaw Council of Governments

The Waccamaw Regional Council of Governments oversees the Section 208 program, which coordinates regional planning initiatives focusing on water quality issues affecting Horry, Georgetown, and Williamsburg Counties. The Waccamaw Region Section 208 Water Quality Management Plan was recently updated in 2011 and examines both regional wastewater treatment needs and the need to address concerns related to non-point source pollution. One of the main focus areas in the plan is to expand the use of green infrastructure and Low Impact Development management strategies in the region. The Waccamaw Regional COG staff worked closely with several stakeholders to outline potential LID applications on a site scale, neighborhood scale, and even on a watershed scale. The importance of these innovative stormwater management techniques was emphasized throughout the plan.

The Waccamaw Regional COG has led other water quality planning projects in the region, most recently in the Murrells Inlet community. Local stakeholders sought to develop a watershed-based plan to address fecal coliform impairments in Murrells Inlet's Shellfish Harvesting Areas. Local stakeholders from both Horry and Georgetown Counties have worked closely with state agencies including SC DHEC and SC DNR to recommend strategies to improve water quality and restore local oyster reef habitats. Through extensive monitoring, data analysis and an assessment of potential sources of bacteria, the planning steering committee recognized that most of these sources are land-based and are being transported to the main channel primarily through stormwater runoff. Recently there have been LID project installations in Murrells Inlet. Expanding LID applications throughout the community is something that is promoted as a major recommendation in the Murrells Inlet Watershed-Based Plan.

For more information: www.wrcog.org

Case Study provided by Dan Newquist, Coastal Waccamaw Council of Governments

tion. Also, the area slated for intense development is likely already impaired. Encouraging redevelopment and infill of these areas is recommended as it provides an opportunity to improve water quality conditions by treating existing impervious cover through the use of BMPs designed for highly urban areas (e.g., green alleys, stormwater planters, green rooftops, streetside bioretention, etc.). Redevelopment should be done in a smart way, so as to make it attractive to homeowners. This would include planning to have walking distance amenities including local shopping areas, parks, nature trails, access to water, etc.

Codes and ordinances supported by qualified staff are important for successful planning for future conditions. Finally, policy that has flexibility to make changes based on new information can better support planning now for future growth conditions and patterns.

Code and Ordinance Checklists

The regulatory framework of federal, state, and local regulations and codes is another defining factor of coastal areas. In some cases, there are regulatory overlays, such as the Coastal Zone Management Act, and most coastal states have more stringent regulations along the immediate coastline. Factors at the site, district/neighborhood, and regional scales can drive the creation of unnecessary impervious cover and other land cover conditions that produce excessive runoff. These factors are embedded in a community's land use codes and policies. A comprehensive approach to stormwater management should therefore include an examination of a locality's land development regulations, policies, and ordinances. For example, a subdivision ordinance dictates minimum houses per acre, street width, and the distance a house is set back from the road. All of these measures create impervious surface. It is for the municipality to determine whether the creation of this impervious surface and the generation of the associated runoff are appropriate. In this way, the municipality can align its development regulations with its stormwater goals. Table 2.3-2 lists common land use development regulations, codes, and policies that could be reviewed for consistency with stormwater goals.

Table 2.3-2. Managing Stormwater in Your Community
Common land use development regulations, codes, and policies that can drive impervious cover.
♦ Zoning ordinances specify the type of land uses and intensity of those uses allowed on any given parcel. A zoning ordinance can dictate single-use, low-density zoning, which spreads development throughout the watershed, creating excess impervious cover. ♦ Subdivision codes or ordinances specify specific development elements for a parcel: housing footprint minimums, distance from the house to the road, the width of the road, street configuration, open space requirements, and lot size—all of which can influence impervious cover. ♦ Street standards or road design guidelines dictate the width of the road for expected traffic, turning radius, the distance for other roads to connect to each other, and intersection design requirements. Road widths, particularly in new neighborhood developments, tend to be unnecessarily wide, creating considerable impervious cover. Often, curb and gutter are required with road design which makes roadside infiltration swales and practices unfeasible and encourages pipe and pond collection systems. ♦ Parking requirements generally set the minimum, not maximum, number of parking spaces required for retail and office parking. Setting minimums leads to parking lots designed for peak demand periods, which can create acres of unused pavement during the rest of the year. ♦ Minimum setback requirements can spread development out by leading to longer driveways and larger lots. Establishing maximum setback lines for both residential and retail development brings buildings closer to the street, reducing the impervious cover associated with long driveways, walkways, and parking lots. ♦ Site coverage limits can disperse the development footprint and make each parcel farther from its neighbor, leading to more streets and roads and thereby increasing total impervious cover throughout the watershed. ♦ Height limitations limit the number of floors for any building. Limiting height can spread development out if square footage cannot be met by vertical density.

Reviewing current codes and ordinances is recommended to identify opportunities for improvements, such as LID, as well as to identify obstacles to improvements. The code and ordinance reviews can be done by vested stakeholder and/or decision maker groups. Often the process to discuss options serves to educate the group but also spurs innovative solutions and ideas. Several checklists exist to guide the code and ordinance review process, including:

- The US EPA's Water Quality Scorecard focuses on incorporating green infrastructure practices at the municipal, neighborhood, and site scales. This is available at http://www.epa.gov/smartgrowth/water_scorecard.htm.
- The Better Site Design Codes and Ordinances Worksheet (known as the COW) focuses on 22 Better Site Design development principles for projects such as streets and roads, sidewalks, parking lots, open space requirements, etc. These better site design development principles are outlined in Table 3.1-1 in Chapter 3 and the COW worksheet is available at www.cwp.org.

- ✧ The Eight Tools (of Watershed Protection) Audit identifies regulatory and programmatic tools and gaps in watershed protection. This is available at www.cwp.org.
- ✧ Additional reviews may focus on permit compliance (e.g., US EPA's MS4 Program Audit, Stormwater Pollution Prevention Plan, industrial or commercial discharges, etc.) building codes, transportation, or other code and ordinance areas.

It is important to outline the codes and ordinance review goal and potential outcomes, then choose the tool to meet that identified need. Finally, watershed groups, local governments, and states can tailor the tool to better meet the local conditions, current policies, or anticipated outcomes. The COW has been altered and used in several other locations. In fact, the Coastal Community Watershed Management Checklist was based on the COW and updated for the coast. This Coastal Community Watershed Management Checklist includes improved stormwater management benchmarks and is detailed in the next section.

Coastal Community Watershed Management Checklist

One prominent tool that was developed for coastal code and ordinance review is the Center for Watershed Protection's Coastal Community Watershed Management Checklist. Local codes, policies, and incentive programs can, of course, provide an additional and locally-tailored level of protection, and these local initiatives are the chief focus of this checklist.

The Center for Watershed Protection developed this planning checklist to address critical coastal watershed management issues and challenges related to water quality and natural resource protection goals. The Checklist provides an inventory of best practices and policies that local coastal governments, elected officials, watershed managers, and other stakeholders can use to assess the status of watershed protection in their community, and to identify areas for improvement through the use of example resources and case studies.

The Checklist has twenty-eight questions organized by the following six sections:

1. Land Use Planning
2. Hazard Mitigation Planning
3. Pollution Sources
4. Shoreline Management
5. Site Design
6. Stormwater Management

The Checklist Evaluation Worksheet contains all six sections in an Excel spreadsheet for scoring.

These sections are not stand-alone; rather, they represent opportunities for integrated approaches to coastal watershed management. In some cases, related questions are linked across sections. Users are encouraged to consider all six sections in order to gain a comprehensive evaluation of their community's progress toward integrated coastal watershed management. Recognizing that no single checklist can apply equally to all coastal communities, and that some policies or management approaches may be more important than others, this planning tool is intended to help compare one community's approaches to others, and to increase awareness of management options and examples that have had positive benefits in other coastal communities.

Scoring is provided for each question in the Checklist based on the answers provided by the community. A summary score provided at the end of each section is intended to identify the top three strengths and areas for improvement in the community. Key resources and example case studies are provided to support potential changes in areas identified for improvement within a community.

The Checklist provides multiple benefits to coastal communities, such as opportunities to identify:

- Important coastal watershed management strategies
- Current practices and policies in their community
- Ways to enhance or improve these practices and policies
- Resources and case studies that are needed for improved practices and policies

For example, a coastal community could use the Checklist to learn that their stormwater management program could be improved by providing incentives for the use of low impact development (LID). Examples of other communities that use LID are provided in the Checklist in addition to other resources to support program changes. The Checklist is available online at http://www.cwp.org/coastal-community-watershed-management-checklist.

How to Incorporate LID into Local Land Use Regulations

All of the tools provided in this manual can be implemented through changes to local land use regulations. Depending on the tools a given community may adopt, these provisions will provide a good starting point for adapting local ordinances to include LID principles.

The first step in the process could involve a code and ordinance review as described in this section. The Code & Ordinance Review should identify areas where the 21 Better Site Design Guidelines have not been addressed adequately. Here are some suggestions for how to incorporate low impact development principles into ordinances (adapted from NCCE, 2009 and RI DEM & CMC, 2011):

I. Avoid the impacts of development to natural features and pre-development hydrology

Protect as much undisturbed open space as possible to maintain pre-development hydrology.

- Provide a definition of "open space."
- Adopt a Conservation Development Ordinance to protect open space and predevelopment hydrology.
- Permit open space developments/conservation developments by right, not only by waiver.
- Require that limits of disturbance are clearly identified as part of any development plan submittal to minimize loss of open space.

Maximize the protection of natural drainage areas, streams, surface waters, and jurisdictional wetland buffers.

- Amend regulations to require that new lots are created out of freshwater and/or coastal wetland jurisdictional areas, to the extent practical.
- Revise regulations to direct building envelopes away from steep slopes, riparian corridors, hydric soils, and floodplains, to the extent practical.

- ✧ Develop a community buffer program to establish a naturally-vegetated buffer system along all streams and wetlands to supplement and expand upon the minimum requirements of DHEC-OCRM requirements.

Minimize land disturbance, including clearing and grading, and avoid areas susceptible to erosion and sediment loss.

- ✧ Adopt or continue to enforce an erosion and sedimentation control ordinance that addresses all land development activities.
- ✧ Adopt a grading ordinance to require applicants to maintain as much natural vegetation as possible and limit clearing, grading, and land disturbing activities to the minimum required for construction maintenance and emergency services.
- ✧ Adopt provisions in the Zoning Ordinance and/or Subdivision Regulations for preserving forest cover, protecting significant trees, and providing adequate tree canopy in developed areas.
- ✧ Restrict the minimum requirement for building footprints, construction access, and setbacks.
- ✧ Establish slope protection criteria.
- ✧ Create requirements for the retention of native vegetation and tree canopy.
- ✧ If on-site wastewater treatment is to be used, allow reserve septic fields to remain uncleared.
- ✧ Allow or encourage BMPs in required landscape areas and open spaces (but not riparian buffers, which should remain undisturbed).

Minimize soil compaction and restore soils compacted as a result of construction activities or prior development.

- ✧ Approve requirements within land development regulations that prohibit the compaction of soils in areas needed for post-construction stormwater recharge.
- ✧ Require regular inspection of site construction practices by the municipality to ensure that soils are properly preserved and restored.
- ✧ Direct contractors to reestablish permeability of soils compacted by construction vehicles; for example, till or amend soils of lawn areas prior to seeding.

II. Reduce the impacts of land alteration to decrease stormwater volume, increase groundwater recharge, and minimize pollutant loadings from a site.

Provide low-maintenance, native vegetation that minimizes the use of lawns, fertilizers, and pesticides.

- ✧ Adopt landscaping standards that require the preservation of as much natural vegetation as possible and encourage low-maintenance native landscaping.
- ✧ Prohibit the installation of plant species that may be found on the most recent listing of invasive species as published by the South Carolina Exotic Pest Plant Council.
- ✧ Establish limits for lawn areas in favor of other groundcovers or vegetation.

Minimize impervious surfaces.

- ✧ Planning Development:
  - Adopt compact growth ordinances such as Conservation Development, mixed use, or planned development to minimize impervious surfaces.
  - Incentivize Retrofitting and Infill Development.
  - Examine the feasibility of adopting impervious cover limits for the entire community or for specific watersheds.
  - Relax side yard setbacks and allow narrower frontages for flexible lot placement.
  - Reduce height restrictions and increase floor areas ratios to reduce building footprints.
  - Amend density standards and allowances to encourage natural area protection in exchange for higher densities.
- ✧ Roadway Design:
  - Tailor street width standards to be as narrow as possible while providing adequate circulation for projected traffic volumes; permit a minimum pavement width of 18 to 22 feet on low-traffic local streets in residential areas.
  - Require street right-of-way widths to be the minimum width necessary to accommodate travel lanes, pedestrians and vegetated open swales safely.
  - Revise residential street design to limit or eliminate the use of curbing where possible to allow side of the road drainage into vegetated open swales.
  - Where curbs are necessary to protect the roadway edge, allow perforated curbs (a.k.a. curb cuts) or flat "aprons" (that are flush with the road surface).
  - Modify the requirements for dimension, design, and surface material of cul-de-sacs to reduce total impervious cover and provide greater design flexibility. Allow landscaped islands and bioretention in cul-de-sacs.
  - Adopt flexible sidewalk design standards that help to balance limits on impervious cover with pedestrian needs. For example, permit sidewalk placement on one side of the street in low-density residential areas or provide an alternative pedestrian circulation layout that uses common areas, rather than street rights-of-way. Design sidewalks to disconnect runoff from the stormwater conveyance system and encourage the use of pervious materials.
  - Permit placement of utilities under the paved section of the right-of-way or immediately adjacent to the road edge to allow for swales to be located adjacent to the roadway.
- ✧ Parking Design:
  - Require driveway lengths and widths to be reduced to the extent possible, encourage shared driveways, and promote the use of pervious surfaces wherever appropriate.
  - Adopt both minimum and maximum parking ratios to provide adequate parking while reducing excess impervious cover.

- Adopt innovative parking design standards that allow for reductions in parking stall and travel lane width.
- Encourage shared parking wherever feasible in order to reduce total impervious cover.
- Allow off-site parking to accommodate re-development and mixed-use compact growth.
- Revise parking lot landscaping requirements to be flexible and encourage LID techniques; for example, require vegetated islands with bioretention functions.
- Allow or require pervious materials for spillover parking and parking lanes.

Manage Impacts at the Source

Infiltrate precipitation as close as possible to the point it reaches the ground using vegetated conveyance and treatment systems.

- ✧ Revise regulations to allow and encourage LID vegetated treatment systems, such as bioretention, swales and filter strips, to promote recharge and treatment of runoff.
- ✧ Break up or disconnect the flow of runoff over impervious surfaces.
- ✧ Amend regulations to encourage runoff to be diverted over pervious surfaces to foster infiltration, runoff reduction, and pollutant removal, where appropriate.
- ✧ Provide source controls to prevent or minimize pollutants in stormwater.
- ✧ Revise regulations to encourage or require appropriate pet waste disposal to prevent pet waste from entering stormwater runoff
- ✧ Require commercial and industrial development to sweep their parking areas on an annual basis.
- ✧ Street sweeping should be done on community streets to limit pollutant transport to water bodies and reduce maintenance of catch basins.
- ✧ Consider adopting a wastewater management district to encourage or require all septic systems to be inspected and maintained regularly.
- ✧ Revise regulations to limit lawn areas and encourage alternative ground covers that require less irrigation and fertilization, where possible.
- ✧ Consider adopting a stormwater utility district to manage the existing impacts of stormwater runoff.

Re-vegetate previously cleared areas to help restore groundwater recharge and pollutant removal.

- ✧ Revise regulations to encourage re-vegetation of cleared areas with native species, where possible.

Form-Based Code

The adoption of alternative zoning ordinances to supplement or reform outmoded local codes can help communities meet water quality and land-use planning goals. Stormwater management is addressed largely by engineering solutions. However, nonconventional land-use planning strategies and regulatory tools, such as form-based codes, are often overlooked as a way to achieve water quality standards.

A form-based regulatory approach focuses on designating appropriate form and scale of development that is contextually sensitive to the surrounding landscape. This contrasts with Euclidean (conventional) zoning, which focuses on segregation of land uses. The form-based codes incorporate new standards for building façades and public spaces, yet conventional regulatory mechanisms, such as building heights and setbacks, are still utilized. While form-based code's primary organizing principle differs from Euclidean codes, it is not a complete departure from conventional zoning regulations, and instead serves as an alternative regulatory option for communities to employ at the regional, neighborhood, or site scale.

In addition to promoting contextually sensitive design, form-based codes foster interconnected patterns of development for the built environment and public realm. Advocates of the form-based approach assert that this is a viable regulatory mechanism for managing stormwater, resulting in development with significantly less impact on sensitive environments and resources.

A number of elements are commonly included in a form-based code, such as a regulating plan, public realm standards, and building form standards. A regulating plan serves as a map, outlining streets and public open spaces and designating where different building form standards apply. Typically, the urban-rural transect model is used for the form-based code regulating plan framework, depicting a gradient of urban forms that range from rural to highly urbanized zones. These designated zones specify the form and character of development appropriate for each zone. Most often the regulating plan is applied to areas within a framework of streets and blocks as opposed to large unrefined geographic areas.

Through the use of a regulating plan, high-density development could be concentrated away from environmentally sensitive areas. Similarly, a form-based code could prescribe appropriate LID practices for public spaces, such as use of bioretention cells or swales, type of vegetation used along public easements, lakes, streams, and streetscapes, or pervious materials for sidewalks – all designed within the context of the surrounding environment. Additional elements can be required to address community-specific needs, such as environmental resource standards to regulate stormwater drainage and infiltration, and landscaping standards to provide tree protection. For example, low impact development practices could be specified for watershed protection and restoration through reduced impervious cover. It is important to note that these standards would need to align with local BMP manual standards to be effective. A transect model could be used to indicate how the different types of LID practices would fit into the character of the zone. This in turn would help to ensure LID practices match with appropriate environmental conditions and development context.

The concept of a form-based code is just beginning to emerge in South Carolina municipal zoning regulations, yet several coastal communities are currently working towards the development and adoption of a form-based approach to zoning. There are, however states in the region that have considered or embraced this new regulatory concept. For instance, communities in Chatham County

North Carolina began exploring the potential for utilizing form-based code to achieve water quality standards for the Jordan Lake Watershed (Berg, 2009; Berg & Bendor, 2010). Also, in Florida the town of Bradenton successfully adopted a form-based code that includes an environmental resource standards element focusing on stormwater management (http://formbasedcodes.org/content/uploads/2014/02/bradenton-form-based-code.pdf).

More examples of where this regulatory tool has been adopted and implemented can be found on the Form-Based Codes Institute Website: www.formbasedcodes.org.

Incorporating LID into Ordinances Case Study: Richland County, SC Open Space Ordinance

From 1980 to 2010, Richland County's population increased by 43 percent to 386,000 residents. Significant urban sprawl has increased stormwater runoff and degraded water quality throughout the undeveloped portions of the County.

In late 2008, funded through a grant from the U.S. Army Corps of Engineers, Richland County partnered with the Center for Watershed Protection to form the Development Roundtable. Richland County's local codes and ordinances were systematically examined by the Roundtable with an eye toward promoting more environmentally-sensitive and economically viable development. The Roundtable included County staff (Administration, Planning, Stormwater and Conservation) and representatives from the development community and environmental and conservation groups. In October 2009, a consensus document entitled "Recommended Development Principles" was published. This document formed the basis for numerous revisions to the County's Land Development ordinances from 2010 through 2012. Ordinance revisions ranged from street and parking lot design, stream buffers, tree conservation, and stormwater management practices.

The open space design and management issue was the final and one of the most contentious issues before the Roundtable. Open space design goals focused on how best to incorporate smaller residential lot sizes to minimize total impervious area, reduce construction and infrastructure costs, provide recreational space, conserve natural areas and promote watershed protection. Over a period of approximately one year, Roundtable participants debated the merits of various open space requirements and how each requirement would benefit the development community and the environment. Open space design was simulated on numerous proposed subdivisions and compared with a conventional minimum lot size zoning requirement. This iterative process produced consensus on open space design principles benefiting both the development and environmental communities. Based on the consensus principles reached by the Roundtable, County staff drafted an optional Open Space Design ordinance. Adopted by County Council in 2013, the ordinance permits variation in lot sizes and relaxation of strict minimum lot size standards, and preserves sensitive lands for conservation within developments. Varied lot sizes not only provide home buyers a variety of more compact and sustainable housing options, but also reduce stormwater runoff by preserving open space, tree cover, stream buffers, wetlands and floodplains consistent with site characteristics.

The ordinance requires all "constrained open space" – a term coined by the County – in the development to be set aside and permanently protected. These areas, considered difficult to develop, include FEMA Special Flood Hazard Areas, stream buffers, wetlands, highly erodible soils with slopes greater than 25 percent, and open water. If the constrained open space comprises 25 percent of the development, no further open space set aside is required to use the ordinance. Constrained open space areas are based on a 1:1 ratio of open space area to actual acreage. Not only does the constrained open space requirement provide important environmental benefits, it avoids development costs and environmental externalities to mitigate stream, wetland, and floodplain impacts.

Developers are further incentivized to set aside "unconstrained open space" areas to obtain a density bonus over the base density in certain low-density residential districts.

Richland County, SC Open Space Ordinance (continued)

The County developed an unconstrained open space credit system based on a number of natural site factors such as location within a 303d listed water, extended stream buffers, hydrologic soil groups and slopes, protection of forests by type and age, and prime agricultural soils. Engineered unconstrained open space credits may be obtained by incorporating low impact development (LID) best management practices (BMPs) such as permeable pavement, infiltration and bioretention systems. Each unconstrained open space credit category listed above has a weight to incentivize setting aside additional open space areas normally not protected within a typical development. For example, installation of bioretention has a weight of two; therefore, every acre of bioretention open space set aside counts as two unconstrained open space credits. Density bonuses, up to a maximum of 20 percent, are based on the total number of unconstrained open space credits set aside in each development. This incentive is significant since LID BMPs are not currently required in County development permits.

The Open Space Design ordinance provides maximum design flexibility to each developer based on the specific natural resource features on the property and the proposed development layout. A copy of the Open Space Ordinance can be found in Section 26-186 of the Land Development Code for Richland County at this website: http://www.richlandonline.com/Government/Departments/PlanningDevelopment.aspx

Case Study Provided by Tracy Hegler, Director, Richland County planning and Developmental Services Department; James B. Atkins, Ph.D., Director, Richland County Conservation Department; Quinton Epps, Richland County General Stormwater Manager

Conservation, Land Use, and Stormwater Management Incentives

Incentives can be an important aspect of land conservation and LID management. Better site design principles that were discussed in this manual include opportunity for incentives, such as higher density units allowed when open space is preserved (See Laurel Oak Preserve Case Study) or conserved or reduced parking lot size when shared parking is used. Generally, fewer parking spaces allow more space for building, which is often an inducement for developers. Other motivations to use LID could be the environmental, recreation, tourism, and improved public health benefits outlined that are associated with clean water goals. Finally, monetary incentives through outright purchase of land for protection or tax reductions for lands placed in easements are also common incentive examples. These are only a few conservation and land use incentives; many other opportunities exist to promote watershed and stormwater goals.

Costs are incentives from two perspectives: 1) the actual cost of land development, LID implementation, and land conservation, and 2) how much these variables save the development cost or profit margin. The amount features cost (actual dollars spent) and the amount of a commodity saved is equal to added value (revenue). For example, space preserved by using smaller LID practices is a savings because the cost was not spent on this commodity and can be realized as a savings or profit margin in the overall revenue. Incentives for willingness to pay or perceptions of conservation, land use, and/or stormwater management should also be considered. For example, Oak Terrace Preserve homeowners were willing to pay more for residences in what they considered to be a “green” community (Vandiver and Hernandez, 2009).

Conservation Incentive Case Study: Laurel Oak Grove, James Island, SC

Gross Acreage: 6.34 ac
Open Space Acreage: 3.54 ac
Number of lots: 22
Net Density: 3.54 units/ac
Zoning: City of Charleston cluster development

Laurel Oak Grove was successfully able to integrate several low impact development techniques and LEED certification into affordable housing. When complete, Laurel Oak Grove will have 22 houses (13 in Phase 1 and 9 in Phase 2) situated on 6.3 acres with approximately half of the property in preserved open space. The basis of the site design is founded on the concept of "cohousing" – a practice that clusters houses at a higher density surrounding communal features, such as courtyards. The City of Charleston has a special zoning ordinance for this type of development for the purpose of "permitting unique developments that utilize flexible design that is sensitive to natural areas, provides quality open space, decreases stormwater runoff by reducing impervious surfaces, reduces the cost of infrastructure, and provides a mixture of lot sizes and housing options." HOA dues will be used to pay for the maintenance of common areas, but homeowners also receive 20 hours of educational classes about the green features of their homes and landscapes.

Central bioretention basin serves a dual purpose for community open space and stormwater treatment.

In addition to high density and conserved open space, the site also minimizes impervious surfaces. The 3-ft wide sidewalks are narrower than the typical 5-ft widths. Houses do not have individual driveways; parking is situated along the perimeter of the roadway. The parking spaces are gravel, and are limited to two per house. The asphalt road allows for resident access to the parking and houses on one side of the property; a gated, gravel access road for utilities and emergency vehicles was provided on the back side.

The soils on site have a high infiltration rate, allowing for shallow infiltrations basins and perforated underdrain as the main components of the stormwater management system. The narrow (20' wide) asphalt roadways are bordered by flat ribbon curbs, which allow stormwater to flow to pervious gravel parking areas. Gravel trenches and perforated underdrain pipes are underneath the gravel parking areas so that stormwater runoff will flow through the rock, into the underdrain, and into the infiltration basins. Under saturated soil conditions, the water passes from the infiltration basins into overflow catch basins and into an underground submerged piping system which discharges into low lying, undeveloped areas of the property. The infiltration basins serve a secondary purpose as attractive, vegetated common space features for the homeowners – and are located central to the individual houses.

Case study provided by Tamara Avery, Land Development Manager at Sea Island Habitat for Humanity; Jenny Palmer, P.E., Senior Civil Engineer at Seamon Whiteside; Amanda Herring, Senior Zoning Planner, City of Charleston

Concept plan for Laurel Oak Grove (provided by Seamon Whiteside + Associates)

Stormwater management incentives can also include the ability to meet local Total Maximum Daily Loads (TMDLs). For example, some LID practices may be more effective than traditional BMPs like dry or wet ponds at removing a pollutant of concern (e.g., bacteria) from the environment. Stormwater management is easiest and least costly when done at the earliest stages of land development, such as during the early development stage where there is an opportunity to conserve natural lands (see Section 3.2) and use better site design. Stormwater management increases in complexity and cost as sites involve more urban infrastructure and more stormwater management infrastructure (e.g., pipes or LID structural components). Therefore, there are monetary incentives to incorporate better stormwater management through conservation of natural land, better site design, non-structural LID, and structural LID in a stepwise fashion. LID incentives include:

- Decentralizing the stormwater treatment practice
- Reducing the size and cost of the practice
- Reducing soil disturbance (which decreases grading and compaction, while providing more storage capacity in soils)
- Reducing impervious cover
- Supporting TMDL requirements

Incentives can encourage adoption of LID practices in the community. The US EPA's LID Barrier Busters Fact Sheet titled, "Encouraging Low Impact Development" (US EPA, 2012) listed the following four most common type of local incentive mechanisms to plan, design, and build LID projects.

1. Stormwater fee discount or credit – LID practices result in a stormwater credit and/or for those municipalities where there is a stormwater fee, LID practices receive a discount from the fee.
2. Development incentives – Municipalities can offer incentives such as reduced permit fees, expedited permit process, higher density development allowance, and/or exemptions from permitting requirements if LID practices are used.
3. Rebates and installation financing – Municipalities can offer grants, matching funds, low-interest loans, tax credits, and/or reimbursement when LID practices are used.
4. Awards and recognition programs – Municipalities can recognize the people and places where LID practices are implemented. Recognition examples include newspaper articles, website announcements, notes in utility bill mailings, and/or LID-design contests.

Examples of LID in Local Ordinances

Some local governments have included recommendations in design manuals or ordinances that encourage low impact development planning and practices. The list in Table 2.3-1 pulls together the best available information at the time of publication and may be subject to change. Resource information for these ordinances is included in the References section at the end of this chapter.

Table 2.3-3. LID Requirements from Ordinances in the Coastal Zone	
Municipality	**Requirement**
Beaufort County	♦ Established 10% effective imperviousness threshold for development or redevelopment ♦ Pollutants (phosphorus, nitrogen, and bacteria) are specifically targeted for control; treatment achieved by 10% effective imperviousness (N&P) and 5% effective imperviousness (FC) ♦ River protection buffer of 50 feet ♦ Detention and retention ponds shall be designed with relatively flat side slopes along the shoreline, and with meandering shorelines where possible to increase the length of shoreline, thus offering more space for the growth of littoral vegetation for pollution control purposes ♦ No new stormwater discharge shall be permitted onto any beaches/ shorelines
Charleston County	Zoning and Land Development Regulations Ordinance establishes limits on building density, buffer & setback requirements, parking lot islands, tree protection, planting species selection, and screening requirements for ponds
Georgetown County	When wet ponds are employed, retention/planting of littoral vegetation, particularly native wetland plants selected for nutrient and contaminant uptake capacity, shall be included
Horry County	♦ Hwy 707/Holmestown Road overlay zones set limits of 65% imperviousness for the total lot area, unless parking areas utilize LID strategies to infiltrate runoff. A 25-ft vegetated buffer is to be provided along the highway and side/rear setbacks are to be established as vegetated buffers ♦ A landscape plan for all portions of the drainage system shall be part of the stormwater management and sediment control plan to address the following: • Tree saving and planting plan • Types of vegetation that will be used for bank stabilization, erosion control, sediment control, aesthetics, and water quality improvement • Any special requirements related to the landscaping of the drainage system and efforts necessary to preserve the natural aspects of the drainage system • Landscaping shall not be installed within the easement unless it is a part of the drainage system
City of Hardeeville	The Municipal Zoning & Development Ordinance (MZDO) states that impervious areas must drain to pervious surfaces before going into a storm drain system; pervious parking is encouraged
City of Myrtle Beach	"Vegetated buffer strips shall be created and/or preferably retained in their natural state along the banks of all watercourses, waterbodies, or wetlands. The buffer shall be wide enough to allow for periodic flooding, provide access to the waterbody, and act as a filter to trap sediment in runoff"

Table 2.3-3. LID Requirements from Ordinances in the Coastal Zone	
Municipality	**Requirement**
City of North Myrtle Beach	♦ Street design requirement includes landscape requirements ♦ Landscape buffers ♦ Pervious parking spaces are required for all spaces above minimum requirement
Town of Bluffton	♦ All projects shall have in-series BMPs ♦ All stormwater management systems shall contain at minimum one wet detention BMP, one vegetative BMP, and one filter or infiltration-based BMP ♦ 50% of commercial parking must be pervious
Town of Hilton Head	♦ The use of wetlands for storing and purifying runoff is strongly encouraged. Regulated wetlands shall not be disturbed by the construction of detention ponds in them or sufficiently near to deprive them of required runoff or to lower their normal water table elevations. ♦ Landscape design and plantings should further opportunities for percolation, retention, detention, filtration and plant absorption of site-generated stormwater runoff ♦ No new stormwater discharge shall be permitted onto any beaches/ shoreline ♦ Channeling runoff directly into natural waterbodies from pipes, curbs, lined channels, hoses, impervious surfaces, rooftops or similar methods shall not be allowed unless methods of filtration are provided. Instead, runoff shall be routed over a longer distance through sheet flow, swales, drywells or infiltration ditches and other methods to increase percolation, allow suspended solids to settle and remove other pollutants
Town of Mt. Pleasant	♦ Pervious material required for parking spaces beyond minimum requirement
Town of Pawley's Island	♦ The maximum allowable impervious surface area is between 1,000 and 4,000 square feet and shall not exceed 40% of the lot size ♦ Driveways and off-street parking are specifically prohibited from being constructed of impervious material
Town of Summerville	♦ When possible, provide a 20-ft minimum buffer between the property line and the end of all pipes or energy dissipation measures installed

2.4 Neighborhood Planning Considerations for Coastal SC

Among the strategies for improved stormwater management is the use of innovative community and subdivision designs that reduce the impact on water quality and required municipal services.

LID and Compact Development

Compact development patterns generate far less stormwater per unit of development than the typical single use suburban model. Additionally, on the watershed scale, more compact development patterns provide the opportunity to "localize" hydrologic impacts.

According to 2010 census data (summarized in Table 2.4-1), South Carolina's eight coastal counties experienced 24.3 percent population growth in the last decade, which exceeds the state average of 15.3 percent. Beaufort County experienced a 34.1 percent population increase during this time, while Horry County similarly experienced a 37.0 percent increase in population (SC Budget and Control Board, 2014). These numbers do not reflect the increase in commercial development, secondary homes, and vacation resorts and it is estimated that land development occurs at more than double the rate of actual population growth (Beach, 2002 and USDA, 2000).

Table 2.4-1. Resident Population of South Carolina by County*

County	Resident Population (April 2000)	Resident Population (April 2010)	Numeric Change	Percent Change
Beaufort	120,937	162,233	41,296	34.1
Berkeley	142,651	177,843	35,192	24.7
Charleston	309,969	350,209	40,209	13.0
Colleton	38,264	38,892	628	1.6
Dorchester	96,413	136,555	40,142	41.6
Georgetown	55,797	60,158	4,361	7.8
Horry	196,629	269,291	72,662	37.0
Jasper	20,678	24,777	4,099	19.8
TOTAL	981,338	1,219,958	238,620	24.3

** excerpted from South Carolina Budget and Control Board's Community Profiles*

Urban sprawl growth patterns often generate unnecessary impervious cover. But it is important to consider the overall pattern of development. As can be seen in Figure 2.4-1, overall impervious cover for a watershed decreases as site density increases, assuming the same amount of growth.

For example, in the Greenville-Spartanburg region of South Carolina, one of the fastest growing regions of the country, land consumption is currently five times the rate of population growth. This pattern indicates low-density development, or sprawl (Campbell, et al. 2007). Upstate Forever, a local non-profit organization, partnered with Clemson University to examine the water quality

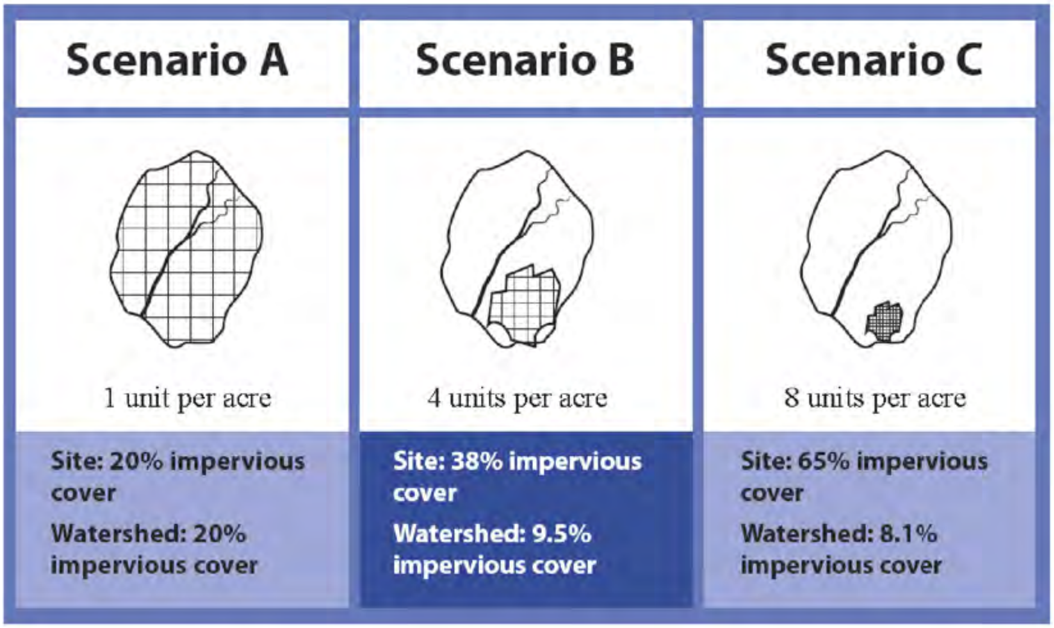

Figure 2.4-1. Illustration of Using Higher Density to Reduce Impervious Cover This illustration, adapted from the U.S. EPA publication "Protecting Water Resources with Higher Density Develoment," shows how increasing density at the site level decreases impervious cover for the watershed (EPA, 2006).

impacts of various growth patterns ranging from the current sprawl to more compact development (land consumption and population growth rates are equal). The researchers found that more compact development would cut the amount of sediment and nutrient (nitrogen and phosphorous) pollution from future development in half. Even though population growth remained the same in each scenario, minimizing the developed land area would result in overall watershed benefits (Privette, et al. 2011).

Planned Unit Development

As part of the 1994 comprehensive land-use planning legislation, a provision for planned development districts (PDDs) was codified into SC law (SC 6-29-740) to achieve comprehensive plan objectives for local governments. The purpose of the provision was to allow for flexibility in the development process, encouraging innovative site planning for residential, commercial, institutional, and industrial developments. Local governing authorities may establish these districts as amendments to locally adopted zoning ordinances with the overall goal of improving design, character, and quality of mixed-use developments while preserving natural features of open spaces. A development permitted as part of a PDD is referred to as a planned unit development (PUD).

PUDs offer a comprehensive approach to the design of large scale developments, as opposed to the conventional lot-by-lot approach typically allowed in community zoning codes and regulations. Unlike conventional development, a PUD allows developers to by-pass standard zoning and development regulations in exchange for site-specific design and development innovations, such as placement of structures, mixed land uses, conservation of open spaces, and natural resource preservation.

The PUD has become an increasingly popular land development practice across rural areas of the U.S. coastal zone, and is a commonly utilized planning tool in large undeveloped land tracts of coastal jurisdictions in South Carolina. All eight coastal counties and a number of municipalities within their borders have adopted/authorized PUD provisions in their local zoning codes; however, there is significant variation in PUD baseline standards/requirements across or within the local jurisdictions. For example, minimum acreage requirements for PUDs vary across jurisdictions anywhere from 1 acre to 50 acres. Nevertheless, there are a number of common elements often incorporated in varying combinations in PUDs, including: flexibility, open space preservation, resource

Planned Unit Development Case Study: Palmetto Bluff

Palmetto Bluff is a sea island with expansive frontage on the May, Cooper and New Rivers. For most of the last century, Palmetto Bluff has been managed and enjoyed as a private wildlife and forest preserve. The property has been carefully master-planned to grow into a complete, balanced, controlled community within a coastal setting. Its size makes possible the creation of a series of inter-related, yet distinctive settlements and natural preserves. The combination of its location and varied natural features makes this a unique community.

Palmetto Bluff has been designed to preserve the land's beauty, vastness, and rich landscape while taking advantage of the views and sea island setting to create a strong sense of place. Owners, along with their Architect and Landscape Architect are encouraged to work together from the initial phases of design to ensure all aspects of the design are consistent with specific design objectives, such as implementing Sustainable building systems, site development, materials and construction techniques in all development. Reducing consumption of materials and energy, reducing waste and making intelligent choices about how a building is used benefits both Palmetto Bluff as a community and the sensitive sea island landscape as a whole. Palmetto Bluff is committed to the implementation of Sustainable and Low Impact Design concepts such as reducing the house's "footprint" on the land, energy and water conservation measures, reuse and recycling of building materials, and the preservation of the existing forest and river marsh frontage.

The text for the Palmetto Bluff Planned Unit Development is based on the Beaufort County Zoning and Development Standards Ordinance 90/3 with the following amendments:

- River Protection Overlay District
  - The buffer width was changed from fifty (50) feet to an average of one hundred (100) feet, with a minimum of eighty (80) feet.
  - Development setbacks changed from fifty (50) feet to an average of one hundred (100) feet, with a minimum of eighty (80) feet. Additionally, streets and roads to access land within in the PUD can penetrate the buffer provided stormwater runoff is treated.

- Site Design and Development Standards
  - Minimum Off-Street Parking in the planned resort, residential and commercial developments the parking spaces were changed for the following uses. The assumption underlying the change was that a substantial number of visitors would arrive by public transportation, thus requiring fewer spaces than the current requirements.
    - » Auditorium and Theaters: 0.2 spaces for each spectator seat.
    - » Automobile Service Station: One (1) space for each vehicle stored or parked, plus one (1) space for each employee.
    - » Bank: One (1) space for each two-hundred square feet (200 sf) of gross floor space, plus one (1) space for each two (2) employees.
    - » Church: One (1) space for each six (6) seats in the main assembly room.

Palmetto Bluff Contacts: Stephanie Gentemann, Palmetto Bluff Design Review Board; Jay Walea, Palmetto Bluff Conservancy Wildlife Manager; Dallas Wood, Director of Development, Crescent Communities protection, mixed types of housing, uses, and densities, innovative planning and site design, high quality development, public access opportunities, comprehensive plan and or/long-range plan consistency, unified site design, promotion of agriculture and forestry practices, and water quality protection.

Often local codes and ordinances prohibit or restrict the use of LID strategies, requiring special permits or variances which may discourage developers from implementing LID practices in their designs. Because PUD requirements are generally formulated around a flexible site design process and are not subject to existing conventional outdated codes and ordinances, they provide an opportunity/avenue for increasing LID application (e.g., buffers, bioretention cells and swales, clustering development, dedicated open space, pervious driveways and sidewalks). Incorporating LID features into the site design of a PUD can help maintain the predevelopment hydrology of the property and minimize the impacts of runoff, therefore improving overall water quality.

Generally speaking, LID strategies are minimally addressed in existing South Carolina PUDs; however, communities would benefit by incorporating specific language in PUD development agreements encouraging or requiring LID implementation.

Transfer of Development Rights

Preserving and protecting natural lands from development can be accomplished using Transfer of Development Rights (TDRs) and Purchase of Development Rights (PDRs). TDRs are rural areas that can be sold to private builders. The builder pays the rural land owner in exchange for the ability to build in excess of limits where urban growth areas are designated. TDRs are considered a trading system since the TDR value is based on building demand and the TDR is paid by the builder. However, PDRs are programs that pay landowners to not convert farmland to development. PDR programs are often led and funded by the local government (Anderson and Lohof, 1997). TDR and PDR land selection and prioritization can be supported using natural resource inventories, cost, or opportunity. The TDRs and PDRs strive to meet environmental objectives such as habitat protection and open space preservation.

TDRs and PDRs are voluntary so that legal conflicts are avoided and costs are often lower than land purchase. TDRs and PDRs are commonly outlined in local codes, and there are some state PDR programs (Anderson and Lohof, 1997). Communities can use TDRs and PDRs to protect natural lands from development by compensating property owners in exchange for their commitment to limit development in perpetuity.

Incorporating LID into Existing Development

Developments that occurred with no stormwater management controls or with outdated stormwater management controls, represent an opportunity to capture and treat stormwater runoff. Assessing the site for potential to capture and treat stormwater is an opportunity to improve water quality and provide waterway protection to the community. The potential retrofit site should initially be assessed for LID feasibility, utility conflicts, contributing drainage area, LID practice type and size, estimated costs, and any other constraints or considerations. Retrofits can also be done during redevelopment; often, LID practices are required during redevelopment to meet the most up-to-date regulations. Finally, LID retrofits are commonly identified in watershed planning efforts to meet local water quality goals.

Retrofitting

Stormwater retrofits are structural stormwater management practices that can be used to address existing stormwater management problems in a watershed. These practices are installed in upland areas to capture and treat stormwater runoff before it is delivered to the storm drainage system. They are an essential element of a holistic watershed restoration program that can result in improved water quality, increased groundwater recharge, channel protection, and flood control. Stormwater retrofits can address existing problems and help establish a stable, predictable hydrologic regime by regulating the volume, duration, frequency, and rate of stormwater runoff. In addition, stormwater retrofits can serve as demonstration projects that are visual centerpieces to educate residents and build community interest in watershed restoration.

A nationally recognized and commonly employed method to assess stormwater retrofit potential is the Retrofit Reconnaissance Investigation (RRI) manual (Schueler et al., 2007). This manual was developed for and generally is used in urban watersheds. In addition, the Rural Retrofit Assessment (RRA) was compiled to include common agricultural retrofit considerations. The retrofit manual includes a step by step process that can and should be updated to meet local conditions.

Redevelopment

Redevelopment is development that occurs on previously developed land. Redevelopment and new development require stormwater management that meets the local requirements. Redevelopment from a watershed and stormwater management perspective is an opportunity to bring the developed site into compliance with the current stormwater requirements. Redevelopment of impervious surfaces rather than new development of pervious surfaces will prevent further increases in the watershed’s impervious cover. In addition, redevelopment is an opportunity to upgrade aging infrastructure, such as sewer and stormwater pipes, that are deteriorated and causing water impairments (US EPA, 2006; Hicks, 2014).

Redevelopment can be a tool to direct development to urban corridors and away from undeveloped areas (i.e., conservation of natural areas). For example, the US EPA lists the following common programs that include redevelopment as part of a larger investment effort: business development districts, Main Street programs for older downtowns, brownfield programs, vacant property conversions, and others. Redevelopment is another way to target development in already developed areas and also provide up-to-date stormwater management to meet water quality and habitat goals.

Infill Development

Infill development occurs in unused or underused areas such as parking lots, vacant lots, greyfields[1], and/or brownfields[2]. Often, these areas already have transportation, utilities, and other amenities in place. Concentrating growth in urban corridors is preferred due to the ability to re-energize urban growth and reduce stress to the natural habitat in undeveloped watersheds.

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1 Greyfields are defined as “sites in abandoned or underutilized commercial areas” by the EPA (available at http://www.epa.gov/dced/pdf/sg_stormwater_BMP.pdf)

2 Brownfields are defined by the EPA as “real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of hazardous substance, pollutant, or contaminant.” See http://www.epa.gov/swerosps/bf/overview/glossary.htm

Infill development considerations include unintended code barriers, additional site contamination, and/or proximity to the immediate coastline and the associated natural hazards. Development code requirements can be unintended barriers to coastal waterfront redevelopment and may require changes. Additionally, past land use contamination can present real and perceived pollution problems and considerations for infill development.

Redevelopment Development Case Study: Bojangles Restaurant, Mt. Pleasant, SC

On a one-acre lot that once contained a dry cleaning business, a new Bojangles Restaurant was constructed in 2012 along Highway 17 in Mt. Pleasant. The redevelopment plan included modifications to the original building, parking lot, and landscaping plan to incorporate several low impact development BMPs. Perhaps the most unique aspect of this project was native vegetation: many existing trees were preserved and about 45 new trees were planted on the compact, one-acre site. The vegetation is incorporated in ornamental and functional ways: three bioswales along the periphery of the site capture and treat stormwater runoff. The swale along the drive-thru is planted with birch (*Betula nigra*) trees, which are deciduous. The trees provide shade in the summer and allow light to warm the building in the winter. The impervious area in the parking lot was reduced by the incorporation of permeable paving and shared parking spaces with the adjacent business.

Site plan courtesy of J.R. Kramer, Remark Landscape Architecture

Perhaps the biggest opportunity for any stormwater manager is to work with local governments to develop a range of policies and incentives to direct development to already degraded areas. Communities can enjoy a significant reduction in regional runoff if they take advantage of underused properties in abandoned or underutilized commercial areas, such as infill, brownfield, or greyfield sites (Congress for New Urbanism et al., 2001). Redeveloping already degraded sites such as abandoned shopping centers or underutilized parking lots rather than paving greenfield sites for new development significantly reduces total impervious area and water quality impacts.

Protect future development through resource planning to direct growth to redevelopment sites and infill areas. Complete population growth projections at the jurisdictional-scale for all coastal areas in tandem with natural resource identification and mapping to identify key protection areas as growth occurs. These efforts may feed into a local comprehensive plan, policy, or ordinance that guides current and future development patterns into designated areas. Redevelopment in urban areas can protect undeveloped natural resources, support working waterfronts, and incorporate stormwater management where there are no controls or inadequate controls. Infill development is an excellent opportunity for LID stormwater management. As an example, Horry County, SC, has open space advisory boards that are in the process of preparing a plan to promote infill as a prioritization tool (Wood, pers. comm., 2013).

2.5 Regulatory Strategies

Policy implementation for effective stormwater management requires qualified staff, a clear and transparent process, documented procedures, and flexibility. The site plan review process can prepare the applicant for a more successful permit procedure, result in improved LID designs, and reduce staff time. The stormwater management program's process should include documentation with databases, forms and checklists, and staff that support the tracking, inspection, and verification. Flexibility can be built into the program's implementation process by qualified and trained staff; these staff members can have the ability to suggest improvements, alter processes when needed, and offer innovative solutions to permit applicants when needed. Tracking, inspection, and verification provide the level of safety needed to document that the regulations are implemented and ensure that the water quality goals are met to the best of the state's ability. Finally, an enforcement program highlights the importance of compliance with state regulations.

Stormwater management programs should include a clear, comprehensive, transparent site review process, as well as tracking, inspection, verification, and enforcement. LID should be incorporated and highlighted in the stormwater management program.

Site Plan Review Process

Approval of a stormwater plan is an important milestone. After plans are approved, making changes to the situation "on the ground" can be very difficult. Therefore, the plan review and approval process is the best opportunity to get things right with stormwater design. A well-organized stormwater plan review process can help ensure:

- ✧ Stormwater BMP designs meet the standards and specifications in the ordinance and design manual and are being properly applied to the project site.

- ✧ Stormwater plans incorporate innovative practices, such as site design techniques and low-impact development, early in the planning process.
- ✧ BMPs are sited within easements and have adequate access for inspection and maintenance.
- ✧ Proper construction sequences must be specified on plans to ensure that BMPs do not become clogged before the site is stabilized.
- ✧ Adequate maintenance agreements that assign long-term maintenance responsibility are in place.
- ✧ The stormwater BMP plan approval is coordinated with other necessary environmental permits for erosion and sediment control, streams, wetlands, floodplains, and dams.
- ✧ Approved stormwater BMPs are covered by performance bonds to ensure proper installation in the field.
- ✧ The location and specifications of approved stormwater BMPs are properly documented at each site so that inspection and maintenance staff will have the necessary information.
- ✧ The review process generates the appropriate amount of user fees to help defray development review costs.

Local governments have experience with general development plan review, but reviewing LID projects may be a relatively new function within a local agency. A stormwater plan review process does not have to be created anew. The biggest challenges are securing an adequate and well-trained staff and integrating stormwater reviews with other local reviews for drainage, utilities, erosion control, roads, and site layout. More detailed information for site plan review is available in the Managing Stormwater in Your Community Chapter 7, The Stormwater Plan Review Process (CWP, 2008). Finally, ensuring that the stormwater program is fully funded and staffed is another consideration for a successful stormwater program that incorporates LID in the coastal policy.

A Coordinated Approach for Stormwater Management

There is a need for a coordinated approach to stormwater management practice permit, design, build, and maintenance processes. This need was voiced several times in the stakeholder meetings during the development of this manual. A multidisciplinary approach for stormwater management in coastal SC is recommended. Here are key tips to implement this approach in your municipality, locality, agency, and/or group:

1. Set a clear, concise goal to implement low impact development stormwater management practices.
2. Hold and attend trainings to ensure staff and other vested parties are up to date on the subject.
3. Use these training opportunities to communicate common goals, recognize and promote areas that work well, find areas for improvement, develop solutions, and schedule action items from these findings.

4. Coordinate the agency, group, and people that review site plans, permits, designs, and construction.
   a. Recognize problems early to save time and money.
   b. Streamline the process, cross train, and better ensure the practices meet the standards and meet the goal (#1).
5. Integrate development review and inspections. Develop and use standard operating procedures that ensure a coordinated approach is followed.
   a. Use checklists and standard operating procedures.
   b. Use a documentation and tracking system.
6. Develop and follow a performance review to measure success, to make changes as needed, and to update procedures based on the best available information.
   a. Perform on a regular basis.

These steps for a coordinated approach to stormwater management will promote best practices in the field and are designed to adapt to change based on lessons learned and new information. The objective is to set a clear, concise goal in the municipality, locality, agency, and/or group. For more details on how to set up this coordinated approach for stormwater management, see Chapter 7 "The Stormwater Plan Review Process" in *Managing Stormwater in Your Community: A Guide for Building an Effective Post Construction Progran* (Hirschman and Kosco, 2008). Use this goal to overcome existing barriers and work to refine this coordinated approach for stormwater management in coastal South Carolina.

Tracking, Inspection, and Verification

Tracking, inspection, and verification are important local stormwater program components needed to ensure the natural resource protection that was planned for is achieved. Tracking is commonly achieved using a database such as Microsoft Excel and/or Access, geographic location in mapping systems such as Geographical Information System (GIS), and/or paper files. Inspections are part of the permit process and are completed to ensure that the practice was installed, was installed in the correct location, and was installed per the permit plans. Verification inspection ensures that the practice continues to maintain the natural resource protection that was planned over time. Verification protocols for each type of practice should be developed. Inspection and verification maintain a level of safety because they insert checks and balances into the Stormwater Program to identify practices that are in compliance and identify practices that require corrective or preventative maintenance to meet the compliance threshold. For example, the MS4 permit in South Carolina requires inspection of stormwater BMPs once during each 5-year permit cycle. Tracking is a mechanism that compiles the past and present practices. A standardized, rapid inspection approach should be in place to track, inspect, and verify the low impact development practices. Additional information for tracking, inspection, and verification are available in Hirschman and Kosco (2008) in Section 6.5. "Outlining the Policy and Procedures Manual."

Enforcement

Enforcement is a last resort to bring a stormwater practice into permit compliance. The permitting authority should have a standard process with trigger thresholds, recommended actions, and ultimately strong enforcement options for noncompliance. For example, if a verification field inspection indicates that the practice is not in compliance (e.g., not performing as designed and permitted) then the facility manager should be given a defined time frame (e.g., up to two months) to bring the practice into compliance. Enforcement is a necessary tool to keep the state Stormwater Program in compliance with US EPA federal regulations. Enforcement of stormwater regulations is handled by the SCDHEC BOW's Water Pollution Enforcement Section.

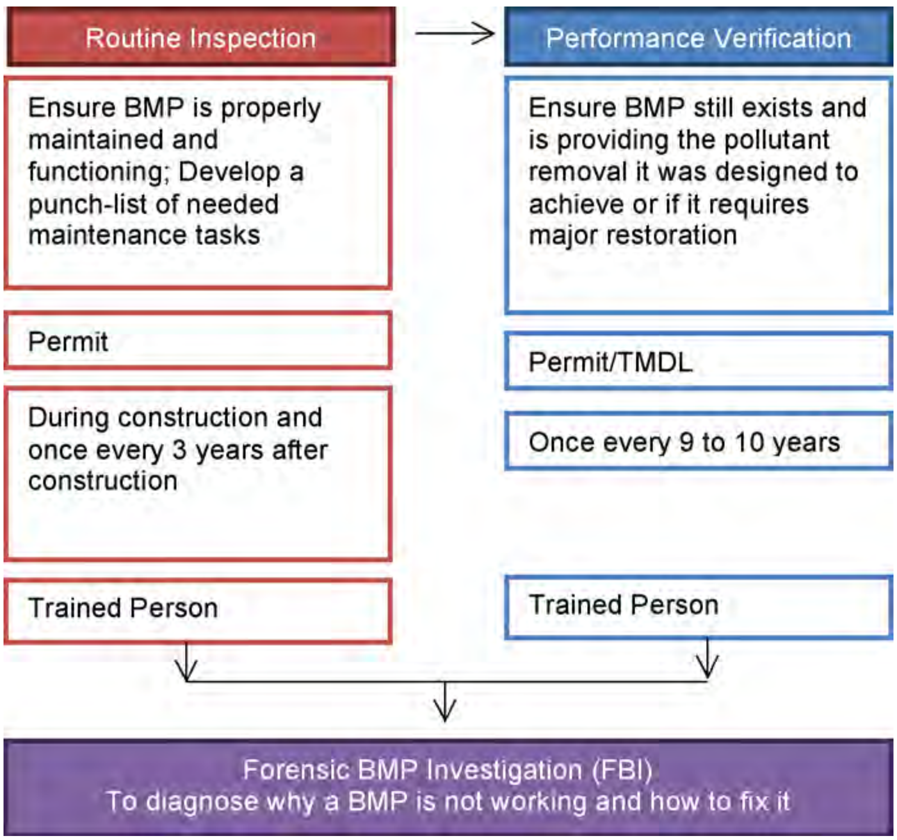

Figure 2.5-2. Routine inspections and performance verification are shown with descriptions, application, timeframe, personnel, and endpoint. Adapted from Goulet and Schueler (2012).

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Chapter 3:

Conservation Principles and Neighborhood Site Design for Low Impact Development

3.1 Introduction to Conservation Principles and Neighborhood Site Design

Many coastal communities are facing the challenge of balancing land development and economic growth with the protection of their unique and valuable local natural resources. The population growth level estimated by Allen and Lu (2003) for the Charleston, Berkeley, and Dorchester area is expected to reach 49% from 1994 to 2030 (263,000 people). Driven by such population growth, the land development process significantly alters the landscape by converting open areas, such as forests and agriculture, into urban or commercial land uses. During this process, clearing and grading are used to remove vegetation and topsoil, while cutting and filling are used to alter natural drainage features and depressional areas to create clear and level building sites. These land disturbing activities have direct negative impacts on both terrestrial and aquatic resources, often leading to a nearly complete loss of natural function. A lack of balance between land development and natural resource protection can result in a wide range of unintended negative impacts such as degradation and/or loss of the freshwater, estuarine, and marine resources found within the coastal plain.

Site assessment and design for LID seeks to minimize impervious cover, conserve more natural areas, and use pervious areas more effectively to treat stormwater runoff. This approach affords greater protection to water resources by reducing both stormwater runoff volume and pollutant loads into downstream waters.

Clearly, a change in development patterns at both the watershed and site scales is needed to balance continued land development with natural resource protection. Fortunately, development projects can be planned and designed to reduce their impact on coastal resources, both aquatic and terrestrial, particularly when an effort is made to protect and **conserve natural areas**, **reduce impervious cover**, and **integrate stormwater management** with site design. These principles, which are collectively known as Better Site Design (BSD), can provide impressive reductions in post-construction stormwater runoff rates, volumes, and pollutant loads. Also, they can reduce development costs and increase property values (MacMullan and Reich, 2007; Winer-Skonovd et al., 2006; US EPA, 2007). BSD techniques are applied most readily on new residential and commercial development projects. In addition, many of the techniques are applicable to redevelopment or infill scenarios. Table 3.1-1 provides an overview of the 22 BSD development principles with additional stormwater and other resource issues included. While some of these principles can be applied easily by a developer, others may require changes in local regulations. More detailed information for site assessment and design can be found in documents from the Center for Watershed Protection (CWP, 1998; CWP, 2009; CWP, 2010).

Table 3.1-1. Twenty-two Better Site Design Model Development Principles (CWP, 1998) and updated Stormwater and Other Resource Issues (CWP, 2013).

Principle	Description
Street Width	Design residential streets for the minimum required pavement width needed to support travel lanes; on-street parking; and emergency, maintenance, and service vehicle access. These widths should be based on traffic volume.
Street Length	Reduce total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.
Right-of-Way (ROW) Width	Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate the travel-way, sidewalk, and vegetated open channels. Utilities and storm drains should be located within the pavement section of the ROW wherever feasible.
Cul-de-sacs	Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Consider alternative turnarounds.
Vegetated Open Channels	Where density, topography, soils, and slope permit, vegetated open channels should be used in the street right-of-way to convey and treat stormwater runoff.
Parking Ratios	The required parking ratio governing a particular land use or activity should be enforced as both a maximum and a minimum in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance taking into account local and national experience to see if lower ratios are warranted and feasible.
Parking Codes	Parking codes should be revised to lower parking requirements where mass transit is available or where enforceable shared parking arrangements are made.
Parking Lots	Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in spill over parking areas.
Structured Parking	Provide meaningful incentives to encourage structured (e.g. parking garage)and shared parking to make it more economically viable.
Parking Lot Runoff	Wherever possible, provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands.
Open Space Design	Advocate open space development that incorporates smaller lot sizes to minimize total impervious areas, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection.

Table 3.1-1. Twenty-two Better Site Design Model Development Principles (CWP, 1998) and updated Stormwater and Other Resource Issues (CWP, 2013).

Principle	Description
Setbacks and Frontages	Reduce side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.
Sidewalks	Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.
Driveways	Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes.
Open Space Management	Clearly specify how community open space will be managed and designate a sustainable legal entity responsible for managing both natural and recreational open space.
Rooftop Runoff	Direct rooftop runoff to pervious areas, such as yards, open channels, or vegetated areas. Avoid routing rooftop runoff to the roadway and the stormwater conveyance system.
Buffer System	Create a variable width, naturally vegetated buffer system along all perennial streams. These buffers should also encompass critical environmental features such as the 100-year floodplain, steep slopes and freshwater wetlands.
Buffer Maintenance	The buffer system should be preserved or restored with native vegetation that can be maintained throughout the planning, delineation, construction, and occupancy stages of development.
Clearing and Grading	Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to build lots, allow access, and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner by grouping areas of open space together.
Tree Conservation	Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native plants. Wherever practical, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas to promote natural vegetation.
Land Conservation Incentives	Incentives and flexibility in the form of density compensation, buffer averaging, property tax reduction, stormwater credits, and by-right open space development should be encouraged to promote the conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, off-site mitigation consistent with locally adopted watershed plans should be encouraged.
Stormwater Outfalls	New stormwater outfalls should not discharge unmanaged stormwater into jurisdictional wetlands, aquifers, or sensitive areas.
Stormwater and Other Resource Issues (CWP, 2013)	Allow pervious paving in driveways, streets, and parking lots. Provide design standards, maintenance guidance, and inspection protocols. Protect streams and wetlands by ensuring all needed permits are issued prior to the clearing and grading permit. Require setbacks between septic systems and streams. Protect rural land using Transfer of Development Rights and Purchase of Development Rights programs.

3.2 Conservation of Natural Areas

Some of the key conservation principles for coastal South Carolina include protecting critical resources (such as open space, tree canopies, native vegetation, soils, and buffers) and reducing impervious cover. These conservation principles, as noted in Table 3.1-1, are part of an overall watershed approach to stormwater management. The conservation principles are detailed here and include available science, policy recommendations, and examples.

Coastal counties across the country contain 53% of the nation's population, yet account for only 17% of U.S. land area, excluding Alaska (Crossett et al., 2004). Furthermore, the coastal counties of the southeastern United States have seen unprecedented growth over the last 30 years, with populations increasing by 64% between 1970 and 1990 (US EPA, 2002). More specifically, between 1973 and 1994, the population of Charleston, SC grew 40% with a disproportionate increase in urban land area of 250% (Allen and Lu, 2003). Most researchers predict that during the next 20 to 30 years, the Southeast will continue to experience high population growth (DeVoe and Kleppel, 1995; NOAA, 1999; Crossett et al., 2004) and most of this growth will occur along the coast due to the influx of retirees and job seekers (US Census Bureau, 1998; Crossett et al., 2004). Alig et al. (2004) noted that the Southeast has more built land per capita than any other coastal plain region. In South Carolina, this development equated to an economic output of about $40 billion in 2000 and 25% of the state's employment growth (Holland and Sanger, 2008). Coastal land is valuable, and establishing future land development patterns to protect the natural resource will secure the economic value for future generations.

The rapid pace of land conversion to accommodate the coastal population boom has resulted in significant losses of forests, wetlands, and other ecologically valuable lands. For example, the Atlantic and Gulf of Mexico coastal watersheds experienced a net loss of more than 385,000 acres of wetlands between 1998 and 2004 even though the country as a whole showed a net gain in wetland acres during this time (Steadman and Dahl, 2008). Loss of wetlands and forests, combined with the addition of impervious cover associated with urbanization, has been shown to result in a rapid decline in the condition of coastal plain streams, tidal creeks, and estuaries.

Despite the abundance and economic importance of natural features found in the coastal plain, a relatively small proportion is designated for protection by coastal communities. According to a Watershed Planning Needs Survey of Coastal Plain Communities (Law et al., 2008) conducted by the Center for Watershed Protection, 54% of communities reported that less than 10% of the land area in their community was designated for conservation.

Promoting conservation can provide several ecosystem services produced by the interaction of living and non-living elements. Examples of these benefits were discussed in *Environmental Benefits of LID* in Chapter 1 and are summarized by the Sustainable Sites Initiative:

- Global and local climate regulation
- Air and water cleansing
- Water supply and regulation
- Erosion and sediment control
- Hazard mitigation

- ✧ Pollination
- ✧ Habitat functions
- ✧ Waste decomposition and treatment
- ✧ Human health and well-being benefits
- ✧ Food and renewable non-food products
- ✧ Cultural benefits

Land Conservation Strategies

Urban sprawl in the coastal plain has reduced the amount of ecologically valuable lands, such as forests and wetlands. Allen and Lu (2003) modeled Berkeley, Charleston, and Dorchester urban growth for the next 30 years and found a 5:1 growth ratio (urban growth to population growth) that resulted in 618 square miles of natural or rural land converted to an urban land use. The urban land area predicted by 2030 reduces the area of forest land by 30%, cultivated farmland by 50%, wetlands by 35%, and tidal creeks by 70%. The urban growth in the region around Charleston, SC is estimated to consume forest and agricultural land at a rate six times greater than that of human population growth.

Permanently protecting the most ecologically valuable lands in coastal watersheds is a vital part of improving coastal water quality to reach 303(d) benchmarks[1] in the face of accelerated urbanization. Because local governments have control over land use decisions, they are often the best entity to help fill in the gaps in state or federal natural resources protection. For example, the need for local wetland protection is reflected in the Law et al. (2008) survey results of residents in the US coastal plain (including 12 responses from SC out of 73 total), which shows that 37% of respondents indicated that ditching of wetlands is a problem in their communities and 46% agreed that more should be done to protect their local wetlands.

Protection is difficult without properly documenting natural assets. An up-to-date natural resources inventory is invaluable to assist local governments with conservation of sensitive resources. Natural resources inventory maps can provide geospatial information for natural habitat areas present in a community, including water resources, soils, sensitive natural resource areas, critical habitats, and other unique coastal resources. Prioritization of specific sites is an important step to guide decisions about how to target conservation programs, funding, and local protection regulations. This is especially useful for communities with extensive natural resources who wish to accommodate future growth while protecting the most sensitive or valuable lands.

An effective prioritization system often begins by identifying the lands with the most environmental value (e.g., for drinking water protection, habitat conservation or flood control, or other goals). Next, the identified lands are then ranked by evaluating feasibility factors, potential threats, and using community input, if available. See Table 3.2-1 for some examples of ranking criteria.

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[1] The term 303(d) list refers to the list of impaired and threatened waters that the Clean Water Act requires all states to submit for EPA approval every two years. The states identify all waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards. The states then establish priorities for development of Total Maximum Daily Loads (TMDLs) based on the severity of the pollution and the sensitivity of the uses to be made of the waters, among other factors. For more information, please see http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/overview.cfm

Table 3.2-1. Example Criteria for Prioritizing Conservation Areas

Type of Ranking Criteria	Example Measures
Environmental	♦ Adjacency to existing protected land ♦ Location in watershed ♦ Continuity, contiguity, and connectivity of vegetative cover ♦ Ecological significance (e.g., forest structure or presence of habitat for rare, threatened, or endangered species)
Vulnerability	♦ Development pressure (based on location of parcels within urban growth area, zoning, distance from major road, or as indicated in a build-out analysis or other development threat data set/map) ♦ Current protection status ♦ Projected level of sea level rise
Feasibility	♦ Landowner willingness to sell or donate ♦ Status of development plans for the parcel ♦ Cost per acre ♦ Anticipated management costs
Community	♦ Community acceptance of project ♦ Recreational value

Many tools are available to assist with natural resource prioritization. Some tools calculate ranking criteria (e.g., patch size of remaining forest, relative influence of a parcel on downstream water quality, connection to nearby resources), while others can take the user's input data and automatically generate the prioritization.

Ranking land parcels for conservation based on environmental value requires an understanding of the specific functions of interest. For example, some communities may be concerned primarily with conserving lands that protect remaining forest land or critical habitats, while other communities may be more focused on acquiring lands that protect downstream water quality and protect shorelines from erosion. Once the functions of interest have been determined, then the necessary data to assign functions to specific natural resources can be collected. As an example, Tiner (2003) provides a method to assign functions to wetlands based on wetland type and landscape position. This information can be used to identify wetlands that are important for specific functions (Table 3.2-2). If desired, field assessment can be used to supplement and refine the preliminary functional assessment.

Documenting environmental values associated with natural resources may not be sufficient to convince elected officials or residents that a particular parcel or natural resource is worth conserving. However, placing an economic value on the services provided by specific natural resources may serve as a useful tool to justify their protection. Economic valuation of ecosystem services aims to make ecosystem goods and services directly comparable to other sectors of the economy, and can also be incorporated into a prioritization system. An overview of the process of ecosystem valuation and available methods is provided at http://www.ecosystemvaluation.org/.

Table 3.2-2. Wetland Functions, Services and Replacement Options

Wetland Functions Associated with Services*		Replacement Options
Flood protection	♦ Surface water detention ♦ Coastal storm surge detention	♦ Stormwater treatment practices (storage) ♦ Dikes and levees ♦ Advanced floodplain construction design
Recreation	♦ Provision of habitat for fish and other aquatic animals ♦ Provision of waterfowl and waterbird habitat ♦ Provision of other wildlife habitat	♦ Wetland restoration ♦ Species stocking
Maintain drinking water quality	♦ Nutrient transformation ♦ Retention of sediments and other particulates	♦ Water filtration plants ♦ Develop new water source
Shoreline property protection	♦ Shoreline stabilization ♦ Coastal storm surge detention	♦ Revetments ♦ Stream bank stabilization and repair practices ♦ Stormwater treatment practices for channel protection
Maintain baseflow in streams	♦ Streamflow maintenance	♦ Deeper wells ♦ Alternative water source
Wildlife habitat and biodiversity	♦ Provision of habitat for fish and other aquatic animals ♦ Provision of waterfowl and water bird habitat ♦ Provision of other wildlife habitat ♦ Conservation of biodiversity	♦ Wetland restoration ♦ Species stocking
Commercial products from wetlands (e.g., peat, timber, cranberries, rice, fish, shellfish)	♦ Provision of habitat for fish and other aquatic animals ♦ Provision of waterfowl and waterbird habitat ♦ Provision of other wildlife habitat ♦ Conservation of biodiversity	♦ Wetland restoration
Reduce pollutants in streams and stormwater	♦ Nutrient transformation ♦ Retention of sediments and other particulates	♦ Stormwater facilities with water quality criteria

** functions derived from Tiner, 2003*

Incorporating existing local economic data into efforts to educate the public about natural resource values is one alternative to an economic valuation study. For example, collecting data on tourist expenditures and tying these dollars to natural areas in the community (e.g., total amount spent on hunting or fishing) can help make the case for preserving the quality of these resources for future visitors and the local economy.

After identifying and prioritizing parcels with significant natural resources, the resulting map and prioritization of sites for conservation should be included in the local watershed plan, open space plan, and the comprehensive land use plan (if one exists). This allows the community to use this information when making decisions about where to locate future growth, and provides a sound basis for targeting lands for conservation as funds become available. Land conservation planning does not just end here though; communities can play an active role in advocating for raising conservation funds. In fact, many local governments do this successfully given that roughly two-thirds of land conservation funding nationwide comes from local sources, such as sales tax, property tax, and revenue bonds. The natural resources inventory and site ranking can also be used to develop natural resource protection regulations (e.g., an overlay zone for protection of shoreline wetlands and their buffers).

For more information about natural resource inventories and prioritization see the following resources:

- ✧ South Carolina Natural Resources Department – Start with the state natural resource department for the mapping resources and other resources available.
    - **http://www.dnr.sc.gov/**
    - See also the SC Heritage Trust Program at **http://www.dnr.sc.gov/mlands/hpprogram.html**
- ✧ The Community Resources Inventory was designed specifically for coastal South Carolina
    - **www.cri-sc.org**
- ✧ NOAA Coastal County Snapshots
    - **http://www.csc.noaa.gov/digitalcoast/tools/snapshots**
    - Search by county to find information related to flood exposure, wetland benefits, and economic value of jobs related to marine resources.
- ✧ Nature Serve - The NatureServe network collects and analyzes data about the plants, animals, and ecological communities of the Western Hemisphere.
    - **http://www.natureserve.org/biodiversity-science/species-ecosystems**
- ✧ National Wetland Inventory (NWI) Maps – show the wetland geographic extent.
    - **http://www.fws.gov/wetlands/index.html**
- ✧ Wetlands-At-Risk Protection Tool (WARPT)
    - **http://www.wetlandprotection.org/**
- ✧ US Geologic Survey's National Gap Analysis Program - species ranges and distribution for conservation planning.
    - **http://gapanalysis.usgs.gov/species/**

- ✧ "Natural Resource-Based Planning for Watersheds: A Practical Starter Kit," a UConn Cooperative Extension manual by Chet Arnold and Jim Gibbons of UConn's NEMO (Non-point Education for Municipal Officials) Team.
  - **http://nemo.uconn.edu/tools/publications.htm**

Preserve and Maintain Open Space

Stormwater managers should begin to address stormwater at a regional scale by promoting the preservation of open space and critical ecological features in a site plan. Preserving open space is critical to maintaining water quality at the regional level. Large, continuous areas of open space reduce and slow runoff, absorb sediments, serve as flood control, and help maintain aquatic communities. Preserving ecologically important land, such as wetlands, buffer zones, riparian corridors, and floodplains, is critical for regional water quality.

Open space development, also known as cluster design, is a compact form of development that concentrates density on one portion of the site in exchange for reduced density elsewhere. Minimum lot sizes, setbacks, and frontage distances are relaxed to provide common open space (CWP, 1998). Not only does open space design allows for environmental benefits such as stream protection, but it also provides other benefits like preservation of rural character. Open space design results in less impervious cover and therefore less stormwater runoff. Compared to traditional development, open space development can reduce the annual runoff volume from a site by 40-60%, nitrogen loads by 42-81%, and phosphorus loads by 42-69% (CWP, 1998).

Better Site Design recommends that communities consider making open space development a "by-right" development option (e.g. the property owner has the right to develop or redevelop without reviews as along as the development is consistent with existing ordinances and/or plans for the area) in order to ensure certainty and speed of project approval, which are prime considerations for developers. Zoning is an important consideration for open space design as flexibility in design sharply declines as the density of the base zone increases. Additionally, open space developments can be significantly less expensive to build than conventional subdivision developments as a result of savings in road building and stormwater management (CWP, 1998).

Open Space Case Study: Spring Island, Beaufort County

One example of open space development in the Lowcountry can be found on Spring Island. On the 3,000 acre island, about one third of all land is left as undeveloped, preserved natural areas. The initial plan approved by Beaufort County in 1985 included 5,000 units; the developer chose to reduce that amount by over 90 percent to a total of 410 units, resulting in a gross density of over 7 acres per home site.

Site plan for Spring Island

Protect Critical Resources: Existing Soils, Vegetation, and Wetlands

Coastal plain natural resources form the basis of the local economy in many communities because they are important for recreation and commercial activities, such as fishing and shellfish harvesting. In fact, the economic benefit provided by coastal and estuarine resources has been estimated at more than $800 billion dollars nationally (Pendleton, 2008). A 2009 study by the University of South Carolina's Moore School of Business found that 235,000 jobs and $30 billion in economic benefits are tied the state's natural resources. In addition, coastal resource-based tourism generates $3.5 billion annually and supports 81,000 jobs (USC 2009). While local officials in coastal communities may recognize these values, often they do not prioritize land conservation to protect water quality. The connection between uplands and water resources is less obvious and it is difficult to measure the value of the 'free' services provided by these lands. Voluntary land conservation is expensive; however, once these resources are lost, they are expensive to replace. For example, the cost to create wetlands for flood control is on the order of 100 times what it would cost to protect existing wetlands through simple land protection efforts (Costanza et al., 1997).

The Atlantic Coastal Plain hosts an abundance of natural resources, such as hardwood and pine forests; rivers, streams and their floodplains; and extensive wetland complexes. Important coastal resources found here include maritime forests, estuaries, dunes, beaches, groundwater aquifers, tidal creeks, tidal wetlands, and shellfish beds. These natural areas provide a variety of ecological benefits ranging from flood protection and water quality improvement to shoreline protection and wildlife habitat.

Inland Atlantic Maritime Forest is critically imperiled habitat along the coast and has suffered significant losses (Lord, 2013). Coastal plain wetland ecosystems include depressions, pocosins, Carolina Bays, cypress domes, marshes, and bottomland hardwood forests; certain habitats, such as Carolina Bays and longleaf pine savannahs, are rare or unique to this area and support threatened or endangered species. For example, longleaf pine savannahs are home to the endangered red-cockaded woodpecker, gopher tortoise, indigo snake, and many threatened songbird populations. The South Carolina Lowcountry is one of the few places in the country to find three unique genera of carnivorous plants: Venus flytraps are found along edges of pocosins, pitcher plants inhabit the wetter depressions of longleaf pine habitats or Carolina bays, and sundews establish themselves on seepage slopes and bogs. These rare and unique plant and animal communities add distinct character and ecological services to the coastal area and should be protected. The SC Department of Natural Resources published a Best Management Practices for Wildlife in Maritime Forest Developments to provide guidance to minimize the impacts on wildlife and their habitats as development along the coast continues. See http://www.dnr.sc.gov/marine/pub/BMPSforCoastWeb.pdf for more information.

South Carolina's tree cover in the coastal plain consists of oak-hickory-pine forest with deciduous and evergreen hardwoods. Most of the coastal plain was cleared for agriculture in the 1700s and the reforestation that occurred since that time represents the current forest cover. Trees provide several benefits that include habitat for birds and wildlife, recreation, temperature and noise reduction, air and water quality improvements, and coastal storm buffers (McPherson et al., 2006). Trees and forests offer several environmental benefits; however, land development procedures commonly remove all or most trees (see following Protect Tree Canopy section). Preserving open space and providing land conservation protect trees and forests.

Land Use Planning Science to Policy Case Study: Northern Beaufort County, South Carolina Regional Plan

Local scientific data and reports (e.g., water monitoring and population growth projections) and community feedback highlighted the need for a Regional Plan and provided the basis for the plan's basic elements, such as Beaufort County's Stormwater Best Management Practice (BMP) Manual, Beaufort Resource Protection elements, and Beaufort Special Area Management Plan. Facing a growth projection of approximately 53% by 2025, Beaufort County, the City of Beaufort, and the Town of Port Royal developed a regional comprehensive plan to combat uninhibited urban growth and develop common goals. A steering committee with representatives from each jurisdiction and a technical advisory committee developed the plan. Each jurisdiction agreed to use the regional planning framework in the plan as guidance for local-level planning decisions. The strategy includes a land use plan, transportation planning strategy, the fiscal impacts of growth, environmental standards, regional planning initiatives, and a framework for implementation. Additionally, the plan delineates a future growth boundary that includes preserving over 60% of land for rural use. Recommendations to protect natural resources included regional adoption of the Beaufort County Stormwater BMP Manual, which requires both water quality and quantity control, promotes vegetative buffers, and prohibits development adjacent to high quality water bodies. The Northern Beaufort County Regional Plan is the starting point for an ongoing collaborative regional planning process, dialogue, and action (McBride Dale Clarion 2007). In South Carolina, local research was the starting point for a Regional Plan that led to three improved zoning ordinances and updated comprehensive plans that contain common language for improved water protection, better land use planning, and the prevention of coastal sprawl (Drescher et al., 2011).

Forested wetlands in coastal plains are a transitional land cover type and are especially vulnerable to urban growth and climatic variability (Dai et al, 2013). In the Waccamaw Neck of Georgetown County, SC, a ten year study of coastal forested wetlands indicated that typically wet sites were more impacted by drought conditions than dry or intermediate sites as measured by the aboveground net primary production (Conner et al., 2011).

Coastal wetlands protect inland areas from storm impacts, reduce upland pollutant loads to the nearshore waters, and serve as habitat for fish, birds, and shellfish (Nixon, 1980; Jordan et al., 1986; Valiella, 2000; Morris et al., 2002). Brinson (1993) developed the hydrogeomorphic (HGM) approach of classifying wetlands based on their hydrologic regimes and landscape position. The HGM classification of wetlands also determines the types of functions provided by the wetland (Table 3.2-3).

Table 3.2-3. Hydrogeomorphic Wetland Classification[1]

HGM Wetland Type	Description	Common Functions and Values
Depressional	Topographic depression with closed contours that may have inlets or outlets, or lack them	♦ Flood storage ♦ Habitat ♦ Pollution treatment ♦ Erosion control
Slope	Surface discharge of groundwater on sloping land that does not accumulate	♦ Habitat ♦ Pollution prevention ♦ Erosion control
Flat	Low topographic gradients, such as old glacial lake beds, with moderate to abundant rainfall	♦ Habitat ♦ Pollution prevention ♦ Flood storage ♦ Limited recreation
Riverine	Occur in the floodplain and riparian corridor of larger streams and rivers (e.g., 2nd order and higher)	♦ Flood conveyance and storage ♦ Shoreline protection and erosion control ♦ Pollution treatment ♦ Fish and waterfowl habitat ♦ Recreation
Fringe	Adjacent to lakes or estuaries	♦ Habitat ♦ Pollution treatment ♦ Water supply protection (lake fringe only) ♦ Shoreline protection and erosion control ♦ Recreation

[1]based on Brinson (1993)

Although wetlands are valuable ecosystems, wetland loss is common especially in coastal areas. The latest Status and Trends of Wetlands in The US 2004-2009 (Dahl, 2011) reported the loss of approximately 111,000 acres of emergent estuarine wetlands; this is 2.4% of the total wetland area. Key findings include:

- In salt water systems, the trend is towards an increase in non-vegetated tidal wetlands.
- The increase in tidal non-vegetated area came primarily from former vegetated salt marsh.
- Ninety nine percent of losses of estuarine emergent wetlands were attributed to the effects of coastal storms, land subsidence, sea level rise, saltwater intrusion, or other ocean processes.

Coastal Wetlands and Climate Change

The focus on functions provided by natural resources is one that may be particularly useful to coastal communities subject to sea level rise. Conserving coastal wetlands and their buffers is an effective strategy to protect communities from coastal storms and hurricanes. However, coastal wetlands are also most at risk of impacts from sea level rise, especially in places where levees or seawalls restrict their inland migration. Coastal communities will need to determine local elevation changes and the wetland surface accretion rates to better understand wetland sustainability in their area (US EPA, 2009).

Communities that are further inland can also use wetland protection as one aspect of adapting to changing rainfall patterns by identifying areas with high value for flood control. Stream and river corridors should also rise to the top of the conservation priorities to simultaneously reduce flood damage and stormwater runoff.

- ✧ Rising sea levels are expected to continue to inundate or fragment low-lying coastal habitats.
- ✧ Coastal habitats will likely be increasingly stressed by climate change impacts that have resulted from sea level rise and coastal storms of increasing frequency and intensity.

South Carolina has lost about 28% of wetlands to agriculture and urbanization. The 28% wetland loss represents an estimated 6.4 million acres of wetlands present in 1780 which decreased to 4.6 million acres. In fact, Charleston's downtown "upland" peninsula area resulted from filled in salt marshes in the 1700s (Yarrow, 2009). Wetlands serve a critical role for protecting and restoring coastal water quality, habitat, and resiliency from storms. Although wetlands should never be used as the sole stormwater management practice (it is illegal according to the Clean Water Act), protecting wetlands provides many stormwater benefits. Therefore, wetland protection and restoration is an important stormwater management strategy.

The Tidal Creek booklet by Holland and Sanger (2008) outlined tidal creek recommendations at the municipality and county scale, the watershed or neighborhood planning scale, and at the site or homeowner scale based on over fifteen years of coastal SC research. Clemson University Extension Services's Yarrow (2009) provided the following three basic wetland management plan considerations:

1. Inventory – Determine the wetland type that is targeted for management, the ownership, and the wetland size and condition. All the inventory factors help determine the wetland management strategies needed to attain the goals.
2. Management Considerations - Determine how the area is being used at the present time and will be used in the future. Also, consider relevant local, state, and federal policy guidelines and potential assistance programs.
3. Management Goals – Clearly outline the management goals for the wetland and for the owner.

There are several tools to support wetland protection and restoration available through:

- ✧ SC DNR (**http://www.dnr.sc.gov/wildlife/wetlands/**),
- ✧ US Environmental Protection (**http://water.epa.gov/type/wetlands/index.cfm**),
- ✧ US Fish and Wildlife Service (**http://www.fws.gov/wetlands/Status-and-Trends/index.html**), and others.

A recent tool (developed by the Center for Watershed Protection in cooperation with the US EPA Office of Wetlands, Oceans, and Watersheds) for wetland assessment and protection focused on the local government audience is the Wetlands-At-Risk Protection Tool (WARPT). The WARPT is a process for local governments and watershed groups that acknowledges the role of wetlands as an important part of their community infrastructure, and is used to develop a plan for protecting at-risk wetlands and their functions. The basic steps of the process include quantifying the extent of at-risk wetlands, documenting the benefits they provide at various scales, and using the results to select the most effective protection mechanisms. A free webinar, resources, and the WARPT tool are online at http://www.wetlandprotection.org/.

Promote Buffers

Coastal buffers are another important resource to protect and restore. Protection for coastal forests and coastal wetland areas reduce the harmful effects of land use derived stormwater pollution and provide additional benefits such as habitat and property protection, privacy screening, and additional ecosystem services.

In the coastal plain, well managed and adequately sized aquatic buffers are critical for processing nutrients; filtering pollutants; providing habitat for marsh birds, juvenile fish and shellfish species; dissipating wave energy; retaining floodwaters; and providing protection from erosion. For example, the following five criteria are specified within aquatic buffer ordinances for St. Mary's County, MD; Ocean City, MD; Northampton County, VA and Wilmington, NC:

- ✧ Minimum buffer width
- ✧ Minimum requirements for vegetative cover
- ✧ Re-vegetation required if vegetation currently does not exist
- ✧ Program/mechanism to inform new property owners
- ✧ Invasive species control plan, no use of herbicides/pesticides

The SC guidance for buffer ordinances lists the benefits of buffers and suggests solutions to protect property owner rights with flexible buffer ordinances that contain the following (Halfacre-Hitchcock & Hitchcock, 2005):

- ✧ Buffer averaging
- ✧ Density compensation
- ✧ Conservation easements
- ✧ Purchase of development rights
- ✧ Variances
- ✧ Allow selective pruning and clearing to provide a view corridor

South Carolina has several buffer guidance documents that provide buffer definitions, examples, case studies, and recommendations. These buffer guidance documents include:

- The Final Report of the Shoreline Change Advisory Task Force "Adapting to Shoreline Change: A Foundation for Improved Management and Planning in South Carolina" calls for a 25 foot minimum buffer for new development in the coastal zone, tax incentives for buffers, and more shoreline buffers (SCDHEC-OCRM, 2010).
- The SC Task Force for Forested Riparian Buffers report recommends 100 to 300 foot riparian buffers (SCTFFBR, 2000).
- The "Critical Line Buffer Ordinances: Guidance for Coastal Communities" provides an overview for buffer intent, buffer implementation, and provided case studies in the City of Charleston and the Town of Mount Pleasant (Halfacre-Hitchcock & Hitchcock, 2005).
- The SCDHEC "Backyard Buffers for the South Carolina Lowcountry" provides guidance for buffer implementation and maintenance to homeowners (SCDHEC-OCRM, no 2000).
- The Clemson Carolina Clear H2Ownership factsheet series includes guidance for buffer areas adjacent to salt marshes, including a suggested plant list: **http://www.clemson.edu/cy/plants**.

Established by South Carolina's Coastal Tidelands and Wetlands Act, the critical areas in South Carolina (Figure 3.2-1) are the coastal waters, tidelands, and beach/dune systems. In these areas DHEC-OCRM has direct jurisdiction for permits to perform any alteration. Activities covered by a critical area permit include docks, bulkheads, footpaths, and additions to existing structures, such as boat lifts, floating docks, and pier heads. Currently, buffers are added for stormwater management treatment but are not required if stormwater management treatment is accomplished in another way. The NPDES General Permit for Stormwater Discharge From Construction Activities does have buffer requirements during construction, but they are not permanent buffers (SCDHEC, 2013). For more information, see

- Coastal Zone Management Act at **http://www.scstatehouse.gov/coderegs/c030.php**
- Coastal Tidelands and Wetlands at **http://www.scstatehouse.gov/code/t48c039.php**

Issues with long-term enforcement and maintenance are common. The top three enforcement issues identified in the survey include: a lack of standards for long-term maintenance (60%), enforcement limited to plan review (47%), and encroachment and clearing of buffers by property owners (38%). The practicality of identifying and enforcing buffers given very limited resources is a challenge that is by no means unique to the coastal plain.

Nutrient removal by buffers has been directly correlated with buffer width. Bason (2008) conducted a literature review of studies documenting increasing nitrogen removal with buffer width for coastal plain streams. The data indicate that approximately 80% nitrogen removal is achieved by stream buffers of approximately 80-90 feet, where incremental increases in removal efficiency (2% per additional foot of buffer width) are gained beyond this width. In addition, the data suggest that buffer widths of 150 feet or greater are more likely to consistently achieve their maximum potential for nitrogen removal. Wider buffers tended to remove more phosphorus, but no statistically

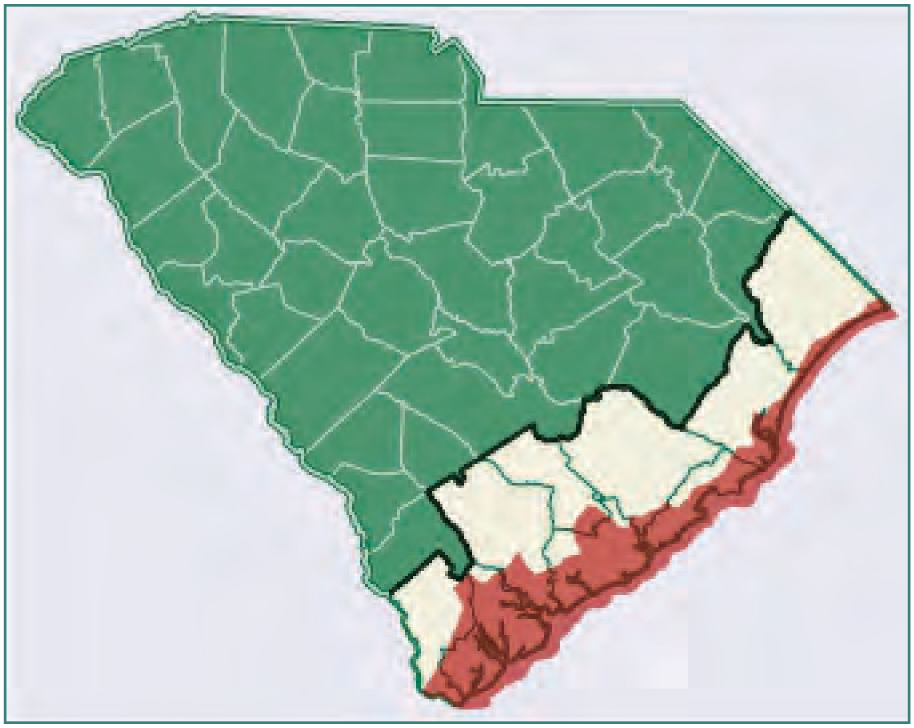

Figure 3.2-1. The Coastal Zone (tan) and Critical Area (red).
Image from SCDHEC-OCRM, available at http://www.scdhec.gov/environment/ocrm/

significant relationship was found. The minimum 80 foot stream buffer recommended for nitrogen removal was roughly estimated to remove around 66% of total phosphorus.

The recommended buffer vegetation in the coastal plain includes trees and herbaceous vegetation. On average, forested buffers remove 36% more nitrogen than grass buffers (Bason, 2008). Deeper roots from trees pick up nitrogen that is in subsurface flow. Forests also provide other benefits when located along waterways, including regulation of temperature, input of organic matter as an energy source to the stream ecosystem, and creation of habitat from leaf litter and woody debris that fall into the stream.

Effective natural resource protection ordinances specify the types of activities that are allowed or prohibited within the protected zone. Generally, buffer ordinances should limit allowable uses to clearing for shoreline access paths, view corridors, and passive recreation. Typically prohibited uses include paved surfaces, primary structures, grading, pesticide application, mowing, motorized vehicles, or any other activity that causes soil disturbance or contributes to pollution. In addition, septic tanks and drain fields as well as stormwater BMPs are often excluded from the buffer, and must be set back at an even greater distance beyond the buffer zone. Coastal communities may wish to modify these allowable and prohibited uses to allow landowners the views of and access to the water that drew them to the property while still protecting the environmental benefits of the buffer.

Where forested buffers are required but do not exist, native vegetation should be restored. Plants can be established in an aquatic buffer through natural regeneration, direct seeding, and/or planting of nursery-grown plants. If stream channels are incised, restoration and reconnection of the stream to the floodplain prior to reforestation will promote nutrient and sediment attenuation, reduce flow and scour, and encourage natural hydrological functions in the stream corridor. Buffer restoration targeted to headwater streams is particularly effective because that is where the largest proportion of annual stream nutrient loading enters the watershed and where the capacity to remove nitrogen is the greatest.

Policies should reflect the riparian buffer minimum widths recommended from scientific research and other design guidance presented in CWP (2010), Franzen et al. (2006), Bason (2008), Vandiver (2005), and others. A community's environmental goals can guide the riparian buffer width needed to meet the desired buffer function. For example, to achieve 80% N removal in the coastal plain, the recommended width ranges from 80 (adequate for N removal) to 150 feet (optimal N removal). However, if a community is concerned about a different pollutant or prescribes lower or higher removal efficiency, the width may vary. See Table 3.2-4 for coastal buffer width recommendations, targeted function, and the percentage of communities within the coastal plain that provide the recommended buffers. Efforts should be directed at maximizing buffer widths through compromise with developers and regulatory agencies.

Table 3.2-4. Coastal plain riparian buffer width recommendations, desired function, and community survey response (Bason, 2008; Law et al., 2008).

Waterbody Type	Recommended Width (ft)[1]	Desired Buffer Function[4]	Coastal Plain Survey Respondents with Buffer Ordinances Providing the Minimum Recommended Width
Nontidal wetlands	50 to 150	Nitrogen removal	31%
Ephemeral streams	80 to 150	Nitrogen removal	38%
Intermittent streams	80 to 150	Nitrogen removal	23%
Tidal wetlands	150[2] to 500[3]	Sea level rise protection	6%
Shoreline	150[2] to 500[3]	Sea level rise protection	6%

[1] Ranges are from Bason (2008) recommended buffer widths for adequate (low end of range) and optimal (high end) protection. Optimal protection option provides an estimated 90% N removal on average with at least 78% removal for most buffers.
[2] For sites with steep (> 0.09 rise/run) wetland/upland boundary. Buffer provides protection for an average of 132 years, based on landward migration rates of tidal wetlands for the Inland Bays.
[3] For sites with gradual (≤ 0.08 rise/run) wetlands/upland boundary. Buffer provides protection for an average of 88 years, based on landward migration rates of tidal wetlands for the Inland Bays.
[4] Desired buffer function is based on community and waterway need. N removal and SLR protection examples are provided.

Other communities may be interested in buffers to protect critical habitat for a species of concern, which can increase the recommended widths even further. Additional reasons to utilize buffers are to provide sediment removal, shoreline stability, and protection of a valued waterbody, 303(d) listed waterbody segment, or aquatic habitat protection. Translating coastal-specific findings to define riparian buffer widths and their ecological and economic benefits is critical for these recommendations to hold up in the face of development pressure and/or in areas that may require wider or restored buffers. In addition to the width recommendations above, the following buffer policy recommendations for effective coastal forested riparian buffers are included here (Drescher et al., 2011):

- ✧ Incorporate buffers into a comprehensive stormwater management strategy that includes source controls through education (Vandiver, 2005).
- ✧ Ensure mapping of buffers and other natural resources features are included in the comprehensive plan.
- ✧ Provide stormwater credits to buffers on a site as part of stormwater management for reduced storm flow.
- ✧ Allow buffer restoration projects in offsite mitigation programs.
- ✧ Enforce penalties and fines for destroying a buffer and require replanting.
- ✧ Do not allow piping through the buffer. Buffers will not reduce stormwater pollution or volume if the stormwater is piped through the buffer.
- ✧ Provide language in the ordinance that clearly defines variances in the buffer regulation to protect the property owner and receiving waters. An effective buffer ordinance also includes specific language detailing buffer inspection, enforcement, maintenance, delineation, allowable uses, restricted uses, and variance criteria (Schueler, 2000a).
- ✧ Provide buffer education to stakeholders in the community.
- ✧ Along the SC coast, groundwater has the potential to serve as a significant pollutant transport mechanism; therefore, it is suggested to use deep-rooted indigenous vegetation as a component of the buffer (Vandiver, 2005).

Protect and Promote Tree Canopy

Native trees, shrubs, herbaceous material, and grasses are important contributors to the overall quality and viability of the environment. Ideally, local government codes will promote the preservation of trees and native vegetation. In some cases tree protection can be done on a neighborhood or development level. Some private communities, such as Palmetto Bluff in Beaufort County, require the property owner to meet with staff naturalists to lay out home sites prior to development such that trees and buffers are protected; additionally, native vegetation is encouraged. High quality forest stands should be preserved prior to development (see *Protect Native Vegetation and Soils* section above). Tools that can be used for tree conservation include:

- ✧ Forest conservation ordinances
- ✧ Open space development practices
- ✧ Planting vegetation in street rights-of-way
- ✧ Preservation of trees during clearing and grading activities
- ✧ Reduced parking lot sizes with vegetated islands

Tree calculators can provide background and justification for the benefit or value of trees. To estimate the value of a tree, parameters such as air quality, water quality, dollars saved, dollars spent, and others are provided in the following tree calculators:

- ✧ US Forest Service Urban FORests Effects (UFORE) using i-Tree
  - **http://www.nrs.fs.fed.us/tools/ufore/**
  - i-Tree at **http://www.itreetools.org/**

- ✧ Natural Tree Benefits Calculator at **http://www.treebenefits.com/calculator/**
- ✧ American Forests Individual Tree Calculating Tools
  - **http://www.americanforests.org/our-programs/urbanforests/urban-forests-tools-resources/urban-forest-assessments-resource-guide/urban-forest-assessment-tools/individual-tree-calculator-tools/**

Research conducted in Charleston, SC was used to calculate tree costs and benefits, based on "typical" trees planted in residential yards, public streets, and parks (McPherson et al., 2006). Coastal plain cities spend about $18 per tree each year, including yard and public trees. Tree benefits were mostly from reduced stormwater runoff and energy as well as increased aesthetics and property values. Urban forests are estimated to reduce stormwater runoff 2 to 7 percent. In Charlotte, NC, street trees reduced stormwater runoff by 28 million cubic feet at an estimated value of $2 million per year. Annual average benefits for different types of trees are summarized here:

- ✧ Large: $107 to $127
- ✧ Medium: $31 to $40
- ✧ Small: $14 to $19
- ✧ Conifer: $40 to $62

The Charleston study used representative species such as Southern live oak (*Quercus virginiana*), Southern magnolia (*Magnolia grandiflora*), flowering dogwood (*Cornus florida*), and loblolly pine (*Pinus taeda*) to model the large, medium, small, and conifer trees, respectively, with growth curves adjusted for city street trees. This report provides an overview for coastal SC tree benefits, estimates values and costs, outlines tree planting guidance, and includes two town scenarios to demonstrate how communities can use the report's information for urban forest improvements.

The landscape community can promote, maintain, and educate the public to use better landscape practices, protect trees and buffer areas, and understand the benefit of plants in and around LID practices. Some trees and shrubs can be added to stormwater management practices such as in bioretention or tree planters (Day and Dickinson, 2008). Using trees for stormwater management has gained momentum in cities. This increased use of trees has led to research guidance for soil substrate (Davis, 2001), tree selection, and site constraints such as utilities, maintenance, and runoff reduction (McPherson et al, 2006; Drescher et al., 2012). Also, trees and shrubs can be added to cities in streets and sidewalks. A survey of 137 cities found that 95% have adopted tree management ordinances and 47% have tree canopy goals (City Policy Associates, 2008).

One important consideration for tree planting is the maintenance needed to keep the tree healthy and ensure that it provides the intended benefits. For example, increased tree canopy in an urban center means more leaf litter accumulates on the streets. While trees in urban areas provide multiple benefits in the community and can help to re-establish a more natural watershed nutrient cycling capacity, there is a potential for leaf litter to add to the nutrient loads associated with already impacted urban streams (Law et al., 2013; Walsh et al., 2005; Cowen and Lee, 1973). In urban watersheds, stormwater runoff quickly washes off the hardened landscape carrying leaf litter into storm drains. The urban system short circuits the natural nutrient processing that a forest would typically provide, such as pollutant transformation via filtering and decomposition; therefore, leaf pick up and street sweeping programs in urban areas are important to reduce leaf litter before it enters the storm drain network and streams. In Charleston County, nearly 59,000 tons of yard waste per year

Tree Protection Case Study: Oak Terrace Preserve, North Charleston, SC

Oak Terrace Preserve is a 55-acre sustainable redevelopment project located in Park Circle, North Charleston. In the 1940s, the federal government built temporary housing on this site for World War II shipyard workers. The houses were never intended for long-term habitation, and eventually fell into disrepair. The property was bought in 2003 by the City of North Charleston through a unique public-private partnership: the City of North Charleston as owner and the Noisette Company as development manager (starting in 2010, the Cedrus Development company took over management of the property). The redevelopment provided green sustainable features in home construction in addition to pocket parks, public space, an LID stormwater management system, and an extensive tree preservation program.

The Oak Terrace Preserve project will consist of approximately 300 single-family homes and 74 townhomes when complete. The project was designed to provide affordable housing, with prices starting in the $200,000s, and to promote sustainable design. Development activity commenced in 2006 (Phase 1) and should continue through 2014 (Phase 3).

An important aspect incorporated into the Oak Terrace Preserve project was the protection of its tree resources. Prior to development, Oak Terrace Preserve was home to over 600 trees, many of them were grand trees with 24 inch or larger diameters, including oaks, magnolias, and additional old-growth trees that are rarely found in a new community. Tree preservation and management was a top priority. A certified arborist performed a tree survey and assessment before construction. During site construction activities, fencing protected the trees and their critical root zone. The certified arborist's continued involvement on site was a major factor for the successful tree protection.

Oak Terrace Preserve has a more enhanced natural and sustainable stormwater management system than is typically designed in today's SC master planned communities. Oak Terrace used a combination of linear bioswales, temporary pocket park detention, and pervious alleyways for stormwater management. The linear bio-swales include engineered soil media designed to be porous and run continuously parallel on one side of the street. The streets are slightly sloped at about a 2% grade to drain to the 15 foot wide, v-shaped bio-swale. Currently, the Home Owner's Association owns and maintains the pervious alleys and pocket parks and other common areas on site (annual HOA fees are $420); the City of North Charleston retains ownership of the roads and bioswales that fall within the road rights-of-way and the HOA maintains the bioswales.

Pervious alleys and protected trees at Oak Terrace Preserve are collected and composted at the 36-acre Bees Ferry Landfill. This compost is then made available for purchase by the bag or ton. For more information, please see http://www.charlestoncounty.org/departments/SolidWaste/compost-facility.htm.

Reduce Impervious Cover

Perhaps the most defining characteristic of urban streams is the increase in the amount and velocity of stormwater or surface runoff to those systems (US EPA, 2012). As shown in Figure 3.2-2, impervious surfaces associated with urbanization reduce infiltration and increase surface runoff, altering the pathways by which water (and any associated contaminants) reaches urban streams. Common impervious surfaces include:

- Roads
- Parking lots
- Rooftops
- Driveways and sidewalks
- Compacted soils

All of the impervious surfaces that are present in a watershed constitute the watershed's impervious cover.

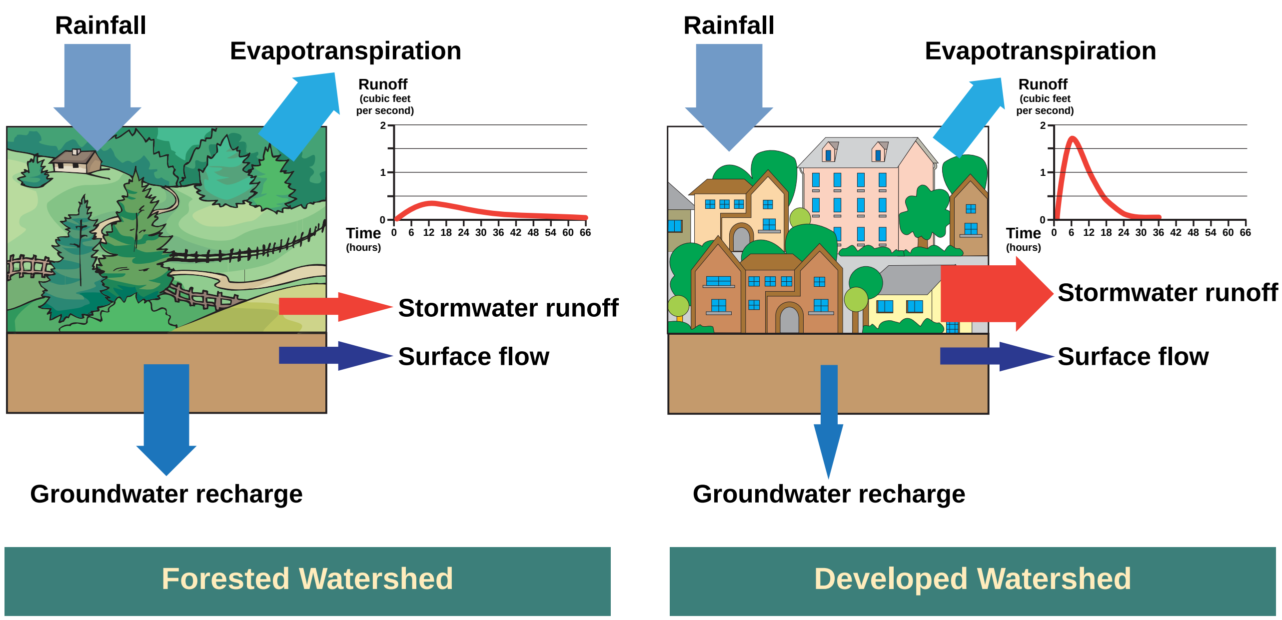

Figure 3.2-2. Visual representation of the differences in the volume and rate of stormwater runoff between an undeveloped forested watershed and a developed urban environment. The magnitude of the differences is represented by the size of the arrows as well as the height and width of the peaks in the graphs. (Image from SC Sea Grant, SC Department of Natural Resources, and National Oceanic and Atmospheric Administration)

Coastal communities struggle to balance the demand for prime real estate and increased revenues with the demand to protect the local resources that make these areas desirable. The coastal plain is a unique area for development and redevelopment due to its proximity to natural resources, limited available space, and stricter "critical zone" regulations. Land use changes over time have increased the impervious cover (IC) and managed turf, consequently reducing the landscape's ability to filter stormwater runoff efficiently or effectively. Managing IC is critical because increased IC is linked to impacts on water quality, wildlife, and human health through degraded water quality impacts (e.g., bacteria) (Mallin, 2000; Mallin et al., 2001; Holland et al., 2004; Schueler and Fraley-McNeal, 2009). The IC model (Schueler, 1994), which relates IC to receiving water quality, was recently updated (Schueler and Fraley-McNeal, 2009; Figure 1). The more recent analysis confirmed the stream quality thresholds identified by earlier research and added ranges to the IC thresholds to account for the variability in the response of watersheds as they transition from sensitive, impacted, non-supporting, and urban drainage classification of stream quality. For example, a watershed with 20 to 25% IC is "impacted" and exhibits a greater number of fair or good streams than "non-supporting"

Figure 3.2-3. Aerial image comparison of two developments with quarter-acre lots: (A) is from Beaufort, SC (~25% impervious surface) and (B) from Mt. Pleasant, SC (45% impervious cover). Images from Anne Blair, NOAA Hollings Marine Laboratory, and Google Earth.

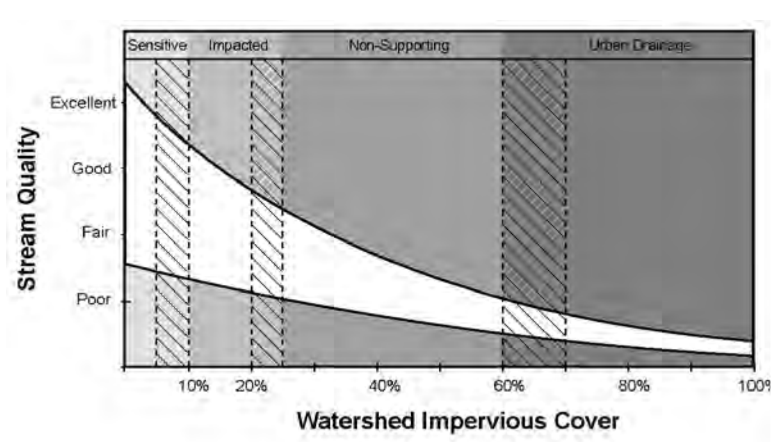

Figure 3.2-4. Impervious Cover Model update (Schueler & Fraley-McNeal, 2009). Reproduced with permission from ASCE.

watersheds but fewer fair or good streams than sensitive watersheds. For a comparison, see Figure 3.2-3. This means that the lives and livelihood of coastal residents deteriorate if urban sprawl continues as anticipated because poor water quality means reduced recreation, tourism, shellfish harvesting, etc.

The Impervious Cover Model (ICM) estimates stream quality based on percentage IC area (Figure 3.2-4). The hatched bars show the threshold from one classification to the next. Sharply defined thresholds were found to be rare and streams typically follow a continuous but variable gradient of stream degradation. The cone represents the observed variability in the response of stream indicators to urban disturbance as represented by the percent IC. For example, there is less variability in stream quality found at higher levels of IC, compared to watersheds with lower IC.

The suburban sprawl development pattern of the past 50 years needs to be reversed if coastal communities are to protect their watershed resources in the face of certain population growth. In its simplest form, comprehensive land use planning should determine where to develop and what development type to allow in each location. Comprehensive planning can direct and improve development patterns, e.g., transfer of development rights, purchase of development rights, and unsubsidized coastal flood insurance (as recently demonstrated by the Biggert-Waters Flood Insurance Reform Act of 2012). Impervious cover removal and preventing the creation of more impervious cover protects natural habitats and waterways. Impervious cover reduction, such as parking lot removal, can also be a standalone BMP or be coupled with additional stormwater management practices such as soil amendments or other LID practices.

Approaches for limiting and mitigating IC increases include:

- ✧ Limit IC at the site level through better layout of the development or by incorporating low impact development (LID), such as pervious pavement.
- ✧ Allocate land uses to the most appropriate areas of the community. Direct development to areas with existing development and infrastructure and/or already degraded subwatersheds and limit it in areas with known hazard areas, natural resources, drinking water sources, and pristine subwatersheds.
- ✧ Use transfer of development rights to encourage property owners near environmentally-sensitive areas (“sending areas”) to transfer their development rights to designated areas (“receiving areas”) that are better able to accommodate growth, such as infill sites. The “receivers” have the benefit of increased development capacity, and the “senders” get financial compensation for their transferred rights.
- ✧ Adopt a watershed or regional approach to land use planning to work with neighboring communities to minimize impacts to shared resources (e.g., drinking water supplies).
- ✧ Preserve ecologically important land by performing a natural resources inventory and directing new development away from these areas.
- ✧ Incorporate coastal hazard response, long-term shoreline change, and emergency management into plans by identifying potential hazard areas, restricting or discouraging development in these areas, or determining how to reduce risk to life and property in areas that were already developed.
- ✧ Encourage redevelopment and infill over conversion of natural lands to new development.

There are coastal South Carolina communities that limit their impervious cover. For example, the Town of Pawley's Island sets limits for impervious cover at 1,000 to 4,000 square feet and not exceeding 40% of the lot size. The Pawley's Island impervious cover limits are per the Article III, Zoning Regulations [3-5.8(A)] Lot Area Coverage. Another example is the Town of Sulllivan's Island, where 50% of the property must be landscaped surfaces. The Town of Sullivan's Island Article III RS-Single Family Residential District, Town, and Zoning Ordinances provide additional details about their impervious cover limits. High percentages of impervious cover in a catchment or watershed result in degraded water quality and poor habitat. These coastal South Carolina communities provide examples for limiting impervious cover for development.

Beaufort County has also established limits on impervious surface cover. Beginning in 1998, the County's BMP manual has incorporated a water quality worksheet designed to evaluate whether a proposed development plan meets the goal of 10% effective imperviousness (Beaufort County, 2012). A site with an "effective" or "equivalent" imperviousness of 10% will generate the quantity of runoff that would be generated by a site with 10% uncontrolled impervious surface. This goal was established based on pollutant-loading characteristics of low-density development with imperviousness of 10%, which prevents pollutants from reaching levels that threaten water quality and environmental wellbeing.

3.3 Neighborhood Site Design Considerations

Some planning guidance for the types of LID designs, such as open space development, have been covered in previous sections of this manual. This section addresses design considerations related to the layout of a neighborhood or development, such as roadways, parking, and landscaping.

LID Roadway Design

Up to 65% of the total impervious cover in the landscape can be classified as "habitat for cars" including streets, parking lots, and driveways (CWP, 1998). Streets constitute 40-50% of impervious cover in traditional residential developments. Shifting to narrower streets can result in a 5-20% reduction in impervious area in typical residential subdivisions (Schueler, 1995). A central concept in LID planning is minimizing impervious cover, and reductions in the total area of streets and parking lots can greatly lower a site's overall impervious cover.

Street Widths:

One way to reduce the amount of impervious cover is to minimize street widths. Residential streets should be designed to be as narrow as possible, based on current and future traffic volumes, without compromising safety (Table 3.3-1).

Table 3.3-1. Example Road Widths for Local Streets

Minimum Road Width (ft)	Parking	Average Daily Trips (ADT)	Number of Dwellings Served
20	Both sides	<200	20
22	One side	200-400	20-40
26	Both sides	400-2,000	40-200
28	One side	>2,000	>200
32	Both sides	>2,000	>200

(RI DEM & CRMC, 2011)

Conventional roadway design often calls for residential streets that are 32 to 40 feet wide, even if they only serve a few dozen homes. In less populated areas or where people make fewer average daily trips (ADTs), these wide stretches of pavement are unnecessary and create a number of problems:

- Vehicle speeds can increase, posing a safety risk to both drivers and pedestrians
- Construction and maintenance costs are higher than costs for a smaller road
- Associated rights of way (ROW) are larger, reducing the available land for development

Several national engineering organizations recommend that residential street widths can be 22 to 26 feet, provided that they serve neighborhoods with traffic volumes less than 500 trips per day, or 50 homes (AASHTO, 1994; ASCE, 1990). The narrower dimensions do not sacrifice emergency access, on-street parking, or vehicle and pedestrian safety. Some communities have implemented narrow street widths successfully (see Table 3.3-2). Residential streets between 18 and 22 feet wide earn positive credit in the CWP Codes and Ordinance Worksheet (CWP, 2013). Another strategy includes requiring permit applicants to minimize street width to the extent possible. For example, in Georgetown County, SC applicants for stormwater permits must show they have reduced road and driveway widths while maintaining a standard consistent with health and safety requirements and the county land use ordinance (GCSC, 2006).

Table 3.3-2. Road Width Recommendations

Road Type	Residential Street Width (ft)	Maximum Average Daily Trips
Beaufort County, SC	20 local residential 26 local residential (1 parking lane) 34 local residential (2 parking lanes) 28 local nonresidential 22 residential collector	240 (max peak hour volume) 240 (max peak hour volume) 240 (max peak hour volume) 1,000 (max peak hour volume) 800 (max peak hour volume)
Dorchester County, SC	22 collector 21 drive 19.5 court 17.5 residential alley 22 commercial alley	>3,000 1,000 -3,000 <1,000 <250 <500
State of New Jersey[1]	20 (no parking) 20 (one side parking)	0 - 3,500 0 - 3,500
Bucks County, PA[1]	12 (alley) 16 - 18 (no parking) 20 - 22 (no parking) 26 (one side) 28 (one side)	-- 200 200 - 1,000 200 200 - 1,000

[1] *CWP, 1994*

A common misconception is that wide streets are a necessity for pedestrian safety. However, it has been shown that narrower streets actually slow traffic, which helps to prevent accidents. Figure 3.3-1 illustrates that accidents are less common with narrower streets (Longmont, CO Study).

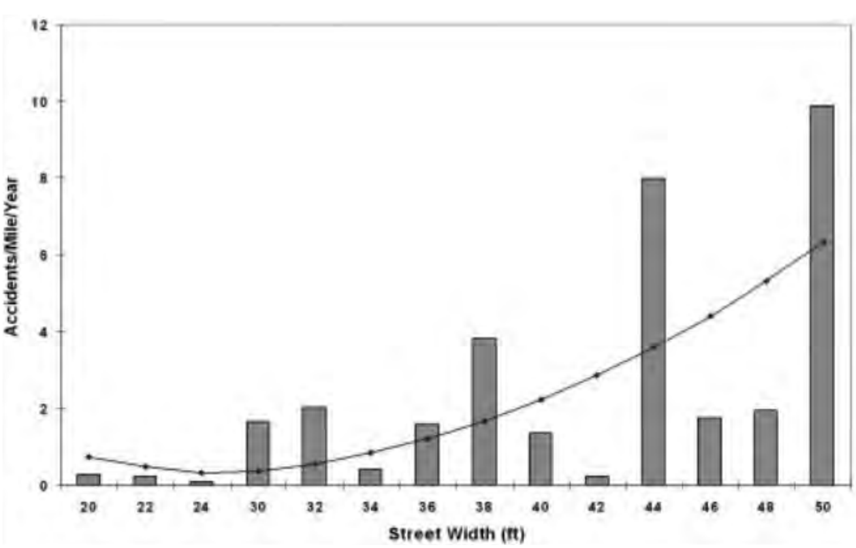

Figure 3.3-1. Relationship between Street Width and Accidents (Swift, et al., 1998 as in CWP, 1998)

Emergency vehicle access is an important consideration in road design and very wide roads are often designed to ensure it. However, the width is often excessive for emergency vehicles including fire trucks. A number of local fire codes (Table 3.3-3) permit roadway widths as narrow as 18 feet. In many residential areas, a minimum roadway width of 26 feet provides a 12-foot driving lane that accommodates fire truck passage as well as 7-foot parking or queuing lanes on each side of the driving lane (CWP, 1998).

Table 3.3-3. Street Width Requirements for Fire Vehicles

Width (ft)	Source
26 local urban streets (parking on both sides)	AASHTO 2011
18-20	US Fire Administration
24 (on-street parking) 16 (no on-street parking)	Baltimore County Fire Department
18 minimum	Virginia State Fire Marshall
24 (no parking) 30 (parking on one side) 36 (parking on both sides) 20 (for fire truck access)	Prince Georges County Department of Environmental Resources
18 (parking on one side) 26 (parking on both sides)	Portland Office of Transportation
(CWP, 1998)	

Right-of-Way Width:

The right-of-way (ROW) is the total land area that contains all of the cross-sectional features of the roadway, including pavement width, curbing, buffers, sidewalks, utilities, drainage, and grading (RI DEM & CRMC, 2011). The South Carolina Department of Transportation defines the ROW as "the land secured and reserved by the Department for the construction, improvement, and maintenance of the highway" (SC DOT, 2008). The Institute of Traffic Engineers (ITE) guidelines recommend a minimum ROW width of 50 feet for low density development and 60 feet for medium and high-density developments (ITE, 1997). Therefore, ROWs between 50 and 60 feet in width are common.

The standard 50 to 60 foot width can be excessive in many situations. While a wide ROW does not necessarily create more impervious cover, it can work against better site design. The wider ROW subjects a greater area to clearing and grading during road construction, and also consumes land that could be used for development. The ROW should only be wide enough to contain the necessary elements as shown in Figure 3.3-2. Generally, widths of 24 to 52 feet are sufficient. See Table 3.3-4 for examples of narrower ROW widths for residential streets. These ROW widths should be preserved even where street widths are narrower and building footprints should not be allowed to expand into ROWs.

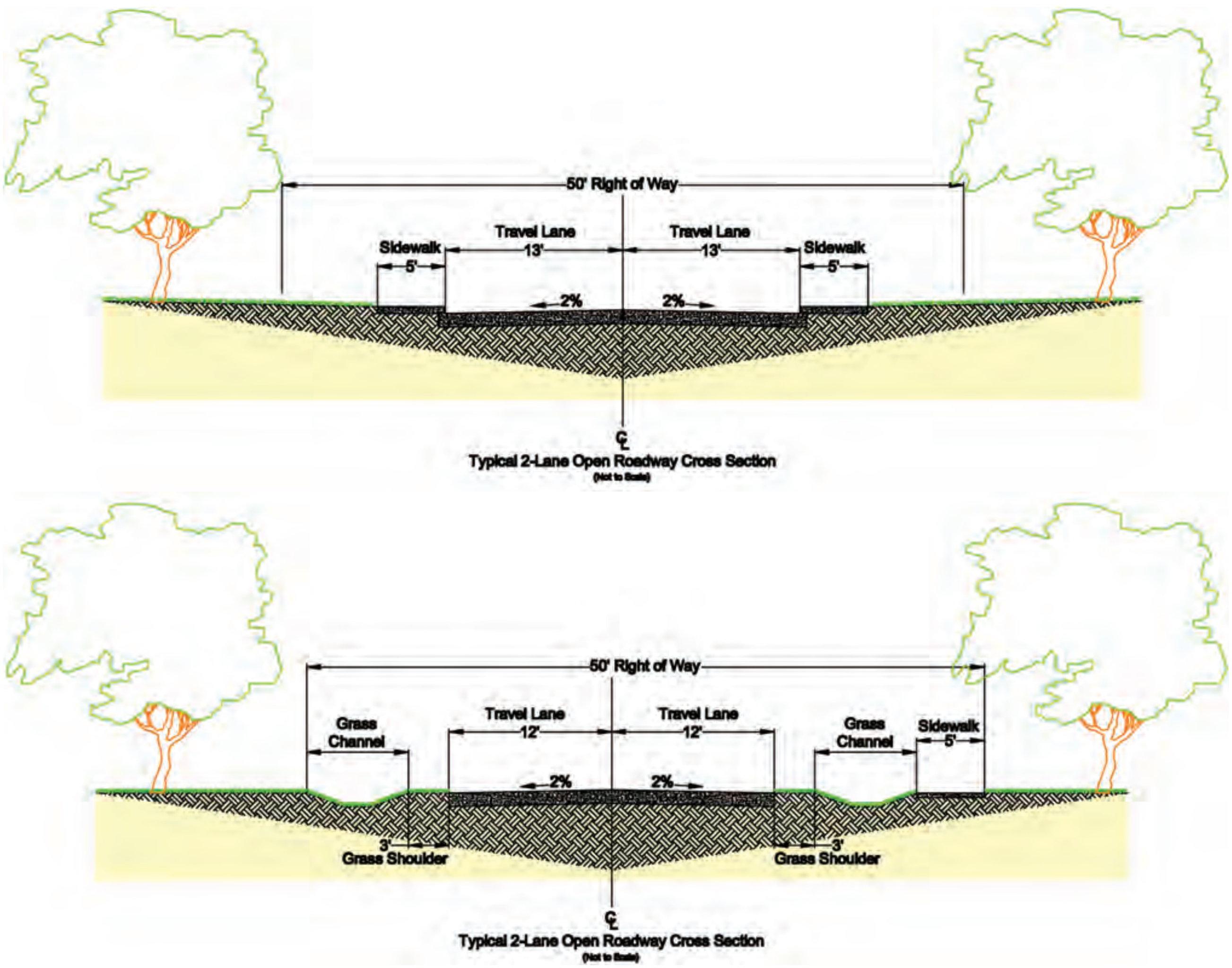

Figure 3.3-2. Right-of-way cross sections. Both roadways have a 50-ft ROW. The top cross-section shows how a typical road produces excessive impervious cover with 26 feet of pavement and sidewalks on both sides of the street. The bottom cross section demonstrates how an LID design includes roadside swales, narrower travel lanes, and a single sidewalk (Image: Center for Watershed Protection).

Table 3.3-4. Examples of ROW Widths

Source	ROW Width (ft)	Pavement Width (ft); Purpose
Berkeley County, SC[1]	50 66	22; local street (curb & gutter) 66; local street (open ditch)
Town of Bluffton, SC[2]	24 24 50 40 50	12; rear lane 24; rear alley 24; road (2 lanes, no parking) 19; street (1 lane, 1 side parking) 26; street (2 lanes, 1 side parking)
Portland, OR[3]	35 40	20; residential street 26; residential street
Montgomery County, MD[3]	20 44 46-60	16; residential alley 20; residential street 26; residential street
ASCE 1990 recommendation[3]	24-26 42-46	22-24; residential alley 26; residential street

[1] *Berkeley County (1999)*
[2] *Town of Bluffton Unified Development Ordinance (2011)*
[3] *Better Site Design (CWP, 1998)*

Municipalities should consider adjusting ROW requirements based on conditions and needs of the site. Additionally, it should be noted that a narrow ROW may not be desirable if stormwater is conveyed by vegetated open channels along the road (see *Open Channels* in Chapter 4). Well-designed swales require 10 to 12 feet along one or both sides of the road, thereby increasing the necessary ROW width.

Cul-de-sacs and Alternate Turnarounds:

Cul-de-sacs became prominent in new residential subdivisions after World War II (Nielsen, 2006). These residential streets are open at one end and feature a large “bulb” at the closed end which allows vehicles to turn around. Many communities require that the cul-de-sac bulb be 50 to 60 feet or more in radius. This results in paved areas over 11,000 square feet just for the turning portion of the roadway (RI DEM & CRMC, 2011). Because of their geometry, even a small reduction in bulb radius leads to a significant reduction in impervious cover.

Ensuring adequate access for emergency and service vehicles often leads to excessive cul-de-sac widths. However, newer fire trucks and other service vehicles have reduced turning radii, and therefore the paved radius may be reduced to 30 to 40 feet in some cases (ASCE, 1990). Additionally school buses do not usually enter cul-de-sacs, but pick up the students at one pre-arranged location. See Table 3.3-5 for examples of communities allowing smaller radii.

Table 3.3-5. Recommended Cul-de-sac Turnaround Radii

Turning radius (ft)	Source
40	Beaufort County, SC
20 (residential alley) 25 (court) 40 (drive)	Dorchester County, SC
40	Horry County, SC
35 (with approval of fire department)	Portland, OR Office of Transportation[1]
38 (outside turning radius)	Bucks County, PA Planning Commission[1]
45	Fairfax County, VA Fire and Rescue Department[1]
35	Baltimore County, MD Fire Department[1]
45	Montgomery County, MD Fire Department[1]
43	Prince Georges County, MD Fire Department[1]

[1] *CWP 1998*

Pervious Islands:

Impervious area can also be minimized through the use of a landscaped vegetated area in the center of a cul-de-sac or road; however, a sufficient paved width must be maintained (ITE recommends a minimum of 25 feet; also note that in the CWP Better Site Design Codes & Ordinances Worksheet that the user gets credit for using less than 35 feet or less than 45 feet). For an additional benefit, the vegetated island can be designed to receive and treat stormwater. For example, the island can be designed as a bioretention area using the criteria in Chapter 4. Concerns regarding sight impairment can be mitigated by using ground-cover or low-growing plants.

Alternative Turnarounds:

T-shaped turnarounds (also known as a hammerhead) and loop roads offer alternative designs to the traditional bulb and loop cul-de-sac (See Figure 3.3-3). T-shaped turnarounds generate approximately 75% less impervious cover than a cul-de-sac with a radius of 40 feet (See Table 3.3-6). They may be appropriate for streets less than 200 feet in length or where lot sizes are large. The minimum dimensions for a T-shaped turnaround are 60 feet by 20 feet. A loop road is a curved road that joins with another road at each end, providing two points of entry and exit. Loop roads can carry double the traffic volume of a cul-de-sac and therefore may serve twice as many units (Bucks County, 1980).

An additional benefit of alternative turnarounds is a reduction in construction costs. Asphalt alone costs $0.50-$1.00 per square foot, so reducing the amount of paved area in a development can result in significant savings (US EPA, 2010).

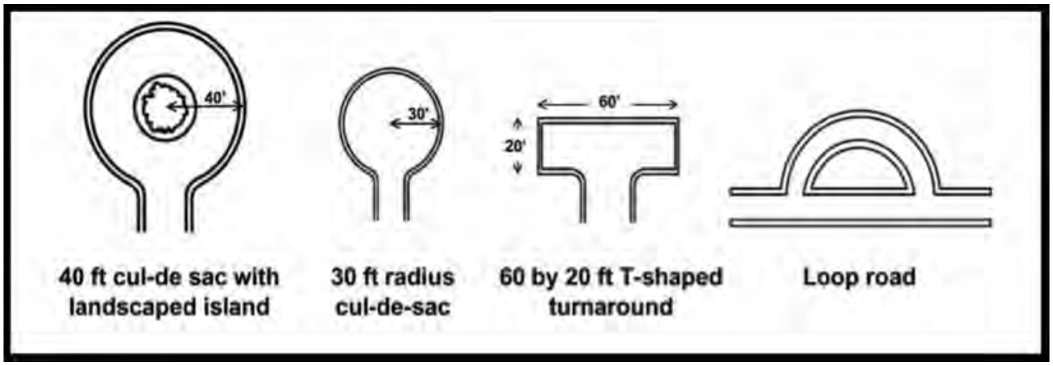

Figure 3.3-3. Alternative Terminus and Loop Designs. (Adapted from Scheuler, 1995)

Table 3.3-6. Impervious Cover Created by Turnaround Option[1]

Turnaround Option	Impervious Area (square ft)
40-foot radius	5,024
40-foot radius with island	4,397
30-foot radius	2,826
30-foot radius with island	2,512
Hammerhead	1,250

[1] *Schueler, 1995*

Intersection Geometry:

The most common intersection design is a four-way intersection with two crossing perpendicular streets. Often, four-way intersections are designed to be much wider than necessary, which increases impervious cover. Larger intersection curb radii can minimize lane encroachments by turning vehicles, but they also lead to greater vehicle speeds and a less pedestrian-friendly environment. Therefore, curb radii should be set to the minimum size required by turning vehicles and lane configurations. AASHTO recommendations are sufficient for the purposes of efficient and safe travel and range from 15 feet for smaller roads to 25 feet for collector streets (AASHTO, 2001).

Tee-style intersections offer several advantages over crosses. They tend to be safer (ITE, 1997), provide attractive terminating vistas, decrease vehicle speeds, and reduce points of pedestrian-vehicle conflict (Burden, 1999). To minimize conflict between adjacent intersections, tees should be spaced at least 125 feet apart (ITE, 1997). A sub-collector road with loop roads terminating in tee-style intersections offers a good opportunity to minimize impervious cover, enhance pedestrian safety, and reduce vehicle speeds, while increasing the overall flow of traffic (RI DEM & CRMC, 2011).

Local codes can make it very difficult to design alternatives to large scale 90-degree cross intersections. Community officials should provide adequate flexibility within their local codes to allow designers to assign the appropriate radius to proposed intersections depending on anticipated traffic volumes and goals for managing impervious surfaces.

Curb Requirements:

Curbs should be eliminated wherever possible in favor of road drainage into open channel systems or other stormwater management practices. While vertical curbing is recommended by ITE for all medium- to high-density developments (ITE, 1997), rolled curbing is the recommended practice for low-density developments (less than four units per acre). Rolled curbing allows runoff to be channeled into surface BMPs like swales or bioretention systems. Rolled curbing also allows for on-street parking using part of the shoulder (WA DOT, 1997), potentially decreasing road paved widths.

There are several disadvantages to using a raised curb design approach, particularly relative to LID implementation. One disadvantage to curbing is cost; it is much more expensive to build a road with curbs and a closed drainage system than one with vegetated shoulders and open swales. By preventing stormwater runoff from infiltrating along the side of the road, curbs may also create concentrations of pollutants, such as debris, sediment, and bacteria. As a result, curbed streets experience increased runoff with higher pollutant concentrations. In addition, curb-and-gutter conveyance systems quickly carry stormwater to downstream water bodies, which increases peak flows that can cause flooding and erosion problems.

One common argument against eliminating curbs is the potential for surface erosion or failure of the road surface at the pavement edge. Often, erosion can be mitigated by hardening the pavement grass interface through the use of grass pavers (concrete or plastic grid pavers) or a low-rising concrete strip or ribbon curb (CWP, 1998). The use of such a strip also increases the visibility of the roadway edge, enhancing traffic safety at night. Another common concern from residents is that open drainage is unattractive, difficult to maintain, and may pose a health risk from standing water. These challenges can be addressed by careful design of the swale system following the criteria outlined in Chapter 4.

Sidewalks:

Codes and ordinances often require excessive sidewalk surface area in residential developments. For example, residential developments can be required to construct and maintain sidewalks on both sides of the street. The sidewalk material required is often impervious concrete or asphalt. Additionally, sidewalks can increase the site footprint further when setbacks are required. Setbacks are often 2 to 10 feet from the road.

Sidewalks promote pedestrian access in the community. Flexible sidewalk codes and ordinances will allow sidewalk placement and design that reduce impervious surfaces and promote pedestrian traffic where it makes the most sense. For example, a tailored approach may include sidewalks on one side of the street, reduced sidewalk width, and/or reduced setbacks from the road. Such approaches can incorporate water quality improvement goals and better community planning goals.

Finally, alternative surfaces such as pervious concrete (see Figure 3.3-4) can be used to promote infiltration. In Oak Terrace Preserve, recycled tire material allowed for more infiltration and provided a softer walking surface than typical concrete sidewalks. Where possible, sidewalks can be graded away from the street surface and toward grassy areas for infiltration and conveyance. Installing pervious sidewalks and grading away from the street allows stormwater to infiltrate prior to entering the stormwater management system.

Recommended better sidewalk practices (CWP, 1998; CGRDC & EMC, 2008):

- ✧ Locate sidewalks on one side of the street
- ✧ Use sidewalks that are 5 feet wide in high-use areas and 4 feet wide elsewhere
- ✧ Utilize pervious surface materials
- ✧ Grade sidewalks to adjacent grassy areas or stormwater management practices

Flexible sidewalk codes and ordinances can reduce the impervious surfaces, promote better pedestrian patterns, and support clean water goals in residential areas. Please refer to www.ada.gov for information and technical assistance with complying with the sidewalk requirements set forth in the Americans with Disabilities Act.

Driveway Design:

As much as 20% of the impervious cover in a typical residential development consists of driveways (Scheuler, 1994). Lot impervious cover should be reduced by minimizing driveway width and length, allowing shared driveways wherever possible, and encouraging alternative pervious sur-

Figure 3.3-4. Oak Terrace Preserve in North Charleston required a maximum of 50% impervious cover on lots. In order to remain under this threshold, the independent contractors developed inventive driveway designs. (Photos: Lisa Vandiver, NOAA Restoration Center)

faces (as depicted in Figure 3.3-4). Most suburban driveways create 400 to 800 square feet of impervious cover, or enough space to park two to four cars. The single-lane driveway for a residential home is typically 10 to 12 feet wide, while the double lanes used for homes with a two-car garage are usually 18 to 20 feet wide. Often, narrower driveways would be sufficient, and communities could reduce overall impervious cover by specifying a narrower driveway width. For example, less than 9 feet for one lane and less than 18 feet for 2 lanes is recommended by the CWP (COW question 14, page 19 in *Better Site Design*).

Subdivision and community codes indirectly influence the length of the driveway by requiring excessive front yard setbacks, which dictate how far houses must be from the street, are required. Driveway length can be reduced by relaxing these front yard setbacks. Flexible setback requirements allow for more creativity in site planning and development, and allow for more compact lots and a greater amount of open space. See *LID and Compact Development* in Section 2.4 for additional guidance.

There are several misconceptions related to front yard setbacks. One is that decreased setbacks and shorter driveways do not provide enough parking spaces. However, the average number of vehicles per household is 1.86 (US DOT, 2011). Typically this can be accommodated between the driveway, garage, and on-street parking (Pisarski, 1996). Another issue raised regarding decreased front yard setbacks is that it will reduce drivers' sight distance, or the length of roadway that can be easily viewed. However, sight distance impediments can be avoided by placing visual obstructions (e.g., garages, front porches) at least two feet back from the curb. This setback is far less than the 30-foot setback required by many jurisdictions (AASHTO, 1994; CWP, 1998). Additionally, the concern that decreasing the front setback will increase traffic noise can be mitigated by traffic calming strategies. As traffic noise is a function of driving speed, narrower streets or other measures to slow traffic will reduce noise (AASHTO, 1994; FHA, 1996).

Another way to reduce the total impervious area generated by driveways is to use shared driveways. These are privately owned and maintained driveways, typically 12 to 16 feet wide. Careful design can provide sufficient space for overflow parking while reducing the overall area required. Important considerations for shared driveways include:

- The maximum allowable number of homes that may be served by a common driveway, typically two to six homes
- The type of shared driveway covenant that will be used by the homeowners to ensure that maintenance responsibilities are clearly described and adequately enforced
- The potential for locating other shared features such as mail repositories and trash removal pads at the end of the driveway. Communities may wish to include design specifications for these areas to ensure aesthetic appeal and the reduction of potential nuisances

Shared driveways are usually discouraged or sometimes even prohibited in local codes. This is primarily because there is a concern that multiple homeowners may not be able to agree on the long-term maintenance of the driveway. Further, depending on the working schedules of different homeowners, many people are concerned with the ability of homeowners to "come and go as they please" for fear that parked cars close to the driveway entrance will block access. These are valid concerns that can be addressed by proper design. For example, a shared driveway that is long enough to accommodate a few automobiles on both sides can be designed so that the entranceway is close to the recommended minimum width of 12 feet as it is unlikely any cars would be parked at the mouth of the driveway. However, where a shared driveway is only long enough to accommodate two parked cars for each owner, the entranceway should be wider to allow adequate access (CWP, 1998).

Most driveways are constructed of concrete or asphalt, but the use of alternative, porous materials can decrease impervious cover. Several alternative driveway surfaces exist that reduce impervious cover and provide increased infiltration. Table 3.3-7 compares the durability, cost, and relative performance of several alternative paving materials.

Table 3.3-7. Summary of Issues Related to Various Types of Alternative Pavements[1]

Material	Initial Cost	Maintenance Cost	Water Quality Effectiveness[2]
Conventional Asphalt/Concrete	Medium	Low	Low
Pervious Concrete	High	High	High
Porous Asphalt	High	High	High
Turf Block	Medium	High	High
Brick	High	Medium	Medium
Natural Stone	High	Medium	Medium
Permeable Pavers	High	High	High
Gravel	Low	Medium	Medium
Wood Mulch	Low	Medium	High
Cobbles	High	Medium	Medium

[1] *BASMAA,1997 as in CWP, 1998; updated based on RI DEM & CRMC, 2010 and UNHSC, 2009*
[2] *Relative effectiveness in meeting stormwater quality goals*

Developers are sometimes concerned that alternative driveway surfaces are less marketable than conventional paving materials. However, the use of these alternative materials, such as permeable pavers, is being sought out by a range of customers (Ewing et al., 1996). In addition, aesthetically pleasing alternative driveways (e.g., brick pavers) are highly marketable. There is also a common misconception that alternative driveway surfaces may limit disability access. Although the Americans with Disabilities Act (ADA) requires accessible routes on firm and stable surfaces to and between public facilities, single family homes are not necessarily bound by this requirement. In addition, developers can choose to provide some houses with conventional paving and some with alternative surfaces that allow for reliable access.

Benefits Related to LID Roadway Design:

Adopting codes that limit the amount of impervious area required for roads and driveways allows for better stormwater management. When impervious area is reduced, the quantity and peak flow of runoff from a neighborhood is significantly reduced. Additionally, allowing flexibility in terms of the drainage network system (curb-and-gutter vs. open section), can help achieve a design goal of greater infiltration and water treatment at the development scale.

Decreasing the total amount of pavement, curbing, sidewalks, and storm sewer infrastructure required for a development can greatly decrease the construction costs (CWP, 1998). In addition, vegetated stormwater practices, such as bioretention areas or open channel drainage, throughout a neighborhood are less expensive than an extensive catch basin/manhole/pipe system that discharges to a larger stormwater management practice, such as a wet pond. The cost of a curb-and-gutter/storm drain pipe system is typically about 2 to 3 times more expensive than an engineered swale (SMBIA, 1990; CWP, 1998). Increased vegetation, narrower streets, destination walkways, and a variety of turnaround styles can also increase the appeal of a neighborhood, and thus, the overall value (CWP, 1998).

For example, consider a jurisdiction that requires all residential streets with one parking lane to be a minimum of 28 feet wide. If the jurisdiction adopts a new standard, 18-foot wide queuing streets, this new standard would reduce the overall imperviousness associated with a 300 foot road by 35% and construction costs by $5,000 (CWP, 1998). Recently, the City of Charleston saved $18,000 by reducing the paved width of the West Ashley Greenway from 10 feet to 8 feet (Behre, 2012).

LID Parking Guidance

Similarly to road and driveway design, impervious cover from a site or development can be reduced significantly by adjusting the design of parking areas. Some effective methods of reducing impervious area include angled parking, smaller spaces, median rather than maximum lot size, and pervious parking materials. In addition, allowing or incentivizing parking practices that decrease the amount of impervious surfaces and/or increase the stormwater management requirements can be effective. It also enhances both aesthetics and function to have features like vegetated swales, bioretention areas, depressed (rather than raised) parking lot islands, and decorative porous pavers (GCSC, 2006).

Parking is a necessity to keep our business communities viable and our residential neighborhoods safe. However, parking lots are often designed to be overly large and local codes do not always allow developers flexibility in terms of innovative approaches to parking. This section discusses planning strategies that emphasize parking efficiency and provides suggestions for reducing impervious cover.

Alternative Parking Surfaces:

Use alternative porous surfaces for parking areas and/or overflow areas where possible. In addition to reducing the parking standards, pervious materials can be used for parking areas and/or overflow parking areas to reduce the total impervious area. Pervious pavers can replace conventional asphalt or concrete, and can range from medium to relatively high effectiveness in meeting stormwater quality goals. The different types of alternative pavers include gravel, cobbles, wood mulch, brick, grass pavers, turf blocks, natural stone, pervious concrete, and porous asphalt, and are outlined in *Driveway Design* (SMRC, 2010; RI DEM & CRMC, 2010). Figure 3.3-5 depicts some local examples of alternative parking surfaces along the coast.

Figure 3.3-5. Local Examples of Alternative Parking Surfaces. Grass paver parking at Coastal Carolina University's Brooks Stadium (Photo: Karen Fuss, Coastal Carolina University) and pervious pavers installed at the Yaupon parking lot in Surfside Beach (Photo: John Adair, Town of Surfside Beach).

Parking Ratios:

Parking ratios should be based on average demand rather than on projected peak demand. The general perception regarding parking requirements is that the public's interest is best served by adopting a conservative approach to minimize the likelihood of an undersupply of spaces. In an effort to provide more than enough parking to satisfy the public's need, local planners have traditionally relied upon minimum parking ratios as the primary tool to regulate parking. Parking ratios are set by local communities and express the number of parking spaces that must be provided for a particular use (e.g., one space per 1,000 square feet of commercial space; one space per three seats for restaurants; or two spaces per bed for hospitals). Parking ratios typically represent the minimum number of spaces needed to accommodate the highest hourly parking during the peak season at the site (Wells, 1994).

However, these ratios are not typically derived from an analysis of local parking needs, but rather from those of neighboring communities or from the parking generation rates and standards that are published by the Institute of Transportation Engineers (ITE) which may or may not apply well in local situations. Table 3.3-8 illustrates the discrepancy between parking ratio and actual parking demand for some typical land uses.

Table 3.3-8. Typical Parking Requirements Compared with Observed Demand[1]

Land Use	Typical Minimum Parking Ratio	Typical Range	Actual Average Parking Demand
Single Family Homes	2 spaces per dwelling unit (d.u.)	1.5 – 2.5	1.11 spaces per d.u.
Shopping Center	5 spaces per 1,000 sq ft GFA[2]	4.0 – 6.5	3.97 per 1000 sq ft GFA
Industrial	1 space per 1,000 sq ft GFA	0.5 – 2.0	1.48 per 1,000 sq ft GFA
Medical/Dental Office	5.7 spaces per 1,000 sq ft GFA	4.5 – 10.0	4.11 per 1,000 sq ft GFA

[1]CWP, 1998
[2] Abbreviated GFA refers to the gross floor area of a building, without storage and utility spaces

When tailoring parking standards, communities should consider requiring a maximum parking allowance that restricts the total number of spaces at a development site. A potential strategy for setting a maximum parking allowance is for each community to consider using its current minimum parking ratio as the new maximum requirement, as was done several years ago in the Town of Exeter, RI. However, in many cases, these allowances could still be too high and each community will need to tailor these maximums through discussions with their planning and permitting agencies to get a sense of what is appropriate in each district (RI DEM & CRMC, 2011).

Another common misconception regarding parking supply is that large supplies of ample free parking are necessary for business viability. In fact, overdevelopment of parking areas consumes valuable developable land area and decreases potential tax revenue. Optimizing the amount of

Minimizing Parking Case Study: City of Greenville, SC

Smaller lots make better use of available land, improve water quality, and save money. Upstate Forever, Furman University, and the City of Greenville conducted a study of commercial parking lots to determine the optimal number of parking spaces for different uses. Researchers used aerial photography and on-the-ground monitoring of 120 commercial parking lots during peak and non-peak hours. The study concluded that there was an excess of off-street parking, with up to 65% of parking spaces empty during peak hours.

Land Use	Peak Parking Occupancy	Excess Parking
Grocery Stores	35%	65%
Other Restaurants	39%	61%
Discount/Dept. Stores	45%	55%
Pharmacies	45%	55%
Medical Facilities	52%	48%
Offices	58%	42%
Drive-thru Restaurants	58%	42%
Shopping Centers	63%	37%
Health Clubs	74%	26%

Based on the findings from the study, the city of Greenville adjusted its parking requirements. For example, the parking requirement for a medical facility was reduced from 5 spaces per 1,000 square feet to 1.7 spaces per 1,000 feet. The change resulted in a reduction of 3.3 spaces per 1,000 square feet and represents an approximate $6,000-$18,000 cost savings for the developer. Under the current code, developers have two options: 1) install the minimum parking spaces required in the new policy or 2) use LID practices to manage the stormwater generated by parking spaces over the minimum requirement. Upstate Forever is working with the City of Greenville to create a third alternative in which developers would pay a fee in-lieu of using LID. This new revenue stream will fund local clean water projects.

active commercial space should be the priority for designated growth areas. Excessive parking requirements would be one of the most influential obstacles toward achieving that goal. Further discussion of fiscal impacts associated with excessive parking requirements can be found in Litman (2006).

Shared and Off-Site Parking:

Parking requirements should be flexible and include shared off-site parking allowances under certain development scenarios. It can be a challenge for businesses to deal with excess parking demand, especially during peak periods. Often, excess demand is a perceived problem. Several studies have documented that occupancy rates tend to be lower than expected, even during peak periods. For example, the City of Olympia found that in 18 out of 31 sites had less than 75% occupancy during peak periods (Wells, 1994). The Center for Watershed Protection BSD guide discusses how to allow and incentivize shared parking, model shared parking agreements, and reduce parking ratios if shared parking is in place (2013, page 16).

For situations where excess demand does occur, creative solutions can mitigate the problem. For example, the businesses in the Avondale district of Charleston, SC share valet service to deal with peak demand (Thursday through Saturday night). Parking issues in adjacent neighborhoods required them to contract with a valet service and nearby businesses that are open during the day only – such as banks and retail stores – to use their parking as valet spaces at night.

As discussed in the *Parking Ratios* section, parking lots are often designed based upon pre-established ratios for each land use, without taking into account whether adjacent land uses can share parking areas. This type of shared parking can significantly reduce the number of required parking spaces needed by allowing adjacent land uses to share parking lots. This arrangement is possible when peak demands for the adjacent land uses occur at different times during the day or week. For example, many businesses or government offices experience their peak business hours during the daytime on weekdays, while restaurants and bars peak in the evening hours and on weekends. This presents an opportunity for shared parking arrangements where several different groups can use an individual parking lot without creating conflicts.

Table 3.3-9 shows a typical approach to calculating shared parking requirements and illustrates that a simple peak demand analysis can significantly reduce the combined requirements for office and retail use shared parking. In this example, the combined minimum requirements are 370 spaces, while the demand analysis shows an actual requirement of 286 spaces: 23% less than required.

Nonetheless, regulations in most communities require all new development and redevelopment to provide all parking on-site. This can make it difficult, if not impossible, for many redevelopment sites and compact mixed use centers to comply with conventional on-site parking demands.

An integral piece to providing adequate flexibility within parking regulations involves allowing on-site parking requirements to be met through off-site facilities. These off-site allowances are particularly important in redevelopment sites and compact mixed use centers, where lot geometry and pre-existing development patterns can make it impossible for existing structures to comply with conventional on-site parking demands. Allowing business owners to negotiate with each other across property boundaries encourages a more integrated private sector approach and a much more efficient use of land. Recommended zoning provisions for off-site parking include the following:

- Establish design standards that require well-marked, safe pedestrian travel paths from the parking lot to the target site (e.g. improvements to sidewalks, lighting, crosswalks, and crossing signals between the site and pedestrian and vehicular access points at the off -site parking location).
- Establish a maximum distance that the parking lot may be from the target site. Typical values range from 350 – 1,000 feet (walking distance).
- Reduce parking ratios for shared parking and provide a model shared parking agreement.
- Finally, a condition of any approval should be a legally defensible agreement between property owners that guarantees access to the parking lot, outlines any shared maintenance agreements, and addresses issues of shared liability.

Table 3.3-9. Example Shared Parking Calculation[1]

	Office Use			Retail Use			Shared
	Minimum Parking Required	Percentage of Parking Required	Adjusted Parking (actual spaces needed)	Minimum Parking Required	Percentage of Parking Required	Adjusted Parking (actual spaces needed)	Parking Requirement by time period
Weekday Daytime	160	100%	160	210	60%	126	286
Weekday Evening	160	10%	16	210	90%	189	205
Weekend Daytime	160	10%	16	210	100%	210	226
Weekend Evening	160	5%	8	210	70%	147	155
Nighttime	160	5%	8	210	5%	10.5	18.5

[1]RI DEM & CRMC, 2011, Adapted from Montgomery County, MD

Stall and Aisle Geometry:

Typical dimensions for a parking stall, or space, are up to 10 feet wide and 20 feet long. The parking aisle refers to the travel lane within a parking facility that allows for cars to reach the parking stalls. Parking aisles are typically 12 feet wide and parking facilities normally have two-way traffic resulting in 24 feet of travel space between opposing parking stalls.

A minor reduction in parking stall dimensions can result in a significant impact on the overall size of a parking lot and impervious area. Reducing stall dimensions to 9 feet wide and 18 feet long would result in a 28% reduction in the stall area. Additionally, encouraging one-way aisles in conjunction with angled parking can reduce the amount of aisle space needed to access each stall, as shown in Figure 3.3-6. Another option is to allow for a portion of parking lots to be comprised of compact car spaces. Compact car spaces can be provided as 8 feet by 16 feet stalls.

One of the major challenges in addressing the dimensional standards of parking stalls and aisles is the perception that larger vehicles will not fit into smaller parking stalls. Many communities fear

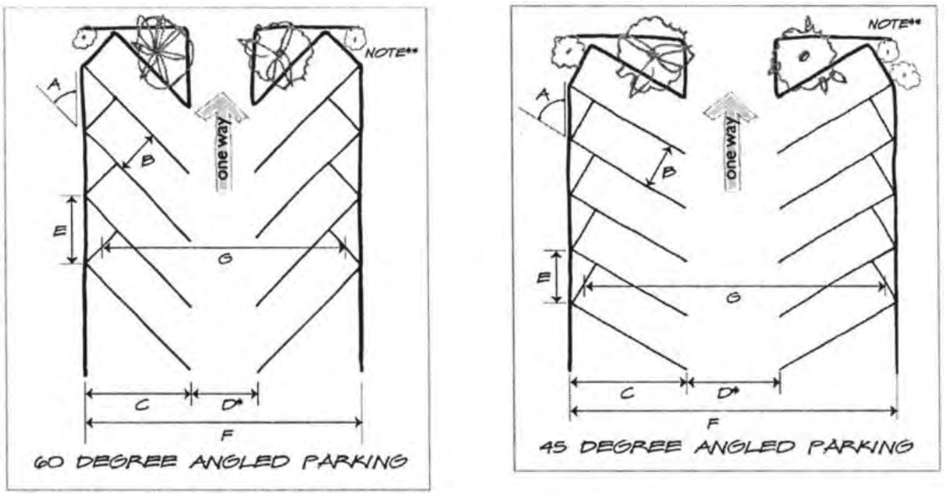

Figure 3.3-6. Angled Parking Design Options (RI DEM 2011)

that limiting stall and aisle dimensions will result in deteriorated parking conditions. However, this perception does not often meet with reality as the majority of larger vehicles, such as sport utility vehicles (SUVs) and vans can comfortably fit into smaller stalls without the risk of damaging other vehicles or conflicting with pedestrian needs (CWP, 1998). Additionally, trends in auto sales show that Crossover Utility Vehicles (CUVs) are becoming a more popular alternative to compact cars than SUVs. In 2012, they were the largest segment of auto sales at 23.8% compared to 7.2% for SUVs (AAM, 2013). CUVs are built on car platforms so they are more easily able to fit into parking spaces designed for cars.

Parking Lot Landscaping:

Parking lot landscaping standards should allow applicants to include LID techniques for managing stormwater runoff. While many communities require parking lot landscaping, they do so in a manner that supports aesthetics and tree canopy cover, but not always in a manner that supports stormwater management. For example, many communities require a certain number of landscaped islands per parking space or a specific spacing of trees within the lot. Providing mechanisms in ordinances for LID treatment practices will allow designers to create systems that are tailored to the unique geometry and topography of a given lot.

LID stormwater practices such as vegetative swales and bioretention basins exhibit unique design characteristics that can be difficult to fit into a regimented landscaping formula. The following are recommended innovative approaches to parking lot landscaping:

- Use vegetative swales to direct stormwater into shallow bioretention areas that temporarily detain the water and allow for partial infiltration while pre-treating the remaining stormwater before it is discharged into waterways.
- For parking lots of 10 or more spaces, require that 10% of the parking lot area be dedicated to landscaped areas that can include LID stormwater practices. A more detailed discussion of landscaping practices and plant selection is provided in the LID Landscaping guidance in this chapter.
- Mandate landscaping within parking areas to "break up" pavement at fixed intervals. However, it is important to provide relief from these frequencies when a developer wishes to use landscaping as part of stormwater management practices so they have the flexibility necessary to site and design vegetated BMPs adequately.

✧ Require a minimum amount of tree canopy coverage over on-site parking lots. Many municipalities use this standard for aesthetics and to mediate the urban heat island effect. Requirements generally range between 25% and 30% canopy coverage.

The Fort Bragg (North Carolina) vehicle maintenance facility parking lot is an excellent example of the benefits of rethinking parking lot design (NRDC, 1999). The redesign incorporated stormwater management features such as detention basins located within grassed islands and an on-site drainage system that took advantage of existing sandy soils. The redesign reduced impervious cover by 40%, increased parking by 20%, and saved 20% or $1.6 million on construction costs over the original, conventional design.

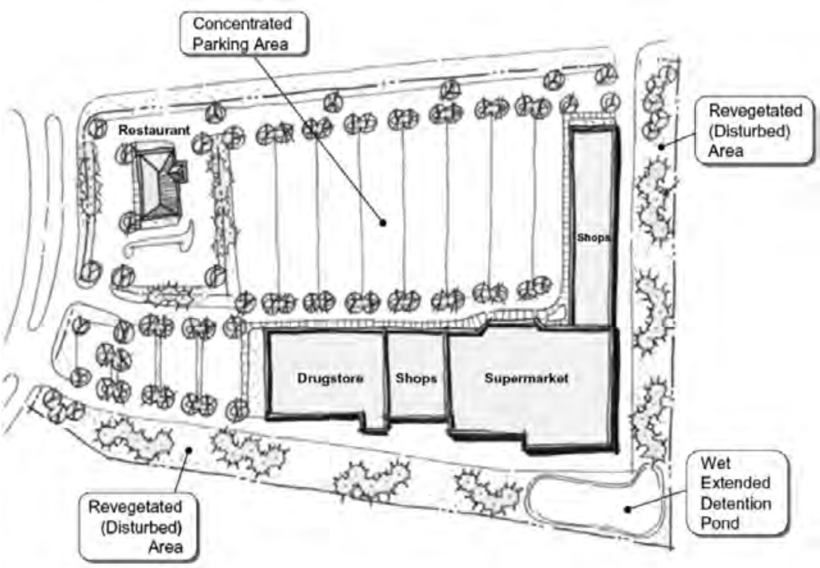

Figure 3.3-7. Conventional Parking Lot Layout (RI DEM, 2011)
Conventional parking designs clear the entire site, that later needs to be revegetated, and creates one massive area for parking.

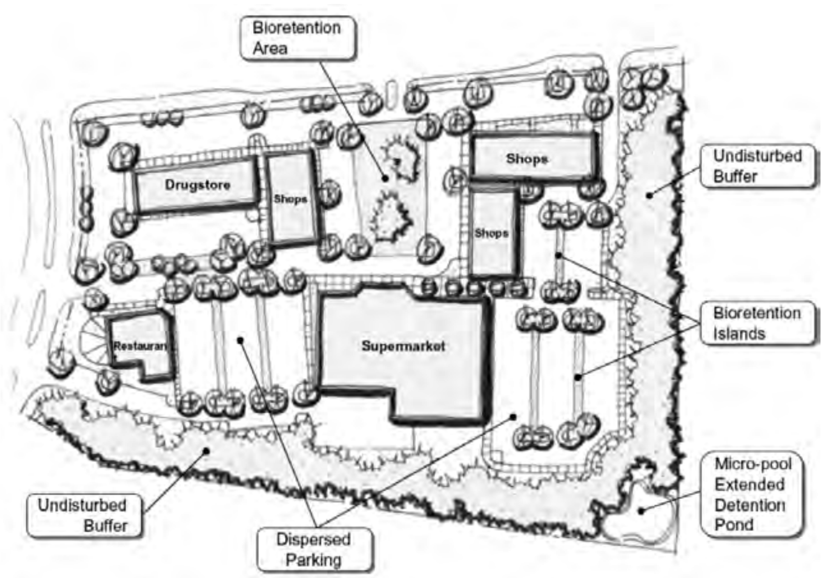

Figure 3.3-8. Parking Lot Layout Using LID Techniques (RI DEM, 2011)
The LID design leaves undisturbed buffers of native vegetation, incorporates landscaped islands that treat stormwater, and disperses the parking into smaller areas.

Summary of Benefits Associated with LID Parking:

Adopting codes that limit the amount of parking spaces required for land development activities and provide flexibility in design can contribute greatly to better stormwater management. By reducing the number and size of required spaces, more flexible parking standards can reduce the amount of impervious area for both residential and non-residential development.

Zoning ordinances that require excessive amounts of parking for non-residential use are one of the primary causes of commercial sprawl. These developments miss a significant economic potential and can fall short of meeting the tax base needs of their host communities (Litman, 2006). Providing flexible parking standards is one of the more important tools for optimizing the economic potential of non-residentially zoned land.

Finally, reducing parking requirements and enhancing design standards for parking areas can help shape a community's character. LID parking design contributes to the revitalization of commercial areas and their overall aesthetic appeal. Replacing vast unbroken expanses of asphalt with smaller, well-landscaped parking areas provides a much more appealing development style and enhances the designer's ability to provide more organized traffic patterns and speeds, as well as pedestrian connectivity (see Figures 3.3-7 and 3.3-8).

LID Landscaping

Many South Carolina counties and municipalities in the Coastal Zone provide landscaping requirements and guidelines as part of their Land Development Ordinances. However, the requirements for location, spacing, size, and maintenance for street trees, planting and screening can vary significantly from one community to the next. Some communities reference LID guidelines and require project proponents to demonstrate LID practices, but lack specificity with respect to soil amendments, preservation of natural vegetation, or utilization of native species. Additionally, landscaping ordinances tend not to document the potential negative impacts of highly fertilized and irrigated turf areas or limit the allowable amount of turf on an applicant's project.

In order to protect water resources, coastal South Carolina communities should develop and adopt an LID Landscaping section in their land development regulations that specifically addresses the link between a functional landscape and the protection of water resource quality.

Landscaping requirements and objectives vary as a function of land use and activity. Residential landscape requirements need to be different from commercial, industrial, or institutional requirements. Project location and density also need to be considered, as the type of plantings and other landscape features within an urban shopping center will be different from a suburban subdivision. Furthermore, LID Landscaping should include various types of landscaped and vegetated areas (see Figure 3.3-9 for an example):

- Residential lots of varying size
- Open space areas
- Recreational areas
- Drainage features, such as swales and stormwater management practices
- Project entrance features

- ✧ Buffer areas from "improved" site areas to water resources (e.g., streams, wetlands, coastal shoreline features)
- ✧ Areas disturbed for utility construction and easements
- ✧ Plazas, parking lots, sidewalks, and building planters
- ✧ Streets, roads, and cul-de-sacs
- ✧ Planting requirements, densities, soil amendments, and requirements for each land use, density and location category
- ✧ Street signage and street/courtyard furniture

It is important to distinguish between "typical" landscaping, such as vegetation in the medians in a parking lot, and LID landscaping, such as vegetation in bioretention used to treat stormwater in a parking lot. First, the landscape and maintenance crews should determine if the area is used for stormwater management. This can be accomplished through the following techniques:

Ask the property owner and/or property manager:

1. Assess the site for common stormwater features such as inlets and outlet structures
2. Consult site plans
3. Consult a stormwater professional, such as a landscape architect or professional engineer

If the area in question is part of an LID stormwater treatment practice, please refer to the guidelines in Chapter 4 or Appendix F for specific maintenance guidance. Also, the Chesapeake Stormwater Network and Center for Watershed Protection have created short (~15 minute) videos for LID Stormwater Construction Practices and Stormwater BMP & LID Maintenance that include landscaping tips in the context of LID construction and maintenance. These videos are available in English and Spanish and available online at: http://www.youtube.com/user/CenterforWatershed?feature=watch.

Figure 3.3-9. LID landscaping incorporating stormwater treatment and native vegetation (Photo: Kathryn Ellis)

The property manager and/or owner should communicate before, during, and after landscaping at an LID site to ensure the proper maintenance occurred. Improper maintenance can lead to LID failure and water pollution impacts. However, proper maintenance will ensure the LID functions as designed for the expected lifetime of the practice.

There are many factors to consider when creating a low impact landscape. The Sustainable Sites Initiative, a collaborative project of the American Society of Landscape Architects, Lady Bird Johnson Wildflower Center, and the United States Botanic Garden, seeks to establish and encourage sustainable practices in landscape design, construction, operations, and maintenance. Table 3.3-10 describes some design, construction, and maintenance factors to assess a holistic low impact landscape design.

Table 3.3-10. Summary of Sustainable Landscaping Practices[1]

Criteria	Suggested landscaping practices
Site Selection	♦ Protect floodplain functions ♦ Preserve wetlands ♦ Preserve threatened or endangered species and their habitats ♦ Select brownfields or greyfields for redevelopment ♦ Select sites within existing communities ♦ Maintain natural, undisturbed areas
Site Design – Water	♦ Reduce potable water used for landscape irrigation ♦ Protect and restore riparian, wetland, and shoreline buffers ♦ Maintain water features to conserve water and other resources ♦ Minimize stormwater runoff ♦ Use alternative paving materials that promote infiltration of precipitation and maximize solar reflectance (albedo)
Site Design – Soil and Vegetation	♦ Control and manage known invasive plants found on site ♦ Use appropriate, non-invasive plants and native plants ♦ Create a soil management plan ♦ Minimize soil disturbance in design and construction ♦ Preserve or restore appropriate plant biomass on site ♦ Preserve or restore appropriate plant communities native to the ecoregion ♦ Use vegetation to minimize building heating and cooling requirements ♦ Reduce urban heat island effects ♦ Reduce the risk of catastrophic wildfire
Site Design – Materials Selection	♦ Reuse salvaged materials and plants ♦ Use recycled content materials ♦ Use regional materials ♦ Support sustainable practices in plant production and materials manufacturing
Site Design – Human Health and Well-Being	♦ Protect and maintain unique natural, cultural and historical places such as shell rings, Carolina Bays, tabby structures, and cemeteries ♦ Provide views of vegetation and outdoor spaces for mental restoration
Construction	♦ Restore soils damaged by previous development ♦ Reuse or recycle vegetation, rocks, and soil generated during construction
Operations and Maintenance	♦ Compost organic matter generated during site operations and maintenance

[1]Adapted from the Sustainable Sites Guidelines and Performance Benchmarks 2009

Benefits of LID Landscaping:

Landscaping, which includes both vegetation and hardscaping, affects stormwater quantity and quality. Landscaping that incorporates LID strategies for stormwater management should absorb and treat stormwater runoff and pollutants to the greatest extent possible on-site. LID landscaping includes the use of vegetated practices and other features that use soil to mimic natural hydrologic features and functions. The following benefits are likely derived from implementing LID landscaping techniques (RI DEM & CRMC, 2011; SCDHEC-OCRM, no date):

1. **More effective stormwater management and water quality treatment.** Vegetation can reduce the amount of stormwater pollution in receiving waterbodies by capturing sediment, nutrients, and chemicals. Vegetation slows the velocity of runoff and helps reduce erosion.
2. **Reduced demand for irrigation and use of potable water supplies.** Once established, native vegetation requires minimal supplemental irrigation. Native plants can attain the moisture they need from normal rainfalls, but a 1,000 square foot lawn requires 10,000 gallons of water per summer to keep it green (SCNPS, 2014). Additionally, the high organic content of the soils encourages healthy growth, absorbs and retains rainwater on site as soil moisture, and minimizes irrigation demands and generation of runoff.
3. **Fewer chemical inputs.** Native plant communities are more resistant to drought and require less fertilizers, pesticides, and herbicides if planted in native soils. In-situ soils are often stripped during development, which causes both native and non-native plants to struggle.
4. **Save money.** Native plant communities can be less costly to maintain and manage because they do not require frequent mowing or chemical inputs (fertilizers and herbicides).
5. **Improve site aesthetics.** Naturalized landscapes may be more enjoyable due to the comfort of shade from trees and the opportunities for recreation activities such as bird watching.
6. **Carbon sequestration.** Carbon is stored in biomass (branches, foliage and roots) and soils when trees, grasses and other plants take up atmospheric carbon dioxide through photosynthesis.

General Standards:

The selection and location of turf, trees, ground cover (including shrubs, grasses, perennials, and flower beds), pedestrian pavement, and other landscaping elements should be used to absorb rainfall, prevent erosion, and meet the functional and visual goals of these standards. Examples of functional and visual goals include defining spaces and directing circulation patterns. Where possible, the landscaping design should combine form and function, invisibly incorporating drainage features into the landscape through applications like shallow surface drainage areas and parking lot islands.

Landscaping should be designed to remain functional and attractive during all seasons of the year through a thoughtful selection of deciduous, evergreen, flowering and non-flowering plant varieties. Prominent natural or man-made features of the landscape such as mature trees, surface waters, or roadways should be retained and incorporated into the landscape plan where possible. The addition of new features, such as ornamental rocks or fencing, is encouraged. One example of a landscape feature is a Carolina Fence™ Garden (SCWF, 2014), which has been designed to include both natural and cultural state symbols of South Carolina: split rail fence, blue granite, Carolina Wren house, and native plants.

Figure 3.3-10. Native perennials, shrubs, and trees planted in buffer between parking lot and natural area (Photo: Kathryn Ellis)

Existing, undisturbed natural areas should be maintained to the maximum extent practical; for example, a minimum of 25% of the lot for single-family homes and 15% for multi-family residential areas (RI DEM & CRMC, 2011). Depending on local ordinances, it may be possible to count existing trees and shrubs retained post-construction for any compatible required plantings. Natural re-growth, mulched planting beds, and alternative groundcover plant varieties are preferred. Lawn areas should be kept to a minimum; however, lawns less than six feet in width, especially adjacent to roads or parking areas, are discouraged since such areas require watering and maintenance, but have little utility and are less likely to thrive (RI DEM & CRMC, 2011).

Less hardy, exotic, or higher maintenance plant varieties may be used to supplement minimum landscaping requirements where appropriate, but are not encouraged. Exotic, invasive species should never be planted and should be removed from the site if they are found pre-development.

- The South Carolina Exotic Pest Plant Council (SC-EPPC) maintains a list of unacceptable exotic invasive vegetation, including English ivy, bamboo, and ligustrum. For more information, please see http://www.se-eppc.org/southcarolina/invasivePlants.cfm.
- Additionally, The South Carolina Native Plant Society (SCNPS) provides native plant alternatives to invasive species: http://scnps.org/wp-content/uploads/2012/04/SCNPS_Alternatives.pdf.

Parking lots should have formal planting areas designed as bioretention areas or swales that accept and treat parking lot runoff. The swales and bioretention areas should contain a mixture of woody and herbaceous material. When curbs are utilized around parking lot bioretention or swale areas, they should have a shallow descending cut to allow drainage to flow from the parking lot into the curbed planting areas for infiltration. See *Section 4.2 Bioretention* in this manual for design criteria.

Disturbed areas intended for natural re-growth should be, at a minimum, graded, loamed, and seeded with wildflowers, perennial grasses, or similar varieties. The planting of native trees, shrubs, and other plant varieties is encouraged. The planting of native shrubs such as blueberry (*Vaccinium sp.*), wax myrtle (*Myrica cerifera)*, native azaleas (*Rhododendron sp.*), American beautyberry (*Callicarpa americana*), and yaupon holly (*Ilex vomitoria*) along the edge of cleared woodlands provides for an attractive transition between natural woodland and more formally landscaped portions of a site. Where woodland areas are intended to serve as buffers (see Figure 3.3-10), such plantings can fill in voids by rapidly reestablishing undergrowth. Perennial flower beds are also encouraged (RIDEM, 2011).

Soil Preparation:

The soils of the Coastal Plain are composed of marine sediments deposited during the millions of years (Eocene Period to present day) it took the Atlantic Ocean to recede from the "fall line" to its current location. Generally, these soils are sandy loams or loamy sands with a fine texture and high clay content. The soils tend to be acidic, have high levels of phosphorus, and are low in cation exchange capacity (CEC) and organic matter content (Polomski, 2007).

Site soil characteristics can modify stormwater runoff and treatment. Topsoil is the uppermost horizon of undisturbed soils and is generally assumed to be about 6 to 8 inches deep. This is the region of maximum biological activity in the soil profile. Eighty percent of the roots are located here, along with a diverse mixture of bacteria, fungi, and other living organisms such as earthworms, insects and moles. The topsoil is also where the majority of nutrient cycling occurs when leaves, twigs, roots and other organisms decompose (Polomski, 2007). The loss of good quality topsoil from sites during construction results in significant increases in runoff quantities; post development, these sites often have compacted soil that mimics impervious cover. This is because the soil horizons underneath topsoil typically have a higher clay content. Additionally, removing topsoil reduces the amount of organic material in soils – which have the ability to absorb many pollutants. In fact, peat and compost provide considerable pollutant removal and are used in various treatment strategies (RIDEM, 2011). See *Appendix C* for more information about compost amendments for soils.

Soil analysis of new or renovated turf areas provides a determination of soil characteristics, including: percentage of organic matter, approximate soil infiltration rate, and pH. At a minimum, soil testing should be conducted before any planting occurs to establish a fertilization plan and make any necessary amendments. Soil testing is provided, for a fee, by professional geotechnical companies or Clemson University Cooperative Extension service. See Clemson Cooperative Extension's Home & Garden Information Center Factsheet 1652 for more information: http://www.clemson.edu/extension/hgic/plants/pdf/hgic1652.pdf.

Soil amendments, when instituted with landscaping, will likely result in increased water conservation, increased nutrient retention, better aesthetics, reduced use of chemicals, and cost-savings to the private property owners and municipalities (RI DEM & CRMC 2011). Use of soil amendments is encouraged to improve water drainage, moisture penetration, soil oxygenation, and/or water holding capacity. Soil amendments are organic matter such as compost, mulch, and forestry by-products, but do not include topsoil or any mix with soil as an element. Incorporation of organic matter such as compost improves the structure of the soil. In sandy soils, compost increases the water holding capacity and nutrient retention. The physical and chemical properties of most soils can be improved significantly by blending in compost. Compost should be well-aged (6-12 months) and well-aerated. Turf grass shall not be utilized for compost since it can have significant levels of pesticides, herbicides, or nutrients. The quantity of compost to be incorporated into a site is determined by the final organic content goal for the soil and is dependent on its existing organic content – a soil test will help determine the appropriate amount to add to existing soils. Please see Appendix C for more information related to soil compost amendments.

Compacted soils restrict root penetration, impede water infiltration, have a higher runoff coefficient, and contain few macropore spaces needed for adequate aeration. Generally, an ideal soil for plant growth is about equally divided between solid materials and pore space on a volume basis, and the pore space is equally divided between air-filled and water-filled pores (Polomski, 2007). Avoiding construction activities on parts of the site will help prevent compaction. In areas where this is not practical, methods to compensate for the compaction shall be employed. To facilitate deep water penetration and soil oxygenation, landscape areas should be deep tilled to a depth of at least 12 inches to restore soils that are compacted during construction.

Existing topsoil should not be removed during construction, but should be stockpiled on site and reused in landscaped areas to promote the retention of native seed stocks and soil microbes. However, properties with existing invasive plant species require some additional precautions. It is possible for invasive plants to sprout from vegetative cuttings associated with land disturbing activities, as well as germinate from soil seed banks for many years after removal. Property managers should disturb as little soil as possible to prevent vegetatively propagating pest plant species, and the invasive plants should be removed as they develop.

For newly landscaped areas where topsoil is limited or nonexistent, or where soil drainage is impeded due to subsurface hardpan, a minimum of six inches of sandy loam topsoil should be spread in all planting and turf areas. This should be in addition to the incorporation of organic matter into the top horizon of the imported soil.

Mulching:

Mulch for areas not used for drainage should be applied regularly and maintained in all planting areas to assist soils in retaining moisture, reducing weed growth, and minimizing erosion. Mulches can be organic, inorganic, or synthetic. Organic mulches include materials such as pine straw and shredded hardwood bark. As they decompose, organic mulches add valuable nutrients to the soil. Inorganic mulches include materials such as decomposed lava rock, cobble, and gravel. Synthetic mulches include rubber pellets, plastic sheets or geotextile fabrics. It is important to note that the use of plastic warms the soils, which can be an advantage in the spring or detrimental in the summer (Polomski, 2007).

Mulches for stormwater management areas should be well-aged (6 months) hardwood mulch also known as “triple shredded mulch” (NCDENR, 2009) and applied to maintain a depth of 2 to 3 inches. Hardwood mulches tend to stay in place, whereas softwood mulches are more likely to float away during storm events. This is a twofold issue where softwood mulch use means a loss of function (i.e., mulch lost) and added organic material to the stormwater piped system (i.e., added gross solid pollutant load).

Vegetation:

Turf areas produce considerably more runoff due to compaction and more pollutant contribution, due to the frequently-occurring overuse of fertilizers and pesticides, as well as excessive irrigation. For example, lawn area in residential development shall be limited to 20% of the overall lot size or 5,000 square feet, whichever is less (RIDEM 2011). Generally, some turf area should be included, but not an expansive monoculture. A more desirable landscape is diverse and provides wildlife habitat, shade, and beauty along with small scale turf areas. As an alternative to lawn, landscape strips should be mulched or planted with native groundcover plant varieties. The South Carolina Native Plants Society provides guidance on reducing lawn size and incorporating native grasses into landscapes in this fact sheet: http://scnps.org/wp-content/uploads/2012/04/SCNPS_AlternativeLawns.pdf.

Using herbaceous and woody native plants is recommended in landscaping and LID BMPs. This category of vegetation helps preserve the beauty and identity of indigenous ecosystems while providing valuable stormwater treatment services. Native plants are species that have an evolutionary history with the biological and physical factors specific to a region. Because native plants are adapted to local soils, insects, and climate conditions, they generally require less watering, pesticides and fertilizing than non-natives do. Plant varieties selected should be salt tolerant where appropriate, drought resistant, able to withstand the moisture regime of its planting location (e.g. upper bank versus bottom of a bioretention unit), and require minimal maintenance. Education and guidance for plant selection in the coastal zone is provided by Clemson's Carolina Yards Program and the South Carolina Native Plant Society (http://scnps.org). SCNPS has two local chapters in the coastal zone: Lowcountry (Charleston area) and South Coast (Beaufort & Hilton Head). For more information, please see

- The SC Native Plant Society list of Coastal Plants is available at **http://scnps.org/wp-content/uploads/2012/04/CoastalNativePlantList.pdf**.
- The Clemson Carolina Yards program plant list is available at **www.clemson.edu/cy/plants**.

Installation Recommendations:

- Planting Specifications should follow recommendations from Clemson University Cooperative Extension (**http://www.clemson.edu/extension/hgic/plants/pdf/hgic1001.pdf**):
  - Areas intended as planting beds for shrubs or hedges shall be cultivated to a depth of not less than 18 inches. All other planting beds shall be cultivated to a depth of not less than 12 inches.
  - Holes for planting trees or shrubs shall be at least twice and preferably up to five times wider than the root ball. Locate the topmost layers of roots in the root ball so that they will be level with the surrounding soil surface; check that there is not an excess layer of soil already covering the root ball. Never place the rootball on loosened soil, as it will settle over time and cause the plant to sink too deep. In poorly drained or compacted soil, the plant should be placed about 2 to 4 inches above the surrounding soil (Polomski & Shaughnessy, 2004).

- Cultivated areas shall be covered with a 2- to 4-inch deep layer of mulch after planting. To reduce chances of stem rot and insect damage, do not allow mulch to touch the stem or trunk (Polomski & Shaughnessy, 2004). Replenish mulch as needed to maintain depth or desired appearance.
- Little if any pruning should be required at the time of transplant from container to ground. All broken or damaged branches should be removed. Trees with poor structure should be pruned at planting to correct the problem (Polomski & Shaughnessy, 2004).
- All plants should be nursery-grown native or low-maintenance species. No invasive species are permitted as per the list kept by the South Carolina Exotic Pest Plant Council (**http://www.se-eppc.org/southcarolina/**).

✧ Retention of Existing Natural Vegetation

- The boundary of areas to be cleared should be well defined in the field with tree markings, construction fencing or silt fencing as appropriate to avoid unnecessary cutting or removal.
- Care should be taken to protect root systems from damage due to excavation or compaction. Maintain the tree protection barrier, noting that impacts from soil compaction are often not evident for years.
- Individual trees and other landscape features to be retained should be clearly marked and bounded in the field.

Maintenance:

Many maintenance problems can be avoided by growing healthy plants in appropriate soil conditions. Ideally, soil testing should be conducted prior to planting and about once a year afterward to monitor any changes. Additionally, selecting low maintenance, drought-, insect-, and disease-tolerant plant varieties is encouraged so that buffer areas and other required landscaping can be maintained with minimal care (e.g. watering, pesticides, or fertilizers). For these reasons, native species are preferred since such plant species are well adapted to the local environment.

Generally, one inch of water is required per week for most plants; this includes both irrigation and rainfall inputs. If the irrigation system is on a timer, consider attaching a rain shut off device so the system will not run when it is raining. Organic matter, such as compost or peat, should be added to the soil before planting to increase the water holding capacity of the soil and to provide nutrients. Thus, the addition of organic material will help avoid maintenance problems and the need for excessive watering. Irrigation systems should be used only as needed. They can be installed with moisture meters or other devices designed to avoid unnecessary or excessive watering. Alternatively, irrigation systems can be manually operated. Whenever possible, less frequent, longer applications of irrigation are preferred as they promote deep root growth essential for plant survivability.

On an as-needed basis, repair any eroded areas and remove sediment, leaves, and debris from landscaping and LID BMPs. Pruning should only be necessary to remove damaged or diseased limbs or for ornamental reasons determined by the property owner. Take into consideration the mature height and spread of a plant before selecting a location to place it. A property owner will have to prune shrubs and trees more regularly if they have grown too large for their environment – for example, under telephone wires or too close to other structures.

Use mulch and dense plantings (taking advantage of groundcovers) to reduce the amount of required weeding. Once plants become established and have a suitable mulch cover, the amount of weeding should decrease over time. A factsheet for mulching (HGIC 1604) is available at Clemson's HGIC website: http://www.clemson.edu/extension/hgic/plants/other/compost_mulch/hgic1604.html.

Perceptions and Realities:

Some misconceptions that have limited the use of LID landscaping are included in Table 3.3-11.

Table 3.3-11. LID Landscaping Perceptions and Realities[1]

Perception	Realities and Challenges
Native plants are not available.	Native plants are becoming more common and typically can be ordered easily. They can be found at many local gardening centers, "big box" stores, and on the internet. As requests for native plants increase, so will the market supply.
Many landscaping contractors are less familiar with planting strategies.	More and more communities and organizations are offering training and education about the benefits of native plant materials, so landscaping contractors are becoming more familiar with these installations.
Some property owners prefer a more manicured appearance.	LID Landscaping can be designed with a more manicured look where necessary. While it is true that native species are preferred, many cultivars will work just as well and can achieve both environmental benefits as well as aesthetic appeal.
Many property owners desire lush green lawn areas and some prefer large expanses of turf.	The switch from a lush green lawn to a natural "xeriscape" will require education and will not be for everyone.
Micro drainage can be difficult to get established, and minor erosion gullying prior to stabilization can be a frequent issue.	Careful design and – equally important – construction oversight and inspection can resolve most of these issues. Some minor gullying is to be expected prior to stabilization and will require minor repairs.
Vegetative systems require a long-term commitment to maintenance.	All stormwater management systems require routine and sometimes non-routine maintenance. However, vegetative systems can reduce the overall maintenance burden by maintaining infiltration capacity even in the midst of significant sediment loading.

[1]*Excerpted from RI DEM & CRMC, 2011*

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Chapter 4:

Guide to Stormwater Best Management Practices

4.1 Introduction

The specifications included in this manual are intended to be used as design guidance, providing the designer with state-of-the-science information on BMP design, while also allowing as much flexibility for designers as possible. With that in mind, the specifications use the terms "should" and "must."

- ✧ Where "should" and similar words are used, the information provided should be considered design guidance, and may be deviated from where necessary, but should be done so with care.
- ✧ Where "must" and similar words are used, the directives are considered inherent to the effectiveness and function of the practice.

These specifications may be adopted as design guidance to enhance existing regulations or rules, in which case, some of the credit equations may not apply. Or they may be adopted as a whole, including the credit equations and associated LID Compliance Calculator spreadsheet tool.

The Runoff Reduction Approach

Runoff reduction is defined as "the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration." Many of the BMPs in this manual utilize these mechanisms to either permanently or over a very long period (in the case of extended filtration), reduce the volume of runoff from a site.

Not all BMPs achieve runoff reduction equally. The level to which a BMP provides runoff reduction is indicated in Table 4.1-1. The rates are expressed as a percentage of the storage volume provided by the BMP. Calculations for determining storage volume are included in each BMP's specifications. The runoff reduction rates in the table are derived from compiled research on the various BMPs' annual runoff reduction capabilities (Hirschman et al., 2008), as well as an analysis of each BMP's operation in a single storm event.

Table 4.1-1. Runoff Reduction Rates for LID and Infiltration Practices

BMP	Runoff Reduction Rate (% of Storage Volume)
Bioretention - Enhanced	100%
Bioretention - Standard	60%
Permeable Pavement - Infiltration	100%
Permeable Pavement - Standard	50%
Infiltration	100%
Green Roof	100%
Rainwater Harvesting	100%
Disconnection to A/B or Amended Soils	50%
Disconnection to C/D Soils	25%
Disconnection to Forest Cover/Open Space	75%
Grass Channel in A/B or Amended Soils	20%
Grass Channel in C/D Soils	10%
Dry Swale	60%

LID Design Considerations for Coastal Conditions

While all of the BMPs included in this manual have the capability of meeting state and local water quality requirements, site conditions, costs, and removal goals may dictate the choice of one BMP over another. A screening process that can be used to help decide what BMPs are best suited for a given development site is outlined below. This process is intended to assist designers in selecting the most appropriate BMPs for use on a development site.

For the most part, the factors presented in this chapter represent guidelines, not rules, for which BMP may be most appropriate at a site. It is important to note that certain BMP design modifications or specific site characteristics may allow for a particular BMP to become better suited at a particular location. Several of these design modifications are described in the individual practice specifications.

Site Conditions, *Stormwater Treatment Requirements*, *Physical Feasibility*, and *Site Applicability* are all important information that should be considered when deciding what stormwater management practices can be used on a development site.

Site Conditions:

While some BMPs can be applied almost anywhere, others require specific conditions to be most effective. Coastal environments provide a unique set of constraints that often require more careful design choices and often allow less design flexibility than other locations. Some of the most common coastal design constraints are described below.

Poorly Drained Soils: There are many instances of poorly drained soils in the coastal environment. This can be a major impediment to the use of infiltration-based practices, including permeable pavement and bioretention. In poorly drained soils, these practices must be designed with an underdrain (where sufficient head exists), so they can be de-watered sufficiently to accommodate subsequent storm events. Where sufficient head does not exist, these practices may not be feasible. Other practices, such as green roofs, rain water harvesting, disconnection, wet ponds, or wetlands may be more appropriate.

Well-Drained Soils: Sandy, well-drained soils are often ideal locations for infiltration-based practices. However, if the soils drain too quickly, they may allow stormwater pollutants to reach groundwater. In areas of very well-drained soils, infiltration practices should be used with care. In areas known to provide groundwater recharge to water supply aquifers, practices with underdrains or impermeable liners should be used instead.

Flat Terrain: Flat terrain may make it difficult to provide adequate drainage for practices that require higher head values, particularly those with underdrains, such as bioretention and permeable pavement. Infiltration-based practices, where feasible, are a better option in areas with flat terrain. Where infiltration is not feasible, rooftop-oriented practices, such as green roofs, rainwater harvesting, and disconnection are still options.

High Groundwater: It can often be difficult to achieve the minimum required 0.5-foot separation between the bottom of a filtering or infiltration-based practice and the seasonal high groundwater table. Where the groundwater table is too high, rooftop-oriented practices (green roofs, rainwater harvesting, and disconnection) are still feasible, as are wet ponds and wetlands that will benefit from having a groundwater connection.

Tidally Influenced Drainage Systems: Tidally influenced drainage systems can prevent the conveyance of stormwater through a BMP and reduce the BMP's effective volume. Some BMPs can be implemented in tidally influenced drainage systems, although portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations. Also, salt-tolerant vegetation may be necessary in these areas.

Pollutants of concern: Sediment, phosphorus, nitrogen, and bacteria are all pollutants of concern in the coastal environment. While all of the BMPs described in this manual have removal capabilities for all of the pollutants, some BMPs are more suited to specific pollutants.

- Sediment and phosphorus are typically removed via gravitational settling and filtration. All of the practices in the manual have high sediment removal potential.
- Nitrogen removal generally requires anaerobic conditions, which makes wet ponds and wetlands better options. Anaerobic zones can also be included in bioretention areas and permeable pavement to improve their nitrogen removal.
- BMP effectiveness for bacteria removal is less understood. Mechanisms for removal typically include settling, exposure to sunlight, and drying. Filtering practices, such as infiltration, bioretention, and green roofs provide all of these mechanisms. Wet ponds and wetlands also provide some of these mechanisms, but also can attract wildlife, which may make these BMPs a source of bacteria in some cases.

Stormwater Treatment Requirements:

Stormwater management requirements for a given site vary based on the site's location. The various rules that may apply are summarized below, and outlined in Figure 4.1-1. Please note that the summaries below are merely a guide, and not intended as a substitute for the actual rule or regulation. It is important to note that this manual, and the associated compliance calculators, make a distinction between treatment and runoff reduction. In particular, runoff reduction is required in the coastal zone when infiltration practices are used, and on sites regulated by the MS4 permit. While all practices included in this manual are assumed to provide treatment for their entire design volume, the runoff reduction percentage depends on the practice design (See Table 4.1-1).

- Coastal Zone Requirements: All projects, regardless of size, that are located within ½ mile of a coastal receiving water, as defined in the SC Coastal Zone Management Program Refinements, must catch and store onsite the first ½ inch of runoff from the site's disturbed area, or the first 1 inch of runoff from the site's built-upon portion, whichever is greater. Storage may be accomplished through retention, detention, or infiltration practices. Storage designs are selected as appropriate for the specific site.
- Shellfish Bed Requirements: For projects located within 1,000 feet of shellfish beds, the first 1½ inches of runoff from the built-upon portion of the property must be retained onsite.
- Small Municipal Separate Storm Sewer Systems (SMS4): Communities subject to the SMS4 Permit are required to develop new development and redevelopment standards for sites greater than 1 acre that "demonstrate the runoff reduction and pollutant removal necessary to approximate pre-development conditions to the MEP [Maximum Extent Practicable] and to protect water quality." Infiltration, evapotranspiration, rain harvesting, and stormwater reuse and recharge are all suggested as means to achieve this requirement.

Note: While a variety of post-construction stormwater standards are suggested as possibilities to meet this requirement, for crediting purposes, this chapter assumes that the following standard will be used, as it is most applicable to the Runoff Reduction approach described above:

> Design, construct, and maintain stormwater management practices that manage rainfall on-site, and prevent the off-site discharge of 1 inch of runoff from the site's disturbed area.

- Water Quality Treatment and Water Quantity Control Requirements Statewide: For projects that are not subject to an SMS4's rules and are greater than 5 acres:
  - Ponds with a permanent pool must store and release over 24 hours the first ½ inch of runoff from the site based upon respective drainage area(s).
  - Ponds without a permanent pool must store and release over 24 hours the first 1 inch of runoff from the site based upon the respective drainage area(s).
  - Infiltration practices must accept the first 1 inch of runoff from impervious surfaces.
- For Water Quantity Control, post-development discharge rates cannot exceed the predevelopment rates for the 2- and 10-year, 24 hour storm event for all sites regulated by the Statewide Stormwater Regulations (this requirement also exists in most SMS4 communities). All BMPs address water quantity to some extent, but many BMPs whose main purpose is water quality treatment typically do not have enough volume to manage larger storm events.

Table 4.1-2 indicates each BMP's capability to meet each category of requirements described above. As with the descriptions above, this table is a summary only. It is not a substitute for the actual rules and regulations. It is strongly recommended that a designer discuss potential designs with the appropriate plan reviewer to ensure compliance.

Table 4.1-2: Stormwater Management Capability for BMPs

BMP	Coastal Zone Requirements[1]	Shellfish Bed Requirements[1]	SMS4 Standard[1]	Water Quality Treatment[2]	Water Quantity Control[1]
Bioretention	Yes	Yes	Yes	Infiltration via Runoff Reduction	Partial
Permeable Pavement	Yes	Yes	Yes	Infiltration via Runoff Reduction	Yes
Infiltration	Yes	Yes	Yes	"Infiltration"	Partial
Green Roof	Yes	Yes	Yes	Infiltration via Runoff Reduction	Partial
Rainwater Harvesting	Yes	Yes	Yes	Infiltration via Runoff Reduction	Partial
Disconnection	Partial	Partial	Partial	Infiltration via Runoff Reduction	Partial
Open Channels	Partial	Partial	Partial	Infiltration via Runoff Reduction	Partial
Filtration	Yes	No	No	Pond without Permanent Pool	No
Dry Detention Practices	Yes	No	No	Pond without Permanent Pool	Yes
Wet Detention Ponds	Yes	No	No	Pond with Permanent Pool	Yes
Stormwater Wetlands	Yes	No	No	Pond with Permanent Pool	Yes

[1]"Yes" means that a given BMP could feasibly be designed to meet a given requirement. It does not mean that all variations and sizes of the BMP will automatically meet the requirement.
[2] This column indicates which of the Water Quality Treatment standards is likely to apply to each BMP. Since the water quality treatment regulations only indicate "ponds with a permanent pool," "ponds without a permanent pool," and "infiltration practices," as the available options, classification of the other BMPs is somewhat difficult. For the sake of presenting complete LID guidance and a unified calculation method, this chapter assumes that the runoff reduction volume provided by certain BMPs can be counted toward meeting the infiltration practice requirement. However, actual treatment capability of a BMP depends greatly upon design of the BMP relative to individual site circumstances.

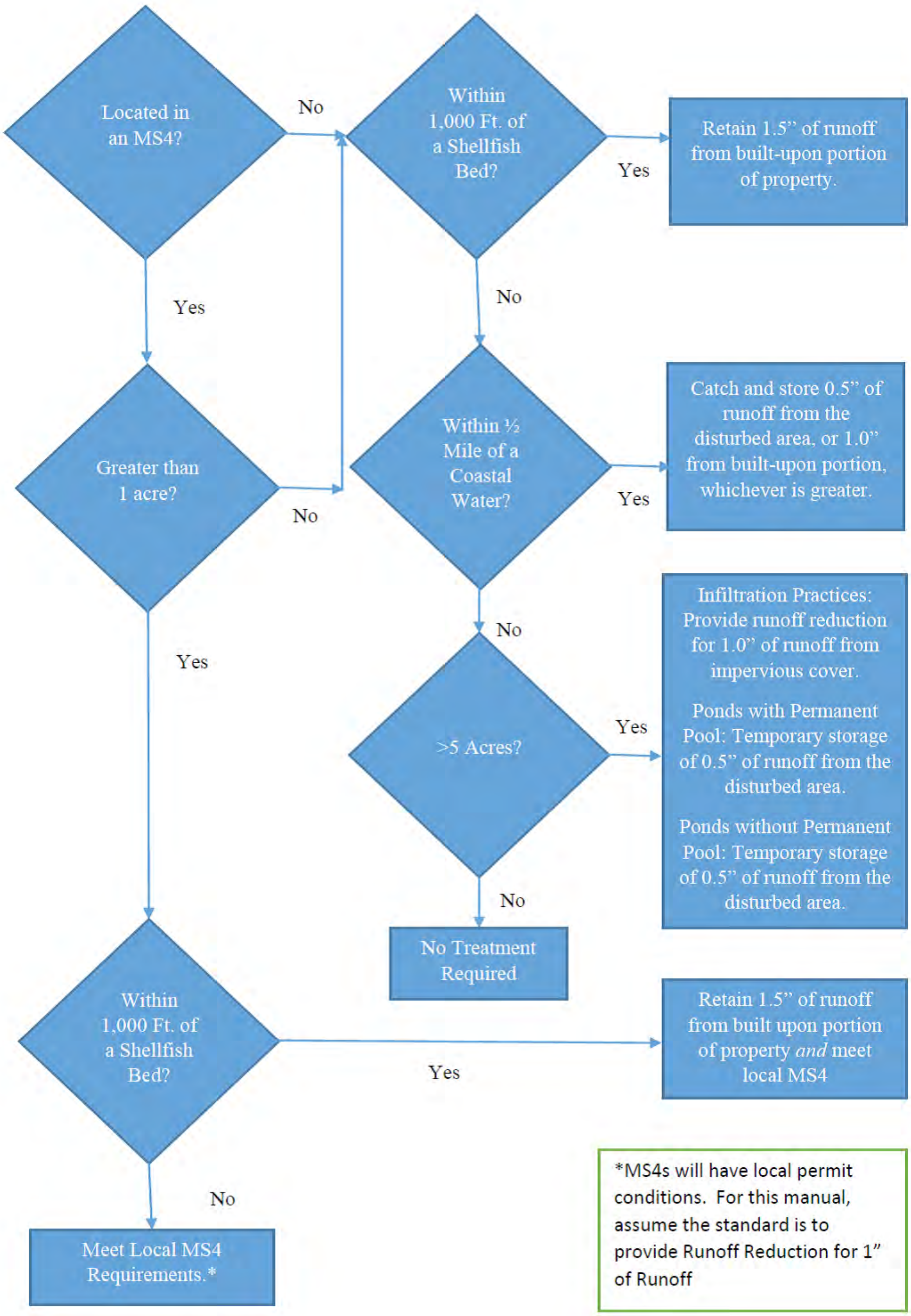

Figure 4.1-1. Flowchart to Determine Stormwater Management Requirements

The Treatment Train

In many LID designs, the concept of the "treatment train" is employed to maximize the utility of each BMP and improve water quality. A treatment train is a group of BMPs designed in series so that runoff flows from one to the next, providing multiple opportunities for both runoff reduction and pollutant removal. When used in conjunction with runoff reduction designs and calculations, treatment trains can provide greater flexibility in the sizing of individual BMPs, as each BMP only needs to achieve a portion of the total runoff reduction or treatment volume.

There can be many additional advantages to utilizing a treatment train approach:

- Different elevations and land use types on site may lend themselves to the use of different BMPs.
- The natural topography of a site can be accounted for, with less need for mass site grading.
- A series of smaller BMPs may be easier to fit within a proposed site design.
- Using different types of BMPs in series provides multiple pollutant removal mechanisms, which can greatly enhance water quality.
- BMPs that do not treat or remove the entire water quality volume can be used in conjunction with other more effective BMPs.

While there are many advantages to using treatment trains, there are some important challenges to be considered as well:

- Complexity is added to a site design when multiple BMPs are used.
- Practice depth can be a difficult limitation when underdrains are utilized. For a fully effective treatment train, the "downstream" BMP must receive both the overflow and the underdrain flow from the first practice.
- BMPs based on disconnection can be difficult to "re-connect" in order to convey them to the next BMP in series.
- Vegetation selection becomes very important for the "downstream" BMP, as it will be drier than it otherwise would be, since the first BMP may remove a lot of the runoff from small storm events.

Many different combinations of treatment trains are possible, but some BMPs work better than others in treatment trains, and for some, the position in the treatment train is very important. Rooftop-based BMPs, like green roofs and rainwater harvesting, are great as the first practice in a treatment train – since they are located at higher elevations, overflow from them can be easily conveyed to an on-the-ground practice. Other qualities of first-in-line BMPs include an absence of underdrains (again, due to the elevation issue), and a concentrated outflow or overflow, allowing easy conveyance to the "downstream" BMP. "Downstream" BMPs have fewer restrictions, beyond typically needing to be at ground level or below. Storage BMPs like dry or wet detention are often used as the last practice in a treatment train so they can collect all of the water from a site after it has been treated for water quality, and provide the required detention for larger storm events.

A few examples of treatment train designs include:

- Overflow from a green roof or rainwater harvesting system could be directed to imperviou surface disconnection.
- An open channel could be used to convey runoff to a bioretention area.
- A stormwater filtering system could provide pretreatment for a stormwater infiltration BMP.
- Overflow from a stormwater infiltration BMP could be routed to a dry detention practice.

Calculations for properly crediting each BMP in a treatment train are included in the Coastal South Carolina LID Compliance Sheet, and described in Appendix A.

Physical Feasibility:

Physical feasibility refers to the physical site conditions necessary to effectively design and install a BMP. Table 4.1-3 includes the feasibility factors listed below. With the exception of minimum depth to water table, none of these factors should be considered inflexible limits. Modifications to BMP design may often be made to account for divergence from the stated minimum and/or maximum values.

- ✧ Contributing Drainage Area (CDA): Volume of water received by a practice can affect BMP performance. This column indicates the contributing drainage areas that typically apply for each BMP.
- ✧ Slope: This column describes the influence that site slope can have on the performance of the BMP. It indicates the maximum or minimum slope on which the BMP should be installed.
- ✧ Minimum Head: This column provides an estimate of the minimum amount of elevation difference needed within the BMP, from the inflow to the outflow, to allow for gravity operation.
- ✧ Minimum Depth to Seasonal High Water Table: This column indicates the minimum distance that should be provided between the bottom of the stormwater management practice and the top of the water table.
- ✧ Soils: This column describes the influence that the underlying soils (i.e., hydrologic soil groups) can have on the performance of the stormwater management practice.

Table 4.1-3: Feasibility Limitations for BMPs					
BMP	**Contributing Drainage Area**	**Slope**	**Minimum Head**	**Minimum Depth to Water Table**	**Soils**
Bioretention	Up to 5 acres	Up to 5%[2]	2.5 – 4 feet	0.5 feet	All soils[3]
Permeable Pavement	Up to 5 times practice surface area	Up to 5%	2 – 4 feet	0.5 feet	All soils[3]
Infiltration	Up to 5 acres	Up to 5%[2]	2 – 4 feet	0.5 feet	Must drain within 72 hours
Green Roof	Green roof area + 25%	No limit	N/A	N/A	N/A
Rainwater Harvesting	No limit	No limit	N/A	N/A	N/A
Disconnection	Up to 1,000 ft^2 per downspout	Up to 5%	N/A	N/A	All soils
Open Channels	Up to 5 acres	Up to 5%[2]	1 – 2 feet	0.5 feet	All soils
Filtration	Up to 10 acres	Up to 5%	2 – 4 feet	0.5 feet	All soils
Dry Ponds	No limit	Up to 15%	4 – 8 feet	0.5 feet	All soils
Wet Ponds	Greater than 10 acres[1]	Up to 15%	4 – 8 feet	No limit	Slow-draining soils preferred
Stormwater Wetlands	Greater than 10 acres[1]	Up to 15%[2]	2 – 5 feet	No limit	Slow-draining soils preferred

[1]CDA can be smaller if practice intersects the water table.
[2]Check dams may be necessary to create sufficient ponding volume.
[3]Slow-draining soils may require an underdrain.

Site Applicability:

Not all BMPs are appropriate for all situations. Table 4.1-4 describes the site applicability for each BMP for the following factors:

- Rural Use: This column indicates whether or not the stormwater management practice is typically suited for use in rural areas and on low-density development sites.
- Suburban Use: This column indicates whether or not the stormwater management practice is typically suited for use in suburban areas and on medium-density development sites.
- Urban Use: This column identifies the stormwater management practices that are typically suited for use in urban and ultra-urban areas where space is at a premium.
- Construction Cost: This column assesses the relative construction cost of each of the stormwater management practices.
- Maintenance: This column assesses the relative maintenance burden associated with each stormwater management practice. It is important to note that all stormwater management practices require some kind of routine inspection and maintenance.

Table 4.1-4: Site Applicability for BMPs

BMP	Rural Use	Suburban Use	Urban Use	Construction Cost	Maintenance
Bioretention	Yes	Yes	Yes	Medium	Medium
Permeable Pavement	Maybe	Yes	Yes	High	High
Infiltration	Yes	Yes	Yes	Medium	Medium
Green Roof	Maybe	Yes	Yes	High	Low
Rainwater Harvesting	Yes	Yes	Yes	Medium	Medium
Disconnection	Yes	Yes	Maybe	Low	Low
Open Channels	Yes	Yes	No	Low-Medium	Medium
Filtration	Maybe	Yes	Yes	High	High
Dry Ponds	Yes	Yes	No	Low	Low
Wet Ponds	Yes	Yes	No	Low	Low
Stormwater Wetlands	Yes	Yes	No	Low	Medium

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4.2 Bioretention

Introduction

Bioretention areas, shallow depressional areas that are filled with an engineered soil media and are planted with trees, shrubs, and other herbaceous vegetation, are one of the most effective stormwater management practices that can be used in coastal South Carolina to reduce post-construction stormwater runoff rates, volumes, and pollutant loads. They also provide a number of other benefits, including improved aesthetics, wildlife habitat, urban heat island mitigation, and improved air quality. See Figures 4.2-1 – 4.2-3 for example designs.

They are designed to capture and temporarily store stormwater runoff in the engineered soil media, where it is subjected to the hydrologic processes of evaporation and transpiration, before being conveyed back into the storm drain system through an underdrain or allowed to infiltrate into the surrounding soils. The engineered soil media is comprised of sand, soil, and organic matter.

Typically, bioretention systems are not designed to provide stormwater detention of larger storms (e.g., 2-year, 10-year), but in some circumstances that may be possible. Bioretention practices should generally be combined with a separate facility to provide those controls.

Figure 4.2-1. Bioretention in Parking Lot (Photo: Center for Watershed Protection)

Figure 4.2-2. Bioretention in a Cul-de-sac (Photo: Center for Watershed Protection)

Figure 4.2-3. Bioretention in a Residential Setting (Photo: NEMO)

KEY CONSIDERATIONS: BIORETENTION

DESIGN CRITERIA:

- Bioretention areas should be designed to completely drain within 72 hours of the end of a rainfall event.
- A maximum ponding depth of 18 inches is recommended within bioretention areas to help prevent the formation of nuisance ponding conditions.
- Unless a shallow water table is found on the development site, bioretention area planting beds should be between 18 – 36 inches deep.
- The distance from the bottom of the practice to the top of the seasonal high water table should not be less than 0.5 feet.
- The infiltration rate of native soil needs to be included in most cases where no under drains are specified.

BENEFITS:

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes, and pollutant loads.
- Can be integrated into development plans as attractive landscaping features.

LIMITATIONS:

- Can only be used to manage runoff from relatively small drainage areas of up to 5 acres in size.

SITE APPLICABILITY:

- Rural Use
- Suburban Use
- Urban Use
- Construction Cost: Medium
- Maintenance: Medium
- Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 100% credit for storage volume of infiltration or enhanced design.
- 60% credit for storage volume of standard design.

Coastal Zone Credit Approach

- 100% credit for storage volume of practice.

Statewide Water Quality Requirement Credit Approach

- Runoff Reduction credit applies to infiltration requirement.

Pollutant Removal[1]
80-90% - Total Suspended Solids
55-90% - Total Phosphorus
65-90% - Total Nitrogen
N/A - Metals
55-90% - Pathogens

[1] *expected annual pollutant load removal*

There are two different types of bioretention design configurations:

- ✧ **Standard Designs.** Practices with a standard underdrain design and less than 24 inches of filter media depth (see Figure 4.2-4). The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed below.
- ✧ **Enhanced Designs.** Practices that can infiltrate the design storm volume in 72 hours (see Figures 4.2-5 and 4.2-6) or practices with underdrains that contain at least 24 inches of filter media depth and an infiltration sump/storage layer (see Figure 4.2-5).

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed below.

Bioretention Feasibility Criteria

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and is infiltrated or returned to the stormwater system via an underdrain. Key constraints with bioretention include the following:

Required Space. Planners and designers can assess the feasibility of using bioretention facilities based on a simple relationship between the contributing drainage area and the corresponding bioretention surface area. The surface area is recommended to be approximately 3 to 6% of the contributing drainage area (CDA), depending on the imperviousness of the CDA and the desired bioretention ponding depth.

Site Topography. Bioretention can be used for sites with a variety of topographic conditions, but is best applied when the grade of the area immediately adjacent to the bioretention practice (within approximately 15 to 20 feet) is greater than 1% and less than 5%.

Available Hydraulic Head. Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the bioretention area into the storm drain system). In general, 4 to 5 feet of elevation above this invert is needed to accommodate the required ponding and filter media depths. If the practice does not include an underdrain or if an inverted or elevated underdrain design is used, less hydraulic head may be adequate.

Water Table. Bioretention must be separated from the water table to ensure that groundwater does not intersect the filter bed. Mixing can lead to possible groundwater contamination or failure of the bioretention facility. A separation distance of 0.5 feet is required between the bottom of the excavated bioretention area and the seasonally high groundwater table.

Tidal Impacts. For systems with an underdrain, the underdrain should be located above the tidal mean high water elevation. For entirely infiltration-based systems, the bottom of the stone reservoir should be located above the mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations. Also, salt-tolerant vegetation may be necessary in these areas.

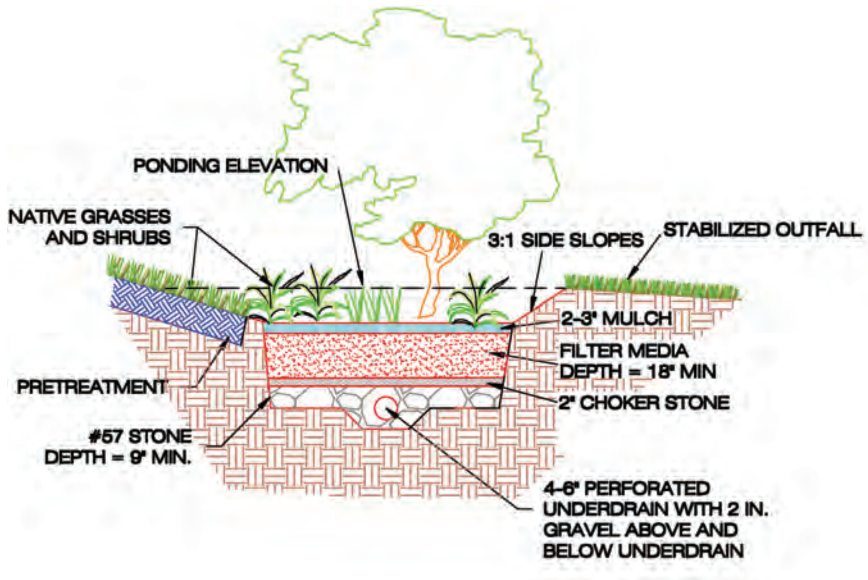

Figure 4.2-4. Bioretention Standard Design

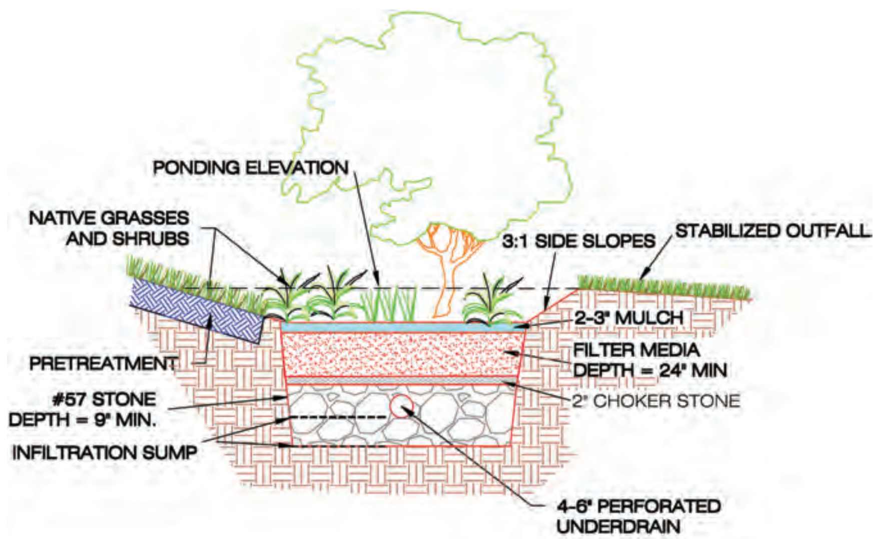

Figure 4.2-5. Bioretention enhanced design with an underdrain and infiltration sump/storage layer

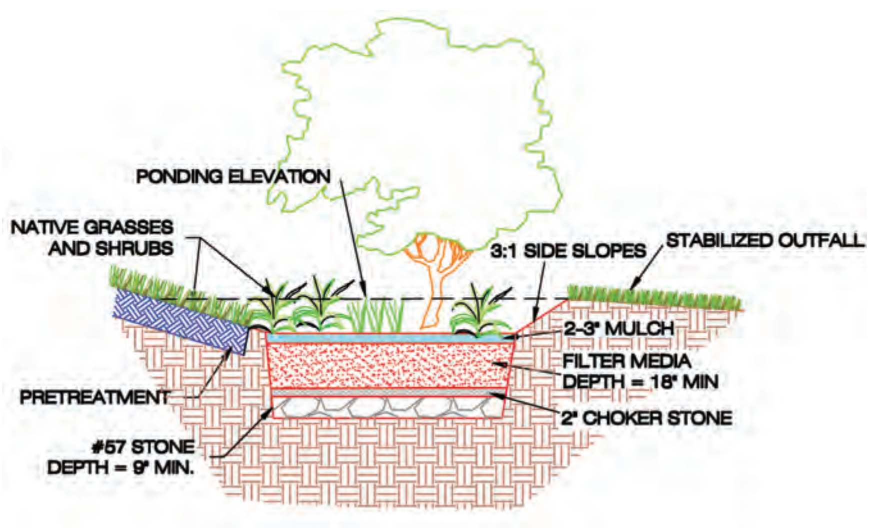

Figure 4.2-6. Bioretention enhanced design without an underdrain

Soils and Underdrains. Soil conditions do not typically constrain the use of bioretention, although they do determine whether an underdrain is needed. Underdrains are required if the measured permeability of the underlying soils is less than 0.3 in/hr. When designing an infiltration-based bioretention practice, designers must verify soil permeability by using the on-site soil investigation methods identified in *Appendix B*, or similar methods.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary.

Contributing Drainage Area. Bioretention cells work best with smaller contributing drainage areas, where it is easier to achieve flow distribution over the filter bed. The maximum recommended drainage area to a traditional bioretention area is 5 acres, and can consist of up to 100% impervious cover. However, if hydraulic considerations are adequately addressed to manage the potentially large peak inflow of larger drainage areas, such as off-line or low-flow diversions, or forebays, there may be case-by-case instances where the maximum drainage area can be adjusted.

Pollutant Hotspot Land Uses. Bioretention may not be an appropriate stormwater management practice for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the bioretention area and subsequent water bodies.

On sites with existing contaminated soils, infiltration is not allowed. Bioretention areas must include an impermeable liner, and the Enhanced Design configuration cannot be used.

No Irrigation or Baseflow. The planned bioretention area should not receive baseflow, irrigation water, chlorinated wash-water, or other such non-stormwater flows. However, irrigation is allowed during the establishment period of the bioretention area to ensure plant survival. In addition, rain gardens or bioretention practices may be incorporated into the design of a Rainwater Harvesting System (See Rainwater Harvesting Specification).

Setbacks. To avoid the risk of seepage and to prevent damage to building foundations and contamination of groundwater aquifers, bioretention areas should be located at least:

- 10 feet from building foundations*
- 10 feet from property lines
- 150 feet from private water supply wells
- 50 feet from septic systems

*For building foundations, where the 10 foot setback is not possible, an impermeable liner may be used along the sides of the bioretention area (extending from the surface to the bottom of the practice) to prevent seepage or foundation damage.

Proximity to Utilities. Designers should ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead utility lines. Interference with underground utilities should be avoided, if possible. When large site development is undertaken, the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Where conflicts cannot be avoided, these guidelines shall be followed:

- ✧ Consult with each utility company on recommended offsets that will allow utility maintenance work with minimal disturbance to the stormwater Best Management Practice (BMP).
- ✧ Whenever possible, coordinate with utility companies to allow them to replace or relocate their aging infrastructure while BMPs are being implemented.
- ✧ BMP and utility conflicts will be a common occurrence in public right-of-way projects. However, the standard solution to utility conflict should be to allow the utility to be located below the BMP, but to ensure that sufficient soil coverage over the utility will be provided.
- ✧ Additionally, when accepting utility conflict into the BMP design, it is understood that the BMP will be temporarily impacted during utility maintenance but restored to its original condition.

Minimizing External Impacts. Urban bioretention practices may be subject to higher public visibility, greater trash loads, pedestrian traffic, vandalism, and even vehicular loads. These practices should be designed in ways that prevent, or at least minimize, such impacts. In addition, designers should recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous vegetation. The urban landscape context may feature naturalized landscaping or a more formal design. When urban bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences, grates, or other measures to prevent damage from pedestrian short-cutting across the practices.

Economic Considerations. Bioretention areas can be particularly cost effective when they are included in areas of the site already planned for landscaping.

Bioretention Conveyance Criteria

There are two basic design approaches for conveying runoff into, through, and around bioretention practices:

1. Off-line: Flow is split or diverted so that only the design storm or design flow enters the bioretention area. Larger flows by-pass the bioretention treatment.
2. On-line: All runoff from the drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir.

If runoff is delivered by a storm drain pipe or is along the main conveyance system, the bioretention area should be designed off-line so that flows to do not overwhelm or damage the practice.

Off-line bioretention. Overflows are diverted from entering the bioretention cell. Optional diversion methods include the following:

- ✧ Create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filters through the soil media. With this design configuration, an overflow structure in the bioretention area is not required.

- ✧ Utilize a low-flow diversion or flow splitter at the inlet to allow only the design storm volume to enter the facility (calculations must be made to determine the peak flow from the design storm). This may be achieved with a weir, curb opening, or orifice for the target flow, in combination with a bypass channel or pipe. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. With this design configuration, an overflow structure in the bioretention area is required (see on-line bioretention below).

On-line bioretention. An overflow structure must be incorporated into on-line designs to safely convey larger storms through the bioretention area. The following criteria apply to overflow structures:

- ✧ An overflow must be provided within the practice to pass storms greater than the design storm storage to a stabilized water course. A portion of larger events may be managed by the bioretention area so long as the maximum depth of ponding in the bioretention cell does not exceed 18 inches.
- ✧ The overflow device must convey runoff to a storm sewer, stream, or the existing stormwater conveyance infrastructure, such as curb and gutter or an existing channel.
- ✧ Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum ponding depth of the bioretention area, which is typically 6 to 18 inches above the surface of the filter bed.
- ✧ The overflow device should be scaled to the application – this may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.
- ✧ At least 3–6 inches of freeboard must be provided between the top of the overflow device and the top of the bioretention area to ensure that nuisance flooding will not occur.
- ✧ The overflow associated with the 2-year and 10-year design storms must be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).

Bioretention Pretreatment Criteria

Pretreatment of runoff entering bioretention areas is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Pretreatment measures must be designed to evenly spread runoff across the entire width of the bioretention area. Several pretreatment measures are feasible, depending on the type of the bioretention practice and whether it receives sheet flow, shallow concentrated flow, or deeper concentrated flows. The following are appropriate pretreatment options:

- ✧ **Leaf Screens** (for small-scale residential applications) used as part of the gutter system serve to keep the heavy loading of organic debris from accumulating in the bioretention cell.
- ✧ **Grass Filter Strips** (sheet flow) that are perpendicular to incoming sheet flow extend from the edge of pavement (i.e., with a slight drop at the pavement edge) to the bottom of the bioretention basin at a 5:1 slope or flatter.

- ✧ **Stone Trenches** that are located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4 inch drop from the pavement edge to the top of the stone. The stone should be sized according to the expected rate of discharge.
    - Note: stone trenches are not recommended for school settings.
- ✧ **Trash Racks** (for either sheet flow or concentrated flow) are placed between the pretreatment cell and the main filter bed or across curb cuts. These will allow trash to collect in specific locations and create easier maintenance.
- ✧ **Pretreatment Cells**, similar to a forebay, are located at piped inlets or curb cuts leading to the bioretention area, and consists of an energy dissipater sized for the expected rates of discharge. It has a storage volume equivalent to at least 15% of the total storage volume (inclusive) with a recommended 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen or rock berm. Pre-treatment cells do not need underlying engineered soil media, in contrast to the main bioretention cell. However, if the volume of the pretreatment cell will be included as part of the bioretention storage volume, the pretreatment cell must de-water between storm events. It cannot have a permanent ponded volume.
- ✧ **Filter Systems**, such as sand filters or proprietary filter designs also may be used for pretreatment.

Bioretention Design Criteria

Design Geometry. Incoming flow should be distributed as evenly as possible across the entire filter surface area.

Ponding Depth. The recommended surface ponding depth is 6 to 12 inches, although ponding depths can be as high as 18 inches. Higher ponding depths require more careful consideration of issues such as safety, fencing requirements, aesthetics, the viability and survival of plants, and erosion and scour of side slopes. This is especially true where bioretention areas are built next to sidewalks or other areas were pedestrians or bicyclists travel.

Side Slopes. Typical bioretention areas should be constructed with side slopes of 3:1 or flatter. In highly urbanized or space-constrained areas, a drop curb design or a precast structure can be used to create a stable, vertical side wall. These drop curb designs should not exceed a vertical drop of more than 12 inches, unless safety precautions, such as railings, walls, grates, etc. are included.

Filter Media. The filter media is the most important element of a bioretention facility in terms of long-term performance.

- ✧ <u>Particle Size Composition.</u> The bioretention soil mixture shall be classified as a loamy sand on the USDA Texture Triangle, with the following particle size composition:
    - 80–90% sand (at least 75% of which must be classified as coarse or very coarse sand)
    - 10–20% soil fines (silt and clay)
    - Maximum 10% clay
    - The particle size analysis must be conducted on the mineral fraction only or fol-

lowing appropriate treatments to remove organic matter before particle size analysis.

- Organic Matter. The filter media must contain 3 to 5% organic matter by conventional Walkley-Black soil organic matter determination method or similar analysis. Soil organic matter is expressed on a dry weight basis and does not include coarse particulate (visible) components.
- Available Soil Phosphorus (P). The filter media should contain sufficient plant available P to support initial plant establishment and plant growth, but not serve as a significant source of P for long term leaching. For the Mehlich I extraction procedure, a range of 5 to 15 mg/kg P is acceptable. For the Mehlich III procedure, a range of 18 to 40 mg/kg P is acceptable.

Figure 4.2-7. Bioretention with a Drop Curb (Photo: DC Green Infrastructure http://www.flickr.com/photos/dcgreeninfrastructure/)

- Cation Exchange Capacity (CEC). The relative ability of soils to hold and retain nutrient cations like Ca and K is referred to as cation exchange capacity or CEC, and is measured as the total amount of positively charged cations that a soil can hold per unit dry mass. CEC is also used as an index of overall soil reactivity and is commonly expressed in milliequivalents per 100 grams (meq/100g) of soil or cmol+/kg (equal values). A soil with a moderate to high CEC indicates a greater ability to capture and retain positively charged contaminants, which encourages conditions to remove phosphorus, assuming that soil fines (particularly fine silts and clays) are at least partially responsible for CEC. The minimum CEC of the filter media is 5.0 (meq/100 g or cmol+/kg). The filter media CEC should be determined by the Unbuffered Salt, Ammonium Acetate, Summation of Cations or Effective CEC techniques (Sumner and Miller, 1996) or similar methods that do not utilize strongly acidic extracting solutions.

The goal of the mixture as described above is to create a soil media that maintains long-term permeability while also providing enough nutrients to support plant growth. The initial permeability of the mixture will exceed the desired long-term permeability of 1 to 2 in/hr. The limited amount of topsoil and organic matter is considered adequate to help support initial plant growth, and it is anticipated that the gradual increase of organic material through natural processes will continue to support growth while gradually decreasing the permeability. Finally, the root structure of maturing plants and the biological activity of a self-sustaining organic content will maintain sufficient long term permeability as well as support plant growth without the need for fertilizer inputs.

The following is the recommended composition of the three media ingredients:

- Sand. Sand should consist of silica-based coarse aggregate, angular or round in shape, and meet the mixture grain size distribution below. No substitutions of alternate materials such as diabase, calcium carbonate, rock dust, or dolomitic sands are acceptable. In particular, mica can make up no more than 5% of the total sand fraction. The sand fraction may also contain a limited amount of particles greater than 2.0 millimeters and less than 9.5 millimeters per the table below, but the overall sand fraction must meet the specification of greater than 75% being coarse or very coarse sand.

Table 4.2-1. Sand Sizing Criteria

Sieve	Size (mm)	% Passing
3/8 in.	9.50	100
No. 4	4.75	95 to 100
No. 8	2.36	80 to 100
No. 16	1.18	45 to 85
No. 30	0.60	15 to 60
No. 50	0.30	3 to 15
No. 100	0.15	0 to 4

Note: Effective particle size (D10) > 0.3mm. Uniformity coefficient (D60/D10) < 4.0.

- Topsoil. Topsoil is generally defined as the combination of the other ingredients referenced in the bioretention filter media: sand, fines (silt and clay), and any associated soil organic matter. Since the objective of the specification is to carefully establish the proper blend of these ingredients, the designer (or contractor or materials supplier) must carefully select the topsoil source material in order to not exceed the amount of any one ingredient. Generally, the use of a topsoil defined as a loamy sand, sandy loam, or loam (per the USDA Textural Triangle) will be an acceptable ingredient and in combination with the other ingredients meet the overall performance goal of the soil media.
- Organic Matter. Organic materials used in the soil media mix should consist of well-decomposed natural carbon-containing organic materials such as peat moss, humus, compost, pine bark fines or other organic soil conditioning material. However, per above, the combined filter media should contain 3 to 5% soil organic matter on dry weight basis (grams organic matter per 100 grams dry soil) by the Walkley-Black method or other similar analytical technique.

In creating the filter media, it is recommended to start with an open-graded coarse sand material and proportionately mix in the topsoil materials to achieve the desired ratio of sand and fines. Sufficient suitable organic amendments can then be added to achieve the 3 to 5% soil organic matter target. The exact composition of organic matter and topsoil material will vary, making the exact particle size distribution of the final total soil media mixture difficult to define in advance of evaluating available materials. Table 4.2-2 summarizes the filter media requirements.

Table 4.2-2. Filter Media Criteria for Bioretention

Soil Media Criterion	Description	Standard(s)
General Composition	Soil media must have the proper proportions of sand, fines, and organic matter to promote plant growth, drain at the proper rate, and filter pollutants	♦ 80% to 90% sand (75% of which is coarse or very coarse); ♦ 10% to 20% soil fines ♦ Max. 10% clay; and ♦ 3% to 5% organic matter
Sand	Silica based coarse aggregate[1]	Sieve / Size / % Passing 3/8 in / 9.50 mm / 100 No. 4 / 4.75 mm / 95 to 100 No. 8 / 2.36 mm / 80 to 100 No. 16 / 1.18 mm / 45 to 85 No. 30 / 0.6 mm / 15 to 60 No. 50 / 0.3 mm / 3 to 15 No. 100 / 0.15 mm / 0 to 4 Effective Particle size (D10) > 0.3mm Uniformity Coefficient (D60/D10) < 4.0
Top Soil	Loamy Sand or Sandy Loam	USDA Textural Triangle
Organic Matter	Well aged, clean compost	Appendix C
P-Index or Phosphorus (P) content	Soil media with high P levels will export P through the media and potentially to downstream conveyances or receiving waters	P content = 5 to 15 mg/kg (Mehlich I) or 18 to 40 mg/kg (Mehlich III)
Cation Exchange Capacity (CEC)	The CEC is determined by the amount of soil fines and organic matter. Higher CEC will promote pollutant removal	CEC > 5 milliequivalents per 100 grams

[1] *Many specifications for sand refer to ASTM C-33. The ASTM C-33 specification allows a particle size distribution that contains a large fraction of fines (silt and clay sized particles - < 0.05 mm). The smaller fines fill the voids between the larger sand sized particles, resulting in smaller and more convoluted pore spaces. While this condition provides a high degree of treatment, it also encourages clogging of the remaining void spaces with suspended solids and biological growth, resulting in a greater chance of a restrictive biomat forming. By limiting the fine particles allowed in the sand component, the combined media recipe of sand and the fines associated with the soil and organic material will be less prone to clogging, while also providing an adequate level of filtration and retention.*

In cases where greater removal of specific pollutants is desired, additives with documented pollutant removal benefits, such as water treatment residuals, alum, iron, or other materials may be included in the filter media if accepted by the local agency.

- Filter Media Depth. The filter media bed depth must be a minimum of 24 inches, although this can be reduced to 18 inches for depth-constrained bioretention practices. Designers should note that the media depth must be 24 inches or greater to qualify for the enhanced design, unless an infiltration-based design is used. Turf, perennials, or shrubs should be used instead of trees to landscape shallower filter beds. See Tables 4.2-4 through 4.2-6 for a list of recommended native plants.

Surface Cover. Mulch is the recommended surface cover material, but other materials may be substituted, as described below:

- Mulch. A 2- to 3-inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, pretreats runoff before it reaches the filter media, and prevents rapid evaporation of rainwater. Shredded hardwood bark mulch, aged for at least 6 months, makes a very good surface cover, as it retains a significant amount of pollutants and typically will not float away. Avoid pine bark mulch, which will float during storms.
- Alternative to Mulch Cover. In some situations, designers may consider alternative surface covers, such as turf, native groundcover, erosion control matting (e.g., coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, expected pedestrian traffic, cost, and maintenance. When alternative surface covers are used, methods to discourage pedestrian traffic should be considered. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water-holding capacity.
- Media for Turf Cover. One adaptation suggested for use with turf cover is to design the filter media primarily as a sand filter with organic content only at the top. Compost tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of organic matter in the filter media composition may be reduced.

Choking Layer. A 2- to 4-inch layer of choker stone (e.g., typically ASTM D448 No. 8 or No. 89 washed gravel) should be placed beneath the soil media and over the underdrain stone.

Geotextile. If the available head is limited, or the depth of the practice is a concern, geotextile fabric may be used in place of the choking layer. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used. Geotextile fabric may be used on the sides of bioretention areas as well.

Underdrains. Many bioretention designs will require an underdrain (see Bioretention Feasibility Criteria). The underdrain should be a 4- or 6-inch perforated schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention practices, with $^{3}/_{8}$-inch perforations at 6 inches on center. The underdrain must be encased in a layer of clean, washed ASTM D448 No.57 stone. The underdrain must be sized so that the bioretention practice fully drains within 72 hours or less.

Multiple underdrains are recommended for bioretention areas wider than 40 feet, and each underdrain should be located no more than 20 feet from the next pipe.

All bioretention practices should include at least one observation well and/or cleanout pipe (minimum 4 inches in diameter). The observation wells should be tied into any of the Ts or Ys in the underdrain system and must extend upward above the surface of the bioretention area.

Upturned Elbow (optional). In cases where limited head is a site constraint and the bioretention must be designed to be relatively shallow (e.g., depth to groundwater, relatively flat sites, or other factors), or where increased nitrogen removal is desired, an upturned elbow underdrain design can be used. For more information on this design consult North Carolina Cooperative Extension publication entitled "Designing Bioretention with an Internal Water Storage (IWS) Layer" (Brown et al., 2009).

Underground Storage Layer (optional). An underground storage layer consisting of chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer to increase the infiltration sump volume or the storage for larger storm events. To qualify for the Enhanced Design, this storage layer must be designed to infiltrate in 72 hours, at ½ the measured infiltration rate. The underground storage layer may also be designed to provide detention for the 2-year, or 10-year storms, as needed. The depth and volume of the storage layer will then depend on the target storage volumes needed to meet the applicable detention criteria.

Impermeable Liner: An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-milliliter (minimum) PVC geomembrane liner. (Follow manufacturer's instructions for installation.)

Material Specifications. Recommended material specifications for bioretention areas are shown in Table 4.2-3.

Table 4.2-3. Bioretention Material Specifications

Material	Specification	Notes
Filter Media	Filter Media to contain: ♦ 70%–88% sand ♦ 8%–26% soil fines ♦ 1%–5% organic matter in the form of aged compost or wood chips	♦ Minimum depth of 24 inches (18 inches for small-scale practices) ♦ To account for settling/compaction, it is recommended that 110% of the plan volume be utilized
Filter Media Testing	♦ P-Index range = 10–30, OR ♦ Between 7 and 23 mg/kg of P in the soil media ♦ CECs greater than 10	
Mulch Layer	Use aged, shredded hardwood bark mulch	Lay a 2- to 3-inch layer on the surface of the filter bed.
Alternative Surface Cover	Use river stone or pea gravel, coir and jute matting, or turf cover.	Lay a 2- to 3-inch layer of to suppress weed growth.
Top Soil for Turf Cover	♦ Loamy sand or sandy loam texture, with less than 5% clay content ♦ pH corrected to between 6 and 7 ♦ organic matter content of at least 2%	3-inch tilled into surface layer.
Geotextile or Choking Layer	Lay a 2 to 4 inch layer of choker stone (e.g., typically No.8 or No.89 washed gravel) over the underdrain stone.	
	An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used	♦ Can use in place of the choking layer where the depth of the practice is limited ♦ Geotextile fabric may be used on the sides of bioretention areas, as well
Underdrain Stone	1-inch diameter stone must be double-washed and clean and free of all fines (e.g., ASTM D448 No. 57 stone)	At least 9 inches deep
Storage Layer (optional)	To increase storage for larger storm events, chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer	
Impermeable Liner (optional)	Where appropriate, use a thirty mil (minimum) PVC Geomembrane liner	

Table 4.2-3. Bioretention Material Specifications		
Material	**Specification**	**Notes**
Underdrains, Cleanouts, and Observation Wells	Use 4- or 6-inch rigid schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention practices, with 3/8-inch perforations at 6 inches on center. Multiple underdrains are necessary for bioretention areas wider than 40 feet, and each underdrain must be located no more than 20 feet from the next pipe.	♦ Lay the perforated pipe under the length of the bioretention cell, and install non-perforated pipe as needed to connect with the storm drain system or to daylight in a stabilized conveyance ♦ Install T's and Y's as needed, depending on the underdrain configuration ♦ Add cleanout pipes that extend to the surface (with caps) at the T's and Y's
Plant Materials	See Bioretention Landscaping Criteria	Establish plant materials as specified in the landscaping plan and the recommended plant list

Signage. Bioretention units in highly urbanized areas should be stenciled or otherwise permanently marked to designate it as a stormwater management facility. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

Specific Design Issues for Streetscape Bioretention. Streetscape bioretention is installed in the road right-of way, either in the sidewalk area or in the road itself. In many cases, streetscape bioretention areas can also serve as a traffic calming or street parking control devices. The basic design adaptation is to move the raised concrete curb closer to the street or in the street, and then create inlets or curb cuts that divert street runoff into depressed vegetated areas within the right-of-way. Designers should consult design standards pertaining to roadway drainage. It may be necessary to provide an impermeable liner on the road side of the bioretention area to keep water from saturating the road's sub-base.

Specific Design Issues for Engineered Tree Boxes. Engineered tree boxes are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree pit is increased and used to capture and treat stormwater. Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, or permeable pavers. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

When designing engineered tree boxes, the following criteria must be considered:

- ✧ The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- ✧ Engineered tree box designs sometimes cover portions of the filter media with pervi-

ous pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.

✧ Installing a grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.

✧ Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a drop-off from the pavement to the micro-bioretention cell.

✧ Each tree should have a minimum rootable soil volume of 1,500 cubic feet.

Specific Design Issues for Stormwater Planters. Stormwater planters are a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. They consist of confined planters that store and/or infiltrate runoff in a soil bed to reduce runoff volumes and pollutant loads. Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater planters generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation.

A stormwater planter typically does not allow for infiltration. It is constructed with a watertight concrete shell or an impermeable liner on the bottom to prevent seepage (Figure 4.2-8). Since a stormwater planter is self-contained and does not infiltrate into the ground, it can be installed

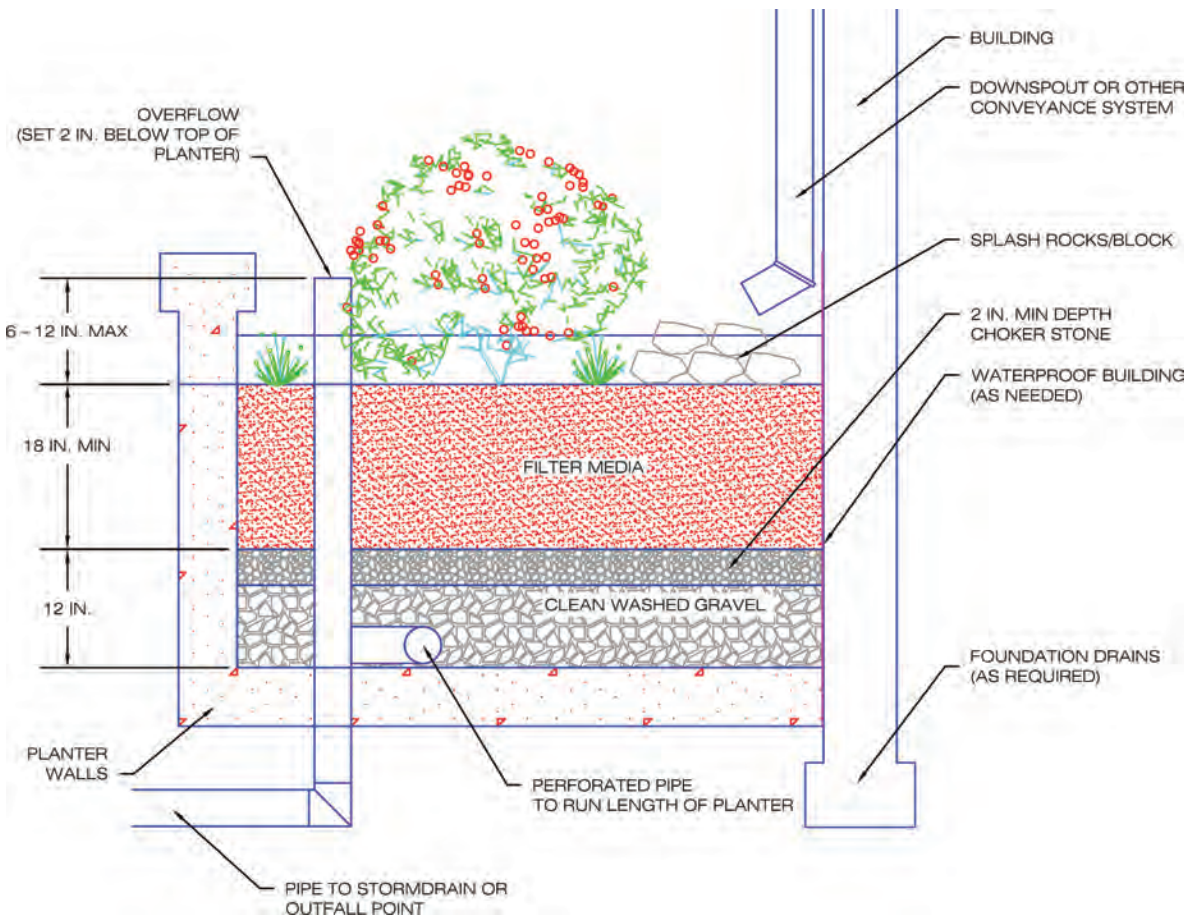

Figure 4.2-8. Stormwater Planter

right next to a building. The minimum filter media depth is 18 inches, with the shape and length determined by architectural considerations. Runoff is captured and temporarily ponded above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded, to avoid water spilling over the side of the planter. In addition, an underdrain is used to carry runoff to the storm sewer system.

All planters should be placed at grade level or above ground. Plant materials must be capable of withstanding moist and seasonally dry conditions. The planter can be constructed of stone, concrete, brick, wood, or other durable material. If treated wood is used, care should be taken so that trace metals and creosote do not leach out of the planter.

Practice Sizing. Bioretention is typically sized to capture the water quality volume or larger design storm volumes in the surface ponding area, soil media, and gravel reservoir layers of the practice.

Total storage volume, *Sv*, is calculated using Equation 4.2-1.

Equation 4.2-1. Bioretention Storage Volume

$$Sv = SA_{bottom} \times [(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})] + (SA_{average} \times d_{ponding})$$

where:

Sv	=	total storage volume of practice (ft^3)
SA_{bottom}	=	bottom surface area of practice (ft^2)
d_{media}	=	depth of the filter media (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer (ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	average surface area of practice (ft^2) (typically = ½ × [top area + SA_{bottom}])
$d_{ponding}$	=	maximum ponding depth of practice (ft)

Equation 4.2-1 can be modified if the storage depths of the soil media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.). The maximum depth of ponding in the bioretention must not exceed 18 inches.

In the LID Compliance Calculator spreadsheet, the Sv for infiltration and enhanced designs is given a 100% runoff reduction credit; the Sv for standard designs is given a 60% runoff reduction credit, since much of the water stored quickly exits the underdrain. For projects in the Coastal Zone, the Sv for all design types is given a 100% credit toward the storage requirement.

Bioretention can also be designed to address, in whole or in part, the detention requirements. The *Sv* can be counted as part of the 2-year or 10-year runoff volumes to satisfy the required detention volumes.

Note: In order to increase the storage volume of a bioretention area, the ponding surface area may be increased beyond the filter media surface area. However, the top surface area of the practice (i.e., at the top of the ponding elevation) may not be more than twice the size of the surface area of the filter media (SA_{bottom}).

Bioretention Landscaping Criteria

Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan must be provided for bioretention areas.

Minimum plan elements include the proposed bioretention template to be used, delineation of planting areas, and the planting plan including the following:

- Common and botanical names of the plants used
- Size of planted materials
- Mature size of the plants
- Light requirements
- Maintenance requirements
- Source of planting stock
- Planting sequence

It is recommended that the planting plan be prepared by a qualified landscape professional (e.g., licensed professional landscape architect, certified horticulturalist) in order to tailor the planting plan to the site-specific conditions.

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. Some popular native species that work well in bioretention areas and are commercially available can be found in Tables 4.2-4 through 4.2-6 (based on CUCES, 2000; MDE, 2000; Carolina Clear, 2009; Lady Bird Johnson Wildflower Center, 2013; and USDA-NRCS, 2013).

The degree of landscape maintenance that can be provided will determine some of the planting choices for bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a “turf and trees” landscaping model where the turf is mowed along with other turf areas on the site. Spaces for herbaceous flowering plants can be included.

Table 4.2-4 Perennials and Grasses Appropriate for Bioretention				
Scientific Name	**Common Name**	**Indicator[1]**	**Inundation**	**Salt Tolerance**
Aletris farinosa	White Colicroot	FAC	Moist soil	None
Andropogon gerardii	Big Bluestem	FAC	No	Moderate
Aquilegia canadensis	Wild Columbine	FACU	No	None
Asclepias incarnata	Swamp Milkweed	OBL	Saturated	None
Asclepias lanceolata	Red Milkweed	OBL	Wet soils	Moderate/ brackish
Aster novae-angliae	New England Aster	FACW	Moist soils, yes	Yes
Athyrium filix-femina	Lady Fern	FAC	Moist to wet soils	None
Canna glauca	Water Canna	OBL	Moist to wet soils	None
Canna flaccida	Golden Canna	OBL	Moist to wet soils	None
Carex stricta	Tussock Sedge	OBL	Saturated, 0-6”	None
Chasmanthium latifolium	River Oats	FAC	Moist soils	None
Chelone glabra	White Turtlehead	OBL	Moist to wet soils	
Conoclinium coelestinum	Blue Mistflower	FAC	Moist to Wet soils	
Crinum americanum	Southern Swamp Lily	OBL	Saturated	
Dulichium arundinaceum	Threeway Sedge	OBL	Saturated, shallow	None
Echinodorus cordifolius	Creeping Burhead	OBL	Saturated, shallow	
Equisetum hyemale	Scouring Rush	FACW	Saturated, shallow	
Eupatorium fistulosum	Joe Pye Weed	FACW	Moist to Wet Soils	
Geranium maculatum	Spotted Geranium	FACU	Moist Soils	
Helianthus angustifolius	Swamp Sunflower Narrowleaf Sunflower	FACW	Wet Soils	
Hibiscus coccineus	Scarlet Swamp Hibiscus	OBL	Saturated, shallow	
Hibiscus moscheutos	Rose Mallow Hibiscus	OBL	Saturated, shallow	Low
Hymenocallis caoliniana	Spider Lily	OBL	Saturated, shallow	None
Iris versicolor	Virginia Iris	OBL	Shallow	None
Juncus effuses	Common Rush	OBL	Shallow <6”	Low

Table 4.2-4 Perennials and Grasses Appropriate for Bioretention				
Scientific Name	**Common Name**	**Indicator[1]**	**Inundation**	**Salt Tolerance**
Liatris spicata	Gayfeather Blazing Star	FAC	Moist Soils	Low
Lobelia cardinalis	Cardinal Flower	FACW	Moist to Wet Soils	None
Lobelia siphilitica	Blue Lobelia	OBL	Moist to wet soils	
Lysimachia ciliata	Fringed Loosestrife	FACW	Moist to wet soils, seasonal flooding	
Mimulus ringens	Allegheny monkeyflower	OBL	Saturated, shallow	
Onoclea sensibilis	Sensitive Fern	FACW	Moist to wet soils	
Osmunda cinnamomea	Cinnamon Fern	FACW	Moist to wet soils	Low
Osmunda spectabilis	Royal Fern	OBL	Moist to wet soils	None
Orontium aquaticum	Golden Club	OBL	Up to 10”	
Panicum virgatum	Switch Grass	FAC	Moist soil	Moderate
Peltandra virginica	Green Arrow Arum	OBL	Shallow < 1’	Low (< 2 ppt)
Pontederia cordata	Pickerelweed	OBL	Shallow < 1’	Low (< 3 ppt)
Physostegia virginiana	Obedient Plant	FACW	Moist soil	
Polygonatum biflorum	Great Solomon’s Seal	FACU	Moist soil	
Rhynchospora colorata	Starrush Whitetop	FACW	Saturated	
Rudbeckia laciniata	Cutleaf Coneflower	FACW	Moist soil	None
Sagittaria latifolia	Common Arrowhead, Duck Potato	OBL	Up to 2.0’	None
Saururus cernuus	Lizard’s Tail	OBL	Shallow < 4”	None
Schizachyrium scoparium	Little Bluestem	FACU	Moist soil	None
Schoenoplectus tabernaemontani	Softstem Bulrush	OBL	Wet soil to standing water	Fresh or Brackish
Solidago sempervirens	Seaside Goldenrod	FACW	Yes	High
Sorghastrum nutans	Indiangrass	FACU	Moist soil	Moderate
Spartina alterniflora	Saltmarsh Cordgrass	OBL	Yes	High

Table 4.2-4 Perennials and Grasses Appropriate for Bioretention

Scientific Name	Common Name	Indicator[1]	Inundation	Salt Tolerance
Spartina bakeri	Sand cordgrass	FACW	Moist to wet soils	Fresh - Saline
Spartina patens	Saltmeadow Cordgrass	FACW	Wet soils	High
Thalia dealbata	Powdery Alligator-flag	OBL	up to 1.5’	Yes
Tradescantia virginiana	Virginia Spiderwort	FAC	Moist soils	None
Vernonia noveboracensis	Ironweed	FACW	Moist soils	None

[1] *Wetland Indicator Status (USACE, 2010):*

- *OBL (Obligate) almost always is a hydrophyte, rarely found in uplands (occurs in wetlands >99% of the time)*
- *FACW (Facultative Wetland) usually a hydrophyte, but occasionally found in uplands (occurs in wetlands 67-99% of the time)*
- *FAC (Facultative) commonly occurs either as a hydrophyte or a non-hydrophyte (occus in wetlands 33-67% of the time)*
- *FACU (Facultative Upland) occasionally is a hydrophyte, but usually occurs in uplands (occurs in wetlands 1-33% of the time)*

Table 4.2-5. Shrubs Appropriate for Bioretention				
Scientific Name	**Common Name**	**Indicator[1]**	**Inundation**	**Salt Tolerance**
Baccharis halimifolia	Groundsel Tree Salt Myrtle	FAC	Wet soils	High
Callicarpa americana	Beautyberry	FACU	Moist soils	None
Cephalanthus occidentalis	Button Bush	OBL	Up to 3 ft	Low
Clethra alnifolia	Summersweet Sweet Pepperbush	FACW	Moist to wet soils	None
Cyrilla racemiflora	Swamp Titi	FACW	Moist to wet soils	Low
Hamamelis virginiana	Witch Hazel	FACU	Moist to wet soils	None
Hypericum prolificum	Shrubby St. John's Wort	FAC	Moist soils, flood tolerant	None
Ilex glabra	Inkberry	FACW	Wet soils, flood tolerant	Moderate
Ilex verticillata	Winterberry Holly	FACW	Moist to wet soils	None
Ilex vomitoria	Yaupon Holly	FAC	Moist soils	Moderate
Itea virginica	Virginia Sweetspire	FACW	Moist to wet soils	None
Kosteletzkya virginica	Seashore Mallow	OBL	Moist to wet soils	Moderate
Lindera benzoin	Spicebush	FACW	Seasonal inundation	None
Myrica cerifera	Wax Myrtle	FAC	Moist to wet soils	Moderate
Photinia pyrifolia	Red Chokeberry	FACW	Moist soils	Low
Rhododendron canescens	Dwarf Azalea	FACW	Moist soils	None
Rhododendron viscosum	Swamp Azalea	OBL	Wet soil	None
Rosa carolina	Carolina Rose	FACU	Moist to wet soils	Moderate
Sabal minor	Dwarf Palmetto	FACW	Moist to wet soils	None

Table 4.2-5. Shrubs Appropriate for Bioretention				
Scientific Name	**Common Name**	**Indicator[1]**	**Inundation**	**Salt Tolerance**
Sambucus canadensis	Elderberry	FACW	Moist to wet soils	None
Serenoa repens	Saw Palmetto	FACU	Occasionally wet	None
Vaccinium corymbosum	Highbush Blueberry	FACW	Wet soil	High
Viburnum dentatum	Arrowwood	FAC	Moist to wet	None

[1] *Wetland Indicator Status (USACE, 2010):*

- *OBL (Obligate) almost always is a hydrophyte, rarely found in uplands (occurs in wetlands >99% of the time)*
- *FACW (Facultative Wetland) usually a hydrophyte, but occasionally found in uplands (occurs in wetlands 67-99% of the time)*
- *FAC (Facultative) commonly occurs either as a hydrophyte or a non-hydrophyte (occus in wetlands 33-67% of the time)*
- *FACU (Facultative Upland) occasionally is a hydrophyte, but usually occurs in uplands (occurs in wetlands 1-33% of the time)*

Table 4.2-6. Trees Appropriate for Bioretention[1]

Scientific Name	Common Name	Indicator[2]	Inundation	Salt Tolerance
Acer rubrum	Red Maple	FAC	Seasonal inundation	None
Amelanchier canadensis	Serviceberry	FAC	Moist to wet soils	Moderate
Betula nigra	River Birch	FACW	Moist soils	None
Carpinus caroliniana	American Hornbeam	FAC	Periodic flooding	None
Celtis occidentalis	Hackberry	FACU	Moist soils	Low
Chamaecyparis thyoides	Atlantic White Cedar	OBL	Wet soils	None
Chionanthus virginicus	Fringetree	FACU	Moist soils	None
Cornus florida	Flowering Dogwood	FACU	Moist soils	None
Crataegus aestivalis	Mayhaw May Hawthorn	OBL	Wet soils	None
Diospyros virginiana	Persimmon	FAC	Variable moisture	Low
Gordonia lasianthus	Loblolly Bay	FACW	Moist soils	None
Ilex cassine	Dahoon Holly	FACW	Moist soils	Low
Ilex opaca	American Holly	FAC	Wet soils	Moderate
Juniperus virginiana	Eastern Red Cedar	FACU	Moist soils	Low
Liquidambar styraciflua	Sweetgum	FAC	Moist soils	None
Liriodendron tulipifera	Tulip Tree	FAC	Moist soils	Low
Magnolia virginiana	Sweetbay Magnolia	FACW	Moist soils	None
Nyssa aquatica	Water Tupelo	OBL	Wet soils	None
Nyssa biflora	Ogeechee Tupelo	OBL	Moist to wet soils	None
Nyssa sylvatica	Black Gum, Black Tupelo	FAC	Moist soils; seasonal flooding	Moderate
Ostrya virginiana	Hop Hornbeam, Ironwood	FACU	Moist soils	None

Table 4.2-6. Trees Appropriate for Bioretention[1]				
Scientific Name	**Common Name**	**Indicator[2]**	**Inundation**	**Salt Tolerance**
Platanus occidentalis	American Sycamore	FACW	Saturated soils; seasonal flooding	None
Quercus bicolor	Swamp White Oak	FACW	Moist to wet soils	None
Quercus lyrata	Overcup Oak	OBL	Yes	None
Quercus michauxii	Swamp Chestnut Oak	FACW	Moist soils	None
Quercus nuttallii	Nuttall Oak	FACW	Extended flooding	None
Quercus pagoda	Cherrybark Oak	FACW		None
Quercus palustris	Pin Oak	FACW	Moist to wet soils	Low
Quercus phellos	Willow Oak	FACW	Moist soils	None
Quercus shumardii	Shumard Oak	FAC	Short-term flood-ing	None
Sassafras albidum	Sassafrass	FACU	Moist soils	None
Taxodium ascendens	Pond Cypress	OBL	Moist soils	High
Taxodium distichum	Bald Cypress	OBL	Wet soils; stand-ing water	High
Ulmus americana	American Elm	FAC	Moist soils	Low

[1] *Consider characteristics of trees – such as mature height & spread, aggressive root structures, knee development, etc. – in order to select the species most appropriate for the site. All these species will tolerate some degree of flooding; however, make sure that other site constraints (outfall structures, berms, utilities, hardscapes, etc.) will not be negatively impacted as a specimen grows and matures.*

[2] *Wetland Indicator Status (USACE, 2010):*

- *OBL (Obligate) almost always is a hydrophyte, rarely found in uplands (occurs in wetlands >99% of the time)*
- *FACW (Facultative Wetland) usually a hydrophyte, but occasionally found in uplands (occurs in wetlands 67-99% of the time)*
- *FAC (Facultative) commonly occurs either as a hydrophyte or a non-hydrophyte (occus in wetlands 33-67% of the time)*
- *FACU (Facultative Upland) occasionally is a hydrophyte, but usually occurs in uplands (occurs in wetlands 1-33% of the time)*

Planting recommendations for bioretention facilities are as follows:

- ✧ The primary objective of the planting plan is to cover as much of the surface area of the filter bed as quickly as possible. Herbaceous or ground cover layers are as important or more important than more widely spaced trees and shrubs.
- ✧ Native plant species should be specified over non-native species.
- ✧ Plants should be selected based on a specified zone of hydric tolerance and must be capable of surviving both wet and dry conditions ("Wet footed" species should be planted near the center, whereas upland species do better planted near the edge).
- ✧ Woody vegetation should not be located at points of inflow; trees should not be planted directly above underdrains but should be located closer to the perimeter.
- ✧ Shrubs and herbaceous vegetation should generally be planted in clusters and at higher densities (i.e., 10 feet on-center and 1 to 1.5 feet on-center, respectively).
- ✧ If trees are part of the planting plan, a tree density of approximately one tree per 250 square feet (i.e., 15 feet on-center) is recommended.
- ✧ Plant trees using the guidelines provided in the Clemson University Cooperative Extension document entitled, "Planting Trees Correctly" (Polomski et al., 2004). In particular, dig holes deep enough that the topmost roots in the root ball are level with the ground (soil media) surface, and place 2 to 3 inches of mulch above these roots. Also, dig the hole two to five times wider than the root ball to allow for root growth.
- ✧ Tree species should be those that are known to survive well in the compacted soils and the polluted air and water of an urban landscape.
- ✧ If trees are used, plant shade-tolerant ground covers within the drip line. Note that the planting plan should account for succession, where shade tolerant plants may be planted to cover a greater area as the tree canopy grows.

Bioretention Construction Sequence

Erosion and Sediment Controls: Bioretention areas should be fully protected by silt fence or construction fencing. Bioretention areas must remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Where this is unavoidable, the impacted area must not be excavated below 2 feet above the final design elevation of the bottom of the practice until further compaction by heavy equipment can be avoided. Once the area is excavated to grade, the impacted area must be tilled to a depth of 12 inches below the bottom of the practice. Large bioretention applications may be used as sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the erosion and sediment control plan specifying that (1) the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the post-construction (final) invert (bottom of the facility), and (2) the facility must contain an underdrain. The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent bioretention facility, including dewatering, cleanout, and stabilization.

Bioretention Installation: The following is a typical construction sequence to properly install a bioretention basin. These steps may be modified to reflect different bioretention applications or expected site conditions:

Step 1: Construction of the bioretention area may only begin after the entire contributing drainage area has been stabilized with vegetation, or designed with a temporary bypass. It may be necessary to block certain curb or other inlets while the bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

Step 2: The designer, the installer, and the local agency inspector should have a preconstruction meeting, checking the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed bioretention area. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the inspector. Material certifications for aggregate, soil media, and any geotextiles should be submitted for approval to the inspector at the preconstruction meeting.

Step 3: Temporary erosion and sediment controls (e.g., diversion dikes, reinforced silt fences) are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the construction process.

Step 4: Any pretreatment cells should be excavated first and then sealed to trap sediments.

Step 5: Excavators or backhoes should work from the sides to excavate the bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the bioretention area. Contractors should use a cell construction approach in larger bioretention basins, whereby the basin is split into 500- to 1,000-square foot temporary cells with a 10- to 15-foot earth bridge in between, so that cells can be excavated from the side.

Step 6: It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

Step 7: If using a geotextile fabric, place the fabric on the sides of the bioretention area with a 6-inch overlap on the sides. Place the appropriate depth of No. 57 stone on the bottom, install the perforated underdrain pipe, place No. 57 stone to 3 inches above the underdrain pipe, and add the choking layer or appropriate geotextile layer as a filter between the underdrain and the soil media layer.

Step 8: Apply the soil media in 12-inch lifts until the desired top elevation of the bioretention area is achieved. Wait a few days to check for settlement and add additional media, as needed, to achieve the design elevation. Note: The batch receipt confirming the source of the soil media must be submitted to the local agency inspector.

Step 9: Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

Step 10: Install the plant materials as shown in the landscaping plan, and water them as needed.

Step 11: Place the surface cover (i.e., mulch, river stone, or turf). If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (Step 10), and holes or slits will have to be cut in the matting to install the plants.

Step 12: If curb cuts or inlets are blocked during bioretention installation, unblock these after the drainage area and side slopes have good vegetative cover. It is recommended that unblocking curb cuts and inlets take place after two to three storm events if the drainage area includes newly installed asphalt, since new asphalt tends to produce a lot of fines and grit during the first several storms.

Step 13: Conduct the final construction inspection using a qualified professional, providing the local agency with an as-built, then log the GPS coordinates for each bioretention facility, and submit them for entry into the maintenance tracking database.

Construction Supervision. Supervision during construction is recommended to ensure that the bioretention area is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists that include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

Bioretention Maintenance Criteria

When bioretention practices are installed, it is the owner's responsibility to ensure they, or those managing the practice, (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a maintenance covenant or agreement, as required by the locality.

Maintenance of bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides.

Maintenance tasks and frequency will vary depending on the size and location of the bioretention, the landscaping template chosen, and the type of surface cover in the practice. A generalized summary of common maintenance tasks and their frequency is provided in Table 4.2-7.

Table 4.2-7. Typical Maintenance Tasks for Bioretention Practices	
Frequency	**Maintenance Tasks**
Upon establishment	♦ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed ½ inch of rainfall. Conduct any needed repairs or stabilization. ♦ Inspectors should look for bare or eroding areas in the contributing drainage area or around the bioretention area, and make sure they are immediately stabilized with grass cover. ♦ One-time, spot fertilization may be needed for initial plantings, depending on soil test results. ♦ Water to achieve approximately 1 inch of total water (irrigation plus rainfall) per week or to prevent wilting during the first growing season (March- November). Long periods of deep watering are preferred to frequent, shallow watering. ♦ Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.
At least 4 times per year	♦ Mow grass filter strips and bioretention with turf cover. ♦ Check curb cuts and inlets for accumulated grit, leaves, and debris that may block inflow.
Twice during growing season	♦ Spot weed, remove trash, and rake the mulch.
Annually	♦ Conduct a maintenance inspection. ♦ Supplement mulch in devoid areas to maintain a 3-inch layer. ♦ Remove sediment in pretreatment cells and inflow points.
Once every 2–3 years	♦ Remove and replace the mulch layer.
As needed	♦ Add reinforcement planting to maintain desired vegetation density. ♦ Remove invasive plants using recommended control methods. ♦ Remove any dead or diseased plants. ♦ Stabilize the contributing drainage area to prevent erosion. ♦ Prune trees and shrubs.

The most common non-routine maintenance problem involves standing water. If water remains on the surface for more than 72 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter. These are listed below, starting with the simplest approach and ranging to more involved procedures (i.e., if the simpler actions do not solve the problem):

- ✧ Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be cleaned out.
- ✧ Remove accumulated sediment and till 2 to 3 inches of sand into the upper 6 to 12 inches of soil.
- ✧ Install sand wicks from 3 inches below the surface to the underdrain layer. This reduces the average concentration of fines in the media bed and promotes quicker drawdown times. Sand wicks can be installed by excavating or auguring (i.e., using a tree auger or similar tool) down to the top of the underdrain layer to create vertical columns which are then filled with a clean open-graded coarse sand material (e.g., ASTM C-33 concrete sand or similar approved sand mix for bioretention media). A sufficient number of wick drains of sufficient dimension should be installed to meet the design dewatering time for the facility.
- ✧ Remove and replace some or all of the soil media.

It is recommended that a qualified professional conduct a spring maintenance inspection and clean-up at each bioretention area. Maintenance inspections should include information about the inlets, the actual bioretention facility (sediment buildup, outlet conditions, etc.), and the state of vegetation (water stressed, dead, etc.) and are intended to highlight any issues that need or may need attention to maintain stormwater management functionality.

An example maintenance checklist for bioretention areas is included in *Appendix F*.

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4.3 Permeable Pavement Systems

Introduction

Permeable pavement systems represent alternative paving surfaces that capture and temporarily store the design volume by filtering runoff through voids in the pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially infiltrate into the soil. This allows permeable pavement systems to provide measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads.

KEY CONSIDERATIONS: PERMEABLE PAVEMENT SYSTEMS

DESIGN CRITERIA:

- Permeable pavement systems should be designed to completely drain within 48 hours.
- If the infiltration rate of the native soils located beneath a permeable pavement system do not meet or exceed 0.3 in/hr, an underdrain should be included in the design.
- The distance from the bottom of the practice to the top of the seasonal high water table should not be less that 0.5 feet.

BENEFITS:

- Helps reduce post-construction stormwater runoff rates, volumes and pollutant loads without consuming valuable land.
- Particularly well suited for use on urban development sites and in low traffic areas, such as overflow parking lots.

LIMITATIONS:

- Relatively high construction costs, which are typically offset by savings on stormwater infrastructure (e.g., storm drain system).
- Permeable pavement systems should be installed only by experienced personnel.

SITE APPLICABILITY:

- Rural Use
- Suburban Use
- Urban Use
- Construction Cost: High
- Maintenance: High
- Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 100% credit for storage volume of infiltration design.
- 50% credit for storage volume of standard design.

Coastal Zone Credit Approach

- 100% credit for storage volume of practice

Statewide Water Quality Requirement Credit Approach

- Runoff Reduction credit applies to infiltration requirement.

Pollutant Removal[1]
80% - Total Suspended Solids
60-80% - Total Phosphorus
60-80% - Total Nitrogen
N/A - Metals
45-75% - Pathogens

[1] *expected annual pollutant load removal*

Figure 4.3-1. Permeable pavement parking spaces in North Myrtle Beach, SC (Photo: Travis DuPree)

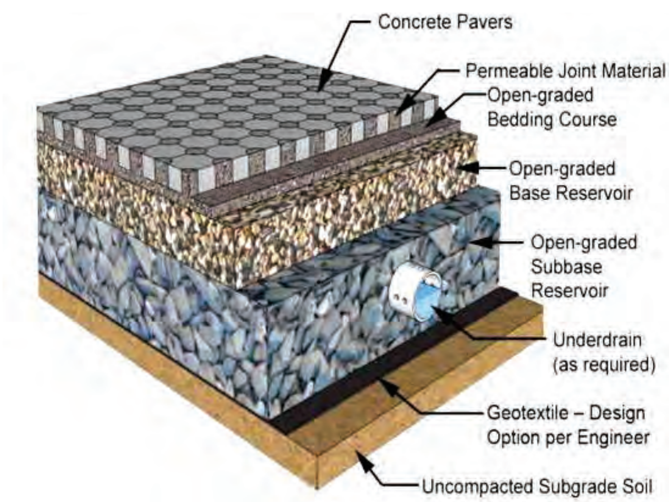


Figure 4.3-2. Permeable pavement section detail (Source: David Smith, ICPI)

There are a variety of permeable pavement surfaces available in the commercial marketplace, including pervious concrete, permeable pavers, concrete grid pavers, and plastic grid pavers with turf (Figure 4.3-3). Each of these permeable pavement surfaces is briefly described below:

Pervious Concrete. Pervious concrete (also known as porous concrete) is similar to conventional concrete in structure and form, but consists of a special open-graded surface course, typically 4 to 8 inches thick, that is bound together with portland cement. This open-graded surface course has a void ratio of 15% to 25% (conventional concrete pavement has a void ratio of between 3% and 5%), which gives it a high permeability that is often many times more than that of the underlying native soils, and allows rainwater and stormwater runoff to rapidly pass through it and into the underlying stone reservoir. Although this particular type of permeable pavement surface may not require an underlying base layer to support traffic loads, site planning and design teams may wish to provide it to increase the stormwater storage capacity provided by a pervious concrete system.

Porous Asphalt. Porous asphalt is similar to pervious concrete, and consists of a special open-graded surface course bound together by asphalt cement. The open-graded surface course in a typical porous asphalt installation is 3 to 7 inches thick and has a void ratio of between 15% and 20%. Porous asphalt is thought to have a limited ability to maintain its structure and permeability during hot summer months and, consequently, is currently not recommended for use in coastal South Carolina. If it is used on a development site in the coastal region, it should be carefully monitored and maintained over time.

Figure 4.3-3. Various Permeable Pavement Surfaces. Clockwise from top left: (a) Pervious concrete parking lot, Reebok Crossfit Hilton Head Island (Photo: K. Ellis); (b) Permeable pavers at Islanders Beach Park, on Hilton Head Island (Photo: K. Ellis); (c) Concrete grid pavers at Morse Park Landing, Murrells Inlet (Photo: K. Ellis); and (d) Grass pavers at Verizon store in North Myrtle Beach (Photo: Nicole Saladin).

Permeable Pavers. Permeable pavers (PP) are solid structural units (e.g., blocks, bricks) that are installed in a way that provides regularly spaced openings through which stormwater runoff can rapidly pass through the pavement surface and into the underlying stone reservoir. The regularly spaced openings, which generally make up between 8% and 20% of the total pavement surface, are typically filled with pea gravel (i.e., ASTM D 448 Size No. 8, $^{3}/_{8}$ inch to $^{1}/_{8}$ inch). Typical PP systems consist of the pavers, a 1.5- to 3-inch thick fine gravel bedding layer and an underlying stone reservoir.

Concrete Grid Pavers. Concrete grid pavers (CGP) are precast concrete units that allow rainfall and stormwater runoff to pass through large openings that are filled with gravel, sand, or topsoil and turf (Figure 4.3-3c). CGP are typically 3.5 inches thick and have a void ratio between 20% and 50%, which means that the material used to fill the spaces between the grids has a large influence on the overall permeability (i.e., void space) of a CGP system. A typical CGP installation consists of the pavers, 1- to 1.5- inch sand or pea gravel bedding layer, and an underlying stone reservoir. Void Structured Concrete is a similar design type that utilizes molded cast in place concrete rather than pavers.

Plastic Grid Pavers. Plastic grid pavers (PGP) are similar to CGP. They consist of flexible, interlocking plastic units that allow rainfall and stormwater runoff to pass through large openings that are filled with gravel, sand, or topsoil and turf. Since the empty plastic grids have a void ratio of between 90% and 98%, the material used to fill the spaces between the grids has a large influence on the overall permeability (i.e., void space) a PGP system.

When designing a permeable pavement system, planning and design teams must not only consider the storage capacity of the system, but also the structural capacity of the underlying soils and the underlying stone reservoir. The infiltration rate and structural capacity of the native soils found on a development site directly influence the size of the stone reservoir that is needed to provide structural support for a permeable pavement system and measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads. Site planning and design teams should strive to design permeable pavement systems that can accommodate the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). If this cannot be accomplished due to site characteristics or constraints, site planning and design teams should consider using permeable pavement systems in combination with other runoff reducing low impact development practices.

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. There are three different types of permeable pavement design configurations:

- **Standard Designs**. Practices with a standard underdrain design and no infiltration sump or water quality filter (see Figure 4.3-4).
- **Infiltration Designs**. Practices with no underdrains that can infiltrate the design storm volume in 48 hours (see Figure 4.3-5).
- **Hybrid Designs**. Practices with underdrains that contain a water quality filter layer and an infiltration sump beneath the underdrain sized to drain a portion of the design storm in 48 hours (see Figure 4.3-6).

Figure 4.3-4. Cross section of a standard permeable pavement design

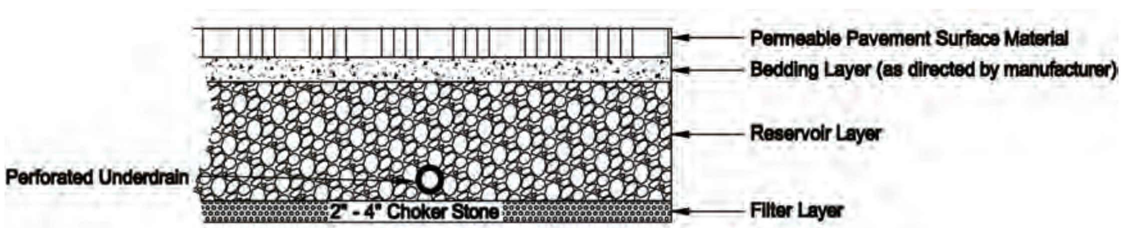


Figure 4.3-5. Cross section of an infiltration permeable pavement design without an underdrain

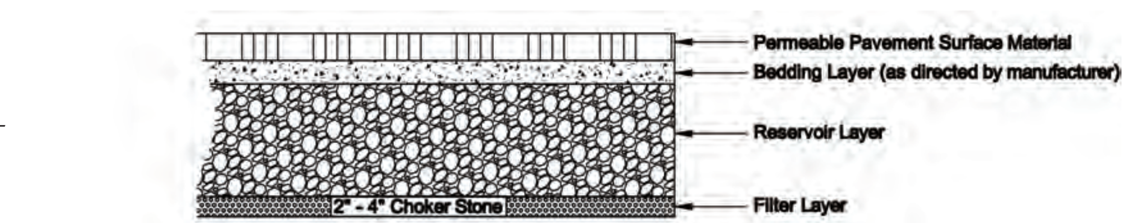
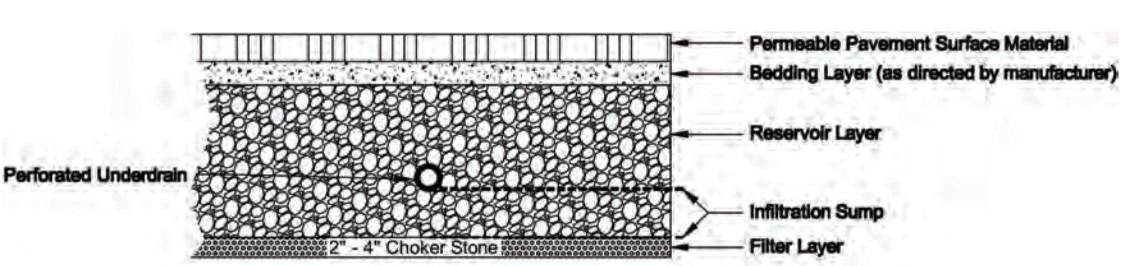


Figure 4.3-6. Cross section of enhanced hybrid permeable pavement design with an underdrain



Permeable Pavement Feasibility Criteria

Since permeable pavement has a very high retention capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

Required Space. A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for space-constrained sites or areas where land prices are high.

Soils. Soil conditions do not typically constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Underdrains are required if the measured permeability of the underlying soils is less than 0.3 in/hr. Infiltration may be promoted in these designs, however, by incorporating an infiltration sump (i.e., a layer of stone below the invert of the underdrain. See Figure 4.3-6). When designing a permeable pavement practice, designers must verify soil permeability by using the on-site soil investigation methods provided in *Appendix B*.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary or if the use of an infiltration sump is permissible (see *Permeable Pavement Design Criteria*).

Contributing Drainage Area. The portion of the contributing drainage area that does not include the permeable pavement should not exceed 5 times the surface area of the permeable pavement (2 times is recommended), and it should be as close to 100% impervious as possible to help prevent clogging of the pavement by sediment from pervious surfaces.

Pavement Surface Slope. Steep pavement surface slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. The permeable pavement slope must be less than 5%. Designers may consider using a terraced design for permeable pavement in areas with steeper slopes. In all cases, designs must ensure that the slope of the pavement does not lead to flow occurring out of the stone reservoir layer onto lower portions of the pavement surface.

Minimum Hydraulic Head. The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head from the pavement surface to the underdrain outlet is typically necessary. This value may vary based on several design factors, such as required storage depth and underdrain location.

Minimum Depth to Water Table. A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 0.5 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Tidal Impacts. For systems with an underdrain, the underdrain should be located above the tidal mean high water elevation. For entirely infiltration-based systems, the bottom of the stone reservoir should be located above the mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations.

Setbacks. To avoid the risk of seepage and to prevent damage to building foundations and contamination of groundwater aquifers, permeable pavement areas should be located at least:

- ✧ 10 feet upgradient from building foundations*
- ✧ 10 feet from property lines
- ✧ 150 feet from water supply wells
- ✧ 50 feet from septic systems

*Where the 10-foot setback from building foundations is not possible, an impermeable liner may be used along the sides of the permeable pavement practice (extending from the surface to the bottom of the practice).

Proximity to Utilities. Interference with underground utilities should be avoided if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Where conflicts cannot be avoided, these guidelines shall be followed:

- ✧ Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the stormwater Best Management Practice (BMP).
- ✧ Whenever possible, coordinate with utility companies to allow them to replace or relocate their aging infrastructure while BMPs are being implemented.
- ✧ BMP and utility conflicts will be a common occurrence in public right-of-way projects. However, the standard solution to utility conflict should be the acceptance of conflict, provided sufficient soil coverage over the utility can be assured.
- ✧ Additionally, when accepting utility conflict into the BMP design, it is understood that the BMP will be temporarily impacted during utility maintenance but restored to its original condition.

Pollutant Hotspot Land Uses. Permeable pavement is not appropriate for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided, or the areas should be diverted from the permeable pavement.

On sites with existing contaminated soils, infiltration is not allowed. Permeable pavement areas must include an impermeable liner, and the Enhanced Design configuration cannot be used.

High Loading Situations. Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail. Sites with a lot of pervious area (e.g., newly established turf and landscaping) can be considered high loading sites and the pervious areas should be diverted if possible from the permeable pavement area. If unavoidable, pretreatment measures, such as a gravel or sod filter strip should be employed (see *Permeable Pavement Pretreatment Criteria*).

High Speed Roads. Permeable pavement should not be used for high speed (>30 mph) roads, although it has been successfully applied for low speed residential streets, parking lanes, and roadway shoulders.

Non-Stormwater Discharge. Permeable pavement should not receive non-stormwater discharges such as irrigation runoff, air-conditioning condensation discharge, chlorinated wash-water, or other such non-stormwater flows.

Economic Considerations. Permeable pavement tends to be expensive relative to other LID practices, but when the cost of land and traditional paving are included in the calculations, permeable pavement becomes much more competitive. Permeable pavement is very space-efficient, since it combines a useful pavement surface with stormwater management for water quality and in some cases for 2-year and 10-year detention requirements.

Permeable Pavement Conveyance Criteria

Permeable pavement designs must include methods to convey larger storms (e.g., 2-year, 10-year) to the storm drain system. The following is a list of methods that can be used to accomplish this.

- Place an overdrain, a perforated pipe horizontally near the top of the reservoir layer, to pass excess flows after water has filled the base.
- Increase the thickness of the top of the reservoir layer to increase storage (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Route overflows to another detention or conveyance system.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary. Pretreatment may be appropriate if the pavement receives runoff from adjacent pervious areas. For example, a gravel or sod filter strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface in order to prevent premature clogging.

Permeable Pavement Design Criteria

Type of Surface Pavement. The type of pavement should be selected based on a review of the pavement specifications and properties and designed according to the product manufacturer's recommendations.

Pavement Bottom Slope. For unlined designs, the bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal and lateral slopes is preferred and 5% is the maximum) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or berms, as shown in Table 4.3-7, can be incorporated into the subsurface to encourage infiltration. In this type of design, the depth of the infiltration sump would be the depth behind the check dams.

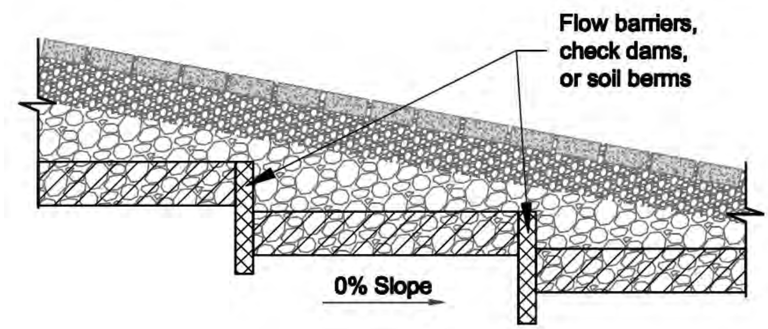


Figure 4.3-7. Type Profile of Permeable Pavement on Sloped Sites

Internal Geometry and Drawdowns.

- **Rapid Drawdown.** Permeable pavement should be designed so that the target storage volume is detained in the reservoir for as long as possible (36 to 48 hours) before completely discharging through an underdrain. A minimum orifice size of 1 inch is recommended regardless of the calculated drawdown time.
- **Infiltration Sump.** To promote greater retention for permeable pavement located on marginal soils, an infiltration sump can be installed to create a storage layer below the underdrain invert. This design configuration is discussed further below.
- **Conservative Infiltration Rates.** Designers must use ½ of the measured infiltration rate during design to approximate long-term infiltration rates (for example, if the measured infiltration rate is 0.7 inches per hour, the design infiltration rate will be 0.35 inches per hour). This requirement is included in Equation 4.3-1 through Equation 4.3-3.

Reservoir Layer. The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer or underlying soils, including the optional infiltration sump. The total thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and frost depth conditions (see Permeable Pavement Feasibility Criteria above). A geotechnical engineer should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, double-washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading (additional chamber structures may also be used to create larger storage volumes).
- The storage layer may consist of clean, double-washed No. 57 stone, although No. 2 stone is preferred because it provides additional structural stability.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface. The use of terracing and check dams is permissible.

Underdrains. Most permeable pavement designs will require an underdrain (see Permeable Pavement Feasibility Criteria above). Underdrains can also be used to keep detained stormwater from flooding permeable pavement during extreme events. Multiple underdrains are recommended for permeable pavement wider than 40 feet, and each underdrain should be located 20 feet or less from the next pipe. The underdrain should be perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with $^{3}/_{8}$-inch perforations at 6 inches on center. The underdrain should be encased in a layer of clean, washed No. 57 stone, with a minimum 2-inch cover over the top of the underdrain. The underdrain system should include a flow control to ensure that the reservoir layer drains slowly (within 36-48 hours).

- ✧ The underdrain outlet can be fitted with a flow-reduction orifice within a weir or other easily inspected and maintained configuration in the downstream manhole as a means of regulating the stormwater detention time. The minimum diameter of any orifice is 1 inch. The designer should verify that the design volume will draw down completely within 36-48 hours.
- ✧ On infiltration designs, an underdrain(s) can be installed and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

All permeable pavement practices must include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation wells should consist of a well-anchored, perforated 4- to 6-inch (diameter) PVC pipe that is tied into any Ts or Ys in the underdrain system. The well should extend vertically to the bottom of the reservoir layer and extend upwards to be flush with the surface (or just under pavers) with a lockable cap.

Infiltration Sump (optional, required for Underdrain Enhanced Designs). For unlined permeable pavement systems, an optional upturned elbow or elevated underdrain configuration can be used to promote greater retention for permeable pavement located on marginal soils (see Figure 4.3-5). The infiltration sump must be installed to create a storage layer below the underdrain or upturned elbow invert. The depth of this layer must be sized so that the design storm can infiltrate into the subsoils in a 48-hour period. The bottom of the infiltration sump must be at least 0.5 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

Filter Layer (optional). To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer can be used. The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8).

Geotextile (optional). Geotextile fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of fabric beneath permeable pavements since it may become a future plane of clogging within the system. Geotextile fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used.

Impermeable Liner. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-mil (minimum) PVC geomembrane liner. (Follow manufacturer's instructions for installation.) Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is recommended at all seams.

Material Specifications. Permeable pavement material specifications vary according to the specific pavement product selected. A general comparison of different permeable pavements is provided in Table 4.3-1 below, but designers should consult manufacturer's technical specifications for specific criteria and guidance. Table 4.3-2 describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

Table 4.3-1. Permeable Pavement Specifications

Material	Specification	Notes
Permeable Pavers (PP)	♦ Surface open area: 5% to 15% ♦ Thickness: 3.125 inches for vehicles ♦ Compressive strength: 55 MPa ♦ Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Pavers (CGP)	♦ Open void content: 20% to 50% ♦ Thickness: 3.5 inches ♦ Compressive strength: 35 MPa ♦ Open void fill media: aggregate, topsoil and grass, coarse sand	Must conform to ASTM C1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	♦ Void content: depends on fill material ♦ Compressive strength: varies, depending on fill material ♦ Open void fill media: aggregate, topsoil and grass, coarse sand	Reservoir layer required to support the structural load.
Pervious Concrete (PC)	♦ Void content: 15% to 25% ♦ Thickness: typically 4 to 8 inches ♦ Compressive strength: 2.8 to 28 MPa ♦ Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt (PA)	♦ Void content: 15% to 20% ♦ Thickness: typically 3 to 7 in. (depending on traffic load) ♦ Open void fill media: None	Reservoir layer required to support the structural load.

Table 4.3-2. Material Specifications for Elements Underneath the Pavement Surface		
Material	**Specification**	**Notes**
Bedding Layer	♦ PP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57 stone ♦ PC: 3 to 4 inches of No. 57 stone if No. 2 stone is used for Reservoir Layer ♦ PA: 3 to 4 inches of No. 57 stone	ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Must be double-washed and clean and free of all fines.
Reservoir Layer	♦ PP: No. 57 stone or No. 2 stone ♦ PC: No. 57 stone or No. 2 stone ♦ PA: No. 2 stone	ASTM D448 size No. 57 stone (e.g., 1 1/2- to 1/2-inch in size); No. 2 Stone (e.g., 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Must be double-washed and clean and free of all fines.
Underdrain	Use 4- to 6-inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface.	
Infiltration Sump (optional)	An aggregate storage layer below the underdrain invert. The material specifications are the same as Reservoir Layer.	
Filter Layer (optional)	The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8).	
Geotextile (optional)	Use an appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability.	
Impermeable Liner (optional)	Where appropriate use a thirty mil (minimum) PVC Geomembrane liner (follow manufacturer's instructions for installation) .	
Observation Well	Use a perforated 4- to 6-inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface or just beneath PP.	

Permeable Pavement Sizing. The thickness of the reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. Permeable pavement structural and hydraulic sizing criteria are discussed below.

Structural Design. If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic
- In-situ soil strength
- Environmental elements
- Bedding and Reservoir layer design

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (CBR) (less than 4 percent), they may need to be compacted to at least 95 percent of the Standard Proctor Density, which may limit their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)

Hydraulic Design. Permeable pavement is typically sized to store the design storm or larger design storm volumes in the reservoir layer. The storage volume in the pavements must account for the underlying infiltration rate and outflow through any underdrains. The design storm should be routed through the pavement to accurately determine the required reservoir depth. The depth of the reservoir layer or infiltration sump needed to store the design storm can be determined by using Equation 4.3-1.

Equation 4.3-1. Reservoir Layer or Infiltration Sump Depth

$$d_p = \frac{\left(\frac{P \times Rv_I \times DA}{A_p}\right) - \left(\frac{i}{2} \times t_f\right)}{\eta_r}$$

where:

d_p	=	depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft)
P	=	rainfall depth for the design storm (ft)
Rv_I	=	runoff coefficient for impervious cover (0.95)
DA	=	total contributing drainage area, including permeable pavement surface (ft^2)
A_p	=	permeable pavement surface area (ft^2)
i	=	field-verified infiltration rate for the subgrade soils (ft/day). If an impermeable liner is used in the design then i = 0.
t_f	=	time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)
η_r	=	effective porosity for the reservoir layer (0.35)

This equation makes the following design assumptions:

- The contributing drainage area (CDA) does not contain pervious areas.
- For design purposes, the field-tested subgrade soil infiltration rate (*i*) is divided by 2 as a factor of safety to account for potential compaction during construction. If the subgrade will be compacted to meet structural design requirements of the pavement section, the design infiltration rate of the subgrade soil shall be based on measurement of the infiltration rate of the subgrade soil subjected to the compaction requirements.
- The porosity (η_r) for No. 57 stone is 0.35.

The depth of the reservoir layer cannot be less than the depth required to meet the pavement structural requirement. The depth of the reservoir layer may need to be increased to meet structural or larger storage requirements.

Designers must ensure that the captured volume will drain from the pavement in 36 to 48 hours. For infiltration designs (no underdrains) or designs with infiltration sumps, Equation 4.3-2 can be used to determine the drawdown time in the reservoir layer or infiltration sump.

Equation 4.3-2. Drawdown Time

$$t_d = \frac{d_p \times \eta_r}{0.5 \times i}$$

where:

t_d	=	drawdown time (day)
d_p	=	depth of the reservoir layer (or the depth of the infiltration sump, for hybrid designs) (ft)
η_r	=	effective porosity for the reservoir layer (0.35)
i	=	field-verified infiltration rate for the subgrad

For design with underdrains, the drawdown time should be determined using the hydrological routing or modeling procedures used for detention systems with the depth and head adjusted for the porosity of the aggregate.

The total storage volume provided by the practice, *Sv*, should be determined using Equation 4.3-3, Equation 4.3-4, or both. For infiltration designs, *Sv* is calculated using Equation 4.3-3. For standard designs, *Sv* is calculated using Equation 4.3-4. For hybrid designs, both equations are used. Equation 4.3-3 provides *Sv* for the infiltration sump and Equation 4.3-4 provides *Sv* for the stone reservoir above the underdrain,

Equation 4.3-3. Permeable Pavement Storage Volume for Infiltration Design

$$Sv = A_p \times \left[(d_p \times \eta_r) + \left(\frac{i \times t_f}{2} \right) \right]$$

where:

Sv = storage volume (ft^3)

d_p = depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft)

η_r = effective porosity for the reservoir layer (0.35)

A_p = permeable pavement surface area (ft^2)

i = field-verified infiltration rate for the subgrade soils (ft/day). If an impermable liner is used in the design then $i = 0$.

t_f = time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)

*Note: For enhanced designs that use an infiltration sump, *dp* is only the depth of the infiltration sump.

Equation 4.3-4. Permeable Pavement Storage Volume for Standard Design

$$Sv = (d_p \times \eta_r \times A_p)$$

where:

Sv = storage volume (ft^3)

d_p = depth of the reservoir layer (ft)

η_r = effective porosity for the reservoir layer (0.35)

A_p = permeable pavement surface area (ft^2)

In the LID Compliance Calculator spreadsheet, the Sv for infiltration designs is given a 100% runoff reduction credit; the Sv for standard designs is given a 50% runoff reduction credit, since much of the water stored quickly exits the underdrain. For projects in the Coastal Zone, the Sv for all design types is given a 100% credit toward the storage requirement.

Note: The hybrid design is not included as a separate practice in the spreadsheet. Instead, it is treated as two separate practices in series. The designer should first enter the Sv in the Infiltration Sump and drainage area for the Porous Pavement – Infiltration Design. Next, select Permeable Pavement-Standard as the downstream BMP, and on this line do not enter any value for the drainage area, and enter the Sv for the stone reservoir above the underdrain.

Detention Storage Design: Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer (including chamber structures that increase the available storage volume), expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet (see Permeable Pavement Conveyance Criteria Section above).

Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs associated with it. However, large-scale permeable pavement applications should be carefully planned to integrate the typical landscaping features of a parking lot, such as trees and islands, in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface. Bioretention areas may be a good design option to meet these needs.

Permeable Pavement Construction Sequence

Experience has shown that proper installation is absolutely critical to the effective operation of a permeable pavement system.

Erosion and Sediment Controls. The following erosion and sediment control guidelines must be followed during construction:

- All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Intended permeable pavement areas must remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment (unless the area has been determined to have a low CBR and will require compaction during the permeable pavement construction phase). Where this is unavoidable, the impacted area should not be excavated below 2 feet above the final design elevation of the bottom of the aggregate reservoir course until further compaction by heavy equipment can be avoided. Once the area is excavated to grade, the impacted area should be tilled to a depth of 12 inches below the bottom of the reservoir layer. Permeable pavement areas must be clearly marked on all construction documents and grading plans.
- During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.
- Any area of the site intended ultimately to be a permeable pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the sub-base, base, and surface materials.

Permeable Pavement Installation. The following is a typical construction sequence to properly install permeable pavement, which may need to be modified depending on the specific variant of permeable pavement that is being installed.

Step 1: Construction of the permeable pavement should only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow and do not install frozen bedding materials.

Step 2: As noted above, temporary erosion and sediment controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials contaminated by sediments must be removed and replaced with clean materials.

Step 3: Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For small pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500-to 1,000-square foot temporary cells with a 10- to 10-foot earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4: The native soils along the bottom of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or geotextile fabric. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95 percent of the Standard Proctor Density to achieve the desired load-bearing capacity. Note: This may reduce or eliminate the infiltration function of the installation, and it must be addressed during hydrologic design.

Step 5: Geotextile fabric should be installed on the sides of the reservoir layer (and the bottom if the design calls for it). Geotextile fabric strips should overlap down-slope by a minimum of 2 feet and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of geotextile fabric 1 foot below the surface to prevent sediments from entering into the reservoir layer. Excess geotextile fabric should not be trimmed until the site is fully stabilized.

Step 6: Provide a minimum of 2 inches of aggregate above and below the underdrains. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7: Spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

Step 8: Install the desired depth of the bedding layer, depending on the type of pavement, as indicated in Table 4.3-2.

Step 9: Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

Installation of Porous Asphalt. The following has been excerpted from various documents, most notably Jackson (2007):

- ✧ Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230°F and 260°F, with a minimum air temperature of 50°F, to ensure the surface does not stiffen before compaction.
- ✧ Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
- ✧ The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95%, additional anti-stripping agents must be added to the mix.
- ✧ Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
- ✧ Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
- ✧ Inspect the facility 18 to 30 hours after a significant rainfall (greater than ½ inch) or artificial flooding to determine the facility is draining properly.

Installation of Pervious Concrete. The basic installation sequence for pervious concrete is outlined by the National Ready Mixed Concrete Association (NRMCA, 2004). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the NRMCA. The basic installation procedure is as follows:

- ✧ Drive the concrete truck as close to the project site as possible.
- ✧ Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid pervious concrete.
- ✧ After the concrete is placed, approximately ⅜ to ½ inch is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
- ✧ Compact the pavement with a steel pipe roller. Care should be taken to ensure over-compaction does not occur.
- ✧ Cut joints for the concrete to a depth of ¼ inch.

- The curing process is very important for pervious concrete. Concrete installers should follow manufacturer specifications to the extent allowed by on-site conditions when curing pervious concrete.
- Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a significant rainfall (greater than ½ inch) or artificial flooding, to determine the facility is draining properly.

Installation of Permeable Pavers. The basic installation process is described in greater detail by Smith (2006):

- Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable pavement systems may require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.
- Place the No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode, with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
- Place and screed the bedding course material (typically No. 8 stone).
- Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than $^{1}/_{3}$ of the full unit size.
- Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with ASTM D 448 No. 8 stone; although, No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.
- Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
- Do not compact within 6 feet of the unrestrained edges of the pavers.
- The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
- Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
- Inspect the facility 18 to 30 hours after a significant rainfall (½ inch or greater) or artificial flooding to determine whether the facility is draining properly.

Construction Supervision. Supervision before, during, and after construction by a qualified professional is recommended to ensure permeable pavement is built in accordance with these specifications. Inspection checklists that require sign-offs by qualified individuals should be used at critical stages of construction, to ensure the contractor’s interpretation of the plan is consistent with the designer’s intent.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- ✧ Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- ✧ The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.
- ✧ Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth. Aggregate loads that do not meet the specifications or do not appear to be sufficiently washed may be rejected.
- ✧ Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- ✧ Make sure the permeable pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.
- ✧ Ensure caps are placed on the upstream (but not the downstream) ends of the underdrains.
- ✧ Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- ✧ Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the BMP maintenance tracking database.

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid down.

Permeable Pavement Maintenance Criteria

Maintenance is a required and crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on ALL permeable pavements:

- ✧ Sanding
- ✧ Re-sealing
- ✧ Re-surfacing
- ✧ Power washing
- ✧ Storage of mulch or soil materials
- ✧ Construction staging on unprotected pavement

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. The frequency of maintenance will depend largely on the pavement use, traffic loads, and the surrounding land use.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Typical maintenance tasks are outlined in Table 4.3-3.

Table 4.3-3. Typical Maintenance Tasks for Permeable Pavement Practices

Frequency	Maintenance Tasks
After installation	♦ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.
Once every 1–2 months during the growing season	♦ Mow grass in grid paver applications.
As needed	♦ Stabilize the contributing drainage area to prevent erosion ♦ Remove any soil or sediment deposited on pavement. ♦ Replace or repair any necessary pavement surface areas that are degenerating or spalling
2–4 times per year (depending on use)	♦ Vacuum pavement with a standard street sweeper to prevent clogging.
Annually	♦ Conduct a maintenance inspection. ♦ Spot weeding of grass applications.
Once every 2–3 years	♦ Remove any accumulated sediment in pretreatment cells and inflow points.
If clogged	♦ Conduct maintenance using a regenerative street sweeper. ♦ Replace any necessary joint material.

When permeable pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs and (2) understand the long-term maintenance plan.

It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each permeable pavement site, particularly at large-scale applications. An example maintenance checklist for permeable pavement areas is included in *Appendix F*.

Permeable Pavement References and Additional Resources

1. AASHTO. 1993. Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials: Washington, DC.
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4.4 Stormwater Infiltration

Introduction

Infiltration practices are shallow excavations, typically filled with stone or an engineered soil mix, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the underlying and surrounding soils over a two day period. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. See Figure 4.4-1, Figure 4.4-2 and Figure 4.4-3.

Infiltration practices are suitable for use in residential and other urban areas where field measured soil infiltration rates are sufficient. To prevent possible groundwater contamination, infiltration must not be utilized at sites designated as stormwater hotspots. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites.

Figure 4.4-1. Infiltration in Median Strip

Figure 4.4-2. Infiltration at Edge of Parking Lot

Figure 4.4-3. Infiltration to Treat Roof Runoff (Micro-Scale)

KEY CONSIDERATIONS: STORMWATER INFILTRATION

DESIGN CRITERIA:

- Pretreatment must be provided upstream of all infiltration practices.
- Infiltration practices must be designed to completely drain within 72 hours.
- Underlying native soils must have an infiltration rate of 0.3 in/hr or more.
- The distance from the bottom of an infiltration practice to the top of the seasonal high water table must be 0.5 feet or more.

BENEFITS:

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes, and pollutant loads.
- Can be integrated into development plans as attractive landscaping features.

LIMITATIONS:

- Can only be used to “receive” runoff from relatively small drainage areas of up to 5 acres in size.
- Should not be used to “receive” stormwater runoff that contains high sediment loads.

SITE APPLICABILITY:

- Rural Use
- Suburban Use
- Urban Use
- Construction Cost: Medium
- Maintenance: Medium
- Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 100% credit for storage volume of practice

Coastal Zone Credit

- 100% credit for storage volume of practice

Statewide Water Quality Requirement Credit Approach

- Runoff Reduction credit applies to infiltration requirement.

Pollutant Removal[1]
80-95% - Total Suspended Solids
65-95% - Total Phosphorus
55-90% - Total Nitrogen
N/A - Metals
65-95% - Pathogens

[1] *expected annual pollutant load removal*

Creative Use of Coastal Resources: Dune Infiltration Systems

One of the advantages of infiltration over other LID BMPs is that it can be installed entirely underground, reducing the space requirements considerably. A dune infiltration system (DIS) is an example of that approach, with the further benefit of utilizing otherwise undevelopable land.

The DIS consists of a series of open-bottomed chambers connected to a stormwater discharge pipe, and installed below a sand dune. The chambers hold water temporarily, allowing the stormwater to infiltrate into the sand, rather than directly onto the beach or into a water body.

Like any infiltration system, accurate sizing of the ponding volume in the chambers, a suitable infiltration rate, and sufficient separation from the seasonally high groundwater table are essential for proper function of the system. More detailed information is provided by the North Carolina State University Cooperative Extension (Burchell et al., 2013): http://www.bae.ncsu.edu/people/faculty/mrburche/publications/ag-781-dune.pdf

(Photo: M. Burchell)

Although infiltration practices can provide significant reductions in post-construction stormwater runoff rates, volumes, and pollutant loads, they have historically experienced high rates of failure due to clogging caused by poor design, poor construction, and neglected maintenance. If infiltration practices are to be used on a development site, great care should be taken to ensure that they are adequately designed, carefully installed, and properly maintained over time. They must only be applied on development sites that have permeable soils (i.e., hydrologic soil group A and B soils) and that have a water table and confining layers (e.g., bedrock, clay lenses) that are located at least 0.5 feet below the bottom of the trench or basin. Additionally, infiltration practices must always be designed with adequate pretreatment (e.g., vegetated filter strip or sediment forebay) to prevent sediment from reaching the practice and causing it to clog and fail.

There are two major variations of infiltration practices, namely infiltration trenches and infiltration basins (Figure 4.4-4). A brief description of each of these design variants is provided below:

- ✧ **Infiltration Trenches:** Infiltration trenches are excavated trenches filled with stone. Stormwater runoff is captured and temporarily stored in the stone reservoir, where it is allowed to infiltrate into the surrounding and underlying native soils. Infiltration trenches can be used to "receive" stormwater runoff from contributing drainage areas of up to 2 acres in size and should only be used on development sites where sediment loads can be kept relatively low (see Figure 4.4-5).
- ✧ **Infiltration Basins:** Infiltration basins are shallow, landscaped excavations filled with an engineered soil mix. They are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration, before being allowed to infiltrate into the surrounding soils. They are essentially non-underdrained bioretention areas and should also only be used on drainage areas up to 5 acres where sediment loads can be kept relatively low (See Figure 4.4-6).

Figure 4.4-4. Infiltration Practices (Photos: CWP). From left to right: (a) infiltration trench and (b) infiltration basin.

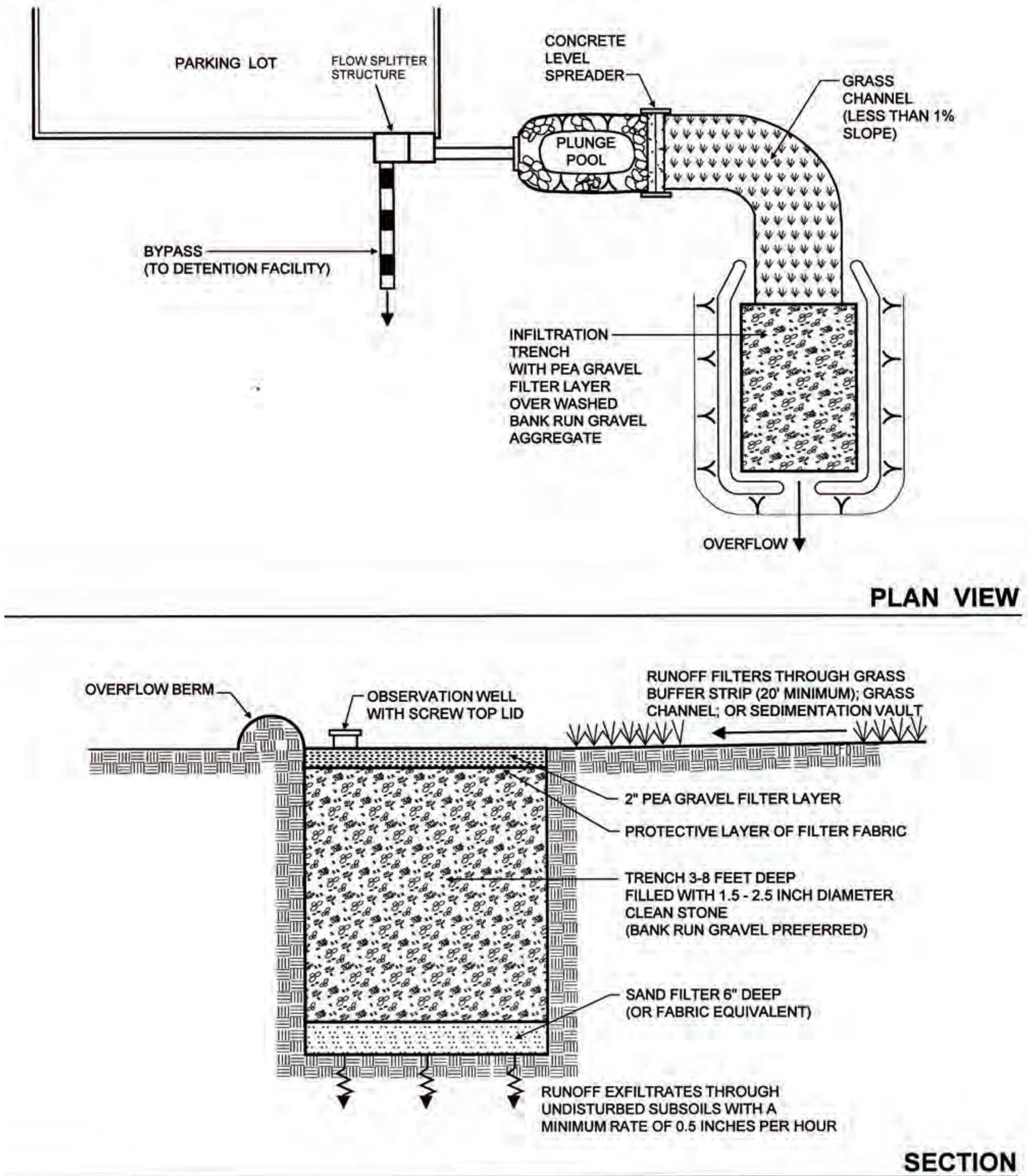

Figure 4.4-5. Schematic of a Typical Infiltration Trench (Source: CWP)

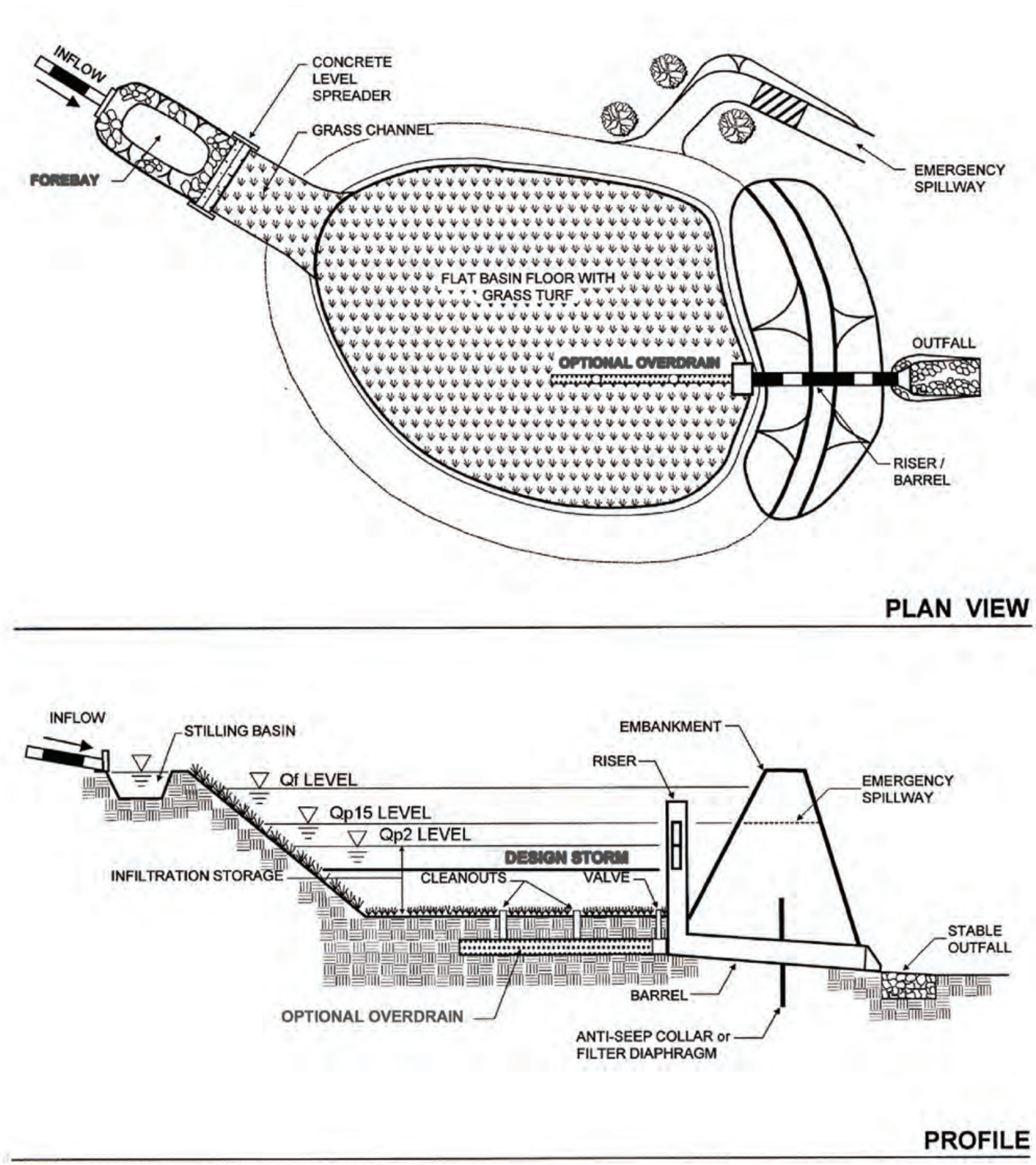

Figure 4.4-6. Infiltration Trench with Grassed Channel Pretreatment (Source: CWP)

Infiltration Feasibility Criteria

Infiltration practices have very high storage and retention capabilities when sited and designed appropriately. Designers should evaluate the range of soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of Hydrologic Soil Group A or B soils, shown on the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) soil surveys, should be considered as primary locations for infiltration practices. Additional information about soil and infiltration are described in more detail later in this section. During initial design phases, designers should carefully identify and evaluate constraints on infiltration, as follows:

Underground Injection Control for Class V Wells. In order for an infiltration practice to avoid classification as a Class V well, which is subject to regulation under the Federal Underground Injection Control (UIC) program, the practice must be wider than it is deep. If an infiltration practice is "deeper than its widest surface dimension" or if it includes an underground distribution system, then it will likely be considered a Class V injection well. Class V injection wells are subject to permit approval by the U.S. Environmental Protection Agency (EPA). For more information on Class V injection wells and stormwater management, designers should consult the EPA's minimum requirements: http://water.epa.gov/type/groundwater/uic/class5/comply_minrequirements.cfm

Contributing Drainage Area. The maximum Contributing Drainage Area (CDA) to an individual infiltration practice should be less than 2 acres for infiltration trenches, and 5 acres for infiltration basins, and as close to 100 percent impervious as possible. The design, pretreatment, and maintenance requirements will differ depending on the size of the infiltration practice.

Site Topography. Infiltration should not be located on slopes greater than 6 percent, although check dams or other devices may be employed to reduce the effective slope of the practice. Further, unless slope stability calculations demonstrate otherwise, infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20 percent.

Minimum Hydraulic Head. Two or more feet of head may be needed to promote flow through infiltration practices.

Minimum Depth to Water Table. A minimum vertical distance of 0.5 feet must be provided between the bottom of the infiltration practice and the seasonal high water table.

Tidal Impacts. The bottom of an infiltration practice should be located above the tidal mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations.

Soils. Initially, soil infiltration rates can be estimated from NRCS soil data, but designers must verify soil permeability by using on-site soil investigation methods. Although the number of infiltration tests needed on a development site will ultimately be determined by the local development review authority, at least one infiltration test is recommended for each infiltration practice that will be used on the development site.

Since clay lenses or any other restrictive layers located below the bottom of an infiltration practice will reduce soil infiltration rates, infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed infiltration practice.

Use on Urban Fill Soils/Redevelopment Sites. Sites that have been previously graded or disturbed do not typically retain their original soil permeability due to compaction. Therefore, such sites are often not good candidates for infiltration practices unless the geotechnical investigation shows that a sufficient infiltration rate exists, and that infiltration of stormwater will not lead to structural or slope stability problems.

Dry Weather Flows. Infiltration practices should not be used on sites receiving regular dry-weather flows from sump pumps, irrigation water, chlorinated wash-water, or other non-stormwater flows.

Setbacks. To help prevent damage to building foundations and contamination of groundwater aquifers, infiltration practices should be located at least:

- 10 feet from building foundations (especially when basements are present)*
- 10 feet from property lines
- 150 feet from water supply wells
- 50 feet from septic systems

*Where the 10 foot setback from building foundations is not possible, an impermeable liner may be used along the sides of the infiltration area (extending from the surface to the bottom of the practice).

Proximity to Utilities. Interference with underground utilities should be avoided, if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Where conflicts cannot be avoided, the following guidelines shall be followed:

- Consult with each utility company on recommended offsets that will allow utility maintenance work with minimal disturbance to the stormwater Best Management Practice (BMP).
- Whenever possible, coordinate with utility companies to allow them to replace or relocate their aging infrastructure while BMPs are being implemented.
- BMP and utility conflicts will be a common occurrence in public right-of-way projects. However, the standard solution to utility conflict should be the acceptance of conflict provided sufficient soil coverage over the utility can be assured.
- Additionally, when accepting utility conflict into the BMP design, it is understood that the BMP will be temporarily impacted during utility maintenance but restored to its original condition.

Pollutant Hotspot Land Uses. Infiltration is not an appropriate stormwater management practice for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the infiltration area and groundwater.

On sites with existing contaminated soils, infiltration is not allowed.

Economic Considerations. Infiltration practices do require a designated space on the site, which in space-constrained areas, may reduce available building space. However, infiltration practices have a relatively low construction cost, and high space efficiency. In some cases, they can even be incorporated into the detention design or landscaped areas.

Infiltration Conveyance Criteria

The nature of the conveyance and overflow to an infiltration practice depends on the scale of infiltration and whether the facility is on-line or off-line. Where possible, conventional infiltration practices should be designed off-line to avoid damage from the erosive velocities of larger design storms. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice should be designed as an off-line practice.

Off-line Infiltration. Overflows can either be diverted from entering the infiltration practice or managed via an overflow inlet. Optional overflow methods include the following:

- Create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filters through the soil media. With this design configuration, an overflow structure in the infiltration practice is not required.
- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design stormwater volume to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. With this design configuration, an overflow structure in the infiltration practice will still be necessary.

On-line Infiltration. An overflow structure must be incorporated into on-line designs to safely convey larger storms through the infiltration area. The overflow mechanism, such as an elevated drop inlet or overflow weir, must be used to direct high flows to a non-erosive down-slope overflow channel, stabilized water course, or storm sewer system designed to convey the 10-year design storm.

Infiltration Pretreatment Criteria

Every infiltration system must have pretreatment mechanisms to protect the long term integrity of the infiltration rate. One of the following techniques must be installed to pretreat 100 percent of the inflow in every facility:

- **Grass Channel.** (See Figure 4.4-7).
- **Grass Filter Strip.** A minimum 20 feet and only if sheet flow is established and maintained.
- **Forebay.** Should accommodate a minimum 15 percent of the design storm volume; if the infiltration rate for the underlying soils is greater than 2 inches per hour, the forebay volume should be increased to a minimum of 50 percent of the design storm volume.

Figure 4.4-7. Infiltration Trench with Grassed Channel Pretreatment (Photo: CWP)

Figure 4.4-8. Infiltration Sand Filter Example (Photo: CWP)

- **Gravel Diaphragm.** Minimum 1 foot deep and 2 feet wide and only if sheet flow is established and maintained.
- **Filter System.** (See Figure 4.4-8).
- **Proprietary Structure.** Must demonstrate capability of reducing sediment and hydrocarbons.

For pretreatment structures at the edge of pavement (e.g., grass filter strips, gravel diaphragms, flow splitters), it is important that there be a 2- to 4-inch drop from the edge of pavement to the top of the grass or stone in the pretreatment structure. This is to prevent accumulation of debris and subsequent clogging at the point where runoff is designed to enter the pretreatment structure (see Figure 4.4-9).

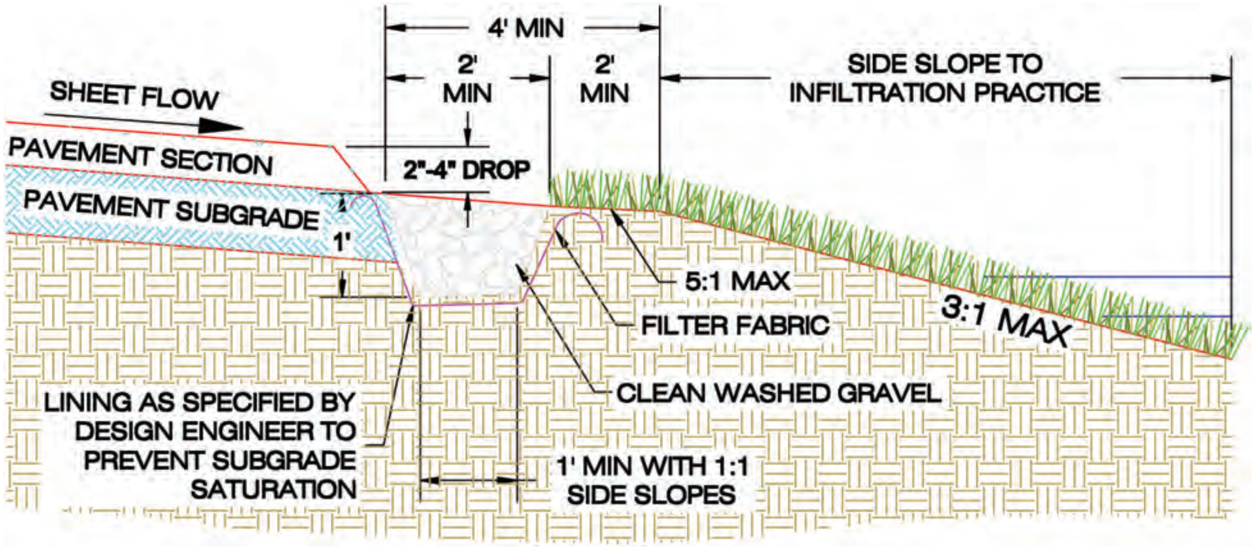

Figure 4.4-9. Typical Detail for Pretreatment at Pavement Edge (Source: CWP)

Exit velocities from the pretreatment chamber should not be erosive (above 6 fps) during the 10-year design storm and flow from the pretreatment chamber should be evenly distributed across the width of the practice (e.g., using a level spreader).

Infiltration Design Criteria

Design Geometry. Where possible, infiltration practices should be designed to be wider than they are deep, to avoid classification as a Class V injection well. For more information on Class V wells see http://water.epa.gov/type/groundwater/uic/class5/index.cfm.

Practice Slope. The bottom of an infiltration practice should be as flat as possible (i.e., 0% longitudinal and lateral slopes is preferred. 5% is the maximum) to enable even distribution and infiltration of stormwater.

Infiltration Basin Geometry. The maximum vertical depth to which runoff may be ponded over an infiltration basin is 24 inches. The side-slopes should be no steeper than 3:1 unless proper erosion protection is provided.

Surface Cover (optional). Designers may choose to install a layer of topsoil and grass above the infiltration practice (see Figure 4.4-10).

The soils used within infiltration basin planting beds should be an engineered soil mix that meets the following specifications:

- Texture: Sandy loam or loamy sand.
- Sand Content: Soils should contain 85%-88% clean, washed sand.
- Topsoil Content: Soils should contain 8%-12% topsoil.
- Organic Matter Content: Soils should contain 3%-5% organic matter.
- Infiltration Rate: Soils should have an infiltration rate of at least 0.3 inches per hour (in/hr), although an infiltration rate of between 1 and 2 in/hr is preferred.

Figure 4.4-10. Example of an Infiltration Trench with Surface Cover (Photo: CWP)

- ✧ Phosphorus Index (P-Index): Soils should have a P-Index of less than 30.
- ✧ Exchange Capacity (CEC): Soils should have a CEC that exceeds 10 milliequivalents (meq) per 100 grams of dry weight.
- ✧ pH: Soils should have a pH of 6-8.

Depending upon the stone layer below, a geotextile or a choker stone layer may be necessary to ensure that the surface cover soil does not intrude into the stone layer.

Surface Stone (optional). A 3-inch layer of clean, washed river stone or No. 8 or 89 stone can be installed over the stone layer.

Stone Layer. Stone layers should consist of clean, washed aggregate with a minimum diameter of 1.5 inches.

Underground Storage (optional). In the underground storage, runoff is stored in the voids of the stones and infiltrates into the underlying soil matrix. Perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials can be used in conjunction with the stone to increase the available temporary underground storage. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention (ED) pond.

Clean Out Observation Well. Infiltration practices should include a clean out and observation well, consisting of an anchored 6-inch diameter perforated PVC pipe fitted with a lockable cap installed flush with the ground surface, to facilitate periodic inspection and maintenance. At least one clean out must be installed for every 100 linear feet of the practice.

Overflow Collection Pipe (Overdrain). An optional overflow collection pipe can be installed in the stone layer to convey collected runoff from larger storm events to a downstream conveyance system.

Trench Bottom. To protect the bottom of an infiltration trench from intrusion by underlying soils, a sand layer should be used. The underlying native soils should be separated from the stone layer by a 6- to 8-inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch).

Geotextile Fabric (optional). If desired, an appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability may be used on the sides of the practice and in place of the sand layer described above.

Material Specifications. Recommended material specifications for infiltration areas are shown in Table 4.4-1.

Table 4.4-1. Infiltration Material Specifications

Material	Description	Notes
Surface Layer (optional)	Topsoil and grass layer.	
Surface Stone	Install a 3-inch layer of river stone or pea gravel.	Provides an attractive surface cover that can suppress weed growth.
Stone Layer	Clean, aggregate with a minimum diameter of 1.5 inches.	
Observation Well	Install a vertical 6-inch Schedule 40 PVC perforated pipe, with a lockable cap and anchor plate.	Install one per 100 feet of length of infiltration practice.
Overflow Collection Pipe (optional)	Use 4- or 6-inch rigid schedule 40 PVC pipe, with 3/8-inch perforations at 6 inches on center.	
Trench Bottom	Install a 6- to 8-inch sand layer (e.g., ASTM C 33, 0.02-0.04 inch).	
Geotextile Fabric (optional)	An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability may be used.	

Practice Sizing: The proper approach for designing infiltration practices is to avoid forcing a large amount of infiltration into a small area. Therefore, individual infiltration practices that are limited in size due to soil permeability and available space need not be sized to achieve the full design storm volume for the contributing drainage area, as long as other stormwater treatment practices are applied at the site to meet the remainder of the design storm volume.

Several equations are needed to size infiltration practices. The first equations establish the maximum depth of the infiltration practice. Equation 4.4-1 calculates the maximum depth of water that can be stored, based upon the measured infiltration rate. Equation 4.4-2 is used to determine the depths of the two main aspects of an infiltration practice – the ponding area and the stone reservoir. These depths may be adjusted to meet design needs (In the case of an infiltration trench, the ponding area depth may be zero. Likewise, in the case of an infiltration basin installed without a stone reservoir, the stone reservoir depth may be zero) so long as d_{water} is not exceeded.

Equation 4.4-1. Maximum Water Depth for Infiltration Practice

$$d_{\max} = \frac{i}{2} \times t_d$$

Equation 4.4-2. Infiltration Practice Depth

$$d_{\max} = d_{pond} + \frac{d_{gravel}}{\eta_r}$$

where:

d_{max}	=	maximum depth of runoff that can be infiltrated (ft)
i	=	field-verified (actual) infiltration rate for the native soils (ft/day)
t_d	=	maximum drawdown time (day) (3 days)
d_{pond}	=	depth of ponded area (ft)
d_{gravel}	=	depth of stone reservoir (ft)
η_r	=	available porosity of the stone reservoir (normally 0.35)

The ponding and stone reservoir depths may be adjusted to meet design goals (In the case of an infiltration trench, the ponding area depth may be very small or zero. Likewise, in the case of an infiltration basin installed without a stone reservoir, the stone reservoir depth may be zero) so long as d_{water} is not exceeded.

These equations make the following design assumptions:

- *Conservative Infiltration Rates.* For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 as a factor of safety to account for potential compaction during construction and to approximate long term infiltration rates. On-site infiltration investigations must be conducted to establish the actual infiltration capacity of underlying soils.
- *Stone Layer Porosity.* A porosity value of 0.35 shall be used in the design of stone reservoirs, although a larger value may be used if perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials are installed within the reservoir.
- *Rapid Drawdown.* Infiltration practices must be sized so that the design volume infiltrates within 72 hours, to prevent nuisance ponding conditions.

Once the maximum depth and the depths of the components are known, calculate the surface area needed for an infiltration practice using Equation 4.4-3.

Equation 4.4-3. Infiltration Practice Surface Area

$$SA = \frac{Sv}{d_{water} + \left(\frac{i}{2} \times t_f\right)}$$

where:

SA	=	surface area (ft^2)
Sv	=	storage volume of the infiltration practice (ft^3)
d_{water}	=	depth of water to be infiltrated (ft) (usually = d_{max}, as determined in Equation 1)
i	=	field-verified (actual) infiltration rate for the native soils (ft/day)
t_f	=	time to fill the infiltration facility (days) (typically 2 hours, or 0.083 days)

The storage volume (Sv) captured by the infiltration practice is defined as the volume of water that is fully infiltrated through the practice (no overflow). In the LID Compliance Calculator spreadsheet, the Sv for infiltration practices is given a 100% runoff reduction credit and, for projects in the Coastal Zone, a 100% credit toward the water quality volume requirements.

This design volume would typically be equal to 1 inch of runoff from the impervious surface in the contributing drainage area. In space-constrained designs, designers may choose to infiltrate less than this full amount. In these cases (when the surface area is fixed), Equation 4.4-3 can be rearranged to solve for *Sv*.

$$Sv = SA \times \left[d_{water} + \left(\frac{i}{2} \times t_f\right)\right]$$

Infiltration practices can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, any perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials installed within the reservoir, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Infiltration Landscaping Criteria

Infiltration trenches can be effectively integrated into the site plan and aesthetically designed with adjacent native landscaping or turf cover, subject to the following additional design considerations:

- ✧ Infiltration practices should not be installed until all up-gradient construction is completed and pervious areas are stabilized with dense and healthy vegetation, unless the practice can be kept off-line so it receives no runoff until construction and stabilization is complete.

- ✧ Vegetation associated with the infiltration practice buffers should be maintained regularly to limit organic matter in the infiltration device and maintain enough vegetation to prevent soil erosion from occurring.

Infiltration Construction Sequence

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence must be followed, including the following elements:

1. Avoid excessive compaction by preventing construction equipment and vehicles from traveling over the proposed location of the infiltration practice. When this is unavoidable, the impacted area should not be excavated below 2 feet above the final design elevation of the bottom of the practice until further compaction by heavy equipment can be avoided. Once the area is excavated to grade, impacted area must be tilled a minimum of 12 inches (30 cm) below the bottom of the infiltration practice.
2. Any area of the site intended to be an infiltration practice generally shall not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for infiltration is unavoidable, the invert of the sediment basin should be a minimum of 2 feet above the final design elevation of the bottom of the proposed infiltration practice. All sediment deposits in the excavated area should be carefully removed prior to installing the infiltration practice.
3. Keep the infiltration practice "off-line" until construction is complete. Prevent sediment from entering the infiltration site by using silt fence, diversion berms, or other means. In the erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to a conventional infiltration basin. The erosion and sediment control plan should also indicate the specific methods to be used to temporarily keep runoff from the infiltration site.
4. Upland drainage areas must be completely stabilized with a thick layer of vegetation prior to commencing excavation for an infiltration practice.

Infiltration Installation. The actual installation of an infiltration practice is done using the following steps:

1. Excavate the infiltration practice to the design dimensions from the side using a backhoe or excavator. The floor of the pit should be completely level, but equipment should be kept off the floor area to prevent soil compaction.
2. Install geotextile fabric on the trench sides (where applicable). Large tree roots should be trimmed flush with the sides of infiltration trenches to prevent puncturing or tearing of the geotextile fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench. The geotextile fabric itself should be tucked under the sand layer on the bottom of the infiltration trench. Stones or other anchoring objects should be placed on the fabric at the trench sides, to keep the trench open during windy periods.

Voids may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in all voids, to ensure the fabric conforms smoothly to the sides of excavation.

3. Scarify the bottom of the infiltration practice, and spread 6 inches of sand on the bottom as a filter layer.
4. Anchor the observation well(s) and add stone to the practice in 1-foot lifts.
5. Use sod, where applicable, to establish a dense turf cover for at least 10 feet around the sides of the infiltration practice, to reduce erosion and sloughing.

Construction Supervision. Supervision during construction is recommended to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists to include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

Infiltration Maintenance Criteria

Maintenance is a crucial and required element that ensures the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging of the stone by organic matter and sediment. The following design features can minimize the risk of clogging:

Stabilized CDA. Infiltration systems may not receive runoff until the entire contributing drainage area has been completely stabilized.

Observation Well. Infiltration practices must include an observation well, consisting of an anchored 6-inch diameter perforated PVC pipe fitted with a lockable cap installed flush with the ground surface, to facilitate periodic inspection and maintenance.

No Geotextile Fabric on Bottom. Avoid installing geotextile fabric along the bottom of infiltration practices if possible. Experience has shown that geotextile fabric is prone to clogging. However, permeable geotextile fabric should be installed on the trench sides to prevent soil piping (i.e., a process that would cause subsurface erosion, forming channels adjacent to the trench).

Direct Maintenance Access. Access must be provided to allow personnel and heavy equipment to perform non-routine maintenance tasks, such as practice reconstruction or rehabilitation. While a turf cover is permissible for small-scale infiltration practices, the surface must never be covered by an impermeable material, such as asphalt or concrete.

Effective long-term operation of infiltration practices requires a dedicated and routine maintenance inspection schedule with clear guidelines and schedules, as shown in Table 4.4-2. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table 4.4-2. Typical Maintenance Activities for Infiltration Practices	
Schedule	**Maintenance Activity**
Quarterly	♦ Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. ♦ Ensure that the contributing drainage area is stabilized. Perform spot reseeding where needed. ♦ Remove sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. ♦ Repair undercut and eroded areas at inflow and outflow structures.
Semi-annual inspection	♦ Check observation wells 3 days after a storm event in excess of ½ inch in depth. Standing water observed in the well after three days is a clear indication of clogging. ♦ Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.
Annually	♦ Clean out accumulated sediments from the pretreatment cell.
As needed	♦ Replace pea gravel/topsoil and top surface geotextile fabric (when clogged). ♦ Mow vegetated filter strips as necessary and remove the clippings.

It is highly recommended that a qualified professional conduct annual site inspections for infiltration practices to ensure the practice performance and longevity of infiltration practices.

An example maintenance checklist for infiltration practices is included in *Appendix F*.

Infiltration References and Additional Resources

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4.5 Green Roofs

Introduction

Green roofs (Figure 4.5-1) are practices that capture and store rainfall in an engineered growing media that is designed to support plant growth. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites. Green roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Extensive green roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established.

Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2-year and 10-year) although some intensive green roof systems may be designed to meet these criteria. Green roof designs should generally be combined with a separate facility to provide large storm controls.

Design variants include Extensive Green Roofs, which have a shallow growing media layer that ranges from 3 to 6 inches thick, and Intensive Green Roofs, which have a growing media layer that ranges from 6 to 48 inches thick. This specification is intended for situations where the primary design objective of the green roof is stormwater management and, unless specified otherwise, addresses the design of extensive roof systems.

Figure 4.5-1. Green Roof (Photo: Center for Watershed Protection)

KEY CONSIDERATIONS: GREEN ROOFS

DESIGN CRITERIA:

- The use of extensive green roof systems (3 to 6 inches deep) should be considered prior to the use of more complex and expensive intensive green roof systems.
- Engineered growing media should be a light-weight mix and should contain less than 20% organic material.
- Waterproofing materials should be protected from root penetration by an impermeable root barrier.

BENEFITS:

- Helps reduce pollutant loads and post-construction runoff volumes without consuming valuable land.
- Particularly well suited for use on urban development and redevelopment sites.

LIMITATIONS:

- Can be difficult to establish vegetation in the harsh growing conditions found on rooftops in coastal South Carolina.
- Typically applied on flat roofs (1% to 2% pitch) but can be installed on roofs with up to 30% pitch if baffles are used.

SITE APPLICABILITY:

- Suburban Use
- Urban Use
- Construction Cost: High
- Maintenance: Low
- Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 100% credit for storage volume of practice

Coastal Zone Credit Approach

- 100% credit for storage volume of practice

Statewide Water Quality Requirement Credit Approach

- Runoff Reduction credit applies to infiltration requirement.

Pollutant Removal[1]
80% - Total Suspended Solids
45-60% - Total Phosphorus
45-60% - Total Nitrogen
N/A - Metals
45-60% - Pathogens

[1] = expected annual pollutant load removal

Green Roof Feasibility Criteria

Green roofs are ideal for use on commercial, institutional, municipal, and multi-family residential buildings. They are particularly well-suited for use on ultra-urban development and redevelopment sites. Key constraints with green roofs include the following:

Structural Capacity of the Roof. When designing a green roof, designers must not only consider the stormwater storage capacity of the green roof but also the roof's structural capacity to support the weight of the additional water. A conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive green roof. As a result, a structural engineer, architect, or other qualified professional should be involved with all green roof designs to ensure that the building has enough structural capacity to support a green roof. See Section 4.5 for more information on structural design considerations.

Hurricane-Prone Areas. As coastal South Carolina is subject to hurricanes, some may be concerned about the durability of green roofs in high winds. Having good vegetative cover and root growth in the growing media is the most effective way to reduce wind erosion of the media during high winds. New green roofs where the plants have not yet deeply rooted are the most susceptible to plant damage and media blow-off in a hurricane. Therefore, it is best to install a green roof three or more months prior to hurricane season, to allow enough time for the plants to get established.

Roof Pitch. Green roof storage volume is maximized on relatively flat roofs (a pitch of 1% to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Green roofs can be installed on rooftops with slopes up to 30% if baffles, grids, or strips are used to prevent slippage of the media. These baffles should be designed to ensure the roof provides adequate storage for the design storm.

Roof Access. Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane) and how the roof structure can accommodate material stockpiles and equipment loads. If material and equipment storage is required, rooftop storage areas must be identified and clearly marked based on structural load capacity of the roof.

Roof Type. Green roofs can be applied to most roof surfaces. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for green rooftops due to pollutants leaching through the media (Clark et al., 2008).

Setbacks. Green roofs should not be located near rooftop electrical and HVAC systems. A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed for small or low green roof applications where parapets have been properly designed.

Contributing Drainage Area. The entire contributing drainage area to a green roof (including the green roof itself) should be no more than 25% larger than the area of the green roof, unless design adaptations are made to ensure that the additional runoff is spread evenly on to the green roof surface.

Local Building Codes. The green roof design should comply with the local building codes with respect to roof drains and emergency overflow devices. Additionally, a structural engineer should certify that the design complies with structural building codes. For green roofs installed on historic buildings or in historic districts, consult local building codes and architectural review criteria to determine if any special requirements exist for green roof design or maintenance.

Economic Considerations. Green roofs tend to be one of the most expensive BMPs on a per cubic foot captured basis. However, a green roof allows stormwater management to be achieved in otherwise unused space, a major benefit in space-constrained locations. Further, green roofs provide many other non-stormwater services with economic benefits, including increased insulation and roof life expectancy.

Green Roof Conveyance Criteria

The green roof drainage layer (refer to *Green Roof Design Criteria* section below) should convey flow from under the growing media directly to an outlet or overflow system such as a traditional rooftop downspout drainage system. The green roof drainage layer must be adequate to convey the volume of stormwater equal to the flow capacity of the overflow or downspout system without backing water up onto the rooftop or into the green roof media. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging. However, an adequate number of roof drains that are not immediately adjacent to the growing media must be provided so as to allow the roof to drain without 3 inches of ponding above the growing media.

Green Roof Pretreatment Criteria

Pretreatment is not necessary for green roofs.

Green Roof Design Criteria

Structural Capacity of the Roof. Green roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer should consult with a licensed structural engineer to ensure that the building will be able to support the additional live and dead structural load and to determine the maximum depth of the green roof system and any needed structural reinforcement.

In most cases, fully-saturated extensive green roofs have loads of about 15 to 30 pounds per square foot, which is fairly similar to traditional new rooftops (12 to 15 pounds per square foot) that have a waterproofing layer anchored with stone ballast. For a discussion of green roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397, Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems.

Functional Elements of a Green Roof System. A green roof is composed of up to eight different systems or layers, from bottom to top, that are combined together to protect the roof and maintain a vigorous cover (see Figure 4.5-2). Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary green roofing systems; whereas, in other cases, the designer or architect must assemble the system. In this case, the designer or architect is advised to consult Luckett (2009), Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004).

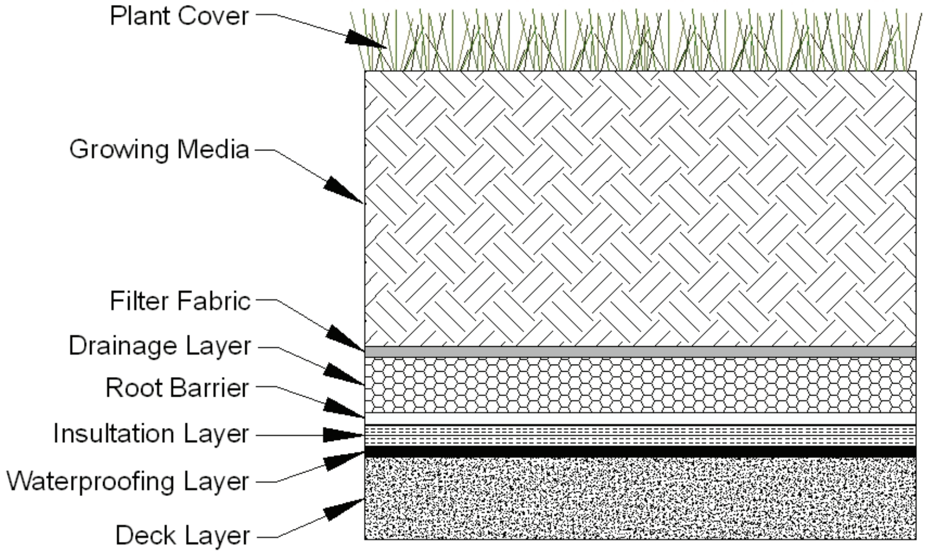

Figure 4.5-2 Green Roof Cross Section

The design layers include:

1. ***Deck Layer:*** The roof deck layer is the foundation of a green roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load bearing capacity, longevity, and potential need for insulation in the green roof system.
2. ***Leak Detection System (optional):*** Leak detection systems are often installed above the deck layer to identify leaks, minimize leak damage through timely detection, and determine leak locations.
3. ***Waterproofing Layer:*** All green roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including hot applied rubberized asphalt, built up bitumen, modified bitumen, thermoplastic membranes, polyvinyl chloride (PVC), thermoplastic olefin membrane (TPO), and elastomeric membranes (EPDM) (see Weiler and Scholz-Barth, 2009 and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the green roof system. The waterproofing material may be loose laid or bonded (recommended). If loose laid, overlapping and additional construction techniques should be used to avoid water migration.
4. ***Insulation Layer:*** Many green rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems. The designer should consider the use of open or closed cell insulation depending on whether the insulation layer is above or below the waterproofing layer (and thus exposed to wetness), with closed cell insulation recommended for use above the waterproofing layer.

5. ***Root Barrier:*** Another layer of a green roof system, which can be either above or below the insulation layer depending on the system, is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers, which have been impregnated with pesticides, metals, or other chemicals that could leach into stormwater runoff, should be avoided in systems where the root barrier layer will come in contact with water or allow water to pass through the barrier.
6. ***Drainage Layer and Drainage System:*** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection and thickness of the drainage layer type is an important design decision that is governed by the desired stormwater storage capacity, the required conveyance capacity, and the structural capacity of the rooftop. The depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive green roof system and increases for intensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., 1-2 inch layer of clean, washed granular material (ASTM D 448 size No. 8 stone or lightweight granular mix), high density polyethylene, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors, and roof leaders. American Society for Testing and Materials (ASTM) E2396 and E2398 can be used to evaluate alternative material specifications.
7. ***Root-Permeable Filter Fabric:*** A semi-permeable needled polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it. The filter fabric must not impede the downward migration of water into the drainage layer.
8. ***Growing Media:*** The next layer in an extensive green roof is the growing media, which is typically 3 to 6 inches deep (minimum 3 inches). The recommended growing media for extensive green roofs is typically composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria, or other similar materials. The remaining media should contain no more than 20% organic matter, normally well-aged compost (see *Appendix C*). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media typically has a maximum water retention of approximately 30%. It is advisable to mix the media in a batch facility prior to delivery to the roof. As there are many different types of proprietary growing medias and roof systems, the values provided here are recommendations only. Manufacturer's specifications should be followed for all proprietary roof systems. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006). The composition of growing media for intensive green roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the green roof planting plan, the growing media must be sufficient to provide enough soil volume for the root structure of mature trees.

9. ***Plant Cover:*** The top layer of an extensive green roof typically consists of plants that are non-native, slow-growing, shallow-rooted, perennial, and succulent. These plants are chosen for their ability to withstand harsh conditions at the roof surface. Guidance on selecting the appropriate green roof plants can often be provided by green roof manufacturers, and can also be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually Sedum species) and accent plants can be used to enhance the visual amenity value of a green roof. See Greenroof Landscaping Criteria for additional plant information. The design should provide for temporary, manual, and/or permanent irrigation or watering systems, depending on the green roof system and types of plants. For most applications, some type of watering system should be accessible for initial establishment or drought periods.

Material Specifications: Standard specifications for North American green roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The ASTM has recently issued several overarching green roof standards, which are described and referenced in Table 4.5-1.

Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" green roof systems or modules.

Table 4.5-1. Extensive green roof material specifications.	
Material	**Specification**
Roof	Structural capacity should conform to ASTM E-2397-05, Practice for Determination of Live Loads and Dead Loads Associated with Green (Green) Roof Systems. In addition, use standard test methods ASTM E2398-05 for Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems, and ASTME 2399-05 for Maximum Media Density for Dead Load Analysis.
Leak Detection System	Optional system to detect and locate leaks in the waterproof membrane.
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	Depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, high density polyethylene, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors, and roof leaders. Designers should consult the material specifications as outlined in ASTM E2396 and E2398. Roof drains and emergency overflow should be designed in accordance with District Construction Code (DCMR, Title 12).
Filter Fabric	Generally, needle-punched, non-woven, polypropylene geotextile, with the following qualities: ♦ Strong enough and adequate puncture resistance to withstand stresses of installing other layers of the green roof. Density as per ASTM D3776 ≥ 8 oz./sq yd. Puncture Resistance as per ASTM D4833 ≥ 130 lb. These values can be reduced with submission of a Product Data Sheet and other documentation that demonstrates applicability for the intended use. ♦ Adequate tensile strength and tear resistance for long term performance. ♦ Allows a good flow of water to the drainage layer. Apparent Opening Size as per ASTM D4751 ≥ 0.06 ≤ 0.2, with other values based on Product Data Sheet and other documentation as noted above. ♦ Allows at least fine roots to penetrate. ♦ Adequate resistance to soil borne chemicals or microbial growth both during construction and after completion since the fabric will be in contact with moisture and possibly fertilizer compounds.
Growth Media	80% lightweight inorganic materials and 20% organic matter (e.g. well-aged compost). Media typically has a maximum water retention of approximately 30%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396-05. Proprietary systems may vary from these specifications.
Plant Materials	Sedum, herbaceous plants, and perennial grasses that are shallow-rooted, low maintenance, and tolerant of direct sunlight, drought, and wind. See ASTM E2400-06, Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems.

Green Roof Sizing: Green roof areas can be designed to capture the entire Water Quality Volume. In some cases, they could be designed to capture larger design storm volumes as well. The required size of a green roof will depend on several factors, including the maximum water retention of the growing media and the underlying drainage and storage layer materials (i.e. prefabricated water cups or plastic modules). As maximum water retention can vary significantly between green roof products, verification of this value should be provided. ASTM tests E2396, E2397, E2398, or E2399, as appropriate, and performed by an ASTM-certified lab are considered acceptable verification. Site designers and planners should consult with green roof manufacturers and material suppliers as they can often provide specific sizing information and hydrology design tools for their products. Equation 4.5-1 below can be used to determine the storage volume retained by a green roof:

Equation 4.5-1. Storage Volume for Green Roofs

$$Sv = \frac{SA \times [(d_m \times \eta_1) + (d_{dl} \times \eta_2)]}{12}$$

where:

Sv	=	storage volume (ft³)
SA	=	green roof area (ft²)
d_m	=	media depth (in) (minimum 3”)
η_1	=	verified media porosity maximum water retention
d_{dl}	=	drainage layer depth (in)
η_2	=	verified drainage layer porosity maximum water retention

Note: If verified maximum water retention values are not available, a value of 0.25 may be used.

In the LID Compliance Calculator spreadsheet, the *Sv* for green roofs is given a 100% runoff reduction credit, and, for projects in the Coastal Zone, a 100% credit toward the storage requirement.

Green roofs can have dramatic rate attenuation effects on larger storm events and may be used, in part, to manage a portion of the 2-year and 10-year events. Designers can model various approaches by factoring in storage within the drainage layer. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Green Roof Landscaping Criteria

Since plant selection, landscaping, and maintenance are critical to the performance and function of green roofs, a planting plan should be provided for green roofs. The planting plan should be prepared for a green roof by a landscape architect, horticulturalist, or other professional experienced with green roofs.

Plant selection for green rooftops is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most green roof installations is a hardy, low-growing succulent, such as *Sedum, Delosperma, Talinum, Semperivum*, or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006).

A list of some common green roof plant species that work well in Coastal South Carolina can be found in Table 4.5-2. In addition, consult local nurseries to expand the list of appropriate plant material.

Table 4.5-2. Ground covers appropriate for green roofs in Coastal South Carolina

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.
Sedum oreganum	Part Shade	Moist	Yellow flowers; native to U.S.
Sedum stoloniferum	Sun	Moist	Pink flowers; drought tolerant
Sedum telephiodes	Sun	Dry	Blue green foliage; native to region
Sedum ternatum	Part Shade	Dry-Moist	White flowers; grows in shade
Talinum calycinum	Sun	Dry	Pink flowers; self sows

Note: Designers should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for a definitive list of green roof plants, including accent plants.

- ✧ Plant choices can be much more diverse for deeper intensive green roof systems. Herbs, forbs, grasses, shrubs, and even trees can be used, but designers should understand they have higher watering, weeding, and landscape maintenance requirements.
- ✧ The species and layout of the planting plan should reflect the location of the building, in terms of its height, exposure to wind, heat stress, orientation to the sun, and impacts from surrounding buildings. (Wind scour and solar burning have been observed on green roof installations that failed to adequately account for neighboring building heights and surrounding window reflectivity.) In addition, plants should be selected that are fire resistant and able to withstand heat, cold, and high winds.
- ✧ Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on green roof plant selection, consult Snodgrass and Snodgrass (2006).

- It is also important to note that, although invasive species should be avoided, most green roof plant species will not be native to Coastal South Carolina (which contrasts with native plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- When appropriate species are selected, most green roofs will not require supplemental irrigation, except for temporary irrigation during drought or initial establishment. The planting window extends from the spring to early fall, although it is important to allow plants to root thoroughly before the first killing frost. Green roof manufacturers and plant suppliers may provide guidance on planting windows as well as winter care. Proper planting and care may also be required for plant warranty eligibility.
- Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary green roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for green roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining and requires minimal mowing, trimming, and weeding.

The green roof design should include non-vegetated walkways (e.g., paver blocks,) to allow for easy access to the roof for weeding and making spot repairs.

Green Roof Construction Sequence

Green Roof Installation. Given the diversity of extensive vegetated roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer's specifications.
- Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system. Alternately, electric field vector mapping (EFVM) can be done to test for the presence of leaks; however, not all impermeable membranes are testable with this method. Problems have been noted with the use of EFVM on black EPDM membranes and with aluminized protective coatings commonly used in conjunction with modified bituminous membranes.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric) taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. If a delay between the installation of the growing media and the plants is required, adequate efforts must be taken to secure the growing media from erosion and the seeding of weeds. The growing media must be covered and anchored in place until planting. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic.

Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.

- ✧ The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- ✧ It generally takes two to three growing seasons to fully establish the vegetated roof. The growing medium should contain enough organic matter to support plants for the first growing season, so initial fertilization is not required. Extensive green roofs may require supplemental irrigation during the first few months of establishment. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds).
- ✧ Most construction contracts should contain a Care and Replacement Warranty that at least 50% coverage after one year and 80% coverage after two years for plugs and cuttings, and 90% coverage after one year for sedum carpet/tile.

Construction Supervision. Supervision during construction is recommended to ensure that the vegetated roof is built in accordance with these and the manufacturer's specifications. Inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision is needed during several steps of vegetated roof installation, as follows:

- ✧ During placement of the waterproofing layer, to ensure that it is properly installed and watertight.
- ✧ During placement of the drainage layer and drainage system.
- ✧ During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth (certification for vendor or source should be provided).
- ✧ Upon installation of plants, to ensure they conform to the planting plan (certification from vendor or source should be provided).
- ✧ Before issuing use and occupancy approvals.
- ✧ At the end of the first or second growing season to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

Green Roof Maintenance Criteria

A green roof should be inspected twice a year during the growing season to assess vegetative cover and to look for leaks, drainage problems, and any rooftop structural concerns (see Table 4.5-3). In addition, the green roof should be hand-weeded to remove invasive or volunteer plants, and plants and/or media should be added to repair bare areas (refer to ASTM E2400).

If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electric Field Vector Mapping), if applicable, to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Check with the membrane manufacturer for approval and warranty information. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the green roof plant communities.

Fertilization is generally not recommended due to the potential for leaching of nutrients from the green roof. Supplemental fertilization may be required following the first growing season, but only if plants show signs of nutrient deficiencies and a media test indicates a specific deficiency. If fertilizer is to be applied, it must be a slow-release type, rather than liquid or gaseous form.

Table 4.5-3. Typical maintenance activities associated with green roofs.

Activity	Schedule
♦ Water to promote plant growth and survival. ♦ Inspect the green roof and replace any dead or dying vegetation.	As needed (following construction)
♦ Inspect the waterproof membrane for leaking or cracks. ♦ Weeding to remove invasive plants (no digging or using pointed tools where there is potential to harm the root barrier or waterproof membrane). ♦ Inspect roof drains, scuppers, and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. ♦ Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.	Semi-annually

An example maintenance checklist for green roofs is included in *Appendix F*.

Green Roof References and Additional Resources

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4.6 Rainwater Harvesting

Introduction

Rainwater harvesting systems store rainfall for future use. Rainwater that falls on rooftops is collected and conveyed into an above- or below-ground storage tank (also referred to as a cistern), where it can be used for non-potable water uses and on-site stormwater disposal/infiltration. Non-potable uses may include landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), flushing of toilets and urinals, fire suppression (sprinkler systems), supply for cooling towers, evaporative coolers, fluid coolers and chillers, supplement water for closed loop systems, steam boilers, replenishment of water features and water fountains, distribution to a green wall or living wall system, laundry, and even delayed discharge to the combined sewer system.

In many instances, rainwater harvesting can be combined with a secondary (down-gradient) stormwater practice to enhance stormwater retention and/or provide treatment of overflow from the rainwater harvesting system. Some candidate secondary practices include:

- Disconnection to a pervious or conservation area (see “Disconnection”)
- Overflow to bioretention practices (see “Bioretention”)
- Overflow to infiltration practices (see “Infiltration”)
- Overflow to grass channels or dry swales (see “Open Channels”)

By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g. increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge, supply of water post storm/hurricane in case of failed municipal infrastructure etc.).

A Rainwater Harvesting Spreadsheet (RHS) is provided as a companion to this specification and is discussed in more detail in the Rainwater Harvesting Design Criteria section below. The spreadsheet is available for download at http://www.northinlet.sc.edu/LID/.

KEY CONSIDERATIONS: RAINWATER HARVESTING

DESIGN CRITERIA:

- Rainwater harvesting systems should be sized based on the contributing area, local rainfall patterns and projected demand for the harvested rainwater.
- Pretreatment should be provided upstream of all storage tanks to prevent leaves and other debris from clogging the system.

BENEFITS:

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads.
- Can be used on nearly any development site.
- Reduces demand on public water supplies, which helps to protect groundwater aquifers from drawdown and salt water intrusion.

LIMITATIONS:

- Stored rainwater should be used on a regular basis to maintain system storage capacity.

SITE APPLICABILITY:

- Rural Use
- Suburban Use
- Urban Use

- Construction Cost: Medium
- Maintenance: Medium
- Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach (applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- Varies[1]

Coastal Zone Credit Approach

- Equal to runoff reduction credit.

Statewide Water Quality Requirement Credit Approach

- Runoff Reduction credit applies to infiltration requirement.

Pollutant Removal[1]

Varies[1] - Total Suspended Solids
Varies[1] - Total Phosphorus
Varies[1] - Total Nitrogen
Varies[1] - Metals
N/A - Pathogens

[1] = varies according to storage capacity of the rainwater harvesting system and demand for the harvested water.

Figure 4.6-1. Example Cistern Application (Photo: Marty Morganello)

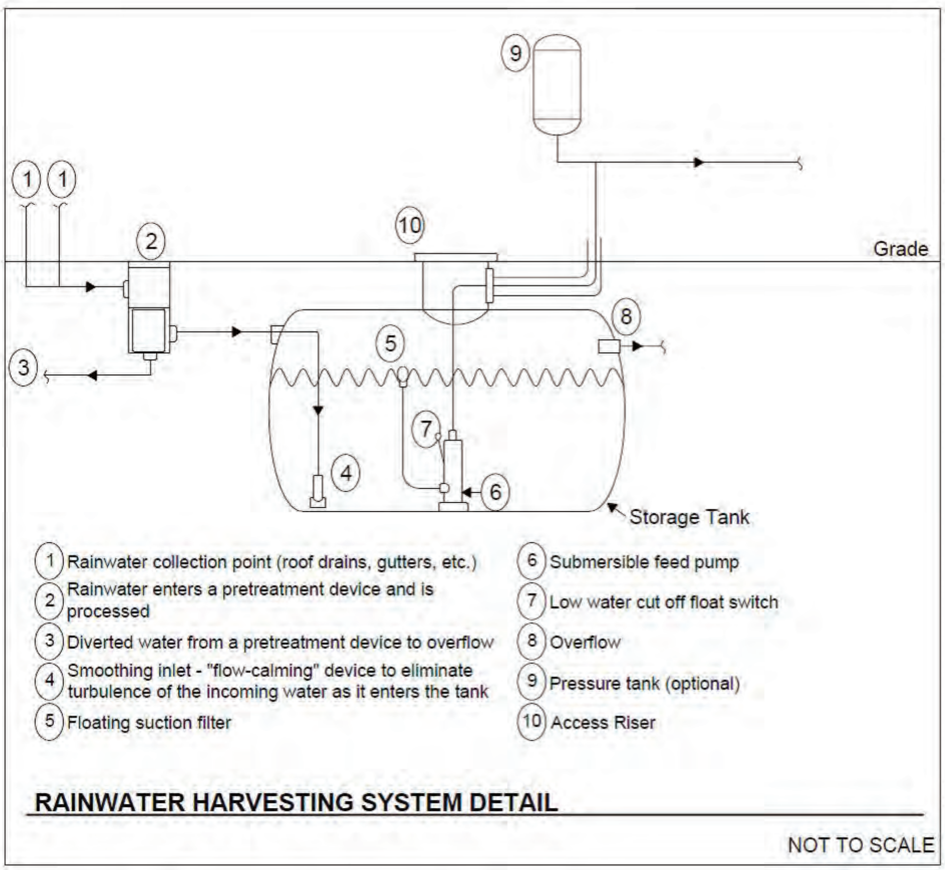

Figure 4.6-2. Underground Rainwater Harvesting System Detail Example

Rainwater Harvesting Case Study: Charleston County Consolidated 911 Dispatch Center

Located in Ladson, the Charleston County Consolidated 9-1-1 Center and Emergency Operations Center was completed in 2013. Typically, the building is staffed by an average of 30 people 24 hours a day, 7 days a week; however, during an activation of the emergency response center, that number could swell to 200 people. Aside from being designed to handle extreme weather events, this building was planned with the goal of being Leadership in Energy and Environmental Design (LEED) certified.

To receive LEED credits for reduced water usage, the designers employed several low impact development best management practices across the site, including grassed parking spaces, xeric landscaping, vegetated stormwater ponds, and a rooftop rainwater harvesting system. Runoff from the 18,500 square foot roof is collected and channeled into pairs of inlets spaced around the periphery of the roof. One set of inlets conveys the stormwater into a 5,000 gallon cistern buried behind the building, and the other inlets act as an overflow bypass. A collar placed around the overflow inlet allows several inches of water to pond on the roof before it is diverted via the overflow into the storm drain system and into one of the three dry detention ponds on the property.

The harvested stormwater then passes through a vortex filter located in a mechanical room in the building's bottom floor, which acts as a pretreatment device to remove coarse sediment from the collected rainwater. This particular system is typically designed for outdoor applications, and was modified with an extended top to protect the interior of the building from splashing from the concentrator. This system separates "dirty" (i.e., sediment-laden) and "clean" stormwater, and dirty stormwater is conveyed to stormwater ponds on the property. The clean (i.e., filtered), stormwater is combined with air conditioning condensate and water flushed from 600-gallon potable water tanks, and then piped to the control panel system, where it undergoes final filtration and UV sterilization. This filtered and sterilized water is then conveyed in purple PVC piping (marked as non-potable water) to supply water for flushing 14 low-flow toilets (1.28 gallon per flush) in the building.

From left to right: rooftop stormwater collection, screening system, and control system.

Rainwater Harvesting Feasibility Criteria

A number of site-specific features influence how rainwater harvesting systems are designed and/or utilized. These should not be considered comprehensive and conclusive considerations but rather recommendations that should be considered during the process of planning to incorporate rainwater harvesting systems into the site design. The following are key considerations for rainwater harvesting feasibility:

Plumbing Code. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should refer to the 2012 Uniform Plumbing Code - Chapter 17 Nonpotable Rainwater Catchment Systems, or local plumbing codes, as applicable. For sizing of conveyance systems refer to Uniform Plumbing Code (UPC) 2012 Edition, Chapter 11: "Storm Drainage" section 1101.11 Roof Drainage - Table D 1.1 Appendix D

Mechanical, Electrical, Plumbing (MEP). For systems that call for indoor use of harvested rainwater, the seal of an MEP engineer is typically required.

Available Space. Adequate space is needed to house the storage tank and any overflow. Space limitations are rarely a concern with rainwater harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Storage tanks can be placed underground, indoors, on rooftops that are structurally designed to support the added weight, and adjacent to buildings. Designers can work with architects and landscape architects to site the tanks creatively. Underground utilities or other obstructions should always be identified prior to final determination of the tank location.

Site Topography. Site topography and storage tank location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system.

The final invert of the outlet pipe from the storage tank must match the invert of the receiving mechanism (e.g. natural channel, storm drain system, etc.) that receives this overflow. The elevation drops associated with the various components of a rainwater harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the rainwater harvesting system is feasible for the particular site.

Also, site topography and storage tank location will affect pumping requirements. Locating storage tanks in low areas will make it easier to get water into the cisterns; however, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter pipes with smaller slopes but will generally reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the building or drainage area to limit the amount of pipe needed.

Available Hydraulic Head. The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern may be sited up-gradient of the landscaping areas or on a raised stand (Raised stands for larger cisterns should be designed by a licensed structural engineer). Pumps are commonly used to convey stored rainwater to the end use in order to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building, which then serves the internal water demands. Also, cisterns can use gravity to accomplish indoor residential uses (e.g. laundry) that do not require high water pressure.

Water Table. Underground storage tanks are most appropriate in areas where the tank can be buried above the water table. The tank should be located in a manner that does not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from "floating"), and conducting buoyancy calculations when the tank is empty. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy (One form of hold down ballast is an automatic fill valve using municipal or well water supply to maintain a minimum depth of water in the underground tank to prevent it from floating). The combined weight of the tank and hold-down ballast must meet or exceed the buoyancy force of the tank. The tank must also be installed according to the tank manufacturer's specifications.

Soils. Storage tanks should be placed on a gravel or sand pad, and a concrete pad is recommended for cisterns over 2,000 gallons. The bearing capacity of the soil upon which the cistern will be placed must be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or have the potential to topple in some cases. Where the installation requires a concrete foundation, the foundation must be designed consistent with the bearing capacity of the soil to support the tank's weight when the cistern is full. Additionally, the pH of the soil should be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems, treating all of the rainwater harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground tanks and piping associated with the system.

Contributing Drainage Area (CDA). The contributing drainage area (CDA) to the cistern is the impervious area draining to the tank. Typically, rooftop surfaces are the only allowable surface in the CDA. If paved areas or other surfaces will be part of the CDA, additional treatment of the collected rainwater will likely be required (such as oil/water separators and debris excluders). Areas of any size, including portions of roofs, can be used based on the sizing guidelines in this design specification. Runoff should be routed directly from the drainage area to rainwater harvesting systems in closed roof drain systems or storm drain pipes. Surface drainage should be avoided to prevent increased contamination of the water.

Contributing Drainage Area Material. The quality of the harvested rainwater will vary according to the roof material or drainage area over which it flows. Harvesting water from certain types of rooftops and CDAs, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal, or any material that may contain asbestos may leach trace metals and other toxic compounds and should be avoided. Wood/Cedar shake roofs should also be avoided as they may retain moisture between rainfall events, allowing for biological growth. If a sealant or paint roof surface is desired, it is recommended to use one that has been certified for such purposes by the National Sanitation Foundation (ANSI/NSF standard). This list can be found at the NSF Website under Protocol P151, "Health Effects from Rainwater Catchment System Components.

Water Quality of Rainwater. Designers should note that the pH of rainfall in Coastal South Carolina tends to be acidic, around 5.0, according to the National Atmospheric Deposition Program (NAPD, 2011), which may result in leaching of metals from roof surfaces, tank lining or water laterals, to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Limestone or other materials may be added in the tank to buffer acidity, if desired or based on pH monitoring within the cistern.

Pollutant Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation, such as hydrocarbons, metals or pesticides. In areas where higher pollution loading is likely, rainwater harvesting should be avoided.

Setbacks from Buildings. Storage tank overflow devices should direct overflow away from buildings to avoid causing ponding or soil saturation within 10 feet of building foundations. Tanks must be designed to be watertight to prevent water damage when placed near building foundations.

Vehicle Loading. Whenever possible, underground rainwater harvesting systems should be placed in areas without vehicle traffic or other heavy loading; construction costs increase significantly if underground harvesting systems are designed to be subjected to these additional loads.

Feasibility in Coastal South Carolina. Rainwater harvesting systems are very well suited to the warm environment of Coastal South Carolina, and may help to relieve some of the pressure on drinking water aquifers if applied on a wide scale. As previously mentioned, the high water table in much of Coastal South Carolina may mean that above ground installations will often be more appropriate.

Economic Considerations. Rainwater harvesting systems can provide cost savings by replacing or augmenting municipal water supply needs.

Rainwater Harvesting Conveyance Criteria

Collection and Conveyance. The collection and conveyance system consists of the gutters, downspouts, and pipes that channel rainfall into storage tanks. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. If the system will be used for management of the 10-year storms, the gutters should be designed to convey the appropriate 10-year storm intensities.

Pipes connecting downspouts to the cistern tank should be at a minimum slope of 1.5% and sized to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

Overflow. An overflow mechanism should be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. The overflow drain must not be equipped with a shutoff valve. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height, according to local regulations. The overflow pipe should be screened to prevent access to the tank by rodents and birds. All overflow from the system should be directed to an acceptable flow path that will not cause erosion during a 2-year storm event.

Rainwater Harvesting Pretreatment Criteria

Pre-filtration is required to keep sediment, leaves, contaminants, and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices should be low-maintenance. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources.

Diverted flows (i.e. first flush diversion and overflow from the filter) must be directed to an acceptable flow path that will not cause erosion during a 2-year storm or to an appropriate BMP on the property.

Various pretreatment devices are described below.

- **First Flush Diverters:** First flush diverters direct the initial pulse of rainfall away from the storage tank (see Figure 4.6-3). While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces.
- **Leaf Screens:** Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built-up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005).
- **Roof Washers:** Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater (see Figure 4.6-4). Roof washers consist of

Figure 4.6-3. First Flush Diverter (Photo: Marty Morganello)

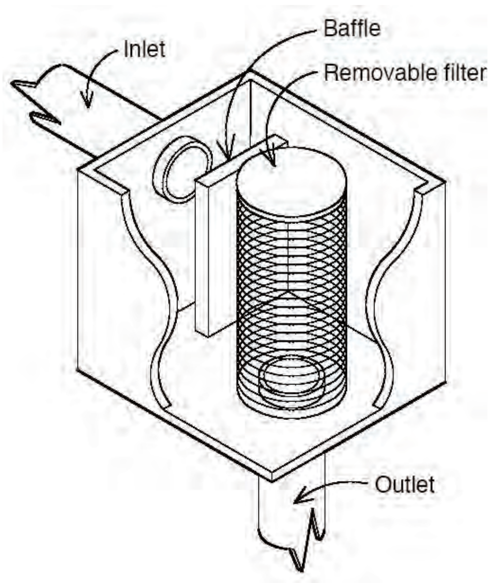

Figure 4.6-4. Roof Washer (TWRB, 2005).

a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

- **Vortex Filters:** For large scale applications, vortex filters can provide filtering of rainwater from larger CDAs. Vortex filters do not collect debris, but rather allow it to wash through the filter in order to minimize maintenance. The debris is washed out of the filter with a portion of the rainwater, thereby reducing slightly the amount of rainwater collected to the storage tank.

Rainwater Harvesting Design Criteria

System Components: Seven primary components of a rainwater harvesting system include:

- Contributing Drainage Area (CDA)
- Collection and conveyance system (e.g. gutter and downspouts)
- Pre-screening and first flush diverter (Pretreatment)
- Storage tank
- Water quality treatment
- Distribution system
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

CDA Surface: When considering CDA surfaces, note smooth, non-porous materials will drain more efficiently. Slow drainage of the CDA leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater will be directed towards uses with significant human exposure (e.g. pool filling, public sprinkler fountain, etc.), care should be taken in the choice of CDA materials, and treatment to potable standards may be required. Some materials may leach toxic chemicals making the water unsafe for humans.

Collection and Conveyance System: See *Rainwater Harvesting Feasibility Criteria*.

Pretreatment: See *Rainwater Harvesting Pretreatment Criteria*.

Storage Tank: The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities typically range from 250 to over 30,000 gallons, but can be as large as 100,000 gallons or more for larger projects. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and to tailor the volume storage needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Storage tank volumes are calculated to meet the water demand and stormwater storage volume objectives, as described in more detail below.

While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site.

Above ground storage tanks should be of an opaque material, approved for above-ground use in direct sunlight or be shielded from direct sunlight. Tanks should be installed in an accessible location to allow for inspection and cleaning. The access opening must be installed in such a way as to prevent surface- or groundwater from entering through any fittings, and must be secured/locked to prevent unwanted entry.

Underground storage tanks must be structurally designed to withstand anticipated earth or other loads. Underground tanks should be provided with manholes with openings located at least 4 inches above the surrounding grade. The access opening must be installed in such a way as to prevent surface- or groundwater from entering through any fittings, and must be secured/locked to prevent unwanted entry.

Additional factors that should be considered when designing a rainwater harvesting system and selecting a storage tank:

- All rainwater harvesting systems should be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. Table 4.6-1 compares the advantages and disadvantages of different storage tank materials.
- Dead storage below the outlet to the distribution system and an air gap at the top of the tank should be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any connection to a municipal backup water supply should have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies.

Distribution Systems: Some rainwater harvesting systems require a pump to convey the water to its final distribution point. Whether it is a submersible pump or an external pump with or without a pressurized storage tank, it should be sized appropriately to the application. Some pump designs may require a back up water supply to ensure proper operation of the pump during low water level periods.

Water Quality Treatment: Depending upon the collection surface, method of dispersal and proposed use for the harvested rainwater, a water quality treatment device may be necessary.

Overflow: See Rainwater Harvesting Conveyance Criteria section.

Table 4.6-1. Advantages and disadvantages of various cistern materials

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must a dark, opaque color for above-ground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 100 gallons); limited application
Galvanized Steel	Commercially available, alterable, and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable, and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build
Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009		

Rainwater Harvesting Material Specifications: The basic material specifications for rainwater harvesting systems are presented in Table 4.6-2. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table 4.6-2. Design specifications for rainwater harvesting systems

Item	Specification
Gutters and Downspout	♦ Materials commonly used for gutters and downspouts include polyvinyl-chloride (PVC) pipe, vinyl, aluminum and galvanized steel. Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. ♦ The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tanks. ♦ Be sure to include needed bends and tees.
Pre-Treatment	At least one of the following (all rainwater to pass through pretreatment): ♦ First flush diverter ♦ Vortex filter ♦ Roof washer ♦ Leaf and mosquito screen (1 mm mesh size)
Storage Tanks	♦ Materials used to construct storage tanks should be structurally sound. ♦ Tanks should be constructed in areas of the site where native soils can support the load associated with stored water. ♦ Storage tanks should be water tight and sealed using a water-safe, non-toxic substance. ♦ Tanks should be opaque to prevent the growth of algae. ♦ Reused tanks should be fit for potable water or food-grade products. ♦ The size of the rainwater harvesting system(s) is determined through design calculations.
Note: This table does not address indoor systems or pumps.	

Design Objectives and System Configuration: Many rainwater harvesting system variations can be designed to meet user demand and stormwater objectives. This specification focuses on providing a design framework for achieving the water quality volume objectives for compliance with state regulations. From a rainwater harvesting standpoint, there are numerous potential configurations that could be implemented. However, in terms of addressing the design storm, this specification adheres to the following concepts in order to meet the stormwater retention goals properly:

- ✧ System design is encouraged to use rainwater as a resource to meet on-site demand or in conjunction with other stormwater retention practices.
- ✧ Peak flow reduction is realized through reduced volume and temporary storage of runoff.

Therefore, the rainwater harvesting system design configurations presented in this specification are targeted for use of rainwater through either internal use or seasonal irrigation. While internal use results in a steady year-round demand for the harvested rain water, seasonal irrigation will vary with the time of year, and the retention value is reduced accordingly.

Design Objectives and Tank Design Set-Ups: Pre-fabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. There are three basic tank design configurations used to meet the various rainwater harvesting system configurations that are described below.

Tank Design 1. The first tank set-up (Figure 4.6-5) maximizes the available storage volume associated with the water quality volume to meet the desired level of stormwater retention. This layout also maximizes the storage that can be used to meet a demand. An emergency overflow exists near the top of the tank as the only gravity release outlet device (not including the pump, manway or inlets). It should be noted that it is possible to address 10-year storm volumes with this tank configuration, but the primary purpose is to address the smaller water quality design storm.

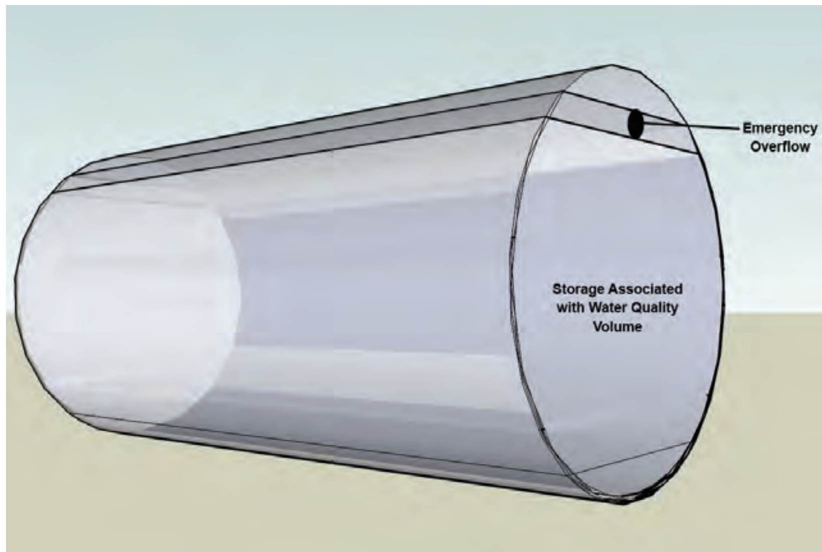

Figure 4.6-5. Tank Design 1: Storage Associated with the Design Storm Volume Only (Source: Alex Foraste)

Tank Design 2. The second tank set-up (Figure 4.6-6) uses tank storage to meet the storage objectives as well as using an additional detention volume to meet some or all of the 10-year storm volume requirements. An orifice outlet is provided at the top of the design storage for the water quality volume level, and an emergency overflow is located at the top of the detention volume level.

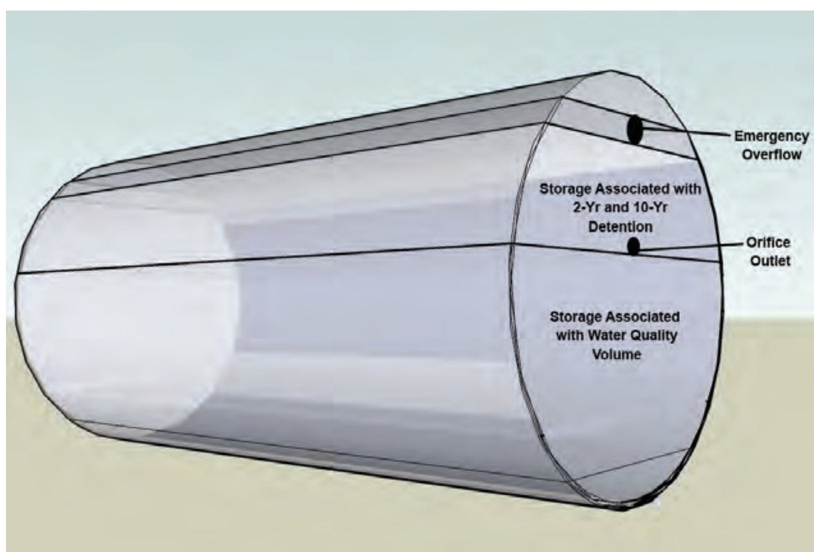

Figure 4.6-6. Tank Design 2: Storage Associated with SWTV, 2-year and 10-year Storms. (Source: Alex Foraste)

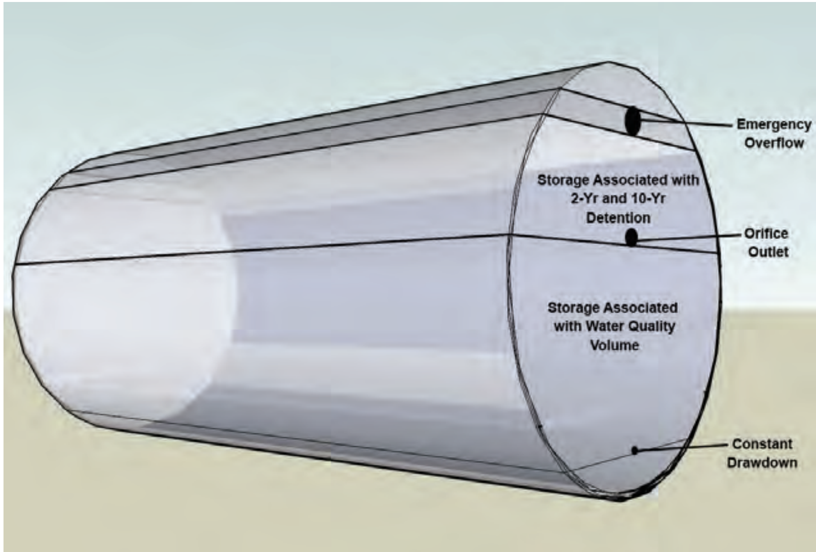

Figure 4.6-7. Tank Design 3: Constant drawdown, Storage Associated with WQTV, 2-year and 10-year Storms. (Source: Alex Foraste)

Tank Design 3. The third tank set-up (Figure 4.6-7) creates a constant drawdown within the system. The small orifice at the bottom of the tank needs to be routed to an appropriately designed secondary practice (e.g., rain garden, urban bioretention, etc.) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release should not be discharged to a receiving channel or storm drain without treatment, and maximum specified drawdown rates from this constant drawdown should be adhered to, since the primary function of the system is not intended to be detention.

For Tank Design 3 volume calculations, the constant drawdown volume should be considered as a part of the secondary practice (e.g. the tank volume acts as additional ponding volume for a bioretention area), rather than a rainwater harvesting practice that requires use of the Rainwater Harvesting Spreadsheet (RHS).

While a small orifice is shown at the bottom of the tank in Figure 4.6-7, the orifice could be replaced with a pump that would serve the same purpose, conveying a limited amount of water to a secondary practice on a routine basis.

Sizing of Rainwater Harvesting Systems: The rainwater harvesting cistern sizing criteria presented in this section were developed using a spreadsheet model that used best estimates of indoor and outdoor water demand, long-term rainfall data, and CDA capture area data (Forasté and Lawson, 2009). It is primarily intended to provide guidance in sizing cisterns and to quantify the storage volume achieved for input into the compliance calculator spreadsheet for stormwater management compliance purposes. A secondary objective of the spreadsheet is to increase the beneficial uses of the stored stormwater, treating it as a valuable natural resource. More information on the RHS can be found below.

Incremental Design Volumes within Cistern: Rainwater tank sizing is determined by accounting for varying precipitation levels; captured CDA runoff; first flush diversion (through filters) and filter efficiency; low water cut-off volume; dynamic water levels at the beginning of various storms; storage needed for the design storm (permanent storage); storage needed for 2-year or 10-year volume (temporary detention storage); seasonal and year-round demand use and objectives; overflow volume; and freeboard volumes above high water levels during very large storms. See Figure 4.6-8 for a graphical representation of these various incremental design volumes.

This specification does not provide design guidance for sizing larger storms (e.g., 10-yr) but rather provides guidance on sizing for the water quality volume (WQV).

The "Storage Associated with the Design Storm" is the storage within the tank that is modeled and available for reuse. While the water quality volume (WQV) will remain the same for a specific CDA, the "Storage Associated with the Design Storm" may vary depending on demand and storage volume retention objectives. It includes the variable water level at the beginning of a storm and the low water cut-off volume that is necessary to satisfy pumping requirements, if needed.

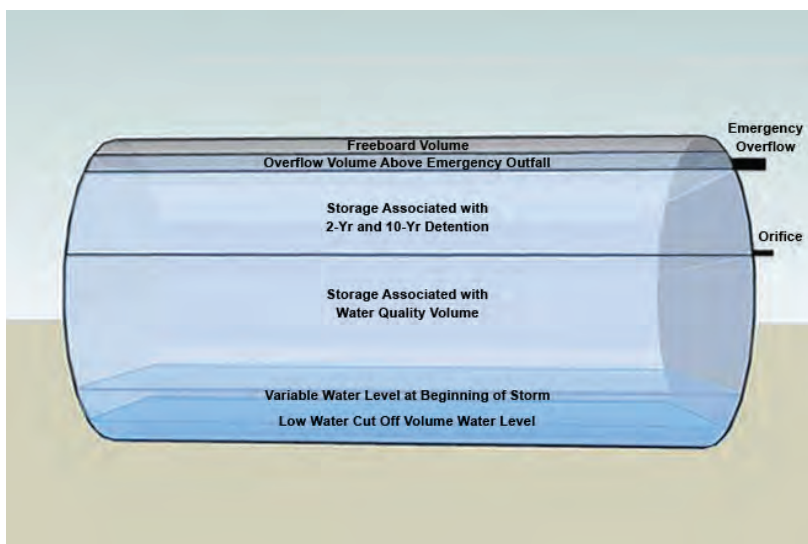

Figure 4.6-8. Incremental Design Volumes Associated with Tank Sizing. (Source: Alex Foraste)

Rainwater Harvesting Spreadsheet

This specification is linked with the Rainwater Harvesting Spreadsheet (RHS). The spreadsheet uses daily rainfall data from December 3, 1982 to December 31, 2012 at Charleston International Airport to model performance parameters of the cistern under varying CDAs, demands on the system and tank size.

The spreadsheet begins with determining the runoff from the CDA. The CDA is assumed to be impervious, so a runoff coefficient of 0.95 is used. The runoff produced by any storm event enters the cistern and is added to the water level that existed in the cistern the previous day, while all of the selected water demands are subtracted on a daily basis. If any overflow is realized, the volume is quantified and recorded. If the tank runs dry (reaches the cut-off volume level), then the volume in the tank is fixed at the low level, and a dry-frequency day is recorded. The full or partial demand met in both cases is quantified and recorded. A summary of the water balance for the system is provided below.

Water Contribution:

- **Precipitation.** The volume of water contributing to the rainwater harvesting system is a function of the rainfall and drainage area captured, as defined by the designer.
- **Municipal Backup (optional).** In some cases, the designer may choose to install a municipal backup water supply to supplement tank levels. Some pump designs may require a back up water supply to ensure proper operation of the pump during low water level periods. Note that municipal backups also may be connected post-tank (i.e. a connection is made to the non-potable water line that is used for pumping water from the tank for reuse), thereby not contributing any additional volume to the tank. Municipal backup designs that supply water directly to the tank are not accounted for in the RHS.

Water Losses:

- **Drainage Area Runoff Coefficient.** The CDA is assumed to convey 95% of the rainfall that lands on its surface (i.e. Rv = 0.95).
- **First Flush Diversion.** The first flush that is directed to filters is diverted from the system in order to prevent clogging it with debris. This value is assumed to be contained within the filter efficiency rate.
- **Filter Efficiency.** It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the runoff will be successfully captured. Typical minimum filter efficiencies are included in the RHS, although they can be altered if appropriate. The RHS applies these filter efficiencies, or interpolated values, to the daily rainfall record to determine the volume of runoff that reaches the tank. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1 inch per hour should be used for the water quality volume. The appropriate rainfall intensity values for the 2-year and 10-year storms shall be used when designing for larger storm events.
- **Drawdown (Storage Volume).** This is the stored water within the cistern that is used for activities such as irrigation, toilet and urinal flushing, cooling towers, constant

drawdown, etc. It is the volume of runoff that is removed from the cistern on a daily basis. This water loss is what creates available cistern space for subsequent storm events, and translates into retention water quality credit volume.

- **Overflow.** This is the volume of water that may be lost during large storm events or successive precipitation events.

Results for Water Quality Volume: The amount of CDA runoff volume that the tank can capture and use or draw down is quantified and recorded. These results are presented on the "Results-Water Quality Volume" tab. This information is used to calculate the storage volume achieved, which is used as an input to the compliance calculator spreadsheet.

- **Maximum Credited Volume.** The maximum credited volume is calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the credited volume achieved versus cistern size. While larger tanks yield higher water quality credit, they are more costly. The curve assists the user to choose the appropriate tank size, based on the design objectives and site needs, as well as to understand the rate of diminishing returns. Above a certain tank size, the credited volume does not increase, because the 1 inch of runoff has been completely captured.
- **Overflow Volume.** The overflow volume resulting from storm events producing 1 inch of runoff is also reported in this tab. A chart of the credited volume and overflow volume versus the cistern size is provided. An example is shown in Figure 4.6-9.

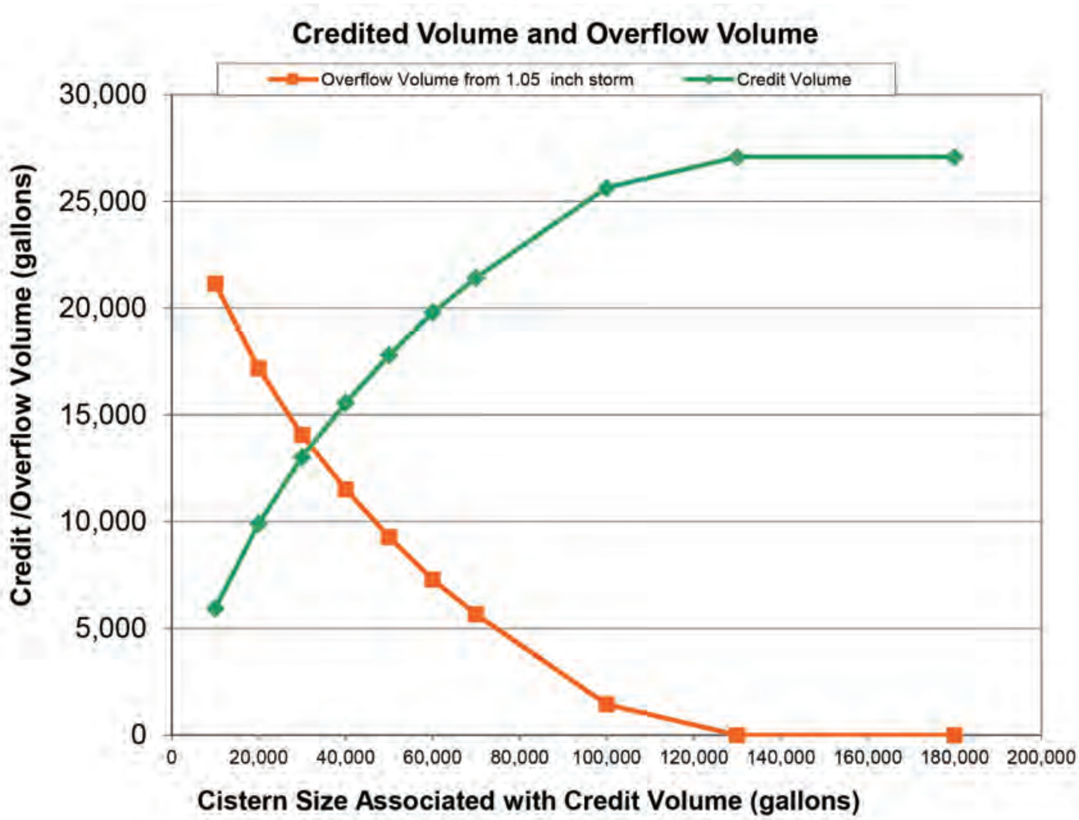

Figure 4.6-9. Credited Volume and Overflow Volume vs. Cistern Size (Example).

These plotted results establish a trade-off relationship between these two performance metrics. In the above example, a 100,000 gallon cistern optimizes the credit volume achieved and the overflow volume (near the inflection point of both curves).

Results – General: The performance results of the rainwater harvesting system for all days during the entire period modeled, including the full spectrum of precipitation events, is included in the "Results-General" tab. This tab is not associated with determining the water quality credit achieved, but rather it may be a useful tool in assisting the user to realize the performance of the various rainwater harvesting system sizes with the design parameters and demands specified.

✧ **Percent Demand Met.** This is where the demand met for various sizes of cisterns and CDA/demand scenarios is reported. A graph displaying the percentage of demand met for various cistern sizes is provided in this tab. This graph is intended to assist the user in understanding the relationship between cistern sizes and optimal/diminishing returns. An example is provided in Figure 4.6-10.

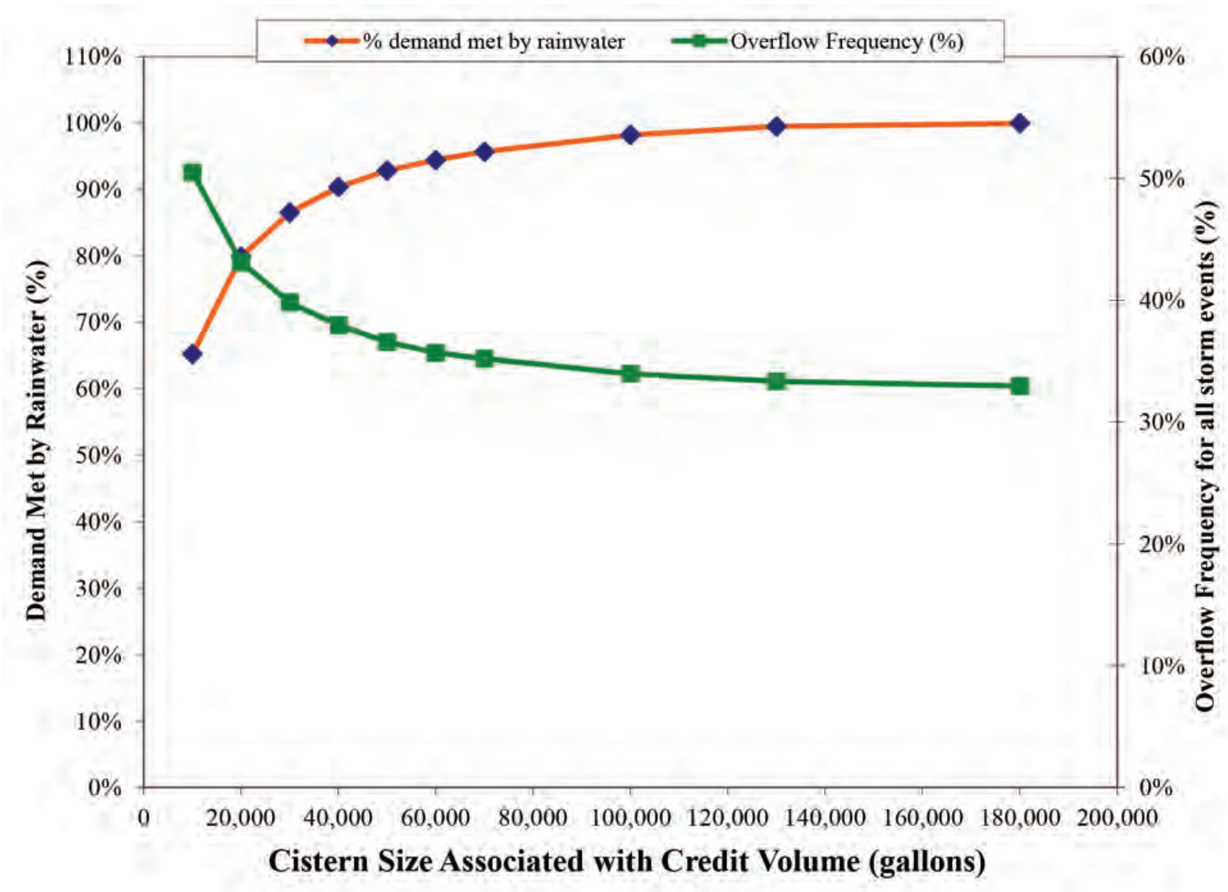

Figure 4.6-10. Demand Met and Overflow Frequency vs. Cistern Size (Example).

At some point, larger cisterns no longer provide significant increases in percentages of demand met. Conversely, the curve informs the user when a small increase in cistern size can yield a significant increase in the percentage of time demand that is met.

- ✧ **Dry Frequency.** Another useful measure is the dry frequency. If the cistern is dry a substantial portion of the time, this measure can inform the user that he/she may want to decrease the size of the cistern, decrease the demand on the system or explore capturing more CDA to provide a larger supply, if feasible. It can also provide useful insight for the designer to determine whether he/she should incorporate a municipal backup supply to ensure sufficient water supply through the system at all times.
- ✧ **Overflow Frequency.** This is a metric of both overflow frequency and average volume per year for the full spectrum of rainfall events. This will inform the user regarding the design parameters and magnitude of demand and associated performance of the system. If the system overflows at a high frequency, then the designer may want to increase the size of the cistern, decrease the CDA captured, or consider other mechanisms that could increase drawdown (e.g. increase the area to be irrigated, incorporate or increase on-site infiltration, etc.).
- ✧ **Inter-relationships and Curves of Diminishing Returns.** Plotting various performance metrics against one another can be very informative and reveal relationships that are not evident otherwise. One such inter-relationship is the percentage of demand met versus cistern size compared to the percentage of overflow frequency versus tank size, depicted on the same graph. A range of cistern sizes tends to emerge, informing the designer where a small increase or decrease in cistern size can have a significant impact on dry frequency and overflow frequency. Conversely, outside this range, changes in cistern sizes would yield small changes to dry frequency and overflow frequency, yet yield a large trade-off compared to the cost of the rainwater harvesting system.

Results from Rainwater Harvesting Spreadsheet to be transferred to Compliance Calculator Spreadsheet. In the LID Compliance Calculator spreadsheet, rainwater harvesting practices receive a runoff reduction credit and a storage credit based upon the average volume available in the cistern.

Two results from this RHS should be transferred to the LID Compliance Calculator spreadsheet, as follows:

1. **Contributing Drainage Area (CDA):** Enter the CDA that was used in the RHS into the Impervious Cover Draining to BMP.
2. **Maximum Credited Volume:** Once the cistern size has been selected, enter the maximum credited volume (cubic feet) from column K in the RHS as the Storage Volume in the LID Compliance Calculator spreadsheet. This credited storage volume, *Sv*, is given 100% credit toward water quality volume requirements.

Completing the Sizing Design of the Cistern:

The total size of the cistern tank is the sum of the following four volume components:

1. **Low Water Cutoff Volume** (Included). A dead storage area must be included so that the pump will not run the tank dry. This volume is included within the Cistern Design Spreadsheet volume modeled.

2. **Cistern Storage Associated with Design Volume** (Included). This is the volume that was designed for using the Cistern Design Spreadsheet.
3. **Adding Channel Protection and Flood Volumes** (Optional). Additional detention volume may be added above and beyond the Cistern Storage associated with the design storm volumes for the 10-year event. Typical routing software programs may be used to design for this additional volume.
4. **Adding Overflow and Freeboard Volumes** (Required). An additional volume above the emergency overflow must be provided in order for the tank to allow very large storms to pass. Above this, overflow water level will be an associated freeboard volume. This volume must account for a minimum of 5% of the overall tank size; however, sufficient freeboard should be verified for large storms. These volumes need to be added to the overall size of the cistern tank.

Rainwater Harvesting Landscaping Criteria

If the harvested water is to be used for irrigation, the design plan elements should include the proposed delineation of planting areas to be irrigated, the planting plan, and quantification of the expected water demand. The default water demand for irrigation is 1.0 inch per week over the area to be irrigated. Justification should be provided if larger volumes are to be used.

Rainwater Harvesting Construction Sequence

Rainwater Harvesting Installation. It is advisable to have a single contractor to install the rainwater harvesting system, outdoor irrigation system, and secondary water quality practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. The American Rainwater Catchment Systems Association (ARCSA) provides professional accreditation for those with expertise in this field. Any back flow prevention devices or connections to municipal water supply must be made by a licensed plumbing contractor.

A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions.

- Choose the tank location on the site.
- Route all downspouts or pipes to pre-screening devices and first flush diverters.
- Properly install the tank.
- Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release).
- Route all pipes to the tank.
- Stormwater should not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized.

Construction Inspection. The following items should be inspected prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed

- ✧ Pretreatment system is installed
- ✧ Mosquito screens are installed on all openings
- ✧ Overflow device is directed as shown on plans
- ✧ Rainwater harvesting system foundation is constructed as shown on plans
- ✧ Catchment area and overflow area are stabilized
- ✧ Secondary stormwater treatment practice(s) is installed as shown on plans

Rainwater Harvesting Maintenance Criteria

Maintenance Inspections

It is highly recommended that periodic inspections and maintenance be conducted for each system.

Rainwater Harvesting System Maintenance Schedule:

Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. Table 4.6-3 describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 4.6-3. Suggested maintenance tasks for rainwater harvesting systems.

Activity	Frequency
Keep gutters and downspouts free of leaves and other debris	O: Twice a year
Inspect and clean pre-screening devices and first flush diverters	O: Four times a year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately	O: Once a year
Inspect condition of overflow pipes, overflow filter path, and/or secondary stormwater treatment practices	O: Once a year
Inspect water quality devices	I: According to Manufacturer
Inspect tank for sediment buildup	I: Every third year
Clear overhanging vegetation and trees over roof surface	O: Every third year
Check integrity of backflow preventer	I: Every third year
Inspect structural integrity of tank, pump, pipe, and electrical system	I: Every third year
Replace damaged or defective system components	I: As needed.
Key: O = Owner I = Qualified third party inspector	

Mosquitoes. In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other insects from entering the tanks. If screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.

An example maintenance checklist for rainwater harvesting is included in *Appendix F*.

Rainwater Harvesting References and Additional Resources

1. Atlanta Regional Commission (ARC). 2001. "Infiltration Trench." Georgia Stormwater Management Manual. Volume 2. Technical Handbook. Section 3.2.5. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/
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5. International Association of Plumbing and Mechanical Officials (IAPMO). 2012. Uniform Plumbing Code. IAPMO: Ontario, CA. Available at http://www.iapmo.org
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8. National Oceanic and Atmospheric Administration (NOAA). 2004. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 2, Version 3.0. Revised 2006. Silver Spring, MD.
9. Texas Regional Water Board (TWDB). 2005. The Texas Manual Rainwater Harvesting. Third Ed. Austin, TX.

4.7 Impervious Surface Disconnection

Introduction

In this practice, runoff from a rooftop or other small impervious surface is directed to a pervious surface or small practice to provide infiltration, filtering, or reuse (Figure 4.7-1 and Figure 4.7-2). Disconnection practices can be used to reduce the volume of runoff created by impervious surfaces. Applicable practices include:

- Simple disconnection to managed turf areas
- Simple disconnection to forest cover or preserved open space
- Simple disconnection to a soil compost amended filter path

Disconnection to alternative practices, such as infiltration (dry wells) or bioretention (rain gardens) are covered in other specifications in this manual. Disconnection practices reduce a portion of the water quality volume. In order to meet requirements for larger storm events, disconnection practices must be combined with additional practices.

Figure 4.7-1. Simple Rooftop Disconnection (Photo: Center for Watershed Protection)

KEY CONSIDERATIONS: IMPERVIOUS SURFACE DISCONNECTION

DESIGN CRITERIA:

- Disconnection area should be at least 15 feet long and 10 feet wide.
- Disconnections should convey stormwater away from buildings to prevent damage to foundations.

BENEFITS:

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads.
- Practices have relatively low construction cost and long-term maintenance burden.

LIMITATIONS:

- Only applicable to very small drainage areas.
- Simple disconnections provides greater stormwater management benefits on A and B soils.
- This practice is difficult to use in series with other practices (treatment train) as the runoff gets dispersed over a wide area.

SITE APPLICABILITY:

♦ Rural use ♦ Suburban use	♦ Construction Cost: Low ♦ Maintenance: Low ♦ Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE

Runoff Reduction Credit Approach (applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 25% - 50% credit for disconnected impervious areas.

Coastal Zone Credit Approach

- 25% - 50% credit for disconnected impervious areas.

Statewide Water Quality Requirement Credit Approach

- Runoff Reduction credit applies to infiltration requirement.

Pollutant Removal[1]

80% - Total Suspended Solids
25% - 50% - Total Phosphorus
25% - 50% - Total Nitrogen
25% - 50% - Metals
N/A - Pathogens

[1] *expected annual pollutant load removal*

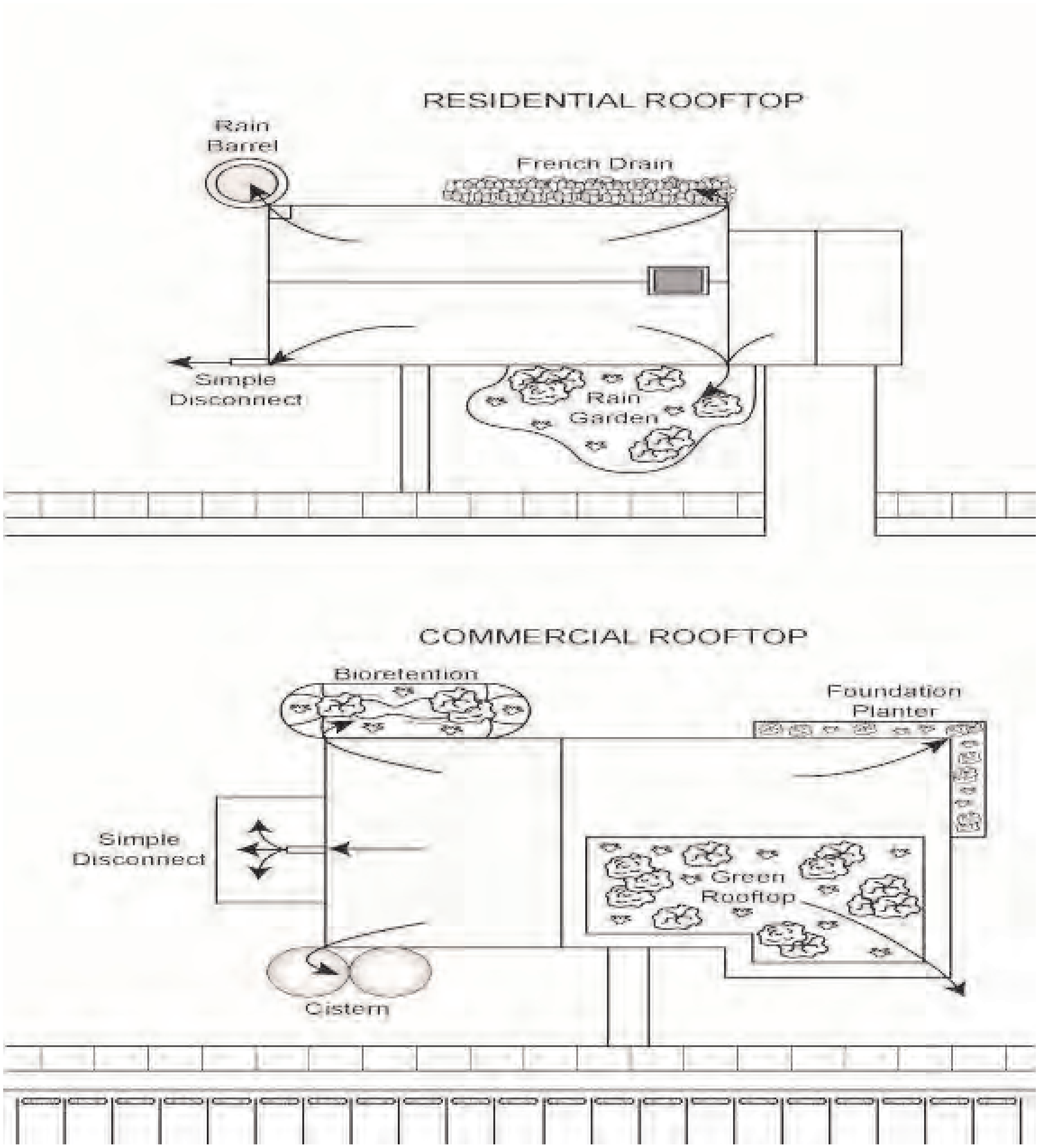

Figure 4.7-2. Roof Disconnection and Alternative BMPs.

Impervious Surface Disconnection Feasibility Criteria

Impervious surface disconnections are ideal for use on commercial, institutional, municipal, multi-family residential and single-family residential buildings. Key constraints with impervious surface disconnections include available space, soil permeability, and soil compaction.

For simple disconnection to turf areas or forest cover/open space the following feasibility criteria exist (Table 4.7-1).

Table 4.7-1. Feasibility criteria for simple disconnection

Design Factor	Disconnection Design
Impervious Area Treated	1,000 ft^2 per rooftop disconnection. For non-rooftop impervious areas, the longest contributing impervious area flow path cannot exceed 75 feet.
Required Space	Minimum 150 feet of disconnection area.
Sizing	The available disconnection area must be at least 10 feet wide and 15 feet long. Maximum disconnection width is 25 feet unless the contributing runoff is conveyed via sheetflow or a level spreader. Maximum disconnection length is 100 feet.
Site Topography	Grade of the receiving pervious area is less than 2%, or less than 5% with turf reinforcement. The slope of the receiving areas must be graded away from any building foundations.
Building Setbacks	5 ft. away from building if the grade of the receiving area is less than 1%.

Required Space. The available disconnection area must be at least 10 feet wide and 15 feet long. The disconnection width is limited to 25 feet unless the contributing runoff is conveyed via sheet flow or a level spreader. The disconnection length can be extended up to 100 feet to increase the volume treated.

Site Topography. Simple disconnection is best applied when the grade of the receiving pervious area is less than 2%, or less than 5% with turf reinforcement. The slope of the receiving areas must be graded away from any building foundations. Turf reinforcement may include erosion control matting or other appropriate reinforcing materials that are confirmed by the designer to be non-erosive for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan approving authority.

Soils. Impervious surface disconnection can be used on any post-construction Hydrologic Soil Group. The disconnection area must be kept well-vegetated with minimal bare spots.

Contributing Drainage Area (CDA). For rooftop impervious areas, the maximum impervious area treated cannot exceed 1,000 sq. ft. per disconnection. For non-rooftop impervious areas, the longest contributing impervious area flow path cannot exceed 75 feet. If inflow is conveyed via level spreader, the maximum flow path length is 150 feet and the level spreader should be designed with an appropriate width as specified in section 6.5.

Setbacks. If the grade of the disconnection area is less than 1%, downspouts must be extended 5 ft. away from building. Note that the downspout extension of 5 feet is intended for simple foundations.

Discharge Across Property Lines. Disconnection areas must be designed such that runoff is not directed across property lines toward other sites.

Economic Considerations. Disconnection is one of the least expensive LID practices available.

Impervious Surface Disconnection Conveyance Criteria

Simple disconnection practices must safely convey the 2-year and 10-year storm events over the receiving area without causing erosion. In some applications, erosion control matting or other appropriate reinforcing materials may be needed to control flow rates anticipated for larger design storms.

Impervious Surface Disconnection Pretreatment Criteria

Pretreatment is not needed for simple impervious surface disconnection.

Impervious Surface Disconnection Design Criteria

The following design criteria apply to each disconnection practice:

Simple Disconnection to a managed turf area. Disconnection to pervious areas with the compacted cover designation is required to meet the feasibility criteria presented above in *Impervious Surface Disconnection Feasibility Criteria*.

During site construction, care must be taken not to compact the receiving pervious area. To prevent soil compaction, heavy vehicular and foot traffic must be kept out of the receiving pervious area both during and after construction. This can be accomplished by clearly delineating the receiving pervious areas on all development plans and protecting them with temporary fencing prior to the start of land disturbing activities (If compaction occurs, soil amendments or post-construction aeration will be required. See Appendix C for information regarding soil amendments).

Simple Disconnection to a forest cover/open space. Disconnection to forest cover/open space is required to meet the feasibility criteria presented in Impervious Surface Disconnection Feasibility Criteria, with the following additions/exceptions:

- Minimum disconnection length: 40 feet.
- Maximum slope of the receiving area: 6% (2% for the first 10 feet).
- Inflow must be conveyed via sheet flow or via a level spreader.
- If inflow conveyed via level spreader, the maximum flow path length is 150 feet and the level spreader must be designed with an appropriate width as specified below.

Simple Disconnection to a Soil Compost-Amended Filter Path. Consult *Soil Compost Amendment Requirements* in *Appendix C*, for detailed information on the design and function of soil compost amendments. The incorporation of compost amendments must meet the design criteria in the specification and include the following design elements:

- Flow from the downspout must spread over a 10-foot wide strip extending down-gradient along the flow path from the building to the street or conveyance system.

- ✧ The filter path must be a minimum 15 feet in length.
- ✧ Installation of a pea gravel or river stone diaphragm, or other accepted flow spreading device is required at the downspout outlet to distribute flows evenly across the filter path.
- ✧ The strip requires adequate "freeboard" so that flow remains within the strip and is not diverted away from the strip. In general, this means that the strip should be lower than the surrounding land area in order to keep flow in the filter path. Similarly, the flow area of the filter strip should be level to discourage concentrating the flow down the middle of the filter path.
- ✧ Use 2 to 4 inches of compost and till to a depth of 6 to 10 inches within the filter path.

Level Spreaders. A level spreader can be used to disperse or "spread" concentrated flow thinly over a vegetated or forested area to promote greater runoff infiltration in the receiving area. A level spreader consists of a permanent linear structure constructed at a 0% grade that transects the slope. The influent concentrated runoff must be spread over an area wide enough to prevent erosion of the receiving area. Detailed information on the design and function of level spreaders can be found in Hathaway and Hunt, 2006 and Van Der Wiele, 2007. The minimum recommended width of the level spreader is:

- ✧ 13 linear feet per each 1 cubic foot/second of inflow if the receiving conservation area has 90% ground cover;
- ✧ 40 linear feet per 1 cubic foot/second of inflow if the receiving conservation area is forested.

Storage Volume. While disconnection practices do not have a discreet storage volume in the same sense as other LID practices, for calculation purposes, the storage volume, *Sv*, may be calculated using Equation 4.7-1:

Equation 4.7-1. Storage Volume for Disconnection Practices

$$Sv = \frac{1}{12} \times SA_{disconnection}$$

where:

Sv	=	storage volume of the disconnection practice (ft^3)
$SA_{disconnection}$	=	surface area of the disconnection area (ft^2)

In the LID Compliance Calculator, the Sv for disconnection is given varying percentage credit toward the water quality volume requirements depending on the design:

- ✧ Simple disconnection to managed turf areas on A/B soils: 50% credit
- ✧ Simple disconnection to managed turf areas on C/D soils: 25% credit
- ✧ Simple disconnection to forest cover or preserved open space: 75% credit
- ✧ Simple disconnection to a soil compost amended filter path: 50% credit

Impervious Surface Disconnection Landscaping Criteria

All receiving disconnection areas must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several types of grasses appropriate for coastal South Carolina area listed in Table 4.7-2. Designers should ensure that selected grass species are suited to the specific conditions on the site, including flow rate, slope, and aesthetic considerations. For more information on stabilization seeding, see the Charleston County Stabilization Specifications.

Table 4.7-2. Recommended vegetation for pervious disconnection areas.

Common Name	Botanical Name
Common Bermudagrass	*Cynodon dactylon*
Common Carpetgrass	*Axonopus affinis*
Bahiagrass	*Paspalum notatum*
Coastal Panicgrass	*Panicum amarum*
Weeping Lovegrass	*Eragrostis curvula*
White Clover	*Trifolium repens*
Indiangrass	*Sorghastrum nutans*
Virginia Wildrye	*Elymus virginicus*
Crimson Clover	*Trifolium incarnatum*
Browntop Millet	*Panicum ramosum*
Sweet Sorghum	*Sorghum bicolor*
Perennial Ryegrass	*Lolium perenne*
Source: Charleston County Stabilization Specifications, December 2011	

Impervious Surface Disconnection Construction Sequence

Construction Sequence for Disconnection to Pervious Areas. For simple disconnection to a pervious area, the pervious area can be within the limits of disturbance during construction. The following procedures should be followed during construction:

- Before site work begins, the receiving pervious disconnection area boundaries should be clearly marked.
- Construction traffic in the disconnection area should be limited to avoid compaction. The material stockpile area shall not be located in the disconnection area.
- Construction runoff should be directed away from the proposed disconnection area, using perimeter silt fence, or, preferably, a diversion dike.
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- The disconnection area may require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction.
- Topsoil and or compost amendments should be incorporated evenly across the disconnection area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.

- ✧ Stormwater should not be diverted into any compost amended areas until the turf cover is dense and well established.

Construction Sequence for Disconnection to Conservation Areas. For simple disconnection to a conservation area, the conservation area must be fully protected during the construction stage of development and kept outside the limits of disturbance on the Erosion and Sediment (E&S) Control Plan.

- ✧ No clearing, grading or heavy equipment access is allowed in the conservation area except temporary disturbances associated with incidental utility construction, restoration operations or management of nuisance vegetation.
- ✧ Any conservation areas shall be protected by super silt fence, chain link fence, orange safety fence, or other measures to prevent sediment discharge.
- ✧ The limits of disturbance should be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, silt fence, snow fence or other protective barrier.
- ✧ If a level spreader is to be used in the design, construction of the level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out. Further, stormwater should not be diverted into the disconnection area until the level spreader is installed and stabilized.

Construction Supervision. Construction supervision is recommended to ensure compliance with design standards. Inspectors should evaluate the performance of the disconnection after the first big storm to look for evidence of gullies, outflanking, undercutting, or sparse vegetative cover. Spot repairs should be made, as needed.

Impervious Surface Disconnection Maintenance Criteria

Maintenance of disconnected downspouts usually involves the regular lawn or landscaping maintenance in the filter path from the roof to the street. In some cases, runoff from a simple disconnection may be directed to a more natural, undisturbed setting (i.e., where lot grading and clearing is “fingerprinted” and the proposed filter path is protected).

An example maintenance checklist for impervious surface disconnection is included in *Appendix F*.

Impervious Surface Disconnection References and Additional Resources

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6. Van Der Wiele, C.F. 2007. Level Spreader Design Guidelines. North Carolina Division of Water Quality. Raleigh, NC. Available online: http://h2o.enr.state.nc.us/su/documents/LevelSpreaderGuidance_Final_-3.pdf
7. Virginia Department of Conservation and Recreation (VA DCR). 2011. Stormwater Design Specification No. 1: Rooftop (Impervious Surface) Disconnection Version 1.8. Available at http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_1_DISCONNECTION_Final_Draft_v1-8_04132010.htm

4.8 Open Channel Systems

Introduction

Vegetated open channels are designed to capture and treat the water quality design storm, and safely convey larger storm events. Examples of vegetated open channels include:

- Grass channel
- Dry swale
- Wet swale
- Two-stage ditch (may be used to provide detention for larger storm events)
- Regenerative stormwater conveyance

Open channel systems shall not be designed to provide stormwater detention except under extremely unusual conditions. Generally, open channel systems must be combined with a separate facility to meet these requirements.

Grass channels. (Figure 4.8-1a & Figure 4.8-2) can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets, and pipes. The performance of grass channels will vary depending on the underlying soil permeability and channel slope. Grass channels, however, are not capable of providing the same stormwater functions as other LID BMPs, as they lack a significant storage volume. Their water quality credit can be boosted when compost amendments are added to the bottom of the channel (See *Appendix C*). Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system where development density, topography, and soils permit.

Dry swales. (Figure 4.8-1b & Figure 4.8-3) are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface material (other than mulch and ornamental plants). The dry swale is a soil filter system that temporarily stores and then filters the desired design storm volume. Dry swales rely on a pre-mixed soil media filter below the channel that is similar to that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Dry swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

Wet swales. (Figure 4.8-1c & Figure 4.8-4) can provide a modest amount of runoff filtering within the conveyance. These linear wetland cells often intercept shallow groundwater to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity. On-line or off-line cells are formed within the channel to create saturated soil or shallow standing water conditions (typically less than 6 inches deep).

Two Stage Ditches. (Figure 4.8-1d & Figure 4.8-5) are a modification of other open channel designs that provides some temporary detention for larger storm events. This option utilizes a modified cross section that includes a low flow conveyance channel to convey the "channel forming" (up to 2-year) event, and a bench with flattened side slopes to convey larger storm events. Originally used as an agricultural practice in the Midwestern United States, it mimics the geometry of a natural stream, thereby harnessing some aspects of natural fluvial functioning. This design option has the potential to provide greater detention for larger storm events, minimizes scour during large storms, increases bank stability, and can enhance nitrogen removal by providing a greater reactive surface for nutrient cycling. However, it requires a wider width than a trapezoidal or parabolic channel, and consequently cannot be applied on sites with a very narrow right of way. Additional information and design criteria can be found in Chapter 10 - Part 654 Stream Restoration Design, National Engineering Handbook (USDA, 2007).

Regenerative Stormwater Conveyance. (RSC) (Figure 4.8-1e & Figure 4.8-6) is a unique conveyance practice that can be used in locations where other conveyance practices are infeasible, or as a restoration practice for eroded or degraded outfalls and drainage channels. RSC utilizes a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand and woodchip beds to treat, detain, and convey storm flow. It can be used in places where grades make traditional stormwater practices difficult to implement. RSC Systems combine features and treatment benefits of Swales, Infiltration, Filtering and Wetland practices. In addition, they are designed to convey flows associated with larger storm events in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

Example from Coastal South Carolina: Crabtree Canal

The Two-Stage Ditch has primarily been applied in the Midwestern United States in agricultural applications. A recent project in Horry County, SC used this design to reconnect the floodplain of the Crabtree Canal to partially restore the Crabtree Swamp (Fuss et al., 2010). This demonstration project is supported by hydrologic modeling in the watershed conducted by Clemson University, which indicated that the two-stage design would decrease velocity and shear stress within the channel (Jayakaran et al., 2009).

The design options presented in this chapter expand application of this design to include channels designed to capture stormwater runoff from smaller drainage areas, in order to enhance pollutant removal in the upper reaches of the drainage system.

Channel before restoration

Channel after restoration

Figure 4.8-1. Open Channel Design Options

Figure 4.8-1a. Grassed Channel (Photo: CWP)

Figure 4.8-1b. Dry Swale (Photo: CWP)

Figure 4.8-1c. Wet Swale (Photo: CWP)

Figure 4.8-1d. Two-Stage Ditch (Photo: Ohio State University Extension)

Figure 4.8-1e. Regenerative Stormwater Conveyance (Photo: Biohabitats, Inc.)

KEY CONSIDERATIONS: OPEN CHANNEL SYSTEMS

DESIGN CRITERIA:

- Depending on the design option, can treat the design water quality storm by detaining this volume with check dams, or by conveying at low velocities and depth to promote filtering and infiltration.
- Design to convey larger storm events safely, and at non-erosive velocities.

BENEFITS:

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads.
- Ideally suited to the coastal environment, where stormwater is conveyed primarily in open channels.

LIMITATIONS:

- Difficult to apply in densely developed areas.
- With the exception of Regenerative Stormwater Conveyance Systems, cannot be used on steep slopes.

SITE APPLICABILITY:

- Rural Use
- Suburban Use
- Construction Cost: Low-Medium
- Maintenance: Medium
- Area Required: Medium

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- Grass Channel: 10% - 20% credit for design volume
- Dry Swale: 60% credit for storage volume
- Wet Swale: 0% credit
- RSC: 100% credit for storage volume

Coastal Zone Credit

- Grass Channel: 10% - 20% credit for design volume
- Dry Swale, Wet Swale, and RSC: 100% credit for storage volume of practice

Statewide Water Quality Requirement Credit Approach

- Grass Channel, Dry Swale, and RSC: Runoff Reduction credit applies to infiltration requirement.
- Wet Swale: At least ½” of runoff must be stored and released over 24 hours

Annual Pollutant Removal[1]
40% - Total Suspended Solids
40%-45% - Total Phosphorus[2]
20%-35% - Total Nitrogen[3]
30% - Metals
N/A – Pathogens[4]

[1] expected annual pollutant load removal
[2] range, with best removal for the wet or dry swales
[3] range with best removal for grassed channels
[4] No data available, but expected poor pollutant removal.

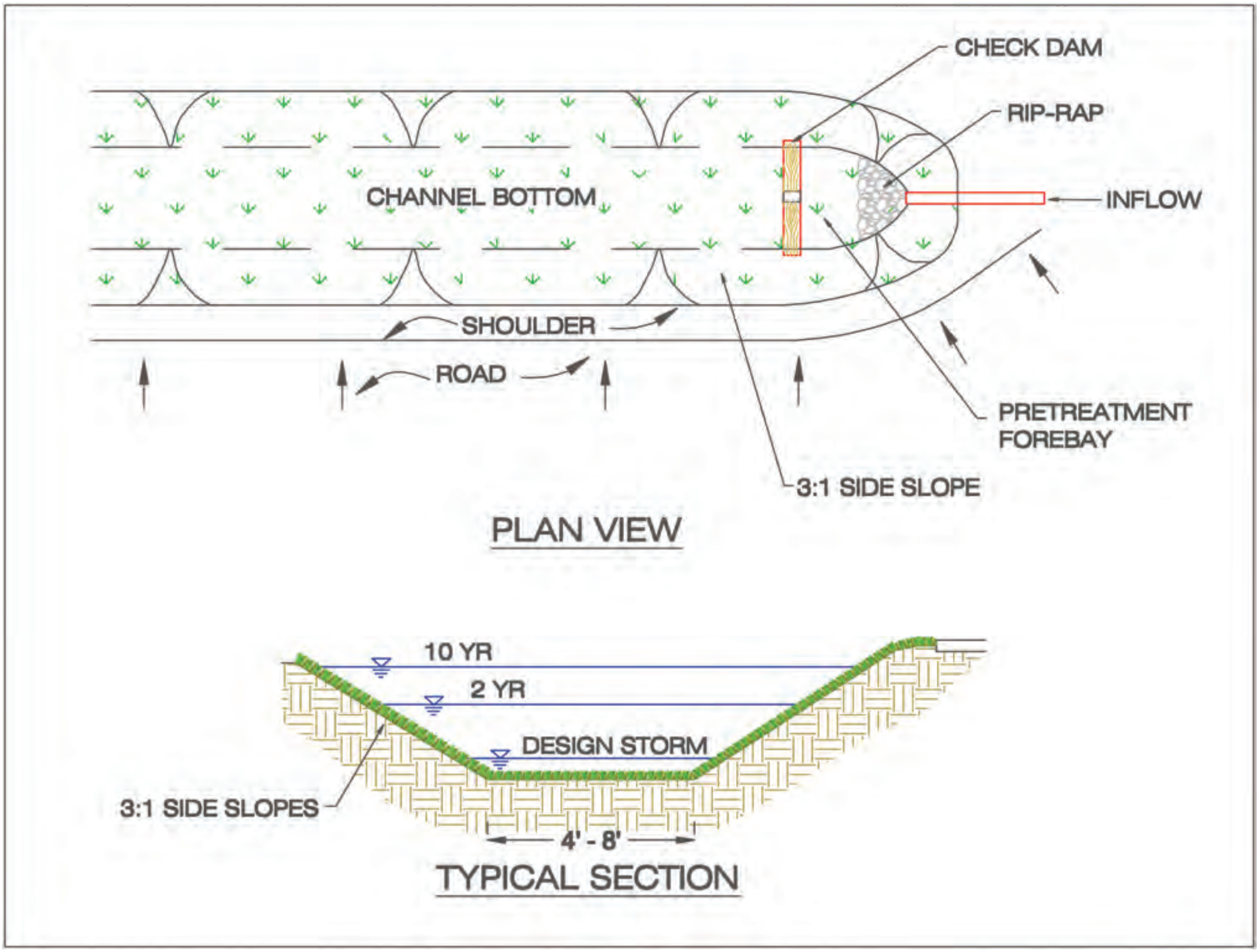

Figure 4.8-2. Grass Channel Typical Plan and Section

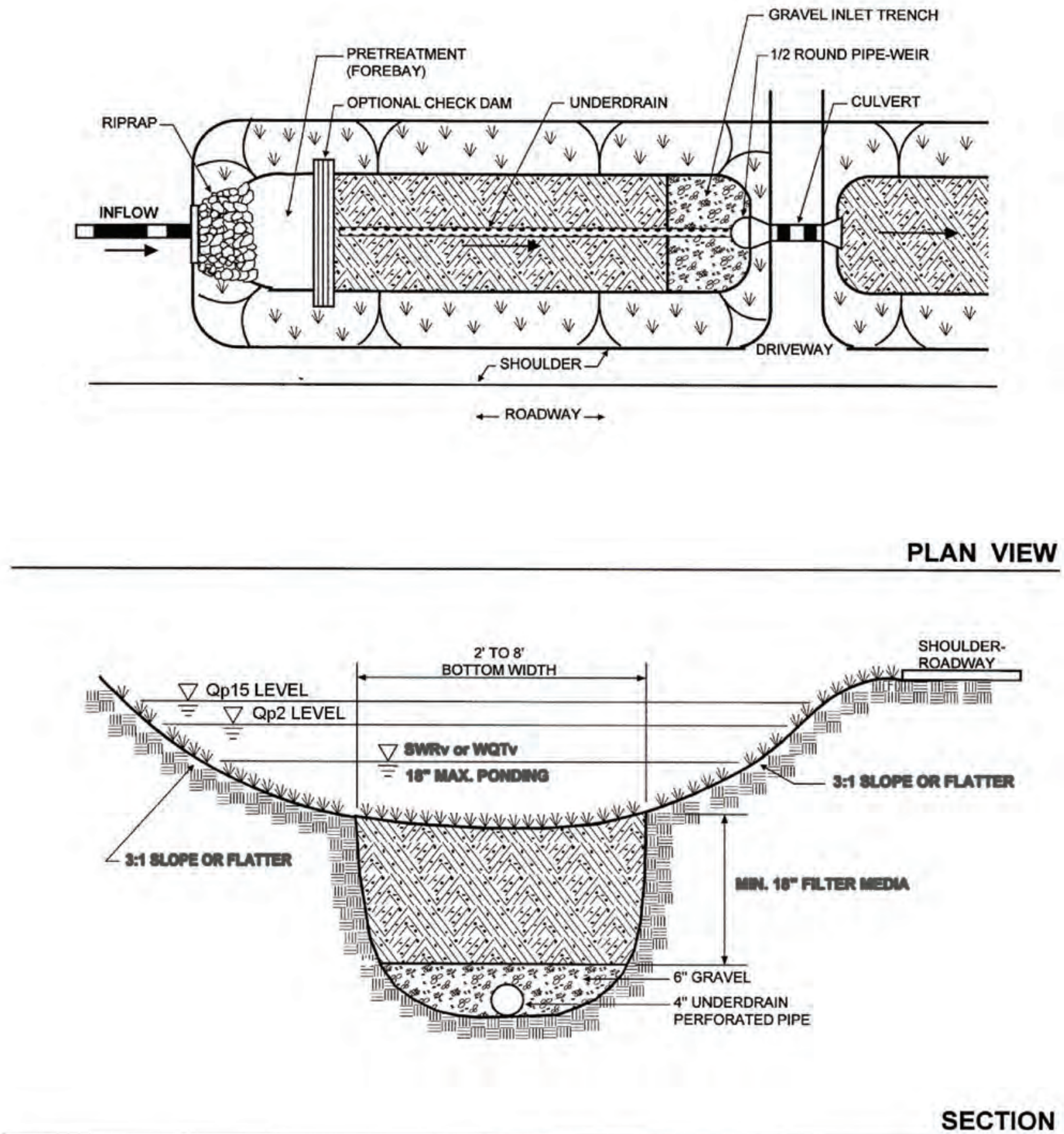

Figure 4.8-3. Dry Swale Typical Plan and Section

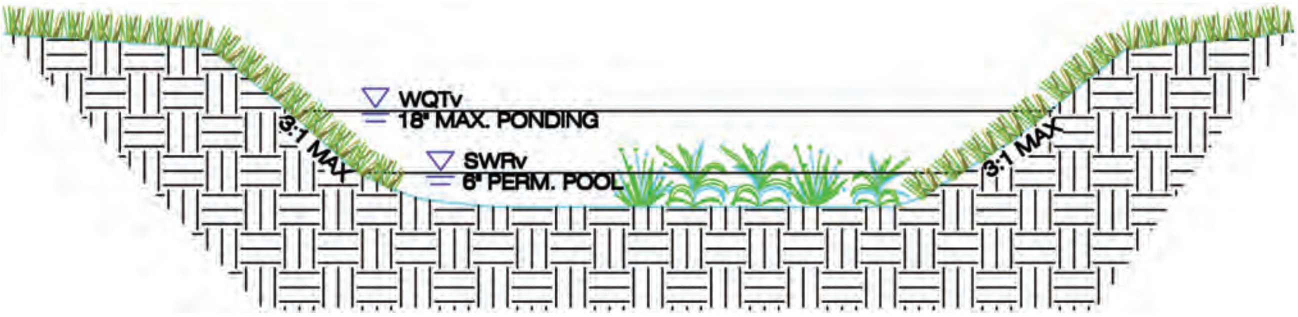

Figure 4.8-4. Wet Swale

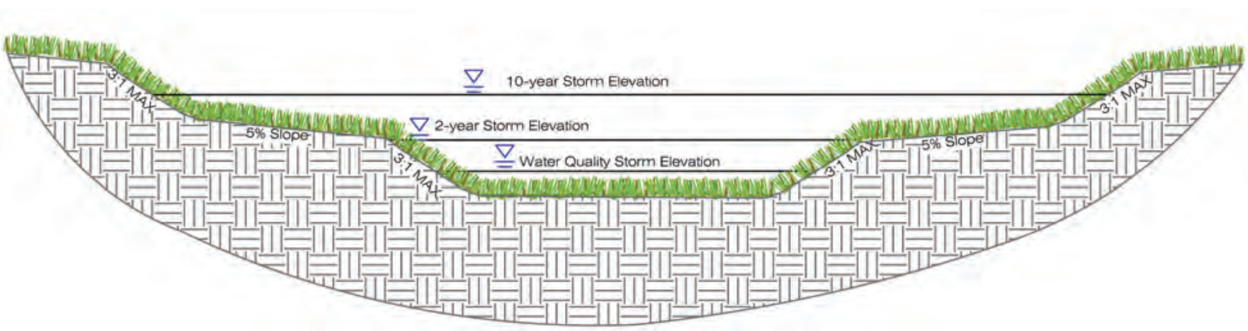

Figure 4.8-5. Two-Stage Ditch

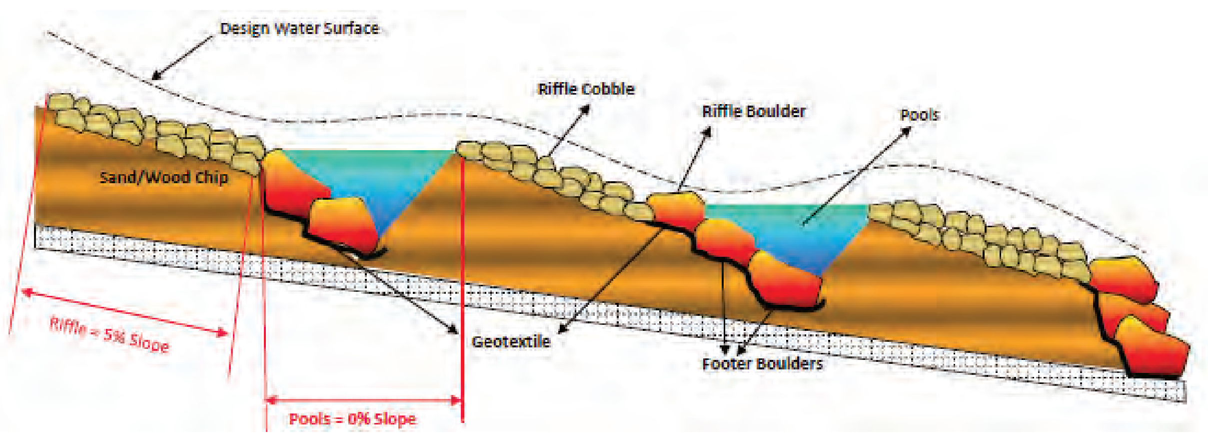

Figure 4.8-6. Regenerative Stormwater Conveyance

Open Channel Feasibility Criteria

Open channel systems are primarily applicable for land uses such as roads, highways, and residential development. Some key feasibility issues for open channels include the following:

Contributing Drainage Area. The maximum contributing drainage area to most open channels should be 2.5 acres, and preferably less. When open channels treat and convey runoff from drainage areas greater than 2.5 acres, the velocity and flow depth through the channel often becomes too great to treat runoff or prevent erosion in the channel. The design criteria for maximum channel velocity and depth are applied along the entire length (See *Open Channel Design Criteria*). Two-stage ditches and RSCs do not have the same restrictions, and generally are feasible for larger drainage areas.

Available Space. Open channel footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Dry Swales should be approximately 3% to 10% of the size of the contributing drainage area, depending on the amount of impervious cover. Wet swale footprints usually cover about 5% to 15% of their contributing drainage area. Grass channels can be incorporated into linear development applications (e.g., roadways) by utilizing the footprint typically required for an open section drainage feature. The footprint required will likely be greater than that of a typical conveyance channel. However, the benefit of the storage volume may reduce the footprint requirements for stormwater management elsewhere on the development site.

Site Topography. Grass channels and wet swales should be used on sites with longitudinal slopes of less than 4%. Check dams can be used to reduce the effective slope of the channel and lengthen the contact time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water. RSC practices are typically used for slopes less than 10%, but can be used on slopes up to 30% if proper cascade structures are used.

For dry swales, check dams will be necessary regardless of the longitudinal slope to create the necessary ponding volume.

Land Uses. Open channels can be used in residential, commercial, or institutional development settings.

When open channels are used for both conveyance and water quality treatment, they should be applied in linear configurations parallel to the contributing impervious cover, such as roads and small parking areas. The linear nature of open channels makes them well-suited to treat highway or low- and medium-density residential road runoff if there is adequate right-of-way width and distance between driveways. Typical applications of open channels include the following, as long as drainage area limitations and design criteria can be met:

- Within a roadway right-of-way
- Along the margins of small parking lots
- Oriented from the roof (downspout discharge) to the street
- Disconnecting small impervious areas

- ✧ Used to treat the managed turf areas of sports fields, golf courses, and other turf-intensive land uses, or to treat drainage areas with both impervious and managed turf cover (such as residential streets and yards)

Open channels are not recommended when residential density exceeds 4 dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel.

Open channels can also provide pretreatment for other stormwater treatment practices.

Available Hydraulic Head. A minimum amount of hydraulic head is needed to implement open channels in order to ensure positive drainage and conveyance through the channel. The hydraulic head for wet swales and grass channels is measured as the elevation difference between the channel inflow and outflow point. The hydraulic head for dry swales is measured as the elevation difference between the inflow point and the storm drain invert. Dry swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and underdrain.

Hydraulic Capacity. Open channels are typically designed as on-line practices which must be designed with enough capacity to convey runoff from the 2-year and 10-year design storms at non-erosive velocities. This means that the swale's surface dimensions are more often determined by the need to pass the 10-year storm events, which can be a constraint in the siting of open channels within existing rights-of-way (e.g., constrained by sidewalks).

Depth to Water Table. Designers should ensure that the bottom of dry swales and grass channels is at least 0.5 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the filter bed, since this could lead to groundwater contamination or practice failure. It is permissible for wet swales to intersect the water table. For RSC, the water table should not inundate pools or reduce available storage.

Soils. Soil conditions do not constrain the use of open channels, although they do dictate some design considerations:

- ✧ Dry swales in soils with infiltration rates of less than 0.3 inches per hour will need an underdrain. Designers must verify site-specific soil permeability at the proposed location using the methods for on-site soil investigation presented in *Appendix B*, in order to eliminate the requirements for a dry swale underdrain. Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.
- ✧ Grass channels situated on low-permeability soils may incorporate compost amendments in order to improve performance (see *Appendix C*).
- ✧ Wet swales work best on the more impermeable Hydrologic Soil Group (HSG) C or D soils, or in areas where the groundwater is very close to the surface.
- ✧ In fill soil locations, geotechnical investigations are recommended to determine if the use of an impermeable liner and underdrain are necessary for open channel designs.

Utilities. Approval from the applicable utility company or agency is required if utility lines will run below or through open channel areas. Typically, utilities can cross linear channels if they are specially protected (e.g., double-casing). Water and sewer lines generally need to be placed under adjacent road pavements to enable the use of open channels.

Avoidance of Irrigation or Baseflow. Open channels should be located so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other continuous dry weather flows.

Setbacks. Open channels should be set back at least 10 feet down-gradient from building foundations and property lines, 50 feet from septic system fields and 150 feet from public or private drinking water wells. The 10-foot building setback may be relaxed if an impermeable building liner is installed.

Pollutant Hotspot Land Uses. Open channels may not be an appropriate stormwater management practice for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the channel and subsequent water bodies.

On sites with existing contaminated soils, infiltration is not allowed. In these conditions, dry and wet swales must include an impermeable liner.

Feasibility in Coastal South Carolina. Open channels are ideally suited to the coastal environment, since open channel drainage is often the norm due to the flat topography. Depending on underlying soil and other characteristics, however, a specific open channel option may be the most appropriate. For example, the wet swale design option is most suited to areas with elevated groundwater tables, while dry swales and grassed channels are best suited for sandy soils of the coastal plain.

Economic Considerations. While most open channel designs provide relatively small water quality credits when compared with other stormwater practices, they nevertheless provide greater quality benefits than traditional conveyance designs, such as curb and gutter.

Open Channel Conveyance Criteria

The bottom width and slope of a grass channel should be designed such that the velocity of flow from the design storm provides a minimum hydraulic residence time (the time for runoff to travel the full length of the channel) of 9 minutes for the peak flows from the water quality volume storm event. Check dams may be used to reduce the flow velocity and achieve the needed hydraulic residence time. Check dams should be spaced based on channel slope and ponding requirements, consistent with the criteria in *Open Channel Design Criteria*.

Open channels should also convey the 2- and 10-year storms at non-erosive velocities (generally less than 6 fps) for the soil and vegetative cover provided. The final designed channel shall provide 1 foot minimum freeboard above the designated water surface profile of the channel. The analysis should evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

The RSC system is typically designed to convey larger storm events, up to and including the 100-year storm event.

Open Channel Pretreatment Criteria

Pretreatment is required for open channels to dissipate energy, trap sediments and slow down the runoff velocity. The selection of a pretreatment method depends on whether the channel will experience sheet flow or concentrated flow. Several options are as follows:

- ✧ **Check Dams** (channel flow): These energy dissipation devices are acceptable as pretreatment on small open channels with drainage areas of less than 1 acre. The most common form is the use of wooden or stone check dams. The pretreatment volume stored should be 10% of the design volume.
- ✧ **Tree Check Dams** (channel flow; Figure 4.8-7): These are street tree mounds that are placed within the bottom of grass channels up to an elevation of 9 to 12 inches above the channel invert. These check dams are similar to traditional check dams, except that the dam is created with a tree mound. Stormwater that is ponded behind the check dam percolate through the excavated soil below the tree's roots. Flows above the elevation of the check dam are conveyed over an armored downstream slope to reduce erosion potential.

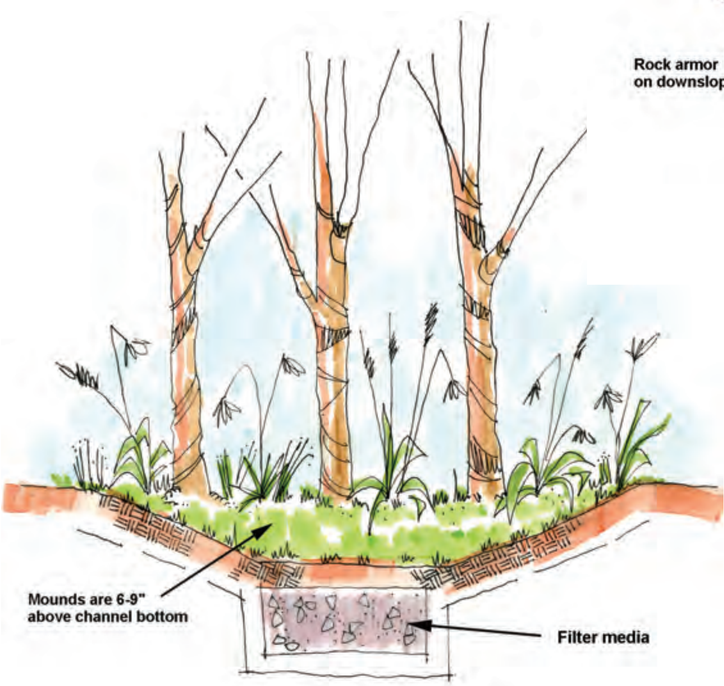

Figure 4.8-7. Tree Check Dam (Source: Cappiella, 2009)

- **Grass Filter Strip** (sheet flow): Grass filter strips extend from the edge of the pavement to the bottom of the open channel at a slope of 5:1 or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) cross slope and 3:1 or flatter side slopes on the open channel.
- **Gravel or Stone Diaphragm** (sheet flow): The gravel diaphragm is located at the edge of the pavement or the edge of the roadway shoulder and extends the length of the channel to pre-treat lateral runoff. This requires a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The stone must be sized according to the expected rate of discharge.
- **Gravel or Stone Flow Spreaders** (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the channel.
- **Initial Sediment Forebay** (channel flow). This grassed cell is located at the upper end of the open channel segment with a 2:1 length to width ratio and a storage volume equivalent to at least 15% of the total design storm volume. The pretreatment volume stored must be 10% of the design volume.

Open Channel Design Criteria

Channel Geometry. Design guidance regarding the geometry and layout of open channels is provided below:

- Generally, open channels should be aligned adjacent to and the same length as the contributing drainage area identified for treatment.
- Open channels should be designed with a trapezoidal or parabolic cross section. A parabolic shape is preferred for aesthetic, maintenance and hydraulic reasons.
- The bottom width of the channel should be between 4 to 8 feet wide to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a channel will be wider than 8 feet, the designer should incorporate benches, check dams, level spreaders or multi-level cross sections to prevent braiding and erosion along the channel bottom.
- Open channel side slopes should be no steeper than 3H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to enhance pretreatment of sheet flows entering the channel.
- In the two-stage ditch option, the benches above the elevation of the 2-year storm event should have between a 0% and 3% side slope. In addition, the width of each bench should, at a minimum, be equal to the top width of the lower conveyance channel.
- RSC has several specific geometry requirements, which are outlined in *RSC Sizing* below.

Check dams. Check dams may be used for pretreatment, to break up slopes, and to increase the hydraulic residence time in the channel. Design requirements for check dams are as follows:

- ✧ Check dams should be spaced based on the channel slope, as needed to increase residence time, provide design storm storage volume, or any additional volume attenuation requirements. In typical spacing, the ponded water elevation at a downhill check dam should match the toe elevation of the upstream check dam. More frequent spacing may be desirable in dry swales to increase the ponding volume.
- ✧ The maximum desired check dam height is 12 inches (for maintenance purposes). However, for some sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils. The average ponding depth throughout the channel should be 12 inches.
- ✧ Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- ✧ Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.
- ✧ Check dams must be designed with a center weir sized to pass the channel design storm peak flow (15-year storm event for man-made channels).
- ✧ For grass channels, each check dam should have a weep hole or similar drainage feature so it can dewater after storms. This is not appropriate for dry swales
- ✧ Check dams should be composed of wood, concrete, stone, compacted soil, or other non-erodible material, or should be configured with elevated driveway culverts.
- ✧ Individual channel segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

Check dams for grass channels should be spaced to reduce the effective slope to less than 2%, as indicated in Table 4.8-1.

Table 4.8-1. Typical Check Dam (CD) Spacing to Achieve Effective Channel Slope		
Channel Longitudinal Slope	**Spacing[1] of 12-inch High (max.) Check Dams[3,4] to Create an Effective Slope of 2%**	**Spacing[1] of 12-inch High (max.) Check Dams[3,4] to Create an Effective Slope of 0 to 1%**
0.5%	–	200 ft. to –
1.0%	–	100 ft. to –
1.5%	–	67 ft. to 200 ft.
2.0%	–	50 ft. to 100 ft.
2.5%	200 ft.	40 ft. to 67 ft.
3.0%	100 ft.	33 ft. to 50 ft.
3.5%	67 ft.	30 ft. to 40 ft.
4.0%	50 ft.	25 ft. to 33 ft.
4.5%[2]	40 ft.	20 ft. to 30 ft.
5.0%[2]	40 ft.	20 ft. to 30 ft.

Notes:
[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.
[2] Open channels with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.
[3] All check dams require a stone energy dissipater at the downstream toe.
[4] Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.

Ponding Depth. Check dams should be used in dry swales to create ponding cells along the length of the channel. The maximum ponding depth in a dry swale should not exceed 18 inches. It may be necessary or desirable to space check dams more frequently than is shown in Table 4.8-1 in order to increase the ponding depth.

Dry Swale Filter Media. Dry swales require replacement of native soils with a prepared soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the dry swale. At least 18 inches of soil media should be added above the choker stone layer to create an acceptable filter. The recipe for the soil media is identical to that used for bioretention and is provided in *Section 4.2 Bioretention*. The soil media should be obtained from an approved vendor to create a consistent, homogeneous fill media. One acceptable design adaptation is to use 100% sand for the first 18 inches of the filter and add a combination of topsoil and leaf compost for the top 4 inches, where turf cover will be maintained.

Dry Swale Underdrain. Some dry swale designs will not use an underdrain (where soil infiltration rates meet minimum standards (see *Open Channel Feasibility Criteria*). When underdrains are necessary, they should have a minimum diameter of 4 to 6 inches and be encased in a 12-inch deep gravel bed. Two layers of stone should be used. A choker stone layer, consisting of #8 or #78 stone at least 3 inches deep, should be installed immediately below the filter media. Below the choker stone layer, the main underdrain layer should be at least 12 inches deep and composed of 1-inch double washed stone. The underdrain pipe should be set at least 4 inches above the bottom of the stone layer.

Impermeable Liner: This material should be used only for appropriate fill applications where deemed necessary by a geotechnical investigation. Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

Dry Swale Observation Well. A dry swale should include observation wells with cleanout pipes along the length of the swale, if the contributing drainage area exceeds 1 acre. The wells should be tied into any T's or Y's in the underdrain system, and should extend upwards to be flush with surface, with a vented cap.

Grass Channel Material Specifications. The basic material specifications for grass channels are outlined in Table 4.8-2.

Table 4.8-2. Grass Channel Materials Specifications

Component	Specification
Grass	A dense cover of water-tolerant, erosion-resistant grass. The selection of an appropriate species or mixture of species is based on several factors including climate, soil type, topography, and sun or shade tolerance. Grass species should have the following characteristics: a deep root system to resist scouring; a high stem density with well-branched top growth; water-tolerance; resistance to being flattened by runoff; and an ability to recover growth following inundation.
Check Dams	♦ Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. ♦ Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust. ♦ Computation of check dam dimensions is necessary, based on the surface area and depth used in the design computations.
Diaphragm	Pea gravel used to construct pretreatment diaphragms should consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter and must conform to local design standards.
Erosion Control Fabric	Where flow velocities dictate, biodegradable erosion control netting or mats that are durable enough to last at least two growing seasons must be used.

Dry Swale Material Specifications. Dry swale material specifications are identical to those for bioretention, and can be found in *Table 4.2-3 Bioretention Material Specifications*.

RSC Material Specifications. RSC has several design elements that are unique to this practice. The practice includes riffle and pool segments, underlain with a sand/ wood chip bed, and with a top dressing of compost and plant material. Table 4.8-3 outlines the materials needed for this practice.

Table 4.8-3. Regenerative Stormwater Conveyance System Material Specifications	
Material	**Specification**
Footer Boulders	Should have a natural appearance and be equivalent in size to Class 3 Rip Rap (average diameter 26.4 inches)
Cobble	Should have a natural appearance and a minimum diameter of 6”
Sand/ Woodchip Bed	♦ The sand component of the sand/wood chip bed should meet the AASHTO-M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand shall be a silica-based coarse aggregate. Substitutions such as Diabase and Graystone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No “rock dust” can be used for sand. Locally-approved pulverized glass may be substituted if the local authority undertakes testing to verify compliance with the particle size specification. No art glass shall be used for a pulverized glass material. ♦ For woodchips, use aged, shredded hardwood chips/mulch. The woodchips should be added to the sand mix, approximately 20 percent by volume, to increase the organic content and promote plant growth and sustainability.
Choker Stone	The choker stone layer between the sand bed and the bank run gravel should be clean, washed #8 or #78 stone.
Bank Run Gravel	The bank run gravel layer that is placed beneath and above the sand bed/choker stone layers should be constructed using clean, washed # 5 or # 57 coarse aggregate.
Compost	The compost used as a top dressing over the RSC System should consist of a 100% organic compost, with a pH of between 6.0 and 7.0, a moisture content of between 30 and 55%, and a particle size of 0.25 inches or less. (See Appendix C for compost specifications)
Wood Chips	The wood chips used within the sand bed should consist of double-shredded or double-ground hardwood mulch that is free of dyes, chromated copper arsenate and other preservatives.
Plant Materials	Plants should be native species, appropriate to the planting/wetness zone where they are located.

Wet Swale Design Issues. The following criteria apply to the design of wet swales:

- ✧ The average normal pool depth (dry weather) throughout the swale should be 6 inches or less.
- ✧ The maximum temporary ponding depth in any single Wet Swale cell should not exceed 18 inches at the most downstream point (e.g., at a check dam or driveway culvert).
- ✧ Check dams should be spaced as needed to maintain the effective longitudinal slope.
- ✧ Individual Wet Swale segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.
- ✧ Wet Swale side slopes should be no steeper than 4H:1V to enable wetland plant growth. Flatter slopes are encouraged where adequate space is available, to enhance pretreatment of sheet flows entering the channel. Under no circumstances are side slopes to be steeper than 3H:1V.

Grass Channel Enhancement Using Compost Soil Amendments. Soil compost amendments serve to increase the runoff reduction capability of a grass channel. The following design criteria apply when compost amendments are used:

- ✧ The compost-amended strip should extend over the length and width of the channel bottom, and the compost should be incorporated to a depth as outlined in *Appendix C*.
- ✧ The amended area will need to be rapidly stabilized with perennial grass species.
- ✧ For grass channels on steep slopes, it may be necessary to install a protective biodegradable geotextile fabric to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate geotextile.

Grass Channel Sizing. Unlike other stormwater practices, grass channels are designed based on a peak rate of flow. Designers must demonstrate channel conveyance and treatment capacity in accordance with the following guidelines:

- ✧ Hydraulic capacity should be verified using Manning's Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance.
  - The flow depth for the peak flow generated by the water quality volume should be maintained at 4 inches or less.
  - Manning's "n" value for grass channels should be 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches and above (Haan et. al, 1994).
  - Peak flow rates for the 2-year and 10-year frequency storms should be non-erosive, in accordance with Table 4.8-5 below (see *Open Channel Landscaping Criteria*), or subject to a site-specific analysis of the channel lining material and vegetation; and the 10-year peak flow rate should be contained within the channel banks (with a minimum of 6 inches of freeboard).
- ✧ Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet should be used.

- ✧ The hydraulic residence time (the time for runoff to travel the full length of the channel) should be a minimum of 9 minutes for the peak flows from the water quality volume or design storm (Mar et al., 1982; Barrett et al., 1998; Washington State Department of Ecology, 2005). If flow enters the channel at several locations, a 9 minute minimum hydraulic residence time should be demonstrated for each entry point, using Equations 4.8-1 – 4.8-5 below.

The bottom width of the grass channel is therefore sized to maintain the appropriate flow geometry as follows:

Equation 4.8-1: Manning's Equation

$$V = (1.49/n) \times R^{2/3} \times S^{1/2}$$

where:

V = flow velocity (ft/s)

n = roughness coefficient (0.2, or as appropriate)

R = hydraulic radius = D = flow depth (ft)

(NOTE: D approximates hydraulic radius for shallow flows)

S = channel slope (ft/ft)

Equation 4.8-2: Continuity Equation

$$Q = V \times (W \times D)$$

where:

Q = design storm peak flow rate (cfs)

V = design storm flow velocity (ft/s)

W = channel width (ft)

D = flow depth (ft)

(NOTE: channel width (*W*) x depth (*D*) approximates the cross sectional flow area for shallow flows.)

Combining Equations 4.8-1 and 4.8-2, and re-writing them provides a solution for the minimum width:

Equation 4.8-3: Minimum Width

$$W = \frac{n \times Q}{1.49 \times D^{5/2} \times S^{1/2}}$$

Solving Equation 4.8-2 for the corresponding velocity provides:

Equation 4.8-4: Corresponding Velocity

$$V = \frac{Q}{W \times D}$$

The width, slope, or Manning's "n" value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning's "n" value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that denser vegetation is actually established. Equation 4.8-5 can then be used to ensure adequate hydraulic residence time.

Equation 4.8-5: Grass Channel Length for Hydraulic Residence Time of 9 minutes (540 seconds)

$$L = 540 \times V$$

where:

L = minimum swale length (ft)

V = flow velocity (ft/sec.)

The storage volume (*Sv*) provided by the grass channel is equal to the total runoff from the design storm, and is used to size the channel (conveyed at a depth of 4 inches or less).

In the LID Compliance Calculator spreadsheet, the Sv for grass channels in A/B soils or with compost-amended channel bottom is given a 20% runoff reduction credit; the Sv for grass channels in C/D soils is given a 10% runoff reduction credit. Storage credits for projects in the Coastal Zone are the same as the runoff reduction credits.

Dry Swale Sizing. Dry swales are typically sized to capture the water quality volume, and are sized exactly as bioretention areas, with check dams providing the necessary ponding volume.

Wet Swale Sizing. While there are no specific state requirements for the size of the permanent pool, pollutant removal can be improved by storing the equivalent of at least ½ inch of runoff in the permanent pool. For the water quality volume to be treated fully, the wet swale must also provide temporary storage of ½ inch of runoff from the site. Within ½ mile from receiving water bodies, the requirement is ½ inch of runoff from the site, or 1 inch of runoff from built-upon areas, whichever is greater. This temporary storage should not exceed a depth of 12 inches above the permanent pool elevation, and must be stored and released over 24 hours.

For water quality calculation purposes, the storage volume, *Sv*, for a wet swale is equal to the temporary storage volume (The *Sv* does not include the permanent pool or the 2-year and 10-year detention volumes.).

In the LID Compliance Calculator spreadsheet, wet swales are not assigned any runoff reduction credit. For projects in the Coastal Zone, the Sv for wet swales is given a 100% credit toward the storage requirement. For the statewide water quality requirements, wet swales are credited as a pond with permanent pool, and at least ½ inch of runoff must be stored and released over 24 hours.

RSC Sizing. RSC design is described in detail by Anne Arundel County (2011). The following description provides an overview of this process, but designers should consult Anne Arundel County (2011) or the latest design variation for RSC for additional design guidelines. The Anne Arundel County guidance can be found at: http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm.

RSC design is an iterative process in which the channel is sized to convey the 100-year storm event, using manning's equation for parabolic channels. Some key sizing considerations include the following:

1. One control structure and pool (riffle-pool) combination is needed for each foot of elevation difference along the channel.
2. The length of each grade control structure or pool is determined by Equation 4.8-6.

Equation 4.8-6: Length of Riffle or Pool

$$L_{pool} = \frac{L_{riffle}}{(Elevation\ Change) \times 2}$$

Note that in areas with steep slopes (10% or greater) the length of the pool or riffle may be small (<10'). In these locations, cascades may be needed as a part of the system design.

3. The minimum width of grade control structures should be 8 ft and the width should be equal to 10 times the channel depth (Figure 4.8-8).
4. The depth of flow in the riffle sections should be less than 4 inches.
5. Cobbles in the riffle section should be sized so that the velocity of the 100-year storm is non-erosive (Table 4.8-4).

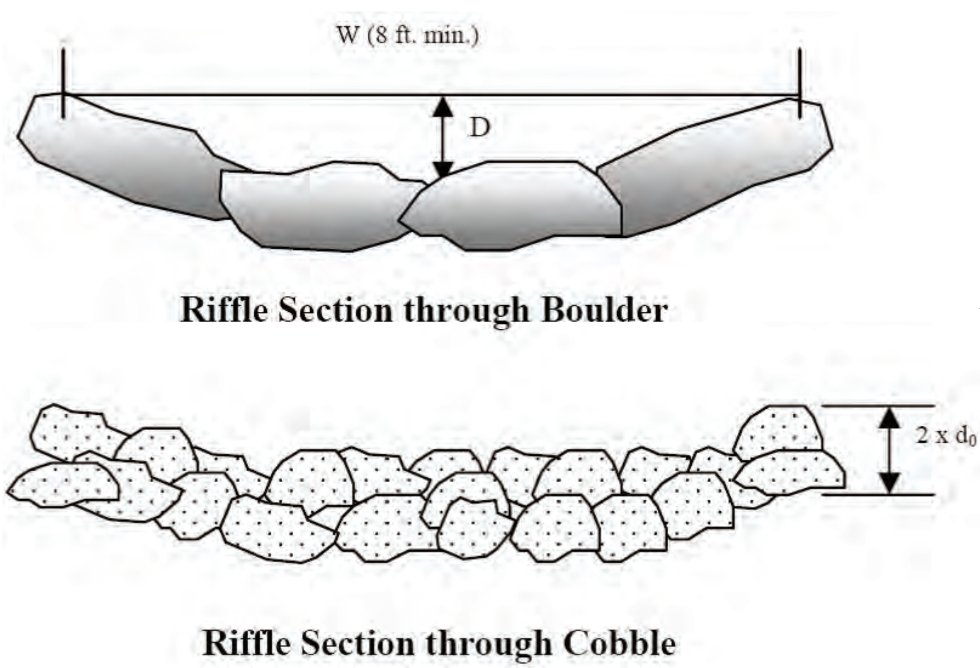

Figure 4.8-8. Typical Width and Depth of Riffle Sections (Source: Anne Arundel County, 2011).

Table 4.8-4. Maximum Allowable Velocity

Cobble size (in)	Allowable velocity (ft/s)
4	5.8
5	6.4
6	6.9
7	7.4
8	7.9
9	8.4
10	8.8
11	9.2
12	9.6
15	10.4

6. Pools should be between 1.5 and 3 feet deep, and equal to the width of the riffle sections.
7. The RSC system is underlain with a sand bed with a 1.5 foot depth and a width between 4 and 14 feet.
8. The downstream edge of the riffle should incorporate a series of boulders in a parabolic shape.
9. Place a cobble apron below the riffle section to allow for a stable transition between the riffle section and the downstream pools when the pools are dry. The cobble apron should be approximately 5 feet wide and 3 feet long.

The total *Sv* in the RSC system (available for water quality treatment) is determined by Equation 4.8-7.

Equation 4.8-7. Storage in RSC Systems

$$S_v = V_{pool} + V_{sandbed}$$

where:

V_{pool} = Volume in pools

$V_{sandbed}$ = Volume in the sand bed (use 25% porosity)

In the LID Compliance Calculator spreadsheet, the Sv for RSCs is given a 100% runoff reduction credit and, for projects in the Coastal Zone, a 100% credit toward the storage requirement.

Open Channel Landscaping Criteria

All open channels must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several types of grasses appropriate for dry open channels (grass channels and dry swales) are listed in Table 4.8-5. Designers should choose plant species that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Designers should ensure that selected grass species are suited to the specific conditions on the site, including flow rate, slope, and aesthetic considerations. For more information on stabilization seeding, see the Charleston County Stabilization Specifications.

Table 4.8-5. Recommended vegetation for open channels.

Common Name	Botanical Name
Common Bermudagrass	*Cynodon dactylon*
Common Carpetgrass	*Axonopus affinis*
Bahiagrass	*Paspalum notatum*
Coastal Panicgrass	*Panicum amarum*
Weeping Lovegrass	*Eragrostis curvula*
White Clover	*Trifolium repens*
Indiangrass	*Sorghastrum nutans*
Virginia Wildrye	*Elymus virginicus*
Crimson Clover	*Trifolium incarnatum*
Bowntop Millet	*Panicum ramosum*
Sweet Sorghum	*Sorghum bicolor*
Perennial Ryegrass	*Lolium perenne*

Source: Charleston County Stabilization Specifications, December 2011

Wet swales should be planted with grass and wetland plant species that can withstand both wet and dry periods as well as relatively high velocity flows within the channel. For a list of wetland plant species suitable for use in wet swales, refer to the wetland planting guidance and plant lists provided in *Section 4.12 Stormwater Wetlands*.

The Landscape design should specify proper grass species based on specific site, soils, and hydric conditions present along the channel.

Open channels should be seeded at such a density to achieve a 90% vegetated cover after the second growing season. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover.

Grass channels should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration. Grass channels should be protected by a biodegradable erosion control fabric to provide immediate stabilization of the channel bed and banks.

Open Channel Construction Sequence

Design Notes. Channel invert and tops of banks should be shown in plan and profile views. A cross sectional view of each configuration should be shown for proposed channels. Completed limits of grading should be shown for proposed channels. For proposed channels, the transition at the entrance and outfall is to be clearly shown on plan and profile views.

Open Channel Installation. The following is a typical construction sequence to properly install open channels, although steps may be modified to reflect different site conditions or design variations. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation. For more specific information on the installation of wet swales, designers should consult the construction criteria outlined in *Section 4.12 Stormwater Wetlands*.

Step 1: Protection during Site Construction. Ideally, open channels should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, temporary erosion and sediment controls such as dikes, silt fences, and other erosion control measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric should be used to protect the channel. For dry swale designs, excavation should be no deeper than 2 feet above the proposed invert of the bottom of the planned underdrain until the site is stabilized and construction of the BMP begins. Dry Swales that lack underdrains (and rely on filtration) must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction.

Step 2: Installation should only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross-section. Erosion and sediment controls for construction of the channel should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the channel until the bottom and side slopes are fully stabilized.

Step 3: Grade the grass channel to the final dimensions shown on the plan. Excavators or backhoes should work from the sides to grade and excavate the open channels to the appropriate design dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the open channel area. If constructing a dry swale, the bottom of the swale should be ripped, roto-tilled or otherwise scarified to promote greater infiltration.

Step 4: (*for Dry Swales*) If constructing a dry swale, place an acceptable filter fabric on the underground (excavated) sides of the dry swale with a minimum 6 inch overlap. Place the stone needed for storage layer over the filter bed. Perforate the underdrain pipe and check its slope. Add the remaining stone jacket, and then pack #57 stone to 3 inches above the top of the underdrain, and then add 3 inches of pea gravel as a filter layer. Add the soil media in 12-inch lifts until the desired top elevation of the dry swale is achieved. Water thoroughly and add additional media as needed where settlement has occurred.

Step 4: **(*Optional, for grass channels*)** Add soil amendments as needed. Till the bottom of the grass channel to a depth of 1 foot and incorporate compost amendments according to *Appendix C.*

Step 5: Install check dams, driveway culverts, and internal pretreatment features as shown on the plan. Fill material used to construct check dams should be placed in 8 to 12-inch lifts and compacted to prevent settlement. The top of each check dam should be constructed level at the design elevation.

Step 6: Hydro-seed the bottom and banks of the open channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to the South Carolina BMP Handbook (SDHEC, 2005).

Step 7: Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

Step 8: Conduct the final construction inspection and develop a punchlist for facility acceptance.

Open Channel Construction Inspection. Inspections during construction are recommended to ensure that the open channel is built in accordance with these specifications.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of dry swale installation:

- ✧ Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side-slopes.
- ✧ Inspect check dams and pretreatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- ✧ For dry swale designs:
  - Check the filter media to confirm that it meets specifications and is installed to the correct depth.
  - Check elevations such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.
  - Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- ✧ Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of an open channel occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows, or fully concentrated flows assumed in the plan actually occur in the field. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams). Also, inspectors should check that dry swale practices drain completely within the minimum 6-hour drawdown period.

Open Channel Maintenance Criteria

Maintenance is a crucial element that ensures the long-term performance of open channels. Once established, grass channels have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams, and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover. Dry swale designs may require regular pruning and management of trees and shrubs. The surface of dry swale filter beds can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pretreatment cells.

Table 4.8-6. Suggested Maintenance Activities and Schedule for Open Channels

Maintenance Activity	Schedule
♦ Mow grass channels and dry swales during the growing season to maintain grass heights in the 4" to 6" range, but no greater than 1/3 of the grass height during any one mowing.	As needed
♦ Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. ♦ Ensure that the contributing drainage area is stabilized. Perform spot-reseeding if/where needed. ♦ Remove accumulated sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. ♦ Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
♦ Add reinforcement planting to maintain 90% turf cover. Reseed any dead spots in vegetation. ♦ Remove any accumulated sand or sediment deposits behind check dams. ♦ Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove trash or blockages at weepholes. ♦ Examine channel bottom for evidence of erosion, braiding, excessive ponding or dead grass. ♦ Check inflow points for clogging and remove any sediment. ♦ Inspect side slopes and grass filter strips for evidence of any rill or gully erosion and repair. ♦ Look for any bare soil or sediment sources in the contributing drainage area and stabilize immediately.	Annual inspection

An example maintenance checklist for the different types of open channels is included in *Appendix F*.

Open Channel Systems References and Additional Resources

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4.9 Stormwater Filtering Systems

Introduction

Stormwater filtering systems are practices that capture and temporarily store the design storm volume and pass it through a filter bed of sand media. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate into the soil.

Stormwater filters are a useful practice to treat stormwater runoff from small, highly impervious sites (see Key Considerations). Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system. The filter consists of two chambers: the first is devoted to settling, and the second serves as a filter bed consisting of a sand filter media.

Stormwater filters are a versatile option because they consume very little surface land and have few site restrictions. They provide moderate pollutant removal performance at small sites where space is limited. However, filters have no retention capability, so designers should consider using up-gradient retention practices, which have the effect of decreasing the design storm volume and size of the filtering practices. Filtering practices are also suitable to provide special treatment at designated stormwater hotspots.

Typically, filtering systems should not be designed to provide stormwater detention of larger storm events, but can be in some circumstances. Filtering practices are generally combined with separate facilities to provide this type of control. However, the three-chamber underground sand filter can be modified by expanding the first or settling chamber, or adding an extra chamber between the filter chamber and the clear well chamber to handle the detention volume, which is subsequently discharged at a pre-determined rate through an orifice and weir combination.

Figure 4.9-1. Perimeter Sand Filter (Photo: CWP)

Although several design variants exist, the perimeter Sand Filter is discussed in this section, as it is well adapted to the flat topography and (often) high water table typical in the coastal plain.

Perimeter sand filters (Figures 4.9-1 and 4.9-2) are enclosed stormwater management practices that are typically located just below grade in a trench along the perimeter of parking lot, driveway or other impervious surface. Perimeter sand filters consist of a pretreatment forebay and a filter bed chamber. Stormwater runoff is conveyed into a perimeter sand filter through grate inlets located directly above the system.

KEY CONSIDERATIONS: STORMWATER FILTERING SYSTEMS

DESIGN CRITERIA:

- The drainage area cannot exceed 2 acres.
- Must drain completely within 72 hours of the end of a rainfall event.
- A maximum ponding depth of 12 inches is recommended to help prevent the formation of nuisance ponding conditions.
- Requires at least 2 feet of head.

BENEFITS:

- Achieves moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff.
- Filtrations systems are ideal for intercepting and treating stormwater runoff from small, highly impervious areas, including stormwater hotspots.

LIMITATIONS:

- Construction and maintenance costs are relatively high.
- Cannot “receive” stormwater runoff that contains high sediment loads.

SITE APPLICABILITY:

- Suburban Use
- Urban Use
- Construction Cost: High
- Maintenance: High
- Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 0% credit for runoff reduction

Coastal Zone Credit Approach

- 100% credit for storage volume of practice

Statewide Water Quality Requirement Credit Approach

- 1” of runoff must be managed

Pollutant Removal[1]
90%- Total Suspended Solids
65% - Total Phosphorus
45% - Total Nitrogen
50% - Metals
80% - Pathogens

[1] *expected annual pollutant load removal*

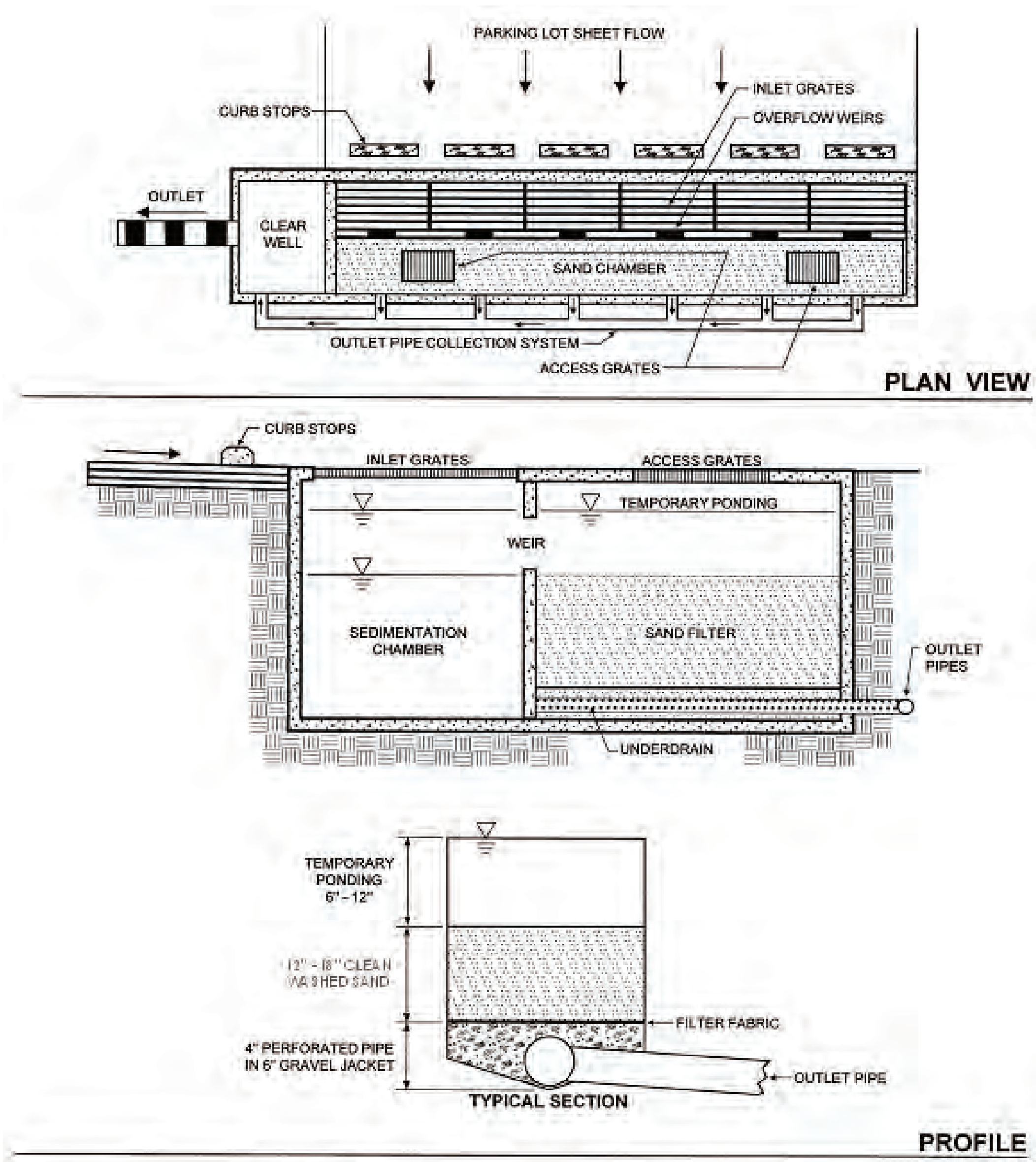


Figure 4.9-2. Perimeter Sand Filter Detail. Note: Material specifications are indicated in Table 4.9-1.

Filtering Feasibility Criteria

Stormwater filters can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served; however, there are situations where they clearly may be the best option for stormwater treatment (e.g., hotspot runoff treatment, small parking lots, ultra-urban areas, etc.). The following criteria apply to filtering practices:

Available Hydraulic Head. The principal design constraint for stormwater filters is available hydraulic head, which is defined as the vertical distance between the top elevation of the filter and the bottom elevation of the existing storm drain system that receives its discharge. Typically, a minimum of 2 feet of head is required for perimeter sand filters.

Depth to Water Table and Bedrock. The designer must assure a standard separation distance of at least 0.5 feet between the seasonally high groundwater table and/or bedrock layer and the bottom invert of the filtering practice.

Contributing Drainage Area. Perimeter sand filters should only be used to treat runoff from sites smaller than 2 acres, with nearly 100% impervious cover.

Space Required. This practice consumes almost no surface area, except for necessary manholes and surface grates.

Land Use. Filtration practices are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other applications include redevelopment of commercial sites or when existing parking lots are renovated or expanded. Filtration practices can work on most commercial, industrial, institutional, or municipal sites and can be located underground if surface area is not available.

Floodplains. Filtration practices should be constructed outside the limits of the mapped 100-year floodplain, unless a waiver is obtained from the local authority.

Site Topography. Filters shall not be located on slopes greater than 6 percent.

Facility Access. All filtering systems shall be located in areas where they are accessible for inspection and for maintenance (by vacuum trucks).

Soils. Soil conditions do not constrain the use of filters. At least one soil boring should be taken within the footprint of the proposed filtering practice to establish the water table and evaluate soil suitability. A geotechnical investigation should be conducted for underground practices such as the perimeter sand filter.

Location Factors. Maintenance requirements for underground sand filters can be significant. Filters may be considered for high density residential areas, but should be maintained by a contractor through a community association.

Setbacks. Filters should be set back at least 10 feet from the property line, and the bottom of the practice should be separated from groundwater by at least 0.5 feet.

Economic Considerations. Perimeter sand filters are expensive relative to other treatment practices, but may be the only option to treat small hotspot drainage areas.

Filtering Conveyance Criteria

Perimeter sand filters are designed as off-line systems so that all flows enter the filter storage chamber until it reaches capacity, at which point larger flows are then diverted or bypassed around the filter to an outlet chamber and are not treated. Runoff from larger storm events must be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for filtering practices.

Stormwater filters should be designed to drain or dewater within 72 hours after a storm event to reduce the potential for nuisance conditions.

Filtering Pretreatment Criteria

Adequate pretreatment is needed to prevent premature filter clogging and ensure filter longevity. Perimeter sand filters are typically designed with a wet pretreatment chamber that is parallel to the filter.

- ✧ Sedimentation chambers are typically used for pretreatment to capture coarse sediment particles before they reach the filter bed.
- ✧ The chamber should be sized to accommodate at least 25 percent of the total design storm volume (inclusive).
- ✧ Sediment chambers should be designed as level spreaders such that inflows to the filter bed have near zero velocity and spread runoff evenly across the bed.

Filtering Design Criteria

Detention time. All filter systems should be designed to drain the design storm volume from the filter chamber within 72 hours after each rainfall event.

Structural Requirements. If a filter will be located underground or experience traffic loads, a licensed structural engineer must certify the structural integrity of the design.

Geometry. Filters are gravity flow systems that normally require ponding above the filter bed. The perimeter sand filter is designed to require minimal hydraulic head, but needs between 6 and 12” of ponding above the filter bed. The design should allow sufficient hydraulic head to include ponding, the filter bed, and the underdrain pipe below the filter.

Type of Filter Media. The normal filter media consists of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter.

Depth of Filter Media. The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. The recommended filter bed depth is 18 inches. An absolute minimum filter bed depth of 12 inches above underdrains is required; however, designers should note that specifying the minimum depth of 12 inches will incur a more intensive maintenance schedule, possibly resulting in greater costs.

Underdrain and Liner. Stormwater filters are normally designed with an impermeable liner and underdrain system that meet the specification criteria provided in Table 4.9-1.

Underdrain Stone. The underdrain should be covered by a minimum 6-inch gravel layer consisting of clean, washed No. 57 stone.

Maintenance Reduction Features. The following maintenance issues should be addressed during filter design to reduce future maintenance problems:

- **Observation Wells and Cleanouts.** Non-structural and surface sand filters must include an observation well consisting of a 6-inch diameter non-perforated PVC pipe fitted with a lockable cap. It should be installed flush with the ground surface to facilitate periodic inspection and maintenance. In most cases, a cleanout pipe will be tied into the end of all underdrain pipe runs. The portion of the cleanout pipe/observation well in the underdrain layer should be perforated. At least one cleanout pipe must be provided for every 2000 square feet of filter surface area.
- **Access.** Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. "Sufficient access" is operationally defined as the ability to get a vacuum truck or similar equipment close enough to the sedimentation chamber and filter to enable cleanouts. Direct maintenance access shall be provided to the pretreatment area and the filter bed. For underground structures, sufficient headroom for maintenance should be provided. A minimum head space of 5 feet above the filter is recommended for maintenance of the structure. However, if 5 feet headroom is not available, manhole access must be installed.
- **Manhole Access (for Underground Filters).** Underground Filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur.
- **Visibility.** Stormwater filters should be clearly visible at the site so inspectors and maintenance crews can find them easily. Adequate signs or markings must be provided at manhole access points for Underground Filters.
- **Confined Space Issues.** Underground Filters are often classified as a confined space. Consequently, special OSHA rules apply, and training may be needed to protect the workers that access them. These procedures often involve training about confined space entry, venting, and the use of gas probes.

Filter Material Specifications. The basic material specifications for filtering practices that utilize sand as a filter media are outlined in Table 4.9-1.

Table 4.9-1 Filtering Practice Material Specifications	
Material	**Specification**
Surface Cover	Use clean, washed No. 57 stone on top of the sand layer.
Sand	Use clean AASHTO M-6/ASTM C-33 medium aggregate concrete sand with a particle size range of 0.02 to 0.04 inch in diameter.
Geotextile/Filter Fabric	Use an appropriate geotextile fabric that meets AASHTO M-288 Class 2, latest edition, requirements.
Underdrain/Perforated Pipe	Use 4- or 6-inch perforated schedule 40 PVC pipe, with ⅜-inch perforations at 6 inches on center.
Underdrain Stone	Use #57 stone or the ASTM equivalent (1 inch maximum).
Impermeable Liner	Where appropriate, use a thirty mil (minimum) PVC Geomembrane.

Filter Sizing. Filtering devices are sized to accommodate a specified design storm volume (typically the WQV). The volume to be treated by the device is a function of the storage depth above the filter and the surface area of the filter. The storage volume is the volume of ponding above the filter. For a given design volume, Equation 4.9-1 below is used to determine the required filter surface area.

Equation 4.9-1. Minimum Filter Surface Area for Filtering Practices

$$SA_{filter} = \frac{DesignVolume \times d_f}{k \times (h_{avg} + d_f) \times t_f}$$

where:

SA_{filter} = area of the filter surface (ft^2)

$DesignVolume$ = design storm volume, typically the WQV (ft^3)

d_f = filter media depth (thickness) (ft), with a minimum of 1 ft

k = coefficient of permeability (ft/day), 3.5 ft/day for partially clogged sand

h_{avg} = average height of water above the filter bed (ft)

t_f = Allowable drawdown time (1.67 days)

The coefficient of permeability (ft/day) is intended to reflect the worst case situation (i.e., the condition of the sand media at the point in its operational life where it is in need of replacement or maintenance). Filtering practices are therefore sized to function within the desired constraints at the end of the media's operational life cycle.

The filter treatment system must be designed to hold at least 25 percent of the design storm volume in temporary ponding prior to filtration (Equation 4.9-2). This volume takes into account the varying filtration rate of the water through the media, as a function of a gradually declining hydraulic head.

Equation 4.9-2 Required Ponding Volume for Filtering Practices

$$V_{ponding} = 0.25 \times DesignVolume$$

where:

$V_{ponding}$ = storage volume required prior to filtration (ft^3)

The total storage volume for the practice (*Sv*) can be determined using Equation 4.9-3 below.

Equation 4.9-3 Storage Volume for Filtering Practices

$$Sv = 4.0 \times V_{ponding}$$

In the LID Compliance Calculator spreadsheet, filtering practices are not assigned any runoff reduction credit. For projects in the Coastal Zone, the Sv for filtering practices is given a 100% credit toward the storage requirement. For the statewide water quality requirements, filtering practices are credited in a similar manner as a pond without a permanent pool, and at least 1 inch of runoff must be treated.

Filtering Landscaping Criteria

No landscaping is necessary for perimeter sand filters.

Filtering Construction Sequence

Erosion and Sediment Control. No runoff shall be allowed to enter the filter system prior to completion of all construction activities, including revegetation and final site stabilization. Construction runoff shall be treated in separate sedimentation basins and routed to bypass the filter system. Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials must be removed and replaced with new, clean filter materials before a regulatory inspector approves its completion. The approved erosion and sediment control plans shall include specific measures to provide for the protection of the filter system before the final stabilization of the site.

Filter Installation. The following is the typical construction sequence to properly install a structural sand filter. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity, and configuration of the proposed filtering application.

Step 1: Stabilize Drainage Area. Filtering practices should only be constructed after the contributing drainage area to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed filtering area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is complete, the sediment control facility will be dewatered, dredged, and regraded to design dimensions for the post-construction filter.

Step 2: Install E&S Controls for the Filtering Practice. Stormwater should be diverted around filtering practices as they are being constructed. This is usually not difficult to accomplish for off-line filtering practices. It is extremely important to keep runoff and eroded sediments away from the filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the filter, and erosion control fabric may be needed during construction on exposed side-slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the filtering practice should be rapidly stabilized by hydro-seed, sod, mulch, or other method.

Step 3: Assemble Construction Materials on-site. Make sure they meet design specifications and prepare any staging areas.

Step 4: Clear and Strip the project area to the desired subgrade.

Step 5: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the filtering practice.

Step 6: Install the Filter Structure and check all design elevations (i.e., concrete vaults for surface, underground, and perimeter sand filters). Upon completion of the filter structure shell, inlets and outlets must be temporarily plugged and the structure filled with water to the brim to demonstrate water tightness. Maximum allowable leakage is 5 percent of the water volume in a 24-hour period. If the structure fails the test, repairs must be performed to make the structure watertight before any sand is placed into it.

Step 7: Install the gravel, underdrains, and choker layer of the filter.

Step 8: Spread Sand Across the Filter Bed in 1-foot lifts up to the design elevation. Backhoes or other equipment can deliver the sand from outside the filter structure. Sand should be manually raked. Clean water is then added until the sedimentation chamber and filter bed are completely full. The facility is then allowed to drain, hydraulically compacting the sand layers. After 48 hours of drying, refill the structure to the final top elevation of the filter bed.

Step 9: Stabilize Exposed Soils on the perimeter of the structure with permanent seeding, as appropriate.

Step 10: Conduct the final construction inspection. Multiple construction inspections by a qualified professional are critical to ensure that stormwater filters are properly built. Inspections are recommended during the following stages of construction:

- ✧ Initial site preparation, including installation/Erosion and Sediment (E&S) controls
- ✧ Excavation/grading to design dimensions and elevations
- ✧ Installation of the filter structure, including the water tightness test
- ✧ Installation of the underdrain and filter bed
- ✧ Final inspection after a rainfall event to ensure that it drains properly and all pipe connections are watertight. Develop a punch list for facility acceptance.

Filtering Maintenance Criteria

Maintenance of filters is required and involves several routine tasks, which are outlined in Table 4.9-2 below. A cleanup should be scheduled at least once a year to remove trash and floatables that accumulate in the pretreatment cells and filter bed. Frequent sediment cleanouts in the dry and wet sedimentation chambers are recommended every 1 to 3 years to maintain the function and performance of the filter. If the filter treats runoff from a stormwater hotspot, crews may need to test the filter bed media before disposing of the media and trapped pollutants. Petroleum hydrocarbon contaminated sand or filter cloth must be disposed of in compliance with state and local disposal requirements. Testing is not needed if the filter does not receive runoff from a designated stormwater hotspot, in which case the media can be safely disposed of in a landfill.

Table 4.9-2 Typical Annual Maintenance Activities for Filtering Practices

Frequency	Maintenance Tasks
2 times per year (may be more or less frequently depending on land use)	♦ Check to see if sediment accumulation in the sedimentation chamber has exceeded 6 inches. If so, schedule a cleanout.
Annually	♦ Conduct inspection and cleanup. ♦ Dig a small test pit in the filter bed to determine whether the first 3 inches of sand are visibly discolored and need replacement. ♦ Check to see if inlets and flow splitters are clear of debris and are operating properly. ♦ Check concrete structures and outlets for any evidence of spalling, joint failure, leakage, corrosion, etc. ♦ Ensure that the filter bed is level and remove trash and debris from the filter bed. Sand or gravel covers should be raked to a depth of 3 inches.
Every 5 years	♦ Replace top sand layer. ♦ Till or aerate surface to improve infiltration/grass cover.
As needed	♦ Remove blockages and obstructions from inflows. Trash shall be removed regularly to ensure the inflow capacity of the BMP is preserved. ♦ Stabilize contributing drainage area and side-slopes to prevent erosion.
Upon failure	♦ Corrective maintenance is required any time the sedimentation basin and sediment trap do not draw down completely after 72 hours (i.e., no standing water is allowed).

Regular inspections by a qualified professional are critical to schedule sediment removal operations, replace filter media, and relieve any surface clogging. Frequent inspections are especially needed for underground and perimeter filters, since they are out of sight and can be easily forgotten. Depending on the level of traffic or the particular land use, a filter system may either become clogged within a few months of normal rainfall or could possibly last several years with only routine maintenance. Maintenance inspections should be conducted within 24 hours following a storm that exceeds ½-inch of rainfall, to evaluate the condition and performance of the filtering practice. Note: Without regular maintenance, reconditioning sand filters can be very expensive.

An example maintenance checklist for filtering practices is included in *Appendix F*.

Stormwater Filtering Systems References and Additional Resources

1. Atlanta Regional Commission (ARC). 2001. Georgia Stormwater Management Manual, First Edition. Available online at: http://www.georgiastormwater.com
2. Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. http://www.sciencetime.org/ConstructedClimates/wp-content/uploads/2013/01/ClaytorSchueler1996.pdf
3. Hirschman, D., Collins, K., and T. Schueler. 2008. Technical Memorandum: The Runoff Reduction Method. Center for Watershed Protection and Chesapeake Stormwater Network. Ellicott City, MD.
4. Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban Stormwater Retrofit Practices, Version 1.0, Urban Subwatershed Restoration Manual No. 3.

4.10 Dry Detention Practices

Introduction

Dry detention practices are explicitly designed to provide stormwater detention (2-year, 10-year, and 100-yr control).

Dry detention practices, also called dry ponds, are widely applicable for most land uses and are best suited for larger drainage areas. An outlet structure restricts stormwater flow so it backs up and is stored within the basin. The temporary ponding reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on the bed and banks of the receiving stream.

Detention vaults are box-shaped underground stormwater storage facilities typically constructed with reinforced concrete. Detention tanks are underground storage facilities typically constructed with large diameter metal or plastic pipe. Both serve as an alternative to surface dry detention for stormwater quantity control, particularly for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area. Prefabricated concrete vaults are available from commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems.

Dry detention practices are credited differently than other BMPs. In order to meet water quality requirements, they must store and release the first 1 inch of runoff over 24 hours. They may also be used solely for detention of larger storm events when water quality treatment is achieved by other BMPs.

Figure 4.10-1. Dry Extended Detention Pond (Photo: Center for Watershed Protection)

KEY CONSIDERATIONS: DRY DETENTION PRACTICES	
DESIGN CRITERIA: ♦ Store and release the first 1 inch of runoff over 24 hours. ♦ Design with sufficient volume to detain design storms (typically the 2-, 10- and 100-year storms). ♦ Provide sufficient maintenance access. ♦ Provide freeboard and an emergency overflow for the 100-year storm event. **BENEFITS:** ♦ Reduces post-construction stormwater runoff rates. ♦ Is a cost-effective flood control practice. **LIMITATIONS:** ♦ Dry ponds are best suited to drainage areas greater than 10 acres. ♦ Does not reduce runoff volumes and provides less pollutant removal than other practices.	**STORMWATER MANAGEMENT PRACTICE PERFORMANCE:** **Runoff Reduction Credit Approach** (applies to Shellfish Bed, SMS4, and infiltration credit approaches) ▶ 0% credit for runoff reduction **Coastal Zone Credit Approach** ▶ 100% credit for storage volume of practice **Statewide Water Quality Requirement Credit Approach** ▶ 1" of runoff must be stored and released over 24 hours **Pollutant Removal**[1] N/A - Total Suspended Solids N/A - Total Phosphorus N/A - Total Nitrogen N/A - Metals N/A - Pathogens [1] Available data suggest minimal pollutant removal.
SITE APPLICABILITY: ♦ Rural Use ♦ Suburban Use ♦ Urban Use ♦ Construction Cost: low ♦ Maintenance: low ♦ Area Required: low	

Dry Detention Practice Feasibility Criteria

The following feasibility issues need to be evaluated when dry detention practices are considered as the final practice in a treatment train:

Space Required. A typical dry detention practice requires a footprint of 1% to 3% of its contributing drainage area, depending on the depth of the pond or storage vault (i.e., the deeper the practice, the smaller footprint needed).

Contributing Drainage Area. A contributing drainage area of at least 10 acres is preferred for dry ponds in order to keep the required orifice size from becoming a maintenance problem. Designers should be aware that small "pocket" ponds typically will:

1. Have very small orifices that will be prone to clogging
2. Experience fluctuating water levels such that proper stabilization with vegetation is very difficult
3. Generate more significant maintenance problems

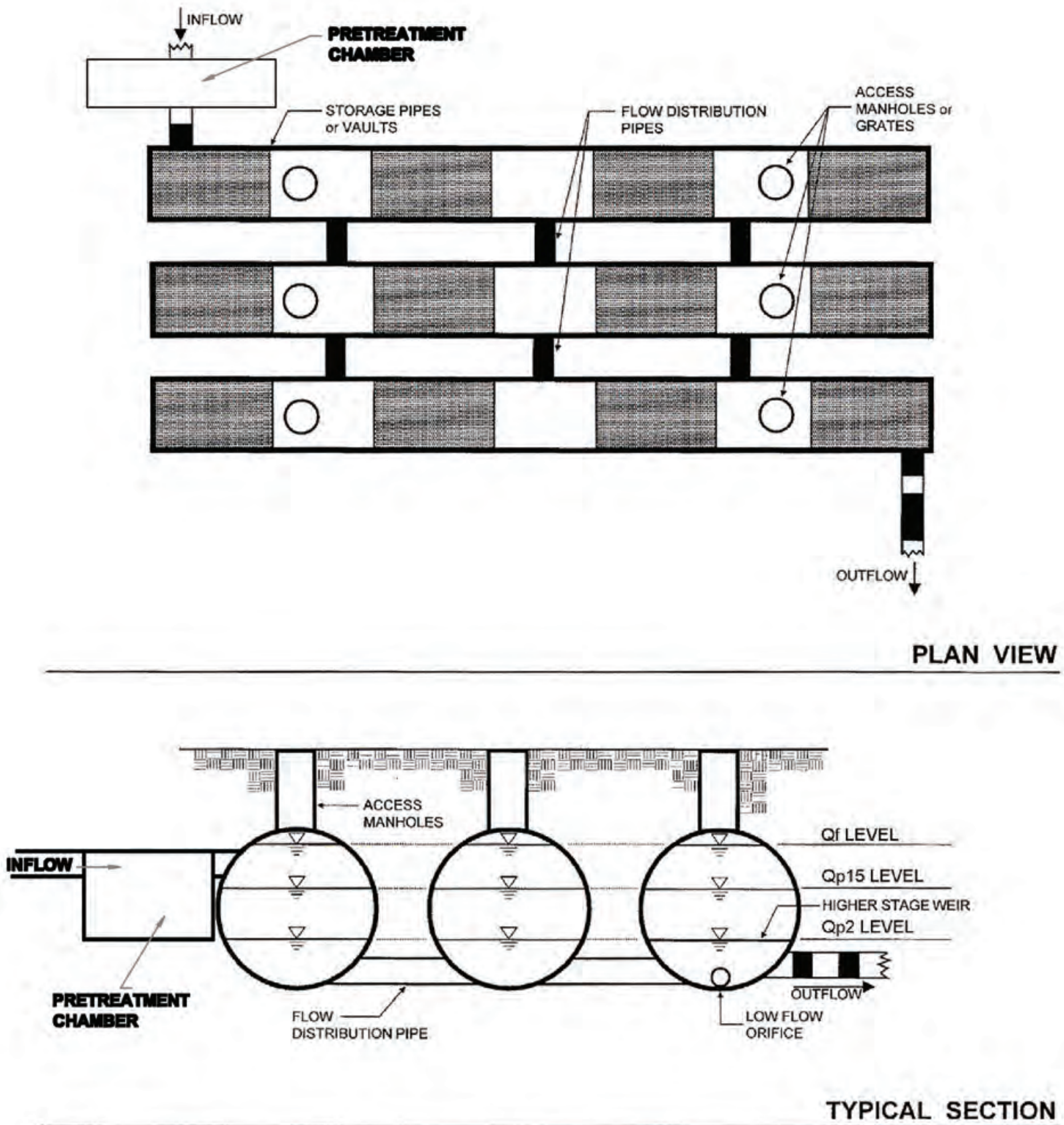
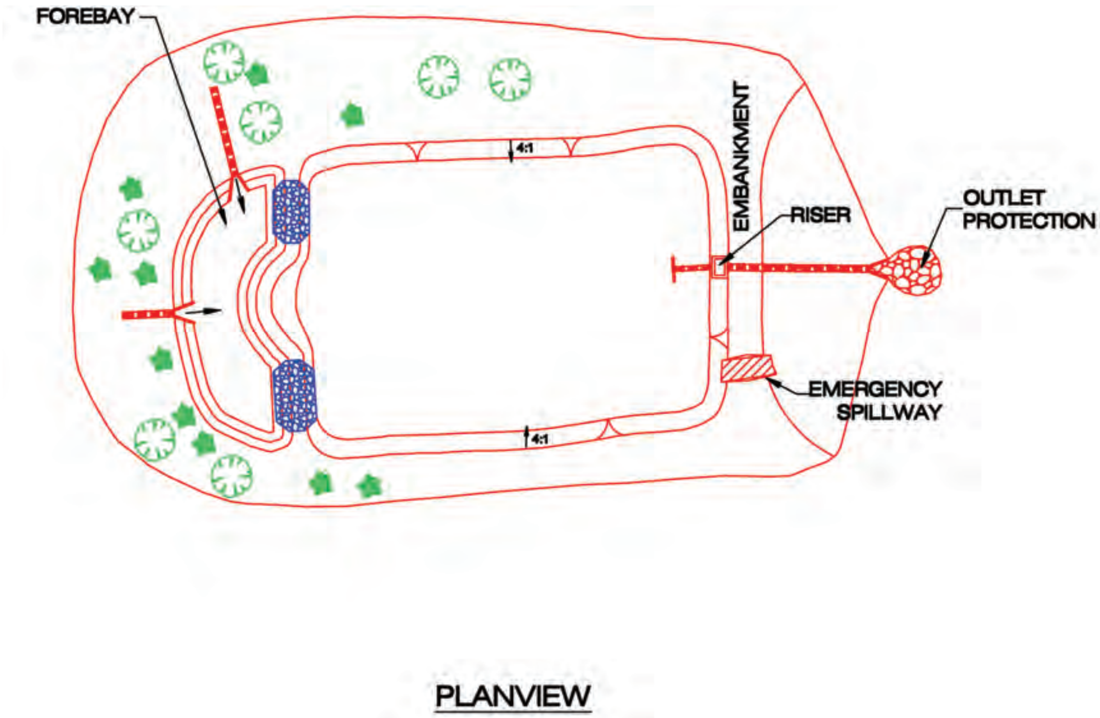


Figure 4.10-2. Example of an underground detention vault and/or tank



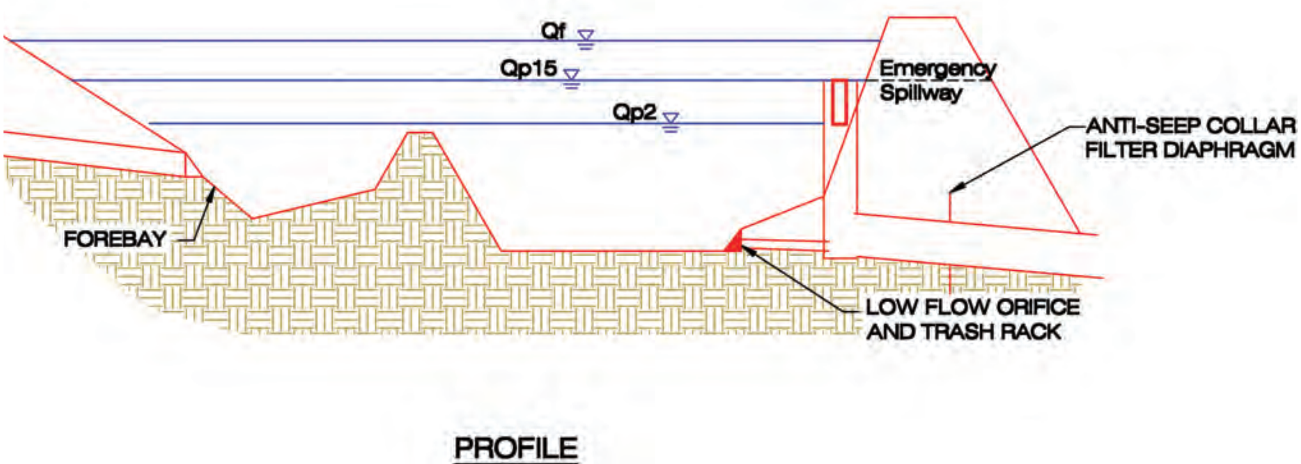


Figure 4.10-3. Example of a Dry Detention Pond

Underground detention systems can be located downstream of other structural stormwater controls providing treatment of the design storm. For treatment train designs where upland practices are utilized for treatment of the water quality volume (WQV), designers can use a site-adjusted Rv or CN that reflects the volume reduction of upland practices and likely reduce the size and cost of detention.

Available Hydraulic Head. The depth of a dry detention practice is usually determined by the amount of hydraulic head available at the site (dimension between the surface drainage and the bottom elevation of the site). The bottom elevation is normally the invert of the existing downstream conveyance system to which the dry detention practice discharges. Depending on the size of the development and the available surface area of the basin, as much as 6 to 8 feet of hydraulic head may be needed for a dry detention practice to function properly for storage. An underground practice will require sufficient head room to facilitate maintenance, at least 5 feet depending on the design configuration.

Minimum Setbacks. Generally, dry detention practices should be set back at least 10 feet from property lines, and 10 feet down-gradient from building foundations.

Depth-to-Water Table and Bedrock. Dry ponds are not allowed if the water table or bedrock will be within 0.5 feet of the floor of the pond. For underground detention facilities, an anti-flotation analysis should be performed to check for buoyancy problems in the high water table areas.

Tidal Impacts. The outlet of a dry detention practice should be located above the tidal mean high water elevation. In tidally impacted areas, detention practices may have minimal benefit, and requesting a variance for detention requirements may be an option.

Tailwater Conditions. The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the dry detention practice.

Soils. The permeability of soils is seldom a design constraint for dry detention practices. Soil infiltration tests should be conducted at proposed dry pond sites to estimate infiltration rates and patterns, which can be significant in Hydrologic Soil Group (HSG) A soils and some group B soils. Infiltration through the bottom of the pond is typically encouraged, unless it may potentially migrate laterally thorough a soil layer and impair the integrity of the embankment or other structure.

Structural Stability. Underground detention vaults and tanks must meet structural requirements for overburden support and traffic loading if appropriate.

Geotechnical Tests. At least one soil boring should be taken at a low point within the footprint of any proposed dry detention practice to establish the water table and bedrock elevations and evaluate soil suitability. A geotechnical investigation is recommended for all underground BMPs, including underground storage systems. Geotechnical testing requirements are outlined in *Appendix C*.

Utilities. For a dry pond system, no utility lines should cross any part of the embankment where the design water depth is greater than 2 feet. Typically, utilities require a minimum 5-foot horizontal clearance from storage facilities.

Perennial Streams. Locating dry ponds on perennial streams will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Economic Considerations. Underground detention can be expensive, but often allows for greater use of a development site. Dry detention ponds are generally inexpensive to construct and maintain. Depending upon the type of development, dry detention practices may be required to treat a larger volume of water than other BMPs. Dry detention practices must store 1 inch of runoff from the site, whereas infiltration practices and other LID BMPs must capture 1 inch of runoff from only the impervious cover on a site.

Dry Detention Practice Conveyance Criteria

Designers should use accepted hydrologic and hydraulic routing calculations to determine the required storage volume and an appropriate outlet design for dry detention practices. For management of the 2-year storm, a control structure with a trash rack designed to release the required pre-development discharge rate should be provided. Ideally, the channel protection orifice should have a minimum diameter of 3 inches in order to pass minor trash and debris. However, where smaller orifices are required, the orifice should be adequately protected from clogging by an acceptable external trash rack

For overbank flood protection, an additional outlet is sized for control of the 10-year storm event, and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure.

Riprap, plunge pools or pads, or other energy dissipaters should be placed at the end of the outlet to prevent scouring and erosion and to provide a non-erosive velocity of flow from the structure to a water course. The design must specify an outfall that will be stable for the 10-year design storm event. The channel immediately below the practice outfall may need to be modified to prevent erosion. This is typically done by calculating channel velocities and flow depths, then placing appropriately sized riprap, over filter fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps depending on the channel lining material). The practice geometry and outfall design may need to be altered in order to yield adequate channel velocities and flow.

Flared pipe sections that discharge at or near the stream invert or into a step pool arrangement should be used at the spillway outlet. An outfall analysis should be included in the stormwater management plan showing discharge velocities down to the nearest downstream water course. Where indicated, the developer/contractor must secure an off-site drainage easement for any improvements to the downstream channel.

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge.

If discharge daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of riprap should be avoided.

The final release rate of the facility should be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow.

The following ***additional*** conveyance criteria apply to underground detention:

- ✧ An internal or external high flow bypass or overflow should be included in the underground detention designs to safely pass the extreme flood flow.

The following ***additional*** conveyance criteria apply to dry ponds:

- ✧ **Primary Spillway.** The primary spillway should be designed with acceptable anti-flotation, anti-vortex, and trash rack devices. The spillway should generally be accessible from dry land. When reinforced concrete pipe is used for the principal spillway to increase its longevity, "O"-ring gaskets (ASTM C-361) should be used to create watertight joints, and they should be inspected during installation. The risk of clogging in outlet pipes with small orifices can be reduced by:
  - Providing a micropool at the outlet structure.
    - Use a reverse-sloped pipe that extends to a mid-depth of the permanent pool or micropool.
    - Install a downturned elbow or half-round CMP over a riser orifice (circular, rectangular, V-notch, etc.) to pull water from below the micropool surface.
    - The depth of the micropool should be at least 4 feet deep, and the depth should not draw down by more than 2 feet during a 30 day summer drought.
  - Providing an over-sized forebay to trap sediment, trash and debris before it reaches the dry pond's low-flow orifice.
  - Installing a trash rack to screen the low-flow orifice.
  - Using a perforated pipe under a gravel blanket with an orifice control at the end in the riser structure.
- ✧ **Emergency Spillway.** Dry ponds should be constructed with overflow capacity to safely pass the 100-year design storm event through either the primary spillway or a vegetated or armored emergency spillway.
- ✧ **Inlet Protection.** Inflow points into dry pond systems should be stabilized to ensure that non-erosive conditions exist during storm events up to the 10-year storm event.

Storage Pretreatment Criteria

Dry Pond Pretreatment Forebay. A forebay should be located at each major inlet to a dry pond to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to dry pond forebay design:

- ✧ A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the dry detention practice's contributing drainage area.
- ✧ The forebay consists of a separate cell, formed by an acceptable barrier. (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- ✧ The forebay should be sized to contain at least 0.1 inches of runoff.
- ✧ The forebay should be designed in such a manner that it acts as a level spreader to distribute runoff evenly across the entire bottom surface area of the main storage cell.
- ✧ Exit velocities from the forebay should be non-erosive or an armored overflow should be provided. Recommended non-erosive velocities are 4 feet per second for the two-year event, and 6 feet per second for the 10-year event.
- ✧ The bottom of the forebay may be hardened (e.g., concrete, asphalt, or grouted riprap) in order to make sediment removal easier.

✧ Direct maintenance access for appropriate equipment should be provided for each forebay.

Underground Detention Pretreatment. A pretreatment structure (sediment sump or vault chamber), sized to capture 0.1 inches of runoff should be provided at the inlet for underground detention systems.

Storage Design Criteria

Dry Pond Internal Design Features. The following apply to dry pond design:

✧ **No Pilot Channels.** Dry ponds must not have a low flow pilot channel, but instead must be constructed in a manner whereby flows are evenly distributed across the pond bottom, to avoid scour, promote attenuation and, where possible, infiltration. A pilot channel often allows runoff from small storms to pass quickly through a stormwater pond without receiving any treatment or peak flow attenuation. Without a pilot channel, runoff from even small storms will spread across the surface of the detention pond. For maintenance purposes, it should be noted that soils may stay wetter between storm events with this design.

✧ **Internal Slope.** The maximum longitudinal slope through the pond should be approximately 0.5% to 1%. The surface of the pond should be as flat as possible so as to allow runoff from even the smallest storms to spread out evenly across the entire pond surface.

✧ **Side Slopes.** Side slopes within the dry pond should generally have a gradient of 3H:1V to 4H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. Ponds with side slopes steeper than 5H:1V should be fenced and include a lockable gate.

✧ **Long Flow Path.** Dry pond designs should have an irregular shape and a long flow path distance from inlet to outlet to increase water residence time, treatment pathways, pond performance, and to eliminate short-cutting. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond, and (2) the length of the shortest flow path (Hirschman et al., 2009):

- The *overall flow path* can be represented as the length-to-width ratio OR the flow path ratio. These ratios should be at least 2L:1W (3L:1W preferred). Internal berms, baffles, or topography can be used to extend flow paths and/or create multiple pond cells.
- The *shortest flow path* represents the distance from the closest inlet to the outlet. The ratio of the shortest flow to the overall length should be at least 0.4. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these "closer" inlets should constitute no more than 20% of the total contributing drainage area.

Safety Features. The following safety features should be considered for dry detention practices:

✧ The principal spillway opening should be designed and constructed to prevent access by small children.

- ✧ End walls above pipe outfalls greater than 48 inches in diameter should be fenced at the top of the wall to prevent a falling hazard.
- ✧ Dry detention practices should incorporate an additional 1 foot of freeboard above the emergency spillway.
- ✧ The emergency spillway should be located so that downstream structures will not be impacted by spillway discharges
- ✧ Underground maintenance access should be locked at all times.

Maintenance Access. All dry detention practices should be designed so as to be accessible to annual maintenance. A 5:1 slope and 15-foot wide entrance ramp is recommended for maintenance access to dry ponds. Also, adequate maintenance access must be provided for all underground detention systems. Access must be provided over the inlet pipe and outflow structure. Access openings can consist of a standard 30-inch diameter frame, grate and solid cover, or a hinged door or removable panel.

Outlets. Trash racks should be provided for low-flow pipes and for risers not having anti-vortex devices.

In order to reduce maintenance problems for small orifices, a standpipe design can be used that includes a smaller inner standpipe with the required orifice size, surrounded by a larger standpipe with multiple openings, and a gravel jacket surrounding the larger standpipe. This design will reduce the likelihood of the orifice being clogged by sediment.

Detention Vault and Tank Materials. All construction joints and pipe joints must be water tight. Cast-in-place wall sections should be designed as retaining walls. The maximum depth from finished grade to the vault invert should be 20 feet. Manufacturer's specifications should be consulted for underground detention structures.

Anti-floatation Analysis for Underground Detention. Anti-flotation analysis is required to check for buoyancy problems in the high water table areas. Anchors should be designed to counter the pipe and structure buoyancy by at least a 1.2 factor of safety.

Dry Detention Practice Sizing. For water quality purposes, the storage volume, *Sv*, for a dry detention practice is the volume of water that is stored, and released slowly over 24 hours – extended detention (The *Sv* does not include the 2-year or 10-year detention volumes.). To fully treat the water quality volume with at dry detention practice, the *Sv* must be equal to 1 inch of runoff from the site.

In the LID Compliance Calculator spreadsheet, dry detention practices are not assigned any runoff reduction credit. For projects in the Coastal Zone, the Sv for dry detention practices is given a 100% credit toward the storage requirement. For the statewide water quality requirements, dry detention practices are credited as a pond without a permanent pool, and at least 1 inch of runoff must be stored and released over 24 hours.

Dry detention practices should be sized to control peak flow rates from the 2-year and 10-year frequency storm event or other design storm. Design calculations must ensure that the post-development peak discharge does not exceed the pre-development peak discharge.

For treatment train designs where upland practices are utilized for treatment of the water quality volume, designers can use a reduced Rv or CN that reflects the volume reduction of upland practices to compute the peak flows from larger storm events.

Dry Detention Practice Landscaping Criteria

No landscaping criteria apply to underground dry detention practices.

For dry ponds, a landscaping plan should be provided that indicates the methods used to establish and maintain vegetative coverage within the dry pond. Minimum elements of a plan include the following:

- ✧ Delineating pondscaping zones within the pond
- ✧ Selecting corresponding plant species
- ✧ Developing the planting plan
- ✧ Establishing the sequence for preparing the wetland bed, if one is incorporated with the dry pond (including soil amendments, if needed)
- ✧ Identifying the sources of native plant material
- ✧ Executing the planting plan (e.g., keeping mowable turf along the embankment and all access areas, but may allow parts of the pond to include unmowed grasses, shrubs, and trees). The wooded wetland concept proposed by Cappiella et al., (2005) may be a good option for many dry ponds.
- ✧ Preventing woody vegetation from being planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- ✧ Avoiding species that require full shade, or are prone to wind damage.

Dry Detention Practice Construction Sequence

Construction of underground storage systems must be in accordance with manufacturer's specifications. All runoff into the system should be blocked until the site is stabilized. The system must be inspected and cleaned of sediment after the site is stabilized.

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

Step 1: Use of Dry Pond for Erosion and Sediment Control. A dry pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (erosion and sediment control requirement vs. water quality treatment requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction dry pond in mind. The bottom elevation of the dry pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a dry pond.

Step 2: Stabilize the Drainage Area. Dry ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the proposed dry pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be dewatered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 3: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 4: Clear and Strip the project area to the desired sub-grade.

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

Step 6: Install the Spillway Pipe.

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

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

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

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

Step 11: Install Outlet Pipes, including downstream riprap apron protection.

Step 12: Stabilize Exposed Soils. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

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

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

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

Dry Detention Practice Maintenance Criteria

Typical maintenance activities for dry detention practices are outlined in Table 4.10-1. Maintenance requirements for underground storage facilities will generally require quarterly visual inspections from the manhole access points to verify that there is no standing water or excessive sediment buildup. Entry into the system for a full inspection of the system components (pipe or vault joints, general structural soundness, etc.) should be conducted annually. Confined space entry credentials are typically required for this inspection.

Table 4.10-1. Typical maintenance activities for dry detention practices

Maintenance Activity	Schedule
♦ Water dry pond side slopes to promote vegetation growth and survival.	As needed
♦ Remove sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. ♦ Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. ♦ Ensure that the contributing drainage area is stabilized. Perform spot-reseeding where needed. ♦ Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
♦ Measure sediment accumulation levels in forebay. Remove sediment when 50% of the forebay capacity has been lost. ♦ Inspect the condition of stormwater inlets for material damage, erosion or undercutting. Repair as necessary. ♦ Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine pond embankment integrity. ♦ Inspect outfall channels for erosion, undercutting, riprap displacement, woody growth, etc. ♦ Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc. ♦ Inspect condition of all trash racks, reverse sloped pipes or flashboard risers for evidence of clogging, leakage, debris accumulation, etc. ♦ Inspect maintenance access to ensure it is free of debris or woody vegetation, and check to see whether valves, manholes and locks can be opened and operated. ♦ Inspect internal and external side slopes of dry ponds for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately. ♦ Monitor the growth of wetlands, trees and shrubs planted in dry ponds. Remove invasive species and replant vegetation where necessary to ensure dense coverage.	Annual inspection

Maintenance of dry detention practices is driven by annual inspections that evaluate the condition and performance of the practice. Based on inspection results, specific maintenance tasks will be triggered. An example maintenance checklist for dry detention practices is included in *Appendix F*.

Dry Detention Practice References and Additional Resources

1. Cappiella, K., Schueler, T., and T. Wright. 2005. Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed. NA-TP-04-05. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA.
2. Hirschman, D., L. Woodworth and S. Drescher. 2009. Technical Report: Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs. Center for Watershed Protection. Ellicott City, MD.
3. Virginia Department of Conservation and Recreation (VA DCR). 2011. Stormwater Design Specification No. 15: Extended Detention (ED) Pond Version 1.8. Available at http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_15_EXT_DETENTION_POND_Final_Draft_v1-8_04132010.pdf

4.11 Wet Detention Ponds

Introduction

Wet detention ponds (Figures 4.11-1 and 4.11-2) are stormwater storage practices that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake, and microbial activity. Ponds are widely applicable for most land uses and are best suited for larger drainage areas. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, wet detention ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Wet detention ponds also provide storage above the permanent pool to provide increased water quality benefits and to meet stormwater management requirements for larger storms.

Wet detention ponds are credited differently than other BMPs. In order to meet water quality requirements, they must store and release at least the first ½-inch of runoff over 24-hours (possibly greater when the site is located within ½ mile of a receiving water body).

Figure 4.11-1. Wet Pond (Photo: Denise Sanger)

KEY CONSIDERATIONS: WET DETENTION PONDS

DESIGN CRITERIA:

- Contributing drainage area of 10-25 acres typically needed for wet and wet extended detention ponds unless groundwater interaction is present. Permanent pools should be designed to be between 3 and 8 feet deep.
- Extended detention above the permanent pool required for at least ½" or runoff.
- A sediment forebay (or equivalent pretreatment) should be provided upstream of all ponds.
- Length to width ratio should be at least 1.5:1, and a ratio of 3:1 is preferred.
- Side slopes should not exceed 3:1 (H:V).

BENEFITS:

- Provides moderate to high pollutant removal.
- Can be attractively integrated into a development site and designed to provide wildlife habitat.

LIMITATIONS:

- Design can be challenging in flat terrain.
- Recent research suggests that ponds implemented in the coastal plain may contribute to eutrophication in receiving waters (Smith, 2012).

SITE APPLICABILITY:

- Rural Use
- Suburban Use
- Construction Cost: Low
- Maintenance: Low
- Area Required Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 0% credit for runoff reduction

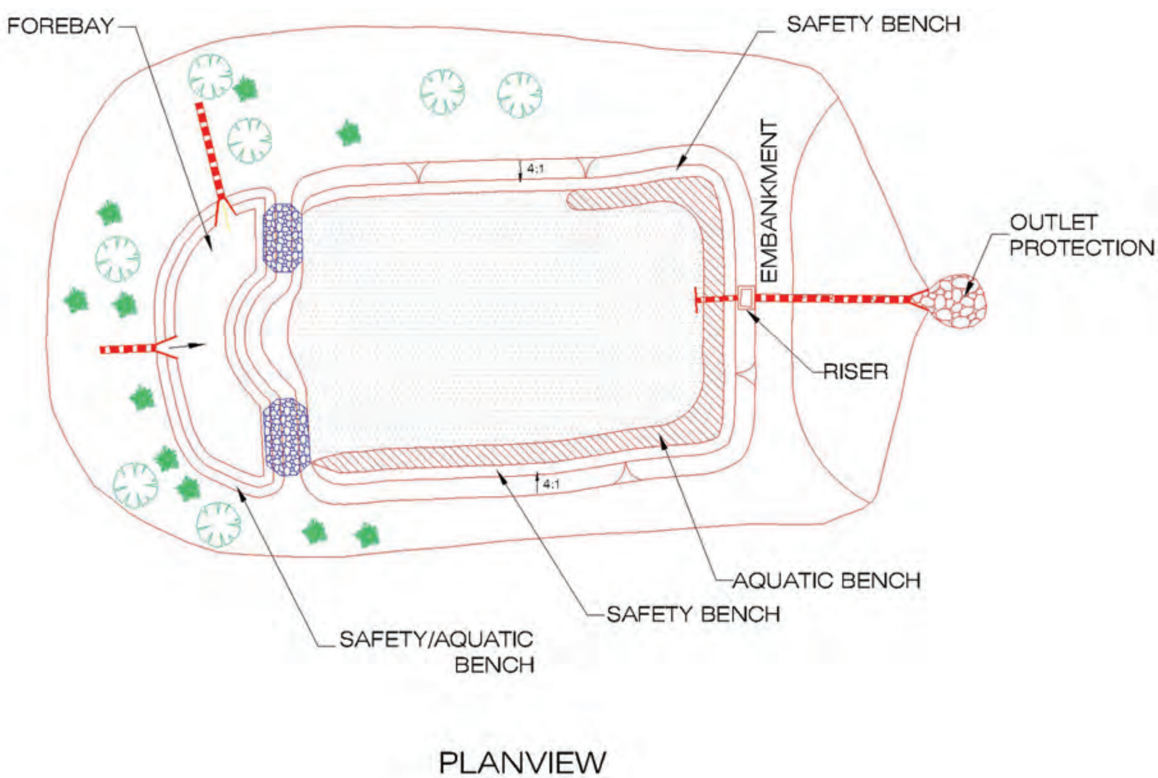
Coastal Zone Credit Approach

- 100% credit for storage volume of practice

Statewide Water Quality Requirement Credit Approach

- At least ½" of runoff must be stored and released over 24 hours

Pollutant Removal
85% - Total Suspended Solids
75% - Total Phosphorus
40% - Total Nitrogen
40% - Metals
70% - Pathogens



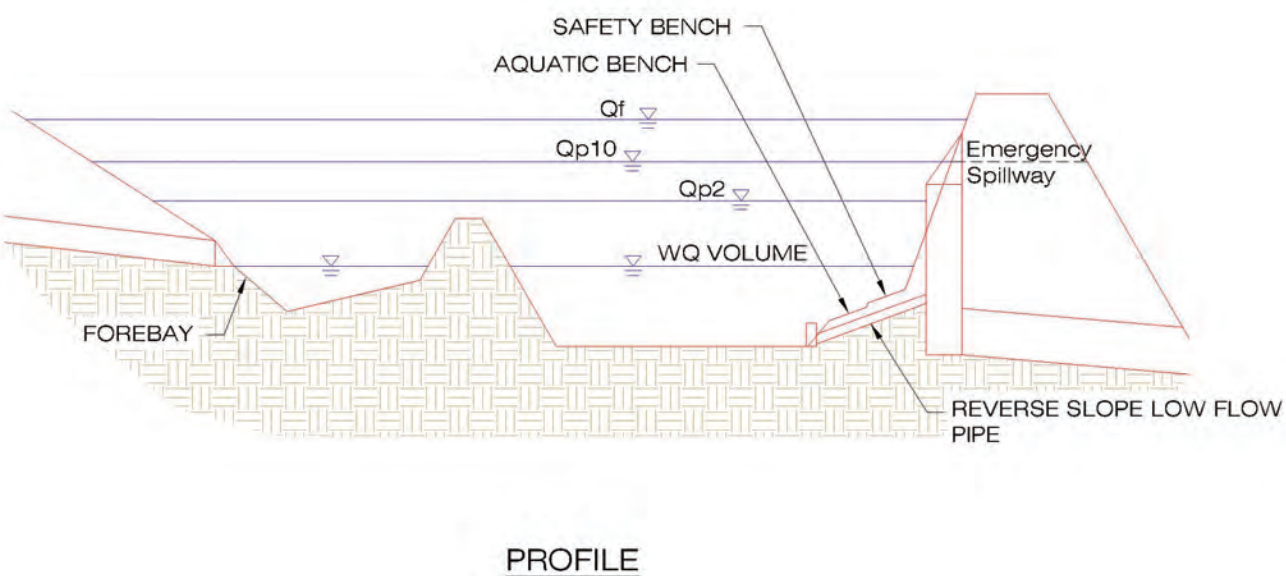


Figure 4.11-2. Wet Detention Pond Design Schematics

Wet Detention Pond Feasibility Criteria

The following feasibility issues need to be considered when wet ponds are considered a final stormwater management practice of the treatment train.

Adequate Water Balance. Wet detention ponds must have enough water supplied from groundwater, runoff, or base flow so that the wet pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation should be performed using the equation provided in *Wet Detention Pond Design Criteria*.

Contributing Drainage Area. A contributing drainage area of 10 to 25 acres is typically recommended for ponds to maintain constant water elevations. Ponds can still function with drainage areas less than 10 acres, but designers should be aware that these "pocket" ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions.

Space Requirements. The surface area of a pond will normally be at least 1% to 3% of its contributing drainage area, depending on the pond's depth.

Site Topography. Ponds are best applied when the grade of contributing slopes is less than 15%.

Available Hydraulic Head. The depth of a pond is usually determined by the hydraulic head available on the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the pond discharges. However, the permanent pool may be located below this elevation. Typically, a minimum of 4 to 8 feet of head are needed to hold the wet pool and any additional large storm storage or overflow capacity for a pond to function.

Minimum Setbacks. Generally, wet ponds should be set back at least 10 feet from property lines, and 10 feet down-gradient from building foundations.

Proximity to Utilities. No utility lines should be permitted to cross any part of the embankment of a wet pond.

Depth-to-Water Table. The depth to the groundwater table is not a major constraint for wet ponds, since a high water table can help maintain wetland conditions. However, groundwater inputs can also reduce the pollutant removal rates of ponds. Further, if the water table is close to the surface, it may make excavation difficult and expensive.

Tailwater Conditions. The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from wet pond.

Soils. Highly permeable soils may make it difficult to maintain a healthy permanent pool. Soil infiltration tests need to be conducted at proposed pond sites to determine the need for a pond liner or other method to ensure a constant water surface elevation. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner (See Table 4.11-1) or groundwater interaction. Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils beneath the proposed pond.

Use of or Discharges to Natural Wetlands. Ponds cannot be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate state or federal regulatory agency. In addition, the designer should investigate the wetland status of adjacent areas to determine if the discharge from the pond will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006, for guidance on minimizing stormwater discharges to existing wetlands).

Perennial Streams. Locating ponds on perennial streams will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Community and Environmental Concerns. Ponds can generate the following community and environmental concerns that need to be addressed during design:

- ✧ **Aesthetic Issues.** Many residents feel that ponds are an attractive landscape feature, promote a greater sense of community, and are an attractive habitat for fish and wildlife. Designers should note that these benefits are often diminished where ponds are under-sized or have small contributing drainage areas.
- ✧ **Existing Forests.** Construction of a pond may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction.
- ✧ **Safety Risk.** Pond safety is an important community concern, since both young children and adults have perished by drowning in ponds through a variety of accidents. Gentle side slopes and safety benches should be provided to avoid potentially dangerous drop-offs, especially where ponds are located near residential areas.
- ✧ **Pollutant Concerns.** Ponds collect and store water and sediment to increase residence time that will increase the likelihood for contaminated water and sediments to be neutralized. However, poorly sized, maintained, and/or functioning ponds can export contaminated sediments and/or water to receiving waterbodies (Mallin, 2000; Mallin et al., 2001; Messersmith, 2007). Further, designers are cautioned that recent research on ponds has shown that some ponds can be hotspots or incubators for algae that generate harmful algal blooms (HABs).
- ✧ **Mosquito Risk.** Mosquitoes are not a major problem for larger ponds (Santana et al., 1994; Ladd and Frankenburg, 2003, Hunt et al., 2005). However, fluctuating water levels in smaller or under-sized ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC (2005).
- ✧ **Geese and Waterfowl.** Ponds with extensive turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl, whose droppings add to the nutrient and bacteria loads, thus reducing the removal efficiency for those pollutants. Several design and landscaping features can make ponds much less attractive to geese. For more guidance on Canada Geese Management, consult Clemson Cooperative Extension's Fact Sheets, found at: http://www.clemson.edu/extension/hgic/water/resources_stormwater/.

Economic Considerations. Wet detention ponds tend to have low construction costs and low space demands (in terms of the land area needed to treat a given volume of water) relative to other LID practices. In addition, the soil excavated to construct ponds can be used as fill, which is often needed for construction on low-lying coastal areas.

Wet Detention Pond Conveyance Criteria

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

Primary Spillway. The spillway should be designed with acceptable anti-flotation, anti-vortex, and trash rack devices. The spillway must generally be accessible from dry land. When reinforced concrete pipe is used for the principal spillway to increase its longevity, “O-ring” gaskets (ASTM C361) shall be used to create watertight joints.

Non-Clogging Low Flow Orifice. A low flow orifice must be provided that is adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection that may allow for smaller diameters. Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging. Options include:

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

Emergency Spillway. Ponds should be constructed with overflow capacity to pass the 100-year design storm event through either the primary spillway or a vegetated or armored emergency spillway.

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

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge.

If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of riprap should be avoided.

The final release rate of the facility may need to be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow.

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

Wet Detention Pond Pretreatment Criteria

Sediment forebays are considered to be an integral design feature to maintain the longevity of all ponds. A forebay should be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:

- ✧ A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the pond's contributing drainage area.
- ✧ The forebay consists of a separate cell, formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- ✧ The forebay should be between 4 and 6 feet deep equipped with an aquatic bench for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface. Small forebays may require alternate geometry to achieve the goals of pretreatment and safety within a small area.
- ✧ The forebay should be sized to contain 0.1 inches of runoff from the contributing drainage impervious area.
- ✧ The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.
- ✧ The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation.
- ✧ Exit velocities from the forebay should be non-erosive or an armored overflow shall be provided. Non-erosive velocities are 4 feet per second for the two-year event, and 6 feet per second for the 10-year event.
- ✧ Direct maintenance access for appropriate equipment should be provided for each forebay.

Wet Detention Pond Design Criteria

Pond Storage Design: While there are no specific state requirements for the size of the permanent pool, pollutant removal can be improved by storing the equivalent of at least 0.5 inches of runoff in the permanent pool. Volume storage may be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, and complex microtopography.

Pond Geometry: Pond designs should have a long flow path from inlet to outlet, to increase water residence time and pond performance. The minimum length to width ratio (i.e., length relative to width) for ponds should be 1.5:1. Greater flowpaths and irregular shapes are recommended. Internal berms, baffles, or vegetated peninsulas can be used to extend flow paths and/or create multiple pond cells.

Permanent Pool Depth: The maximum depth of the permanent pool should not generally exceed eight feet unless the pond is designed for multiple uses.

Micropool: A micropool is a three to six foot deep pool used to protect the low flow pipe from clogging and to prevent sediment resuspension.

Side Slopes: Side slopes for ponds should generally have a gradient no steeper than 3H:1V. Mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Maximum Extended Detention Levels: The total storage, including any ponding for larger flooding events (100-year storm), should not extend more than 5 feet above the pond permanent pool unless specific design enhancements to ensure side slope stability, safety, and maintenance are identified and approved.

Stormwater Pond Benches: The perimeter of all pool areas greater than 4 feet in depth should be surrounded by two benches, as follows:

- A ***Safety Bench*** is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks. Except when the stormwater pond side slopes are 5H:1V or flatter, provide a safety bench that generally extends 8 to 15 feet outward from the normal water edge to the toe of the stormwater pond side slope. The maximum slope of the safety bench is 5%.
- An ***Aquatic Bench*** is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash. Incorporate an aquatic bench that generally extends up to 10 feet inward from the normal shoreline, has an irregular configuration, and extends a maximum depth of 18 inches below the normal pool water surface elevation.

Liners. When a stormwater pond is located over highly permeable soils or fractured bedrock, a liner may be needed to sustain a permanent pool of water if groundwater interaction is not present. If geotechnical tests confirm the need for a liner, acceptable options include the following:

1. a clay liner following the specifications outlined in Table 4.11-1
2. a 30 mil poly-liner
3. bentonite
4. use of chemical additives
5. an engineering design, as approved on a case-by-case basis by the local review authority

A clay liner should have a minimum thickness of 12 inches with an additional 12-inch layer of compacted soil above it, and it must meet the specifications outlined in Table 4.11-1. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table 4.11-1. Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	cm/sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423/424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of standard proctor density
Source: VA DCR (1999).			

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

Non-clogging Low Flow (Extended Detention) Orifice. The low flow ED orifice should be adequately protected from clogging by an acceptable external trash rack. The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation. Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the normal pool.

Riser in Embankment. The riser should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls. The principal spillway opening can be "fenced" with pipe or rebar at 8" intervals for safety purposes.

Trash Racks. Trash racks should be provided for low-flow pipes and for riser openings not having anti-vortex devices.

Pond Drain. Ponds should have a drain pipe that can completely or partially drain the permanent pool. In cases where a low level drain is not feasible (such as in an excavated pond), a pump well should be provided to accommodate a temporary pump intake when needed to drain the pond.

- ✧ The drain pipe should have a protected intake within the pond to help keep it clear of sediment deposition, and a diameter capable of draining the pond within 24 hours.
- ✧ The pond drain should be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

Care should be exercised during pond drawdowns to prevent downstream discharge of sediments or anoxic water and rapid drawdown. The approving authority shall be notified before draining a pond.

Adjustable Gate Valve. Both the outlet pipe and the pond drain should be equipped with an adjustable gate valve (typically a handwheel activated knife gate valve) or pump well and be sized one pipe size greater than the calculated design diameter. Valves should be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner. To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step or other fixed object.

Safety Features.

- ✧ The principal spillway opening should be designed and constructed to prevent access by small children.
- ✧ End walls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.
- ✧ Storage practices should incorporate an additional 1 foot of freeboard above the emergency spillway.
- ✧ The emergency spillway should be located so that downstream structures will not be impacted by spillway discharges.
- ✧ Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.
- ✧ Warning signs prohibiting swimming should be posted.
- ✧ Where permitted, fencing of the perimeter of ponds is discouraged. The preferred method to reduce risk is to manage the contours of the stormwater pond to eliminate drop-offs or other safety hazards. Fencing is recommended at or above the maximum water surface elevation in the rare situations when the pond slope is a vertical wall.
- ✧ Side slopes to the pond should not be steeper than 3H:1V, and should terminate on a 15-foot wide safety bench. Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool. The safety bench may be omitted if slopes are 4H:1V or flatter.

Maintenance Reduction Features: The following pond maintenance issues can be addressed during the design, in order to make on-going maintenance easier:

- ✧ **Maintenance Access.** All ponds should be designed so as to be accessible to annual maintenance. Good access is needed so crews can remove sediments, make repairs, and preserve pond treatment capacity.
  - Adequate maintenance access should extend to the forebay, safety bench, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
  - The riser should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
  - Access roads should (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 15 feet, and (3) have a profile grade that does not exceed 5:1.
  - A maintenance right-of-way or easement should extend to the stormwater pond from a public or private road.

Pond Sizing. Wet detention ponds can be designed to capture and treat the remaining stormwater discharged from upstream practices from the design storm or used as the sole water quality BMP. Additionally, ponds should be sized to control peak flow rates from the 2-year and 10-year frequency storm event or other design storms as required. Design calculations must ensure that the post-development peak discharge does not exceed the pre-development peak discharge.

For treatment train designs where upland practices are utilized for treatment of the water quality volume, designers can use a reduced Rv or CN that reflects the volume reduction of upland practices to compute the peak flows for the 2-year and 10-year storms (Qp_2 and Qp_{10}) that must be treated by the stormwater pond.

For water quality purposes, the storage volume, *Sv*, for a wet detention pond is the volume of water that is provided above the permanent pool elevation, and released slowly over 24 hours – extended detention (The *Sv* does not include the permanent pool or the 2-year and 10-year detention volumes.). To fully treat the water quality volume with at wet detention pond the *Sv* must be equal to ½ inch of runoff from the site. Within ½ mile from receiving water bodies, the requirement is ½ inch of runoff from the site, or 1 inch of runoff from built-upon areas, whichever is greater.

In the LID Compliance Calculator spreadsheet, wet detention ponds are not assigned any runoff reduction credit. For projects in the Coastal Zone, the Sv for wet detention ponds is given a 100% credit toward the storage requirement. For the statewide water quality requirements, wet detention ponds are credited as a pond with permanent pool, and at least ½ inch of runoff must be stored and released over 24 hours.

Water Balance Testing: A water balance calculation is recommended to document that sufficient inflows to wet ponds exist to compensate for combined infiltration and evapotranspiration losses during a 30-day summer drought without creating unacceptable drawdowns (see Equation 4.11-1, adapted from Hunt et al., 2007). The recommended minimum pool depth to avoid nuisance conditions may vary; however, it is generally recommended that the water balance maintain a minimum 24-inch reservoir.

Equation 4.11-1. Water Balance Equation for Acceptable Water Depth in a Wet Pond

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

where:

DP	=	Average design depth of the permanent pool (inches)
ET	=	Summer evapotranspiration rate (inches) (assume 8 inches)
INF	=	Monthly infiltration loss (assume 7.2 inches @ 0.01 inch/hour)
RES	=	Reservoir of water for a factor of safety (assume 24 inches)
MB	=	Measured baseflow rate to the pond, if any (convert to inches)

Design factors that will alter this equation are the measurements of seasonal base flow and infiltration rate. The use of a liner could eliminate or greatly reduce the influence of infiltration. Similarly, land use changes in the upstream watershed could alter the base flow conditions over time (e.g., urbanization and increased impervious cover).

Translating the baseflow to inches refers to the depth within the pond. Therefore, Equation 4.11-2 can be used to convert the baseflow, measured in cubic feet per second (ft^3/s), to pond-inches:

Equation 4.11-2. Baseflow Conversion

$$\text{Pond Inches (per month)} = \frac{MB \times 2.592 \times 10^6 \times (12\ in/ft)}{SA}$$

where:

MB	=	Measured baseflow rate to the pond (in ft^3/s)
2.592×10^6	=	Conversion factor: ft^3/s to ft^3/month.
SA	=	surface area of pond in ft^2

Wet Detention Pond Landscaping Criteria

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

- Delineation of pondscaping zones within both the pond and buffer
- Selection of corresponding plant species
- The planting plan
- The sequence for preparing the wetland benches (including soil amendments, if needed)
- Sources of native plant material
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the stormwater wetland and buffers.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the pond. Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction.
- The soils in the stormwater buffer area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times wider than the diameter of the root ball. Replacement of soils immediately below the planting hole may be beneficial as well.
- Avoid species that require full shade, or are prone to wind damage. Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

For more guidance on planting trees and shrubs in pond buffers, consult Cappiella et al (2006), as well as guidance from Clemson Cooperative Extension available at http://www.clemson.edu/extension/hgic/water/resources_stormwater/.

Wet Detention Pond Construction Sequence

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

Step 1: Use Ponds for Erosion and Sediment Control. A pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (erosion and sediment control requirement vs. storage volume requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction pond in mind. The bottom elevation of the pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a pond.

Step 2: Stabilize the Drainage Area. Ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the proposed pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged, and re-graded to design dimensions after the original site construction is complete.

Step 3: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 4: Clear and Strip the project area to the desired sub-grade.

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

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

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

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

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

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

Step 11: Install Outlet Pipes, including downstream riprap apron protection.

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

Step 13: Plant the Pond Buffer Area, following the pondscaping plan (see *Pond Landscaping Criteria*).

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

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

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

Wet Detention Pond Maintenance Criteria

Maintenance is needed so wet detention ponds continue to operate as designed on a long-term basis. Ponds normally have fewer routine maintenance requirements than other stormwater control measures. Pond maintenance activities vary regarding the level of effort and expertise required to perform them. Routine pond maintenance, such as mowing and removing debris and trash, is needed several times each year (See Table 4.11-3). More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Inspection and repair of critical structural features (e.g., embankments and risers) needs to be performed by a qualified professional (e.g., a structural engineer) who has experience in the construction, inspection, and repair of these features.

Sediment removal in the pond pretreatment forebay should occur every 5 to 7 years or after 50% of total forebay capacity has been lost. Also, sediment removal should be performed if more than 25% of the permanent pool volume is filled. The designer should check to see whether removed sediments can be spoiled on-site or must be hauled away. Currently, in South Carolina, there are no requirements that stormwater pond sediments be tested for chemical or biological contaminants prior to sediment removal. However, sediment testing may be needed prior to sediment disposal because sediments excavated from ponds could potentially be considered toxic or hazardous (Weinstein et al., 2008). In lieu of local regulations for sediment testing, the parameters in Table 4.11-2 may be used:

Table 4.11-2: Ceiling Levels Governing Management of Accumulated Sediment[1]

Parameter	Ceiling Level (ppm or mg/kg)
Total Arsenic	8
Total Cadmium	10
Total Chromium	100
Total Lead	250
pH	Less than 5 or greater than 10 standard units
Electrical Conductivity	8 deciSiemens/meter (dS/m) at 25°C

[1] *excerpt from Wisconsin Administrative Code NR 528.03, Table 2*

Maintenance plans should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest. For information on chemical control methods for aquatic plants, consult Clemson's fact sheet entitled "Aquatic Weed Control Overview" available online at http://www.clemson.edu/extension/hgic/plants/other/landscaping/hgic1714.html.

The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables. More information on planting maintenance can be found in the Wetland Maintenance section.

Table 4.11-3. Typical Pond Maintenance Tasks and Frequency

Maintenance Items	Frequency
♦ Inspect the site at least twice after storm events that exceed a 1/2-inch of rainfall. ♦ Plant the aquatic benches with emergent wetland species, following the planting recommendations contained in section *4.12 Wetland Landscaping Criteria.* ♦ Stabilize any bare or eroding areas in the contributing drainage area or around the pond buffer. ♦ Water trees and shrubs planted in the pond buffer during the first growing season. In general, consider watering every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.	During establishment, as needed (first year)
♦ Remove debris and blockages. ♦ Repair undercut, eroded, and bare soil areas.	Quarterly or after major storms (>1 inch of rainfall)
♦ Mow the buffer and pond embankment.	Twice a year
♦ Remove trash, debris and floatables from the shoreline. ♦ Perform a full maintenance inspection. ♦ Open up the riser to access and test the valves. ♦ Repair broken mechanical components, if needed.	Annually
♦ Reinforce pond buffer and aquatic bench plantings.	One time – during the second year following construction
♦ Remove sediment from forebay.	Every 5 to 7 years
♦ Repair pipes, the riser and spillway, as needed.	From 5 to 25 years

Maintenance of a pond is driven by annual inspections that evaluate the condition and performance of the pond. Based on inspection results, specific maintenance tasks will be triggered.

An example maintenance checklist for wet detention ponds is included in *Appendix F*.

Wet Detention Pond References and Additional Resources

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4.12 Stormwater Wetlands

Introduction

Stormwater wetlands, sometimes called constructed wetlands, are shallow vegetated depressions that receive stormwater inputs for water quality treatment (Figure 4.12-1a and 4.12-1b). Wetlands are typically less than 1 foot deep (although they have greater depths at the forebay and in micro-pools) and possess variable microtopography to promote dense and diverse wetland cover (Figure 4.12-2). Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for water quality improvement by gravitational settling, biological uptake, and microbial activity. Stormwater wetlands also provide storage above the permanent pool to provide increased water quality benefits and to meet stormwater management requirements for larger storms.

Wetlands include various design adaptations to allow them to be applied in specific settings. For example, some designs incorporate trees within the wetland area (Figure 4.12-3). Another design variation, the Linear Pond/Wetland system (Figure 4.12-4) is ideally suited to applications where the wetland is incorporated into a narrow space such as a transportation right of way.

Stormwater wetlands are credited differently than most other BMPs. In order to meet water quality requirements, they must store and release at least the first ½-inch of runoff over 24-hours (possibly greater when the site is located within ½-mile of a receiving water body).

Important Note: all of the pond performance criteria presented in *Section 4.11 Wet Detention Ponds* also apply to the design of stormwater wetlands. Additional criteria that govern the geometry and establishment of created wetlands are presented in this section.

KEY CONSIDERATIONS: STORMWATER WETLANDS

DESIGN CRITERIA:

- Contributing drainage area of 35 acres typically needed for wetlands (less when groundwater connection exists, depending on water balance calculations).
- Extended detention above the permanent pool required for at least ½” or runoff.
- A sediment forebay (or equivalent pretreatment) should be provided upstream of all stormwater wetlands.
- Typically, 70% of the wetland’s surface area should be provided in “high marsh” areas of 6” depth or shallower and approximately 25% should be in deep pools between 18 and 48 inches deep.
- Length to width or flow path to width ratio should be at least 2:1.
- Side slopes should not exceed 3:1 (H:V).

BENEFITS:

- Provides moderate to high pollutant removal.
- Can be integrated attractively into a development site and designed to provide wildlife habitat.
- Can be an effective practice on C/D soils.

LIMITATIONS:

- Requires a large, flat area in a single location.

SITE APPLICABILITY:

- Rural Use
- Suburban Use
- Construction Cost: Low
- Maintenance: Medium
- Area Required: Low

STORMWATER MANAGEMENT PRACTICE PERFORMANCE:

Runoff Reduction Credit Approach
(applies to Shellfish Bed, SMS4, and infiltration credit approaches)

- 0% credit for runoff reduction

Coastal Zone Credit Approach

- 100% credit for storage volume of practice

Statewide Water Quality Requirement Credit Approach

- At least ½” of runoff must be stored and released over 24 hours

Pollutant Removal
80% - Total Suspended Solids
50% - Total Phosphorus
30% - Total Nitrogen
50% - Metals
70% - Pathogens

Wetland Feasibility Criteria

Constructed wetland designs are subject to the following site constraints:

Adequate Water Balance. Wetlands should have enough water supplied from groundwater, runoff, or baseflow so that the permanent pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation should be performed using Equation 4.11-1 provided in Section 4.11 Wet Detention Ponds).

Contributing Drainage Area (CDA). The CDA should be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then up to 35 acres of drainage area may be needed to maintain constant water elevations. Smaller drainage areas are acceptable if the bottom of the wetland intercepts the groundwater table or if the designer or approving agency is willing to accept periodic wetland drawdown.

Space Requirements. Stormwater wetlands normally require a footprint that takes up about 3% of the contributing drainage area, depending on the average depth of the wetland and the extent of its deep pool features.

Steep Slopes. A modification of the Constructed Wetland (and linear wetland or wet swale system) is the Regenerative Stormwater Conveyance (RSC) or Step Pool Storm Conveyance channel. The RSC can be used to bring stormwater down steeper grades through a series of step pools. A description of this practice is provided in *Section 4.8 Open Channel Systems*.

Available Hydraulic Head. The depth of a constructed wetland is usually constrained by the hydraulic head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because constructed wetlands are typically shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.

Minimum Setbacks. Generally, wetlands should be set back at least 10 feet from property lines, and 10 feet down-gradient from building foundations.

Depth to Water Table. The depth to the groundwater table is not a major constraint for constructed wetlands, since a high water table can help maintain wetland conditions. However, designers should keep in mind that high groundwater inputs may reduce pollutant removal rates and increase excavation costs (refer to *Section 4.11 Wet Detention Ponds*).

Soils. Soil tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner or groundwater connection (See Table 4.11-1 in *Section 4.11 Wet Detention Ponds* for liner specifications).

Use of or Discharges to Natural Wetlands. Stormwater wetlands may not be located within jurisdictional waters, including wetlands, without obtaining a Section 404 permit from the appropriate federal regulatory agency. In addition, designer should investigate the status of adjacent wetlands to determine if the discharge from the constructed wetland will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006 for guidance on minimizing stormwater discharges to existing wetlands).

Figure 4.12-1a. Stormwater Wetland at Carolina Forest Recreation Center, Myrtle Beach (Photo: Kathryn Ellis)

Figure 4.12-1b. Stormwater Wetland at Fox Hollow, James Island (Photo: Kathryn Ellis)

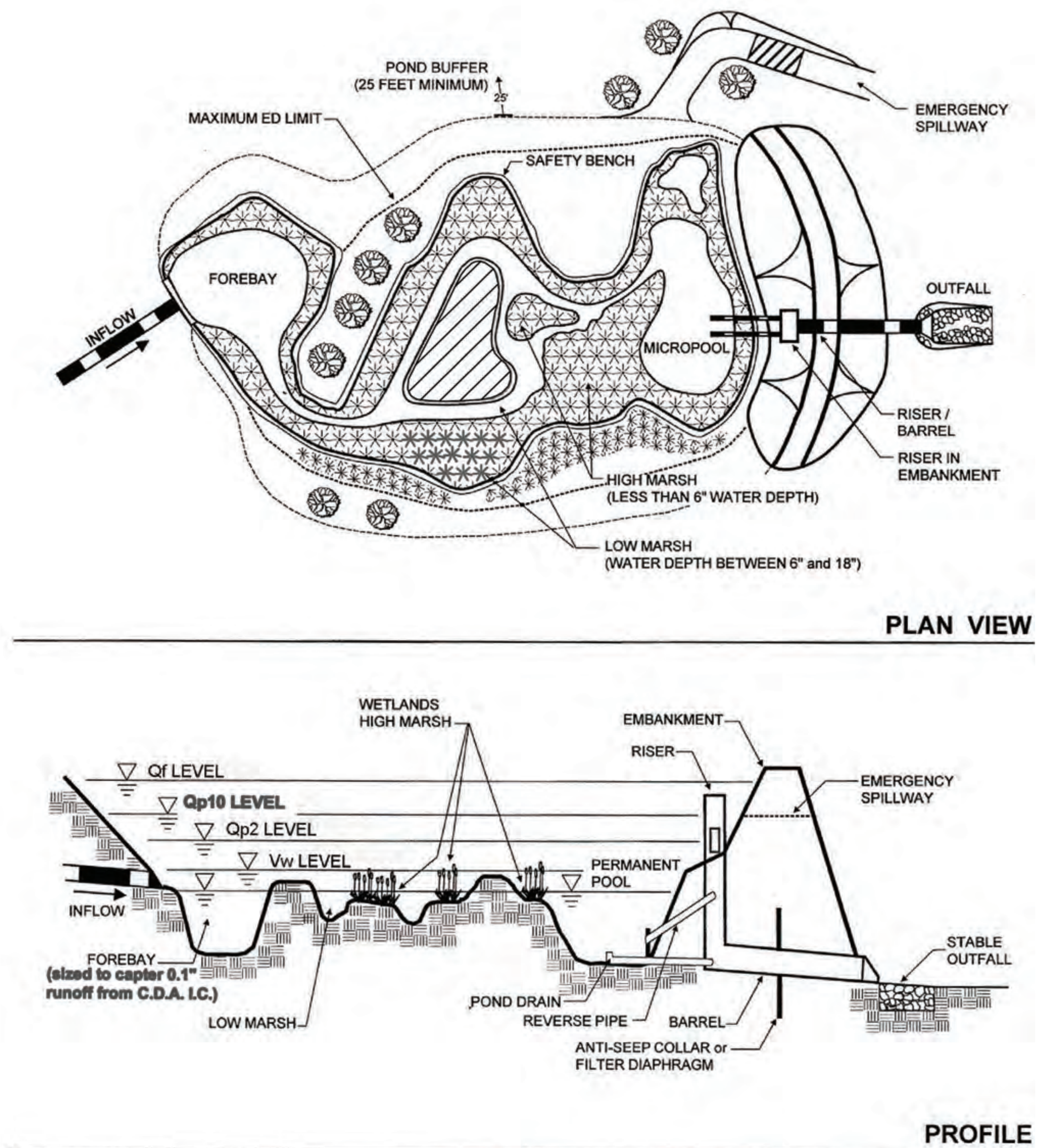

Figure 4.12-2. Example Depiction of Shallow Wetland with Extended Detention

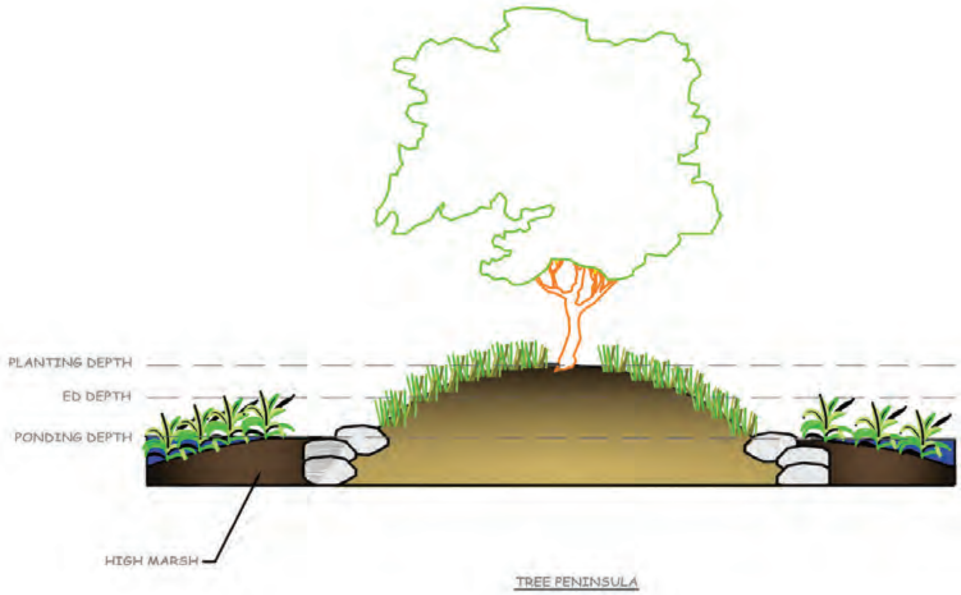

Figure 4.12-3. Example Depiction of Linear Wetland with Trees added to Peninsulas

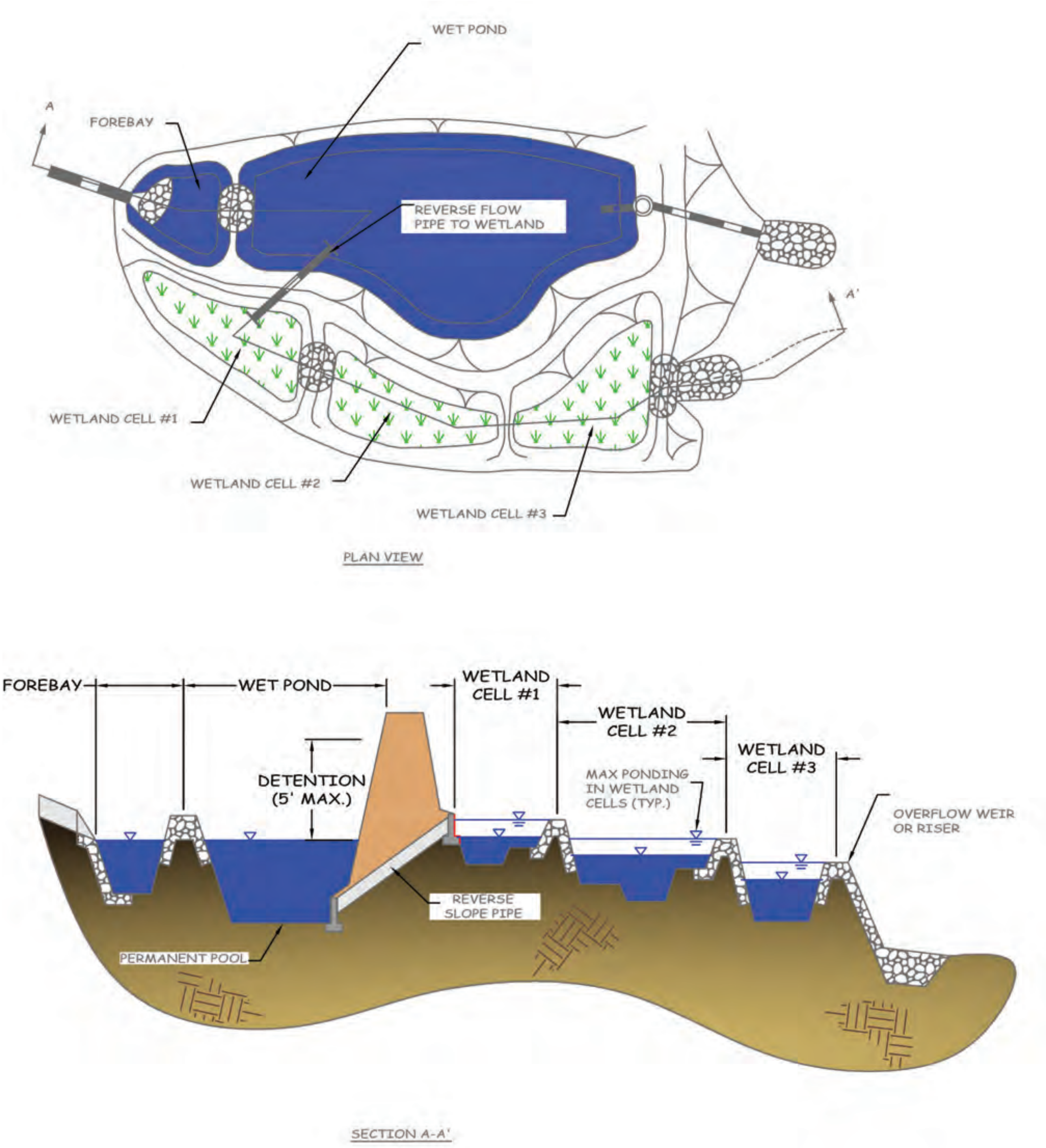

Figure 4.12-4. Example Depiction of Linear Pond/Wetland Combination

Regulatory Status. Wetlands built for the express purpose of stormwater treatment are not considered jurisdictional as long as they are not adjacent to natural wetlands, but designers should check with their wetland regulatory authorities to ensure this is the case.

Perennial Streams. Locating a stormwater wetland along or within a perennial stream will require both Section 401 and Section 404 permits from the state or federal regulatory authority.

Community and Environmental Concerns. In addition to the community and environmental concerns that exist for stormwater ponds, stormwater wetlands can generate the following concerns that should be addressed during design:

- **Aesthetics and Habitat.** Stormwater wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the wetland plant community will evolve over time, since the future plant community seldom resembles the one initially planted.
- **Existing Forests.** Given the large footprint of a stormwater wetland, there is a strong chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout, and he/she may consider creating a forested wetland (see Cappiella et al., 2006).
- **Safety Risk.** Constructed wetlands are safer than wet detention ponds, although forebays and micropools should be designed with aquatic benches to reduce safety risks.
- **Mosquito Risk.** Mosquito control can be a concern for stormwater wetlands if they are under-sized or have a small contributing drainage area. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other aquatic life that prey on mosquito larvae. Few mosquito problems are reported for well designed, properly-sized, and frequently-maintained constructed wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within constructed wetlands such as constant inflows, benches that create habitat for natural predators, and constant pool elevations (MSSC, 2005).

Economic Considerations. If space is available, wetlands can be a very cost effective stormwater practice.

Wetland Conveyance Criteria

Generally, the slope profile within individual wetland cells should be flat from inlet to outlet (adjusting for microtopography). The recommended maximum elevation drop between wetland cells should be 1 foot or less.

Since most constructed wetlands are on-line facilities, they need to be designed to pass safely the maximum design storm (e.g., the 10-year and 100-year design storms). While the ponding depths for the more frequent water quality design storm and 2-year storms are limited in order to avoid adverse impacts to the planting palette, the overflow for the less frequent 10- and 100-year storms should likewise be carefully designed to minimize the depth of ponding. A maximum depth of 4 feet over the wetland pool is recommended.

While many different options are available for setting the normal pool elevation, removable flash-board risers are recommended, given their greater operational flexibility to adjust water levels following construction (see Hunt et al., 2007). Also, a weir can be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

Wetland Pretreatment Criteria

Sediment regulation is critical to sustain stormwater wetlands. Consequently, a forebay shall be located at the inlet, and a micropool shall be located at the outlet. Forebays are designed in the same manner as stormwater ponds (see *Pond Pretreatment Criteria* in Section 4.11). A micropool is a three to six foot deep pool used to protect the low flow pipe from clogging and to prevent sediment resuspension.

Wetland Design Criteria

Internal Design Geometry. Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of stormwater wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume. Whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements are required for stormwater wetlands:

Multiple-Cell Wetlands. Wetlands can be divided into at least four internal sub-cells of different elevations: the forebay, a micro-pool outlet, and two additional cells (Figure 4.12-5). Cells can be formed by sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas (extending as wedges across 95% of the wetland width). The ultimate vegetative target is to achieve a 50-50 mix of emergent and forested wetland vegetation within all four cells.

The first cell (the forebay) is deeper and used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it as sheetflow into successive wetland cells. The surface elevation of the second cell is the normal pool elevation. It may contain a forested island or a sand wedge channel to promote flows into the third cell, which is 3 to 6 inches lower than the normal pool elevation. The purpose of the wetland cells is to create an alternating sequence of aerobic and anaerobic conditions to maximize nitrogen removal. The fourth wetland cell is located at the discharge point and serves as a micro-pool with an outlet structure or weir.

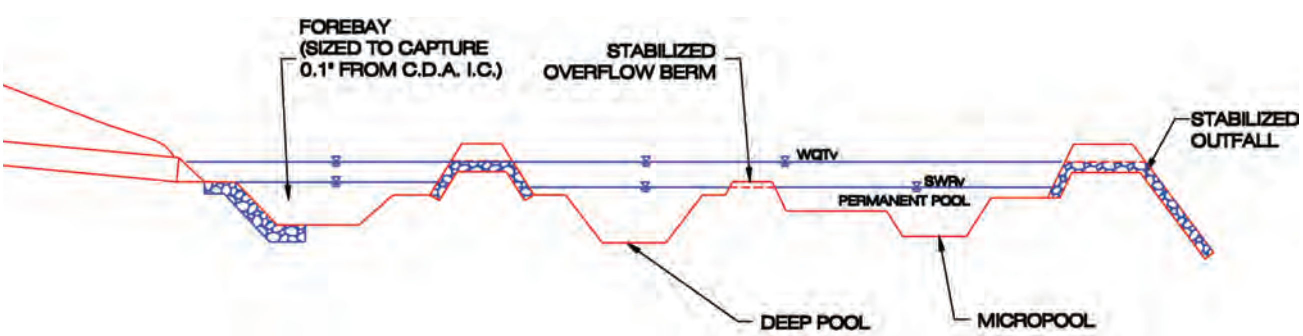

Figure 4.12-5. Typical Stormwater Wetland Cross-Section

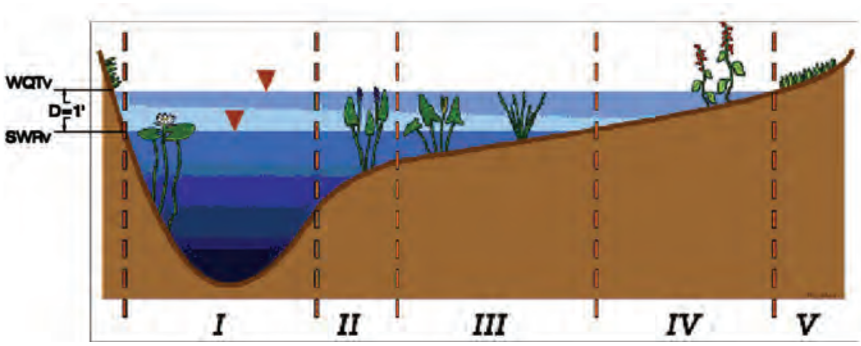

Figure 4.12-6. Interior wetland zones: (I) Deep Pool (depth -48 to -18 inches), (II) Transition Zone (depth -18 to -6 inches), (III and IV) High Marsh Zone (depth -6 to +6 inches), (IV) Extended Detention Zone, and (V) Upper Bank (adapted from Hunt et al., 2007).

Depth Zones. The stormwater wetland should be designed with multiple depth zones including Deep Pools, a Transition Zone, a High Marsh Zone, an Extended Detention Zone, and the Upper Bank (Figure 4.12-.6).

Deep Pools. Approximately 25% of the wetland surface area should be provided in at least three deeper pools – located at the inlet (forebay), center, and outlet (micropool) of the wetland –with each pool having a depth of from 18 to 48 inches. Refer to the sizing based on water balance below for additional guidance on the minimum depth of the deep pools.

Transition Zone. This zone functions as a short transition zone from the deeper pools to the high marsh zone (-6 to -18 inches below the normal pool elevation). In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

High Marsh Zone. Approximately 70% of the wetland surface area should be established in the high marsh zone (-6 inches to +6 inches, relative to the normal pool elevation).

Extended Detention Zone. The depth of the design detention volume (typically ½-inch of the drainage area) should not exceed 1 foot above the wetland's surface.

Upper Bank. This zone extends from 12 to 36 inches above the permanent pool; does not experience inundation, except during infrequent storm events; and should be designed to meet the criteria for banks of pond systems. (See *Wet Detention Pond Design Criteria* in Section 4.11).

Flow Path. In terms of the flow path, there are two design objectives:

- The overall flow path through the wetland can be represented as the length-to-width ratio OR the flow path ratio. A minimum overall flow path of 2:1 should be provided across the stormwater wetland.
- The shortest flow path represents the distance from the closest inlet to the outlet. The ratio of the shortest flow path to the overall length should be at least 0.5. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these "closer" inlets should constitute no more than 20% of the total contributing drainage area.

Side Slopes. Side slopes for the wetland should generally have gradients of 4H:1V or flatter. These mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

Micro-Topographic Features. Stormwater wetlands should have internal structures that create variable micro-topography, which is defined as a mix of above-pool vegetation, shallow pools, and deep pools that promote dense and diverse vegetative cover.

Constructed Wetland Material Specifications. Wetlands are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and filter fabric for lining banks or berms. Plant stock should be nursery grown, unless otherwise approved by the local regulatory authority, and should be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined during local plan review. "Bioretention Plug" plants (i.e., 5-inch deep containers with root volumes equal to a 4-inch pot) are recommended to promote vigorous root growth.

Wetland Sizing. Stormwater wetlands can be designed to capture and treat the remaining stormwater discharged from upstream practices from the design storm or used as the sole water quality BMP. Additionally, wetlands should be sized to control peak flow rates from the 2-year and 10-year frequency storm event or other design storms as required. Design calculations should ensure that the post-development peak discharge does not exceed the pre-development peak discharge.

For treatment train designs where upland practices are utilized for treatment of the water quality volume, designers can use a reduced Rv or CN that reflects the volume reduction of upland practices to compute the peak flows for the 2-year and 10-year storms (Qp_2 and Qp_{10}) that should be treated by the stormwater pond.

For water quality purposes, the storage volume, *Sv*, for a stormwater wetland is the volume of water that is provided above the permanent pool elevation, and released slowly over 24 hours – extended detention (The *Sv* does not include the permanent pool or the 2-year and 10-year detention volumes.). To treat the water quality volume completely with a wet detention pond, the *Sv* must be equal to ½ inch of runoff from the site. Within ½ mile from receiving water bodies, the requirement is ½ inch of runoff from the site, or 1 inch of runoff from built-upon areas, whichever is greater.

In the LID Compliance Calculator spreadsheet, stormwater wetlands are not assigned any runoff reduction credit. For projects in the Coastal Zone, the Sv for stormwater wetlands is given a 100% credit toward the storage requirement. For the statewide water quality requirements, stormwater wetlands are credited as a pond with permanent pool, and at least ½ inch of runoff must be stored and released over 24 hours.

Sizing for Minimum Pool Depth. While there is no minimum drainage area requirement for the system, it may be necessary to calculate a water balance for the wet pond cell when its contributing drainage area is less than 10 acres (Refer to *Section 4.11 Wet Detention Ponds*).

Similarly, if the hydrology for the constructed wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation should be performed, using Equation 4.12-1 (Hunt et al., 2007), to assure the deep pools will not go completely dry during a 30-day summer drought.

Equation 4.12-1. Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland

$$DP = RF_m \times Rv \times [{}^{WS}/_{WL}] - ET - INF - RES$$

where:

DP	=	Depth of pool (inches)
RF_m	=	Monthly rainfall during drought (inches)
Rv	=	Runoff coefficient - fraction of rainfall from contributing drainage area that becomes runoff
${}^{WS}/_{WL}$	=	Ratio of contributing drainage area to wetland surface area
ET	=	Summer evapotranspiration rate (inches; assume 8)
INF	=	Monthly infiltration loss (assume 7.2 inches @ 0.01 inch/hour)
RES	=	Reservoir of water for a factor of safety (assume 6 inches)

Using Equation 4.12-1, setting the groundwater and (dry weather) base flow to zero and assuming a worst case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows (Equation 4.12-2):

Equation 4.12-2. Minimum Depth of the Permanent Pool

Depth of Pool (DP) = 0″ (RFm) – 8″ (ET) – 7.2″ (INF) – 6″ (RES) = 21.2 inches

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool should be at least 22 inches. However, the 18 inch depth noted above is an absolute minimum, even if groundwater flows are present.

Wetland Construction Sequence

The construction sequence for stormwater wetlands depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing an on-line wetland facility and establishing vigorous plant cover.

Stage 1 Construction Sequence: Wetland Facility Construction.

Step 1: Stabilize Drainage Area. Stormwater wetlands should only be constructed after the contributing drainage area to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged, and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 3: Clear and Strip the project area to the desired sub-grade.

Step 4: Install Erosion and Sediment (E&S) Controls prior to construction, including temporary dewatering devices, sediment basins, and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials, or other approved methods of soil stabilization. Sod is preferred over seed to reduce seed colonization of the wetland. During construction the wetland should be separated from the contributing drainage area so that no sediment flows into the wetland areas. In some cases, a phased or staged E&S Control plan may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

Step 5: Excavate the Core Trench for the Embankment and Install the Spillway Pipe.

Step 6: Install the Riser or Outflow Structure and ensure that the top invert of the overflow structure is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al., 2007).

Step 7: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts and compact with appropriate equipment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the wetland. This is normally done by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

Step 9: Install Micro-Topographic Features and Soil Amendments within wetland area. Since most stormwater wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, compost, topsoil, or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor plant survival is likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

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

Step 11: Install Outlet Pipes, including the downstream riprap apron protection. Outlet configurations may vary depending upon the goals of the specific design.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw.

Stage 2 Construction Sequence: Establishing the Wetland Vegetation.

Step 13: Finalize the Wetland Landscaping Plan. At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan after the stormwater wetland has been constructed. Several weeks of standing time is needed so that the designer can predict more precisely the following two things:

- Where the inundation zones are located in and around the wetland; and
- Whether the final grade and wetland microtopography will persist over time.

This allows the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland.

Step 14: Open Up the Wetland Connection. Once the final grades are attained, the pond and/or contributing drainage area connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the wetland to prevent erosion of unplanted features. Inundation should occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

Step 15: Measure and Stake Planting Depths before planting. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field using stakes or flags.

Step 16: Propagate the Stormwater Wetland. Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. Initial Planting of Container-Grown Wetland Plant Stock. If at all possible, the plants should be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.
2. Broadcasting Wetland Seed Mixes. The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of switchgrass or wetland seed mixes as a ground cover is recommended for all zones 3 inches below the normal pool elevation and above. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
3. Allowing "Volunteer" Wetland Plants to Establish on Their Own. The remaining areas of the stormwater wetland eventually will (within 3 to 5 years) be colonized by volunteer species from upstream or the forest buffer. However, avoid or remove invasive plants that may volunteer within the wetland.

Step 17: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergents and herbaceous plants, as predation by geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a criss-cross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 18: Plant the Wetland Fringe and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2-year storm). Consequently, plants in this zone are infrequently inundated (5 to 10 times per year), and should be able to tolerate both wet and dry periods.

Step 19: Construction Inspection. Construction inspections are critical to ensure that stormwater wetlands are properly constructed and established. Multiple site visits and inspections are recommended during the following stages of the wetland construction process:

- Pre-construction meeting
- Initial site preparation (including installation of project E&S controls)
- Excavation/Grading (e.g., interim/final elevations)
- Wetland installation (e.g., microtopography, soil amendments and staking of planting zones)
- Planting Phase (with an experienced landscape architect or wetland expert)
- Final Inspection (develop a punch list for facility acceptance)

Wetland Landscaping Criteria

An initial wetland landscaping plan is required for any stormwater wetland and should be developed jointly by the engineer and a wetlands expert or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance, and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. At a minimum, the plan should contain the following:

Plan view(s) with topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration, different planting zones (e.g., high marsh, deep water, upland), microtopography, grades, site preparation, and construction sequence.

A plant schedule and planting plan specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing. To the degree possible, the species list for the constructed wetland should contain plants found in similar local wetlands.

The local regulatory authority will usually establish any more specific vegetative goals to achieve in the wetland landscaping plan. The following general guidance is provided:

- ✧ Use Native Species Where Possible. Native species can be used that appear in statewide plant lists (also Tables 4.12-1 and 4.12-2). The use of native species is strongly encouraged, but in some cases, non-native ornamental species may be added as long as they are not invasive. Invasive species such as cattails (*Typha latifolia*) and common reed (*Phragmites australis*) should never be planted.
- ✧ Match Plants to Inundation Zones. The first four inundation zones are particularly applicable to stormwater wetlands, as follows:

- Zone 1: -6 inches to -12 below the normal pool elevation
- Zone 2: -6 inches to the normal pool elevation
- Zone 3: From the normal pool elevation to +12 inches above it
- Zone 4: +12 inches to + 36 inches above the normal pool elevation (i.e., above Zone 3)
- Note that the Low Marsh Zone (-6 inches to -18 inches below the normal pool elevation) has been dropped since experience has shown that few emergent wetland plants flourish in this deeper zone.

✧ Aggressive Colonizers. To add diversity to the wetland, 5 to 7 species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers. No more than 25% of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each single species "cluster".

✧ Suitable Tree Species. The major shift in stormwater wetland design is to integrate trees and shrubs into the design, in tree islands, peninsulas, and fringe buffer areas. Deeper-rooted trees and shrubs that can extend to the stormwater wetland's local water table are important for creating a mixed wetland community. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally-grown container or bare root stock is usually the most successful approach, if planting in the spring. It is recommended that buffer planting areas be over-planted with a small stock of fast growing successional species to achieve quick canopy closure and shade out invasive plant species. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.

✧ Pre- and Post-Nursery Care. Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when transporting them to the planting location. As much as six to nine months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries.

✧ Floating Wetlands. Floating wetlands are modular floating wetland designs that can be used to meet some of the requirements for Emergent Vegetation. (Note that floating wetlands may also be included in Pond designs). For more guidance on floating wetlands, consult the document, "Floating Wetlands: Container Gardens for Your Pond" available from Clemson University Cooperative Extension at: http://www.clemson.edu/extension/hgic/water/resources_stormwater/floating_wetlands_container_gardens_for_your_pond.html.

Figure 4.12-7. Floating wetland at Charleston National golf course community, Mt. Pleasant, SC. (Photo: Kathryn Ellis)

Table 4.12-1 Trees and Shrubs Recommended for Stormwater Wetlands			
Shrubs		**Trees**	
Common & Scientific Names	**Zone[1]**	**Common & Scientific Names**	**Zone[1]**
Button Bush (*Cephalanthus occidentalis*)	2, 3	Atlantic White Cedar (*Chamaecyparis thyoides*)	2, 3
Common Winterberry (*Ilex verticillata*)	3, 4	Bald Cypress (Taxodium distichum)	2, 3
Elderberry (*Sambucus canadensis*)	3	Black Willow (*Salix nigra*)	3, 4
Inkberry (*Ilex glabra*)	2, 3	Box Elder (*Acer negundo*)	2, 3
Smooth Alder (*Alnus serrulata*)	2, 3	Green Ash (*Fraxinus pennsylvanica*)	3, 4
Spicebush (*Lindera benzoin*)	3, 4	Red Maple (*Acer rubrum*)	3, 4
Swamp Azalea (*Rhododendron viscosum*)	2, 3	River Birch (*Betula nigra*)	3, 4
Swamp Rose (*Rosa palustris*)	2, 3	Swamp Tupelo (*Nyssa biflora*)	2, 3
Sweet Pepperbush (*Clethra alnifolia*)	2, 3	Sweetbay Magnolia (*Magnolia virginiana*)	3, 4
		Sweetgum (*Liquidambar styraciflua*)	3, 4
		Sycamore (*Platanus occidentalis*)	3, 4
		Water Oak (*Quercus nigra*)	3, 4
		Willow Oak (*Quercus phellos*)	3,4

[1]Zone 1: -6 to -12 OR -18 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above ED zone

Table 4.12-2 Emergent and Submergent Plants Recommended for Stormwater Wetlands					
Plant	**Zone[1]**	**Form**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Arrow Arum *(Peltandra virginica)*	2	Emergent	Up to 1 ft.	High; berries are eaten by wood ducks	Full sun to partial shade
Broad-Leaf Arrow-head (Duck Potato) *(Saggitaria latifolia)*	2	Emergent	Up to 1 ft.	Moderate; tu-bers and seeds eaten by ducks	Aggressive colonizer
Blueflag Iris* *(Iris versicolor)*	2, 3	Emergent	Up to 6 in.	Limited	Full sun (to flower) to partial shade
Broomsedge *(Andropogon virgin-ianus)*	2, 3	Perimeter	Up to 3 in.	High; songbirds and browsers; winter food and cover	Tolerant of fluctuating wa-ter levels and partial shade
Bulltongue Arrowhead *(Sagittaria lancifolia)*	2, 3	Emergent	0-24 in	Waterfowl, small mammals	Full sun to partial shade
Burreed *(Sparganium americanum)*	2, 3	Emergent	0-6	Waterfowl, small mammals	Full sun to partial shad
Cardinal Flower * *(Lobelia cardinalis)*	3	Perimeter	Periodic inundation	Attracts hum-mingbirds	Full sun to partial shade
Common Rush *(Juncus sp.)*	2, 3	Emergent	Up to 12 in.	Moderate; small mammals, wa-terfowl, song-birds	Full sun to partial shade
Common Three Square *(Schoenoplectus americanus)*	2	Emergent	Up to 6 in.	High; seeds, cover, water-fowl, songbirds	Fast colonizer; can tolerate periods of dryness; full sun; high metal removal
Duckweed (*Lemna sp.)*	1, 2	Submer-gent / Emergent	Yes	High; food for waterfowl and fish	May biomagnify metals beyond concentrations found in the water
Joe Pye Weed *(Eutrochium purpureum)*	2, 3	Emergent	Drier than other Joe-Pye Weeds; dry to moist areas; periodic inundation	Butterflies, songbirds, insects	Tolerates all light conditions
Lizard's Tail *(Saururus cernuus)*	2	Emergent	Up to 1 ft.	Low; except for wood ducks	Rapid growth; shade-tolerant

Table 4.12-2 Emergent and Submergent Plants Recommended for Stormwater Wetlands					
Plant	**Zone[1]**	**Form**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Marsh Hibiscus *(Hibiscus moscheutos)*	2, 3	Emergent	Up to 3 in.	Low; nectar	Full sun; can tolerate periodic dryness
Pickerelweed *(Pontederia cordata)*	2, 3	Emergent	Up to 1 ft.	Moderate; ducks, nectar for butterflies	Full sun to partial shade
Pond Weed *(Potamogeton pectinatus)*	1	Submergent	Yes	Extremely high; waterfowl, marsh and shore birds	Removes heavy metals from the water
Rice Cutgrass *(Leersia oryzoides)*	2, 3	Emergent	Up to 3 in.	High; food and cover	Prefers full sun, although tolerant of shade; shoreline stabilization
Sedges *(Carex sp.)*	2, 3	Emergent	Up to 3 in.	High; waterfowl, songbirds	Wetland and upland species
Softstem Bulrush *(Schoenoplectus tabernaemontani)*	2, 3	Emergent	Up to 2 ft.	Moderate; good cover and food	Full sun; aggressive colonizer; high pollutant removal
Swamp Smartweed *(Polygonum hydropiperoides)*	2	Emergent	Up to 1 ft.	High; waterfowl, songbirds; seeds and cover	Fast colonizer; avoid weedy aliens, such as P. Perfoliatum
Spatterdock *(Nuphar lutea)*	2	Emergent	Up to 1.5 ft.	Moderate for food, but High for cover	Fast colonizer; tolerant of varying water levels
Switchgrass *(Panicum virgatum)*	2, 3, 4	Perimeter	Up to 3 in.	High; seeds, cover; waterfowl, songbirds	Tolerates wet/ dry conditions
Sweet Flag ***** *(Acorus calamus)*	2, 3	Perimeter	Up to 3 in.	Low; tolerant of dry periods	Tolerates acidic conditions; not a rapid colonizer
Waterweed *(Elodea canadensis)*	1	Submergent	Yes	Low	Good water oxygenator; high nutrient, copper, manganese and chromium removal

Table 4.12-2 Emergent and Submergent Plants Recommended for Stormwater Wetlands					
Plant	**Zone[1]**	**Form**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Wild celery *(Vallisneria americana)*	1	Submer-gent	Yes	High; food for waterfowl; habitat for fish and invertebrates	Tolerant of murky water and high nutrient loads
Wild Rice *(Zizania aquatica)*	2	Emergent	Up to 1 ft.	High; food, birds	Prefers full sun
Woolgrass *(Scirpus cyperinus)*	3, 4	Emergent	yes	High: waterfowl, small mammals	Fresh tidal and nontidal, swamps, forested wetlands, meadows, ditches

[1]Zone 1: -6 to -12 OR -18 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above ED zone
(Aggressive colonizers are shown in bold type)
**Not a major colonizer, but adds color*

Wetland Maintenance Criteria

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first two years, at least twice after storm events that exceed ½ inch of rainfall.

- **Spot Reseeding.** Inspectors should look for bare or eroding areas in the contributing drainage area or around the wetland buffer, and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every three days for first month, and then weekly during the first growing season (March - November), depending on rainfall. The total amount of water applied to the plants – including rainwater and irrigation – should be approximately 1 inch per week. Long, slow irrigation applications promote deep root growth essential for healthy plants; consider using drip irrigation where practical.
- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as grazing by herbivores, poor quality plant stock, water level changes, drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting to selectively replant portions of the wetland that fail to fill in or survive. If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, a reinforcement planting should be completed.

Managing vegetation is an important ongoing maintenance task at every constructed wetland and for each inundation zone. Following the design criteria above should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the wetland, however, will require some annual maintenance.

Designers should expect significant changes in wetland species composition to occur over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants must be dealt with as soon as they begin to colonize the wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Herbicides must be applied by a licensed, certified applicator, and label instructions must be followed. In addition, if herbicides are applied in stormwater ponds or wetlands, the applicator must have a South Carolina pesticide license and be certified in the aquatic application category. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

- ✧ For more information on invasive plants, consult the South Carolina Exotic Pest Plant Council. Resources are available online at http://www.se-eppc.org/southcarolina/invasivePlants.cfm.
- ✧ Additionally, for more information related to chemical control methods for aquatic plants, please review the fact sheet "Aquatic Weed Control Overview" provided by Clemson's Cooperative Extension Service and available online at http://www.clemson.edu/extension/hgic/plants/other/landscaping/hgic1714.html.

Thinning or harvesting of excess forest growth may be periodically needed to guide the forested wetland into a more mature state. Vegetation may need to be harvested periodically if the constructed wetland vegetation grows beyond the density identified in the planting plan. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Removal of woody species on or near the embankment and maintenance access areas should be conducted every 2 years.

Designers should refer to *Pond Maintenance Criteria* for additional maintenance responsibilities associated with wetlands. Ideally, maintenance of constructed wetlands should be driven by inspections that evaluate the condition and performance of the wetland, with specific maintenance tasks identified during these inspections.

An example maintenance checklist for stormwater wetlands is included in *Appendix F*.

Stormwater Wetland References and Additional Resources

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2. Cappiella, K., T. Schueler and T. Wright. 2006. Urban Watershed Forestry Manual: Part 2: Conserving and Planting Trees at Development Sites. USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.
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4. Minnesota Stormwater Steering Committee (MSSC). 2005. Minnesota Stormwater Manual. Emmons & Oliver Resources, Inc. Minnesota Pollution Control Agency. St. Paul, MN.
5. Powell, B. 2012. "Floating Wetlands: Container Gardens for Your Pond." Clemson University Cooperative Extension. http://www.clemson.edu/extension/hgic/water/resources_stormwater/floating_wetlands_container_gardens_for_your_pond.html

Chapter 5:
Local Case Studies

5.1 Charleston National Floating Wetlands and Pond Buffers

Project Fast Facts:

Location: Mt. Pleasant, SC
Land Use: Residential
Number of Lagoons: 23
Unique LID Components:
- Shoreline blankets
- Floating wetlands

Figure 5.1-1. Floating treatment wetland and pond buffer (Photo: Diane Smith)

Introduction

Charleston National is a residential golf community located north of Charleston in suburban Mount Pleasant, SC. The development was built in the late 1980s and, until recently, has not had any major pond maintenance issues or activities. The stormwater ponds (also referred to as "lagoons" in the community) serve as a water source for the golf course irrigation in addition to meeting stormwater treatment requirements. The Community Association determined that the majority of the nearly 25-year old ponds in Charleston National were in some degree of disrepair and in need of restoration. The impetus to address the erosion problems around the edges of the lagoons arose after an incident when a homeowner on a riding lawnmower fell into a lagoon. The area where the homeowner had been mowing the turfgrass had suffered erosion damage and was unstable. The Charleston National Community Association knew they had to find a solution. They formed a Lagoon Committee ("The Goonies") and worked with a civil engineer to prepare plans for lagoon cleaning and depth restorations. Additionally, members attended the 2012 Charleston Area Stormwater Pond Management Conference and were inspired to find a natural alternative.

Project Description

Pond renovations have been broken into several phases. The first three renovated lagoons were located in the Westchester neighborhood at Charleston National. Subsequent projects were installed in the Egret's Point neighborhood and lagoons adjacent to holes 7 through 8 along the golf course. Charleston Aquatics provided the wetland carpets and floating wetlands. Plant selection included powdery alligator-flag (*Thalia dealbata*), swamp rose mallow (*Hibiscus moscheutos*), red stem thalia (*Thalia geniculata*), bog lily (*Crinum americanum*), soft rush (*Juncus effuses*), golden canna (*Canna flaccida*), blue flag iris (*Iris virginica*), and pickerelweed (*Pontedaria cordata*).

Costs and Project Funding

The cost of the project, including design, labor, and materials was approximately $20,000 for the first three ponds. The funding came from existing HOA funds; a future regime fee may be implemented to help pay for additional ponds to be planted, but has not been established at this time.

Obstacles to Implementing LID

The main constraints for retrofitting the ponds with buffers and floating wetlands involved homeowner education and funding. There was support within both the residential community and golf course amenity to make the necessary changes to improve the ponds – the challenge was to identify funding.

Maintenance Program

Charleston Aquatics has a maintenance agreement with the Charleston National HOA to perform routine maintenance on the wetland blanket plantings on the lagoon embankments and the floating wetlands anchored to the middle of the larger lagoons. This involves harvesting plant material in the fall, thinning plant material on the floating wetlands, and transplanting the thinned plant material to the shoreline buffer plantings.

Figure 5.1-2. Bank erosion prior to restoration treatment (Photo: Diane Smith)

Figure 5.1-3. Embankment after grading and planting (Photo: Diane Smith)

Education and Outreach

The Lagoon Committee produced and distributed an informational flyer for the residents of Charleston National about the retention pond project. In addition to describing the cost and work to be completed, the flyer also provides homeowners with certain guidelines for the renovated lagoons (Figure 5.1-4).

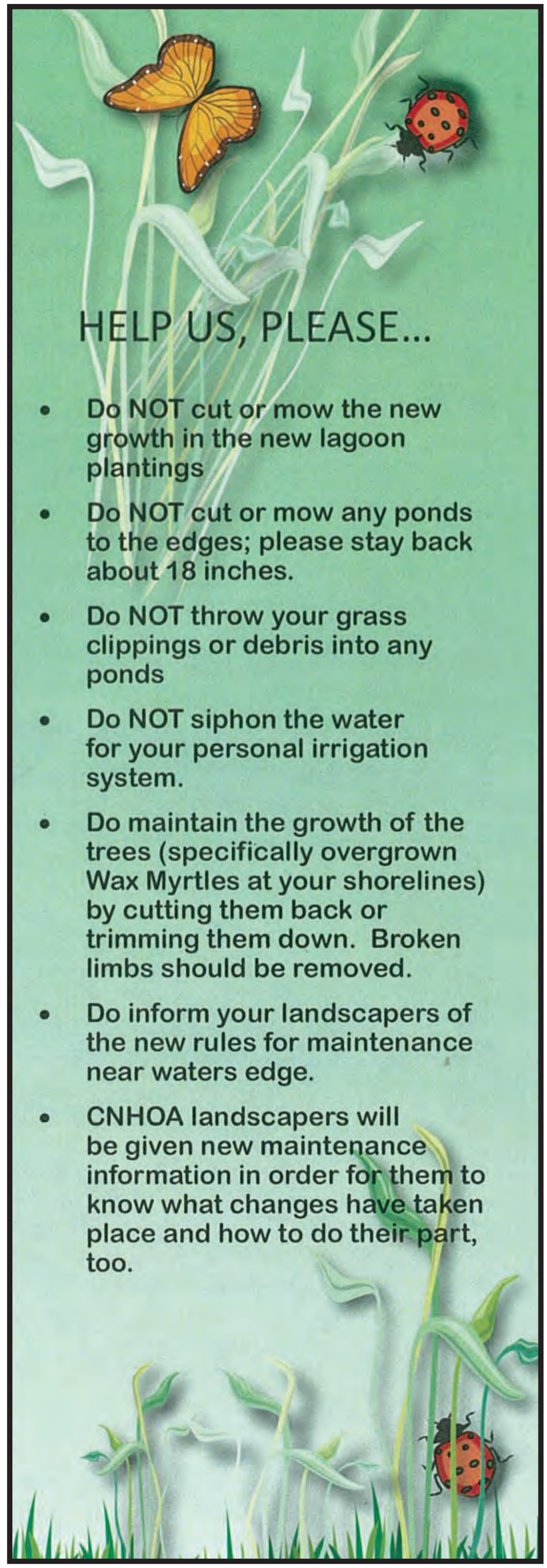

Figure 5.1-4. Informational brochure provided to Charleston National residents

Acknowledgements

Ron Hanson, Charleston National Community Association Lagoon Committee
Bob Horner, PE, Weston & Sampson Engineering
Stu Schuck, Charleston Aquatics

References

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2. Powell, Benjamin. 2012. Shorescaping Freshwater Shorelines. Clemson University Cooperative Extension. Available at http://www.clemson.edu/extension/hgic/water/pdf/015_shorescapes.pdf
3. SCDHEC OCRM. 2000. Backyard Buffers for the South Carolina Lowcountry. South Carolina Department of Health and Environmental Control.
https://www.scdhec.gov/HomeAndEnvironment/Docs/backyard_buffers.pdf

5.2 Horry County Recycling Center Bioretention

Figure 5.2-1. Soil media mixed with recycled glass product from the Horry County Solid Waste Authority. (Photo: Clemson Carolina Clear)

Project Fast Facts:

Location: Loris, SC
Catchment Size: 0.32 acres
Soil: HSG B
Design Volume: 1.5 inch storm
Unique LID Components:

- Recycled glass product used in bioretention media

Unique Features

This project used a recycled glass product provided by the Horry County Solid Waste Authority. The Horry County Stormwater personnel will monitor the site to assess the performance of this product as the main component of the soil media. An early observation and lesson learned is that the product may have benefitted from a thorough washing before installation to remove fine particulates.

In addition to Bermuda sod used on the slopes and forebay, the vegetation used in the bioretention cell included:

- 9 Muhly grass (*Muhlenbergia capillaris*),
- 12 Sweet flag (*Acorus gramineus*),
- 6 Joe Pye weed (*Eupatorium fistulosum*),
- 12 Cardinal flower (*Lobelia cardinalis*), and
- 6 Goldenrod (*Solidago rugosa*).

Figure 5.2-2. Bioretention cell at Loris Recycling Center (Photo: Horry County Stormwater Management)

Cost information

Clemson University Extension Service's Carolina Clear program contracted North Carolina State University partners in the Biological & Agricultural Engineering Department to provide the design, survey, site visits, construction oversight, and bioretention workshop. The project was funded by a USDA NIFA grant. NCSU estimated that the cost for these services was approximately $18,000 for two sites (the second site at the Longs Recycling Facility has not been built yet).

- Equipment[1] = $4,095.36
- Materials[1] = $1,477.71
- Plants[1] = $444.42

Permitting

Because the project was a retrofit of an existing site with no stormwater detention, and because the disturbed area was under one-half acre, the Loris project was exempt from stormwater permitting requirements. However, the site did need an encroachment permit from SC DOT for the bioretention outfall to the state highway ditch.

Maintenance

Horry County Stormwater and Horry County Solid Waste share maintenance responsibilities for this project. Table 5.2-1 outlines the frequency of the various maintenance tasks associated with the bioretention basin.

Table 5.2-1. Maintenance guidelines for bioretention cells[1]

Task	Frequency	Responsibility	Notes
Inspection	Quarterly	Stormwater	Look for erosion, dead plants, ponding for 2-3 days
Weeding	Monthly during growing season		Remove unwanted weeds
Mowing	Monthly, or as needed	Solid Waste Authority	Desired centipede grass height
Mulching	Annually or as needed	Stormwater/ Solid Waste	Rake and fill bare spots
Watering	Immediately after planting and during drought	Stormwater	Use hose behind compactors
Replace dead plants	As needed	Solid Waste	Adjust species if warranted
Clean build up at forebay entrance	As needed	Solid Waste	Clear by hand as needed
Clean out forebay sediment accumulation	As needed	Stormwater	
Clean out underdrains	As needed	Stormwater	Vactor truck – spray into clean-outs or pump from outlet
Miscellaneous upkeep	Monthly	Solid Waste	Trash removal

[1]*prepared by Horry County Stormwater for the Loris Solid Waste Authority Convenience Center Bioretention cell*

Acknowledgements

Andrew Anderson, Extension Associate, NCSU of Biological and Agricultural Engineering

Dave Fuss, Watershed Planner, Horry County Stormwater

Katie Giacalone, Director, Clemson University Center for Watershed Excellence

5.3 Fox Hollow Low Impact Development

Project Fast Facts:

Location: James Island, SC
Gross Acreage: 2.65 acres
Open Space Acreage:
- 0.44 acre park/bioretention
- 0.08 acre wetlands

Number of lots: 9
Net Density: 4.22 homes/acre
Zoning: Charleston County

Figure 5.3-1. The larger of two bioretention/wetland cells in Fox Hollow (Photo: Kathryn Ellis)

Project Description

At Fox Hollow, the developer (New Leaf Builders) wanted to create a low impact development that protected the trees, wetlands, and topography of the site. Unlike conventional development, where mass grading is common, at Fox Hollow the land has been highly conserved – only enough land for the houses and roadway were cleared. Narrow streets and driveways reduce impervious cover in the development. Rather than relying on pipes, a bioswale system conveys stormwater. Bioretention cells replace stormwater ponds.

Project Awards

Named "Best New Community of 2013" by the Charleston Homebuilders Association, Fox Hollow was specifically recognized for its low impact development approach.

Acknowledgments

Engineer: Josh Robinson, PE – Robinson Design Engineers

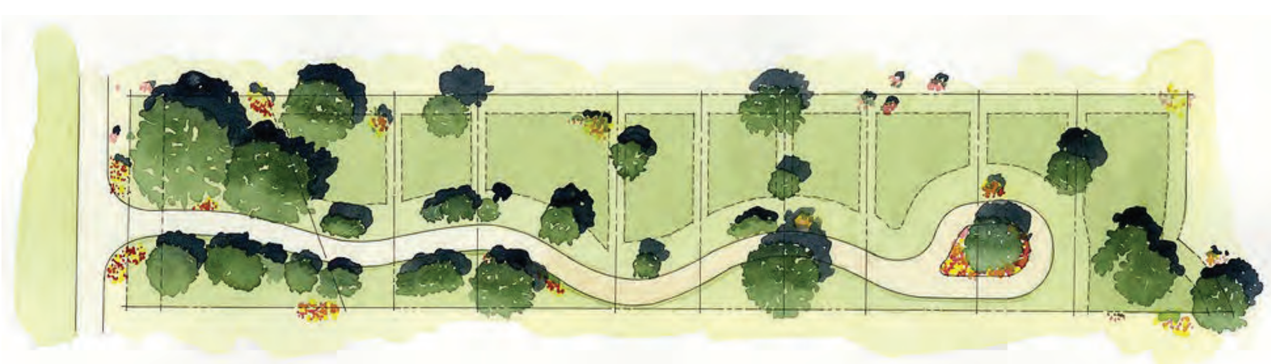

Figure 5.3-2. Site plan for Fox Hollow (Source: Robinson Design Engineers)

5.4 Moore Farms Botanical Garden Green Roof & Rainwater Harvesting

Project Fast Facts:

Location: Lake City, SC
Green Roof Size: 6,000 square feet
Rainwater Harvesting Practices:

- 12,000 gallon cistern to irrigate green roof
- 3,100 gallon cistern for greenhouse
- 4,800 gallon cistern on Fire Tower

Figure 5.4-1. Green roof on the maintenance building at Moore Farms Botanic Gardens (Photo: Kathryn Ellis)

Project Description

Completed in December 2011, the Moore Farms Botanical Garden's 6,000 square foot green roof is situated on top of the Maintenance Facility building with the intention of using it as a research plot to conduct plant performance trials. Moore Farms' goal for the research is to expand the current palette for the warmer zones of the southeast, including Zones 8 and 9.

Additionally, the research aims to increase creativity in the design of green roofs through varied texture and contrast, with "natives and exotics colliding in explosive displays." The roof has 6" of media and is planted with over 130 different species of native and ornamental plants, including grasses, perennials, bulbs, and even vegetables. Plant selection criteria included full sun and drought tolerance. The vegetation is irrigated by drip and spray irrigation. The source of the irrigation water comes from a 12,000 gallon cistern buried under the parking lot by the maintenance building. This system should be large enough to provide sufficient water for nearly a month without any additional rain inputs.

Figure 5.4-2. Walkway, runoff collection gutter, and irrigation system (Photo: Kathryn Ellis)

Irrigation varies by season, with the peak demand occurring during the hottest part of the year. During the summer, the irrigation system will run for a few minutes on an hourly basis. The roof is slanted, at a 4:12 slope, and the runoff from the irrigation or rainfall is collected in a large gutter at the bottom of the slope. The staff has observed that it takes a few hours for any runoff to be generated from the roof after a storm event. Then, the water is channeled from the gutter into the cistern collection system.

Figure 5.4-3. Other green features include a living wall and south-facing windows. (Photo: Kathryn Ellis)

The green roof can be viewed easily from the ground, but for an up-close exploration there are winding staircases leading to a roof-level catwalk. Serving as an extension of the vegetated space on the roof of the maintenance building, the catwalk is covered in a layer of turfgrass.

Although the maintenance building was designed with multiple green features in addition to the green roof and cistern, such as the 400 square foot green wall and south-facing windows, it does not have any official "green" designation. The temperature is monitored with probes in the green roof, and staff members have made note of the insulating effect the green roof provides: even in the hottest part of the day, the roof stays about ten degrees cooler than the ambient temperature. Anecdotally, the roof provides enough insulation that the maintenance building has a reduced use of air-conditioning and heating.

Adjacent to the maintenance building is the greenhouse facility, where another 3,100 gallon cistern system is used to harvest rainwater for irrigation. The bog garden at the entrance to the gardens has a 4,800 gallon cistern water source located on the iconic Fire Tower. The botanic garden staff prefers to use rainwater because it is a better quality than their groundwater source due to the lower levels of sulfur and other undesirable minerals. Young plants, started from seed or rooted from cuttings, are in a delicate stage and require more precise conditions to ensure their success. The only alternative to harvesting rainwater would be to amend the groundwater, such as changing the pH. Once the seedlings and cuttings have matured sufficiently, they will be able to tolerate the groundwater as an irrigation source, but in this stage it is preferable to irrigate them with rainwater whenever possible.

Designers/Manufacturers of Record

Building Architect: Joe Rogers

Building Construction: Coastal Structures

Growing Media: ERTH Products

Green Roof Consultant: Emilio Ancaya, Living Roofs Inc.

Waterproofing Membrane: Owens Corning

Drainage Mat: Enkadrain

GardNet Soil Confinement System: American Hydrotech

Figure 5.4-4. Cast concrete rain barrel connected to watering troughs for irrigating terraced garden (Photo: Kathryn Ellis)

For more information

http://www.moorefarmsbg.org/the-garden/research/
http://www.greenroofs.com/projects/pview.php?id=1537

5.5 Trident Technical College Campus LID Initiatives

Project Fast Facts:

Location: North Charleston, SC
Land Use: Higher Education
Unique LID Components:

- Pervious parking
- Bioswale
- Rainwater harvesting
- Pond buffer & floating wetland
- Possible green roof

Project Awards:

- LEED silver certification

Figure 5.5-1: Pervious parking spaces and bioswale in the TTC Bookstore parking lot. (Photo: Kathryn Ellis)

Project Description

The campus at Trident Tech is home to a series of low impact development demonstration projects. The Civil Engineering Technology program contracted Forsberg Engineering to redesign an existing parking lot adjacent to the college bookstore in 2011. The design incorporated pervious parking and bioswale to intercept and treat stormwater runoff, prior to discharging into the Goose Creek Reservoir.

The Horticulture Technology department also has been pursuing green practices in horticulture. The Sustainability in Horticulture elective class offered by the program emphasizes basic issues affecting sustainability in horticultural environments, such as water retention, harvesting, pesticides, noise pollution, and energy. Some projects the horticulture program has installed in recent years include two 3,000-gallon cisterns, floating wetlands, and stormwater pond buffer vegetation. The cisterns collect rain water from the roof of the greenhouse; the water is filtered and disinfected to supply the cool pads in the greenhouse as well as keep an ornamental pond filled. Currently, the pad system is supplied by potable water so the use of rain water will help offset the costs of maintaining the temperature inside the greenhouse during the hot summer months. Through grant money provided by TTC Green – an initiative that expands Trident Technical College's energy efficiency and sustainability efforts – the Horticulture program was able to install three floating wetland panels and a section of wetland carpet in a stormwater pond adjacent to two large parking lots on campus.

Figure 5.5-2: Native vegetation used in buffer and floating wetland systems in the stormwater pond. (Photo: Kathryn Ellis)

Another interesting project in progress on the TTC main campus is the new nursing building, which will be LEED certified and make use of several LID BMPs. The new facility will incorporate rainwater capture/reuse (via underground cistern), pervious pavement, and potentially a green roof. The building was completed in spring 2014.

Figure 5.5-3: Demonstration green roof and rain barrel (including a bog garden on top) at the TTC Horticulture building. (Photo: Kathryn Ellis)

Acknowledgements

Nursing Building Project

- ✧ Landscape Architect: Bryant Stowe, ADC Engineering
- ✧ Engineer: Jeff Webb, ADC Engineering
- ✧ Architecht: Richard Bing, LS3P Associates

Bookstore Parking Lot Pervious Parking & Bioswale:

- ✧ Engineer: Gray Lewis, Forsberg Engineering

Pond Buffer, Floating Wetland, and Greenhouse Cooling System:

- ✧ TTC Horticulture Program: Tony Bertauski
- ✧ Charleston Aquatics: Stu Schuck

TTC Green: http://www.tridenttech.edu/TTCGreen.htm

5.6 Goodwill Store Bioretention and Pervious Paving

Project Fast Facts:

Location: Johns Island, SC
Land Use: Commercial/Retail
Installation: 2012
Project Size: 1.89 acres
Unique LID Components:
- 4 bioretention cells
- Pervious concrete parking spaces

Other: featured in *Post and Courier* article (see sidebar)

Figure 5.6-1. Aerial image of Johns Island Goodwill Store (Image: Google 2014)

Project Description

Located on a flat property with a large building and parking lot contributing to impervious area, creative and attractive techniques for stormwater treatment were necessary for the Goodwill Store on Johns Island. One solution was to include 41 pervious concrete parking spaces (out of a total 73 spaces on site) in the parking lot. Additionally, curbing was not installed through much of the parking lot, which allowed runoff to flow directly into the four vegetated stormwater treatment facilities on site: one swale, two rain gardens, and one pond. These stormwater management practices intercept and infiltrate the runoff through a special soil media mixture that promotes drainage. After most storm events, the depressions are dry within 24 hours.

Figure 5.6-2. The parking lot at the Johns Island Goodwill store incorporates bioswales and pervious concrete. (Photo: Kathryn Ellis)

Plants native to the Lowcountry are used exclusively in the ornamental landscaping and stormwater practices on site. The vegetation was selected for aesthetics and its ability to survive with a minimum amount of maintenance, which is an asset to the property's managers. Unlike typical grassed ponds, bioretention does not require constant mowing. Additionally, using native vegetation in the stormwater BMPs allowed the City of Charleston to grant a variance from standard procedures and allow the bioretention cells to be placed in required buffer spaces. It was the first project in the City of Charleston that was granted this allowance.

Figure 5.6-3. Bioretention, pervious concrete, and no curb facilitate infiltration of runoff (Photo: Kathryn Ellis).

Lessons Learned and Advice

✧ Communication with contractors before installation will help prevent problems with grading the paving.

✧ Educate property owner on proper landscape maintenance activities. Once the plants become established, they will require little additional hands-on care after the initial irrigation and regular weeding.

✧ Use shredded hardwood mulch (not pine nuggets or pine straw) to prevent mulch floatation and clogging of outlet structures.

Acknowledgements

JR Kramer, Remark Studio Landscape Architecture

Giles Branch, Earthsource Engineering

Sandra Cashion, Piedmont Companies Incorporated

"Landscape pleases the eye, keeps business dry" by Robert Behre, The Post and Courier (March 10, 2013)

The new Goodwill Outlet Store on Johns Island shows how thoughtful landscape architecture not only pleases the eye but also can tackle more mundane tasks. The 1758 Main Road property is flat, and much of it is covered with a sizable building and a parking lot. That posed a challenge as far as dealing with the stormwater runoff. Landscape architect J.R. Kramer of Remark says the solution was to design a series of rain gardens."We've actually engineered these to perform as if they were wetlands," he says. "Instead of your typical detention pond, we tried to make it look a lot better."The site includes four rain gardens, also referred to as "bioswales." They're essentially carefully designed ditches. "It's all about celebrating rain," he says. Each has a special soil mix underneath to ease their drainage. Kramer says most are dry 24 hours after the rain stops. That's important because standing water would invite mosquitoes to breed. Goodwill's rain gardens also have assorted native plants, such as yucca and sabal minor. There's also a bioswale in the middle of the parking lot planted with scouring rush and flanked by parking spaces with permeable concrete, meaning the rainwater can seep through. It's the first project in Charleston to allow bioswales in the required buffers, Kramer says."This is a big step forward for the city," he says. "You always have these requirements. How do you design something within the requirements and still be creative with it?"

The landscape changes with the seasons and looks like a set of wetlands that might have existed there long before someone decided to build. That's a clear contrast from a typical detention pond that always looks manmade, even when there's no sprinkler jet in the middle. "The whole thing was designed to keep its rural character," Kramer says. It complements the simple vernacular design of the brick building, with its metal roof and storm shutters. The choice of plants was driven partly by what would look good and partly by what would thrive with minimum maintenance. "We're treating aesthetics and ecology as equals," he says. While rain gardens require regular weeding at first, that eases after the native plants grow large enough to crowd out weeds. "It doesn't require nearly as much maintenance as mowing the grass all the time," he adds. In the rear, the Goodwill site features an appealing "living fence," a screen of yellow jessamine and coral honeysuckle instead of wood or masonry. A line of deciduous trees completes it.

The Goodwill project was developed by Piedmont Companies Inc. and designed by Dennis Williams of Williams Design in Lincolnton, N.C. The contractor was David E. Looper & Co., while the civil engineer was by EarthSource Engineering of Mount Pleasant.

5.7 Jarvis Creek Park Stormwater Pond & Wetland Project

Project Fast Facts:

Location: Hilton Head, SC
Land Use: Public Park
Drainage Project Completed: 2001
Park Opened to Public: 2003
Watershed/Catchment Area: 1,136 acres
Watershed Imperviousness: 19%
Treatment Volume: 988 acre-feet per year
Unique LID Components: Stormwater pond and wetland combination
Project Awards:

- ♦ SCDNR Stewardship Development Program (2000)
- ♦ Municipal Association of SC Municipal Achievement Award, public works category (2000)
- ♦ SCDNR/FEMA Flood Hazard Mitigation Assistance Grants (1998 -1999, $528,000)

Figure 5.7-1. Stormwater pond at Jarvis Creek Park (Photo: Kathryn Ellis)

Project Description

The Jarvis Creek Project is a combined drainage improvement project and community park at the Town of Hilton Head Island's Jarvis Creek Tract. The tract is approximately 50 acres, of which roughly half are wooded. Historically, the remainder of the property was cleared for pasture as part of the antebellum Honey Horn Plantation. The 1,136 acres of land that drain to the pond and constructed wetlands originate from the nearby Hilton Head Island school complex, a small portion of Honey Horn Plantation residential development, and the commercial development along Main Street.

The drainage project involved construction of a borrow pit on the cleared portion of the tract into which pumps deliver stormwater from upstream the drainage area. The borrow pit forms the central feature of a passive park that was constructed in 2003 following the drainage project. The pond covers 13 acres with about 4,200 linear feet of vegetated shoreline. The pond was originally excavated to a maximum depth of 30 feet and the excavated soil was used to construct the Cross Island Parkway. Additional design elements of the park include interpretive trails, observation piers, and picnic areas (Figure 5.7-2).

As a result of the construction of the pump station, 0.468 acres of wetland were filled. To compensate, the Town constructed a one acre transitional wetland at the outfall of the borrow pit, and a wetland littoral shelf within the borrow pit. It was this innovative wetland mitigation, along with the unique design of the project as a whole, which earned this project a Stewardship Development Award through the South Carolina Department of Natural Resources.

This project represents a creative solution to a difficult problem. In 1995 the Town of Hilton Head Island conducted an Island Wide Drainage Study to identify upcoming stormwater improvement

Figure 5.7-2. Jarvis Creek Park conceptual drawing (Source: Town of Hilton Head)

needs. The study recommended upgrading the stormwater outfall under US 278 and enlarging the natural freshwater creek upstream of tidal Jarvis Creek to reduce problematic flooding in the Main Street commercial areas and Hilton Head Plantation residential areas.

The original drainage plan included widening the natural freshwater creek adjacent to the Jarvis Creek Tract (at that time privately owned) to a bottom width of 35 feet and a depth of approximately 6 feet. The sloping bank would create a 100 foot wide canal. Enlarging the freshwater creek would destroy a large and unique area of upland habitat and over 4 acres of freshwater wetlands.

Work began in fiscal year 1996/7 on the conceptual design and topographic survey of the Jarvis Creek Ditch Project. Significant wetlands and trees were found within the proposed project location. Therefore, the Town began to pursue an option that minimized the wetland impact by rerouting the ditch. Rerouting also meant lengthening the ditch, which in turn increased the amount of excavation and loss of trees and wildlife habitat. Estimated costs increased from $1.6 million to $3.0 million.

It was also during the summer of 1996 that the Town was negotiating the purchase of the Jarvis Creek Tract adjacent to the existing Jarvis Creek ditch. The 50 acre Jarvis Creek tract was purchased by the Town and Town staff began to explore additional design options to solve the drainage problem. A 13-acre lake, capable of storing and conveying the necessary stormwater was envisioned. A pump station was needed in order to move the water from the ditch to the lagoon. From the lake, water would flow through a vegetated spillway that discharges into the headwaters of Jarvis Creek

This alternative plan was adopted, and the site was ideal for creation of the lake because a majority of the site had been previously cleared and used for cattle grazing. The selection of the Jarvis Creek Tract resulted in the protection of 3.5 acres of valuable freshwater wetlands, and the reduction in upland habitat and tree loss.

To accomplish the goal of stormwater improvement, the Town needed to construct a pump station near Hwy 278, which would pump the stormwater through four 48-inch pipes to the lake. The layout of the pipes was a particularly critical decision, given the abundance of specimen size live oaks and pine trees. The pipes were laid out in such a way that the entrance road to the park would eventually be paved on top of the pipes, requiring that only one swath be cleared through the parcel.

In addition, during the construction of the wetland mitigation areas, and during plant selection for the remainder of the parcel, only plants native to Hilton Head Island were used. This selection

Figure 5.7-3. Constructed wetlands adjacent to the pond at Jarvis Creek Park (Photo: Kathryn Ellis)

improved the quality of the parcel for native wildlife by providing their indigenous food and cover sources. The selection of native plants also reduced the need for pest management, irrigation, and long-term maintenance.

The change from a 100-foot wide canal to a stormwater retention lake with wetland filter has had profound impacts on water quality. The stormwater is designed to flow into the lake, through the vegetated wetland mitigation site, into an existing bottomland hardwood wetland, and then into the freshwater creek (Figure 5.7-3). The detention time in the lake and the filtering effect of the wetlands is designed to improve the quality of water flowing into Jarvis Creek. A monitoring station has been installed to monitor the effluent into Jarvis Creek. The data is being collected to address any problems as they arise and to establish a baseline to compare post-drainage project water quality.

The wetland mitigation area is perhaps the most exciting aspect of the project. In designing the wetland, Town staff visited existing reference wetlands in the watershed to determine appropriate plant species. Because the mitigation area is a transitional wetland moving from the saturated lake edge to a higher site, plant species change from aquatic species such as pickerel weed to red maples and cypress on the spillway. In addition to the wetland at the spillway, a littoral shelf on the northwest corner of the lake was constructed in spring 2001.

The design for the Jarvis Creek Park ensured this valuable tract of land remains in the public's trust in perpetuity. The park was designed as a passive recreation area, with trails and picnic areas. Walking trails have been designed around trees, and little vegetation was removed for park infrastructure. A boardwalk guides visitors through the constructed wetland to teach them about wetland mitigation. The majority of the site has been left in its natural state as a haven for wildlife. Because the site is first and foremost a drainage improvement project, the lake and spillway are designed to be functional, while accommodating recreation and educational opportunities.

Stormwater Monitoring:

This project has generated interest and has been studied locally, and there are several plans in place to continue monitoring the project. Because the water quality aspect of the project is fairly innovative, the Town has been evaluating the progress since its inception. Bi-weekly water quality monitoring is conducted at the pump station site near Hwy 278, and at the freshwater creek behind the outfall. This monitoring checks for 10 different water quality parameters including nitrogen, phosphorous, and fecal coliform bacteria. The intention was to get a good baseline of data before the pump station was operational to use as a comparison once the stormwater is actively pumped through the system. This monitoring has been going on since September 1999, and will continue indefinitely. The data collected and the lessons learned at Jarvis Creek Park have been used to influence other stormwater improvement projects in the Town.

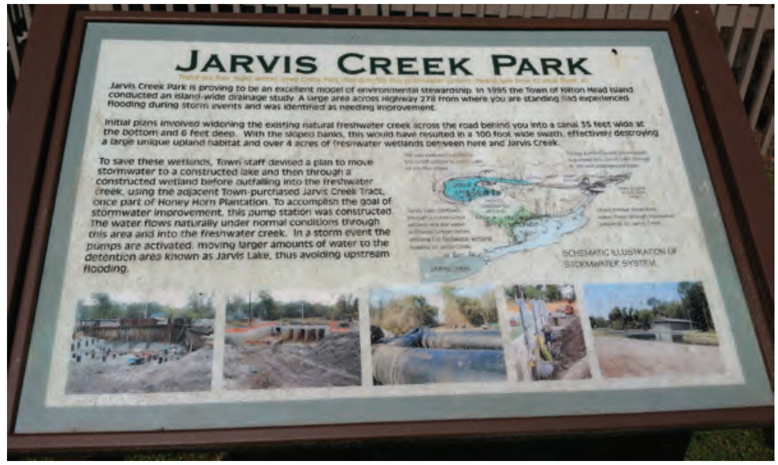

Figure 5.7-4. Educational sign at Jarvis Creek Park (Photo: Kathryn Ellis)

In addition to water quality, the Town actively monitors the progression of the created wetland. Three permanent vegetation plots have been established to monitor plant growth, and quarterly soil samples are taken to ascertain hydric characteristics and measure nutrient levels. Additionally, all observed wildlife species are recorded as the lake evolves from a barren pit into a diverse wildlife habitat. As previously mentioned, the site is protected as open space and the wetlands are protected through restrictive covenants.

Public Education:

The Jarvis Creek project presents a great opportunity for public education about natural resources. Town staff members have conducted several field trips with school children to teach them about wetlands and wetland mitigation. The park design includes interpretive trails (Figure 5.7-4) that educate the public about the native species in the park and about the unique wetlands. The Town arranged a cooperative partnership with the local Hilton Head Island School complex to use the park as an outdoor lab for nature study. Also, the Hilton Head Coastal Discovery Museum provides guided tours through the interpretive trails. Additional creative uses of the park include local track teams and water search and rescue training held by the fire department.

Maintenance Program:

The park itself requires very little maintenance. The four pumps at the pump station are inspected on a yearly basis; real-time monitors were installed in 2007-08 so that pump wear could be monitored and adjusted to decrease maintenance needs. The sump area, ditches, and lake have not received any maintenance since installed.

Miscellaneous:

This project is one of the most innovative in the Town's Capital Improvements Program. Its unique design has been recognized as outstanding by the Association of State Floodplain Managers, and the Town was invited to present the project at their 1998 national conference. In addition, because of its ability to mitigate upstream flooding, the project was awarded the DNR Flood Mitigation Assistance Grant two years in a row. The drainage and pump station portion cost approximately $3.1 million. It was paid partly with Flood Hazard Mitigation Grant monies; the rest was bonded, and the debt service is now being paid by Stormwater Utility fees.

The Town of Hilton Head believes it has created "an exciting project that makes the best of our natural resources, while providing an innovative solution to a complicated problem."

Acknowledgements
Sally Krebs, Sustainable Practices Coordinator, Town of Hilton Head

5.8 Moss Park Constructed Wetlands

Project Fast Facts:

Location: Murrells Inlet, SC
Land Use: Commercial
Installation: 2004
Project Size: 40 acre tract
Unique LID Components:
2 constructed wetlands

Figure 5.8-1. 2009 Horry County Natural Color aerial image of Moss Park constructed wetlands site.

Project Description

The two constructed wetlands in Moss Park are situated in a commercial land use area in Horry County, SC. The EARTHWORKS Group evaluated several stormwater treatment options for their client; ultimately they created a land plan utilizing stormwater wetlands that met the regulatory requirements, while maximizing natural resources and visually enhancing the commercial development. Furthermore, by using stormwater wetlands, the client was able to maximize useable developable space on the property because wetlands count toward open space requirements and wetlands were more space efficient than a pond.

Constructed wetlands provide stormwater retention and water quality benefits. The system was designed to achieve high removal rates of particulate and soluble pollutants through gravitational settling, wetland plant uptake, absorption, physical filtration, and biological degradation. Additionally, wetlands can provide reduction of bacteria and oxygen demanding substances from stormwater runoff.

Cost information

Constructed wetlands are often less expensive and require less maintenance than traditional pipe-and-pond systems due to reduced excavation costs, less materials, and fewer structures to maintain. An additional cost-benefit aspect of constructed wetlands is that they save space through natural site integration, thus providing additional room for site development. This system in particular was more cost effective than other treatment options. Table 5.8-1 gives the itemized cost list (in 2004 dollars) for this project.

Table 5.8-1. Itemized cost information for constructed wetlands at Moss Park

ITEM	ITEM DESCRIPTION	UNITS	AMOUNT	UNIT COST	TOTAL COST
1	Construction Entrance	LS	1	$900.00	$900.00
2	18” RCP	LF	120	$20.00	$2,400.00
3	Fill Existing Ditch	CY	500	$9.50	$4,750.00
4	Check Dam	EA	4	$300.00	$1,200.00
5	Hay Check	EA	20	$25.00	$500.00
6	Rock Outfall	EA	2	$200.00	$400.00
7	Swale Lotline	LF	1700	$3.00	$5,100.00
8	Pond/Wetland Excavation	CY	9355	$3.00	$28,065.00
9	Wetland Plants	LS	2	$1,000.00	$2,000
10	Grassing	AC	4	$3,000.00	$12,000.00
11	Hydric Soils Backfill	CY	1000	$6.00	$6,000.00
12	Rock Trench, Rock Outfall, Pipe	LS	1	$1,200.00	$1,200.00
13	Silt Fence	LF	3256	$2.50	$8,140.00
14	Grassing Dressup Moss Creek Rd.	AC	1.2	$3,000.00	$3,600.00
	Subtotal				**$76,255.00**

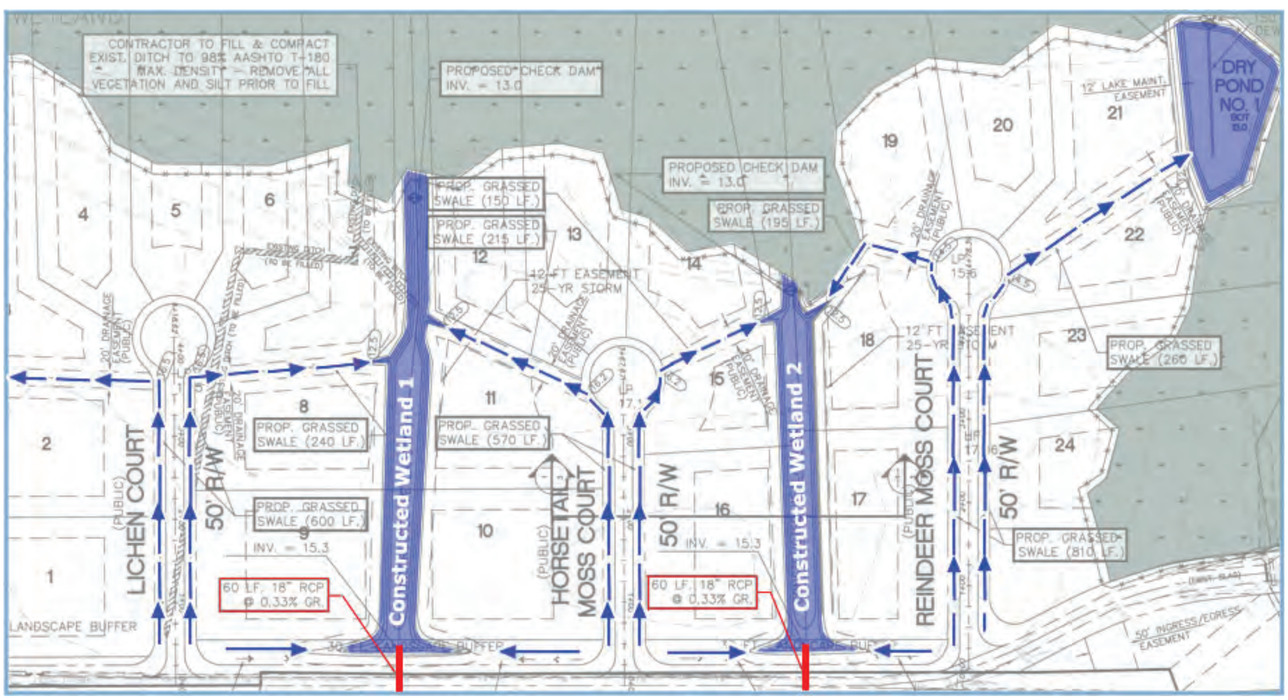

Figure 5.8-2. Plans for Moss Park constructed wetlands (courtesy of The EARTHWORKS Group)

Incentives and Benefits

- There is a strong desire from the regulatory community for this type of project; SCDHEC-OCRM and Horry County were enthusiastic to see a progressive approach adopted for this project and were eager to see it succeed.
- Maintenance costs are more manageable with the constructed wetland than with catch basins, pipes, and ponds. Generally, no maintenance of the constructed wetland system is required. Because the sediments are trapped close to the source due to the plants, sediment removal is not as pronounced. Also, the vegetation is intended to grow naturally, so vegetation maintenance and removal is not required.
- This project was less expensive than the typical pipe and pond and provided flexibility within the useable property which benefitted the client.
- The wetlands provide enhancement of localized vegetative diversity and create excellent wildlife habitat.
- The wetlands add beautification and vegetative screening to the commercial site, which the tenants appreciate.

Lessons Learned

- Select plant species that are less desirable to local vegetarian consumers (wildlife). For example, mast-producing oaks were particularly susceptible to deer foraging, but cypress seemed to have better survival rates.
- Remove invasive species early on so that planted species have a greater chance for survival.

Acknowledgements

Stephen Williams, The EARTHWORKS Group

Appendix A. Compliance Calculator Guidance

A.1 Introduction

The Center for Watershed Protection created the compliance calculator spreadsheet to allow a designer to quickly analyze multiple LID options, and check them against the state water quality requirements. As is clear from the specifications, each LID BMP has different design requirements, equations, and standards that determine its effectiveness. Depending upon the site, it can become difficult to determine which BMP(s) best meets the requirements. With the compliance calculator, it is easier to examine different combinations of BMPs in order to find the best option or set of options. The compliance calculator also can be used by the plan reviewer to quickly verify the compliance status of a plan.

It is important to note that the compliance calculator is not a model, and while it can be used as a design tool, it does not replace the required efforts of a competent designer. The numbers in the spreadsheet do not guarantee that a BMP meets the specifications, is appropriate for its location, or is generally well-designed.

The compliance calculator likely will be a useful tool for many types of development sites. However, there are other tools available that can assist with design of practices, compliance determination, or pollutant removal calculations, some simple, and some much more complex. The applicability of these tools or models will depend upon the characteristics of an individual site and the level of analysis that is desired. Potentially applicable tools include:

SWMM

The EPA Storm Water Management Model (SWMM) is a rainfall-runoff simulation model used mainly in urban areas, often to model complex catchments or watersheds. SWMM models both the generation of runoff from rainfall based upon surface types, and routing through the conveyance system, including pipes, channels, treatment practices, etc. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the quantity and quality of water conveyed through each pipe and channel throughout each simulation period. More information on SWMM is available at http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/.

IDEAL

The Integrated Design, Evaluation, and Assessment of Loadings (IDEAL) model is a water quality model for designing stormwater BMPs and calculating their effectiveness in pollutant removal. The IDEAL model includes a number of available BMPs, including sand filters, detention ponds, bioretention areas, rainwater harvesting, proprietary practices, and others. Specific BMP details, such as ponding or filter media depths can be input into the model, and runoff can be routed between catchments and BMPs as needed. The IDEAL model was originally designed for coastal South Carolina to help designers meet water quality standards. The IDEAL model can be found at http://www.stormopssoftware.com/.

Green Values National Stormwater Management Calculator

The National Green Values™ Calculator (GVC) is a simple calculator tool intended to allow the user to quickly compare the performance, costs, and benefits of LID BMPs. The GVC looks at annual precipitation values and LID practice performance to determine the benefits of various BMP arrangements. The GVC does not calculate flows or water quality results. Instead, it looks at the runoff reduction benefits of various BMPs, and allows the user to select a runoff reduction goal that matches a site's requirements. The GVC can be found at http://greenvalues.cnt.org/national/calculator.php.

A.2 Compliance Calculator Spreadsheet Guidance

The following guidance explains how to use each of the worksheets in the compliance calculator spreadsheet. The spreadsheet is available to download at http://www.northinlet.sc.edu/LID.

Note: All cells in the spreadsheet that are highlighted in blue are user input cells. Cells highlighted in gray are calculation cells, and cells highlighted in yellow are constant values that generally should not be changed.

Site Data Sheet

1. Enter the name of the proposed project on **line 9**.
2. Enter the pre-development land cover areas (in acres) of forest cover, turf cover, and impervious cover on the site for Natural Resource Conservation Service (NRCS) soil types A, B, C, and D in **cells C15-C17**, **E15-E17**, **G15-G17**, and **I15-I17**, respectively.
3. Verify/enter the NRCS runoff curve numbers for each land use/soil type combination in **cells D15-D17**, **F15-F17**, **H15-H17**, and **J15-J17**. Default values have been included in these cells, but they can be changed if necessary.
4. Enter the post-development land cover areas (in acres) of forest cover/open space, turf cover, and impervious cover on the site for Natural Resource Conservation Service (NRCS) soil types A, B, C, and D in **cells C24-C26**, **E24-E26**, **G24-G26**, and **I24-I26**, respectively.
5. Verify/enter the NRCS runoff curve numbers for each land use/soil type combination in **cells D24-D26**, **F24-F26**, **H24-H26**, and **J24-J26**. As with the pre-development entries, default values have been included in these cells, but they can be changed if necessary.
6. Answer yes or no to the questions on **lines 29-31** regarding the location of the site. The required water quality volume (**cell C37**), and the mechanism of treatment (**cell E37**), depend on the answers to these questions, as well as the area disturbed on the site (See Figure A.2-1).
7. For sites regulated by the statewide permit only, the water quality volume and treatment mechanism is recorded as "Practice Dependent" and the required volume varies depending on the type of practice (See Table A.2-1). These practice-specific values are recorded in **cells C39-C41**.

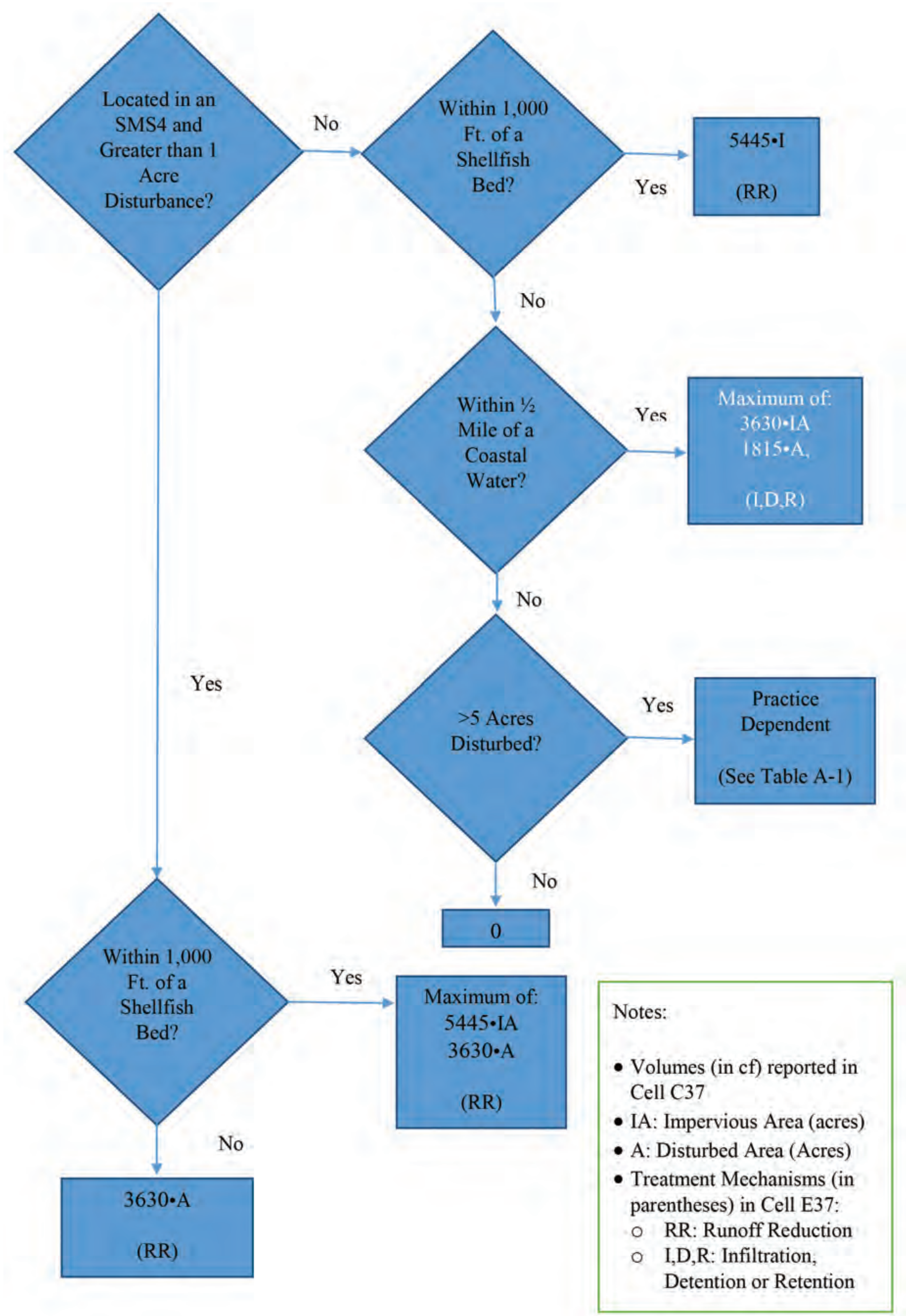

Figure A.2-1. Flowchart to determine stormwater management requirements using the compliance calculator spreadsheet.

Table A.2-1. Practice-Dependent Water Quality Volume and Treatment Mechanisms	
Practice Type	**Water Quality Volume (ft^3)**
LID Practices	3630•IA
Ponds with a Permanent Pool (Wet Swales, Wet Ponds, Wetlands)	1815•A
Ponds without a Permanent Pool (Dry Detention Ponds, Filtration Practices)	3630•A
Note: IA = Impervious Area (acres); A = Disturbed Area (acres)	

BMP Sheet

1. Apply BMPs to the drainage area to address the required water quality volume by indicating the area in square feet of turf cover and impervious cover to be treated by a given BMP in **Columns B and C**. This likely will be an iterative process. The available BMPs include the following:
   - Bioretention - Enhanced
   - Bioretention - Standard
   - Permeable Pavement - Infiltration
   - Permeable Pavement - Standard
   - Infiltration
   - Green Roof
   - Rainwater Harvesting
   - Disconnection to A/B or Amended Soils
   - Disconnection to Forest Cover/Open Space
   - Grass Channel in A/B or Amended Soils
   - Grass Channel in C/D Soils
   - Dry Swale
   - Wet Swale
   - Regenerative Stormwater Conveyance (RSC)
   - Filtration
   - Dry Detention Practice
   - Wet Detention Pond
   - Wetland
2. Enter the BMP storage volume (ft^3) in **Column D**.
3. The volume from direct drainage to the BMP is calculated and reported in **Column E**, using the flowchart provided in Figure A.2-1. Note that the total disturbed area is

reflected as the sum of impervious cover (**column B**) and turf cover (**column C**) draining to the practice.

4. If more than one BMP will be employed in series, any overflow from upstream BMPs (V_{US}) will be accounted for in **column F**.
5. The total volume captured by the practice (V_{CAP}) is reported in **column G** and is equal to the following:

$$V_{CAP} = Maximum\ of\ (Sv, V_{US} + V_{DD})$$

where:

V_{CAP}	=	Water Quality Volume captured by the practice (ft^3)
Sv	=	Storage Volume (ft^3)
V_{US}	=	Volume of runoff from upstream practice (ft^3)
V_{DD}	=	Volume of runoff from direct discharge (ft^3)

6. The Treatment Mechanism (from **cell E37** on the **Site Data Tab**) is reported in **Column H**.
7. The Credit (%) for each treatment mechanism (from Table A.2-2) is reported in **Columns I-K**.
8. The Water Quality Volume Credited is calculated in **Column L**, and is equal to the following:
9.

$$WQv_{CR} = Minimum\ of\ (Sv \times CR, V_{CAP})$$

where:

WQv_{CR}	=	Water Quality Volume Credited (ft^3)
Sv	=	Storage Volume (ft^3)
CR	=	Credit (fraction)
V_{CAP}	=	Volume Captured by the Practice (ft^3)

10. The Remaining Water Quality Volume (**column M**) is calculated as:

$$WQv_R = V_{US} + V_{DD} - WQv_{CR}$$

where:

WQv_R	=	Water Quality Volume Remaining (cf)

V_{US} = Volume from Upstream Practices (cf)

V_{DD} = Volume from Direct Drainage (cf)

11. Any runoff volume remaining can be directed to a downstream BMP by selecting a practice from the pull-down menu in **column N**. Selecting a BMP from the menu will automatically direct the runoff volume remaining to **column F** for the appropriate BMP.
12. The Target Water Quality Volume (WQv_T) is reported in **Cells B31-B35**, from corresponding **Cells C37-C41** on the **Site Data Tab** as follows:
    - For sites where the volume is not practice dependent (i.e., regulated by a rule other than the Statewide Stormwater Rule), the target is reported in **Cell D31** and is equal to the value on **Cell D37** on the **Site Data Tab**.
    - For sites where the volume is practice dependent (i.e., regulated by the Statewide Stormwater Rule only), the target volumes are specific to each practice, and reported in **Cells C33-C35**, which are taken from corresponding **Cells C39-C41** on the **Site Data Tab**.

Table A.2-2. Water Quality Credit for Each Treatment Mechanism

Practice Type	Treatment Mechanism		
	Runoff Reduction	Infiltration, Retention, or Detention	Practice Dependent
Bioretention - Enhanced	100%	100%	100%
Bioretention - Standard	60%	100%	60%
Permeable Pavement - Infiltration	100%	100%	100%
Permeable Pavement - Standard	50%	100%	50%
Infiltration	100%	100%	100%
Green Roof	100%	100%	100%
Rainwater Harvesting	100%	100%	100%
Disconnection to A/B or Amended Soils	50%	100%	50%
Disconnection to C/D Soils	25%	25%	25%
Disconnection to Forest Cover/Open Space	75%	75%	75%
Grass Channel in A/B or Amended Soils	20%	20%	20%
Grass Channel in C/D Soils	10%	10%	10%
Dry Swale	60%	100%	60%
Wet Swale	0%	100%	100%
Regenerative Stormwater Conveyance (RSC)	100%	100%	100%
Filtration	0%	100%	100%
Dry Detention Practice	0%	0%	100%
Wet Detention Pond	0%	100%	100%
Wetland	0%	100%	100%

13. The Water Quality Volume Provided (WQv_p), is calculated in **Cells D31-D35**, as follows:
    - For sites where the volume is not practice dependent (i.e., regulated by a rule other than the Statewide Stormwater Rule), the volume provided is reported in **Cell D31** and is equal to the value in **Cell L26**, which sums the water quality volume credited for all practices in **Column L**.
    - For sites where the volume is practice dependent (i.e., regulated by the Statewide Stormwater Rule only), the target volumes are specific to each practice, also from **Column L**. The value calculated in **Cell D33** is the summation of the WQv_p provided in all LID practices (i.e., practices with greater than 0% Runoff Reduction in Table A.2-2). The value calculated in **Cell D34** is equal to the WQv_p provided in all ponds with a permanent pool (wet swales, wet ponds and wetlands), and the value calculated in **Cell D35** is equal to the WQv_p provided in all ponds without a permanent pool (filtration practices and dry ponds).
14. The fraction of target achieved (either by practice or by the entire site as appropriate) is calculated in **Cells F31-F35).** The % of target achieved is calculated as follows:

$$T = \left(\frac{WQv_P}{WQv_T}, 1 \right)$$

where:

T	=	Treatment (fraction)
WQv_P	=	Water Quality Volume Provided (cf)
WQv_T	=	Water Quality Volume Target (cf)

15. Cell I31 determines if the site target has been reached as follows:
- For sites where the volume is not practice dependent (i.e., regulated by a rule other than the Statewide Stormwater Rule), the target volume is achieved if the Target % in **Cell F31** is 100%.
- For sites where the volume is practice dependent (i.e., regulated by the Statewide Stormwater Rule only), the target volumes is achieved if:
  - The Total % achieved in **Cells F32-F35** is at least 100%, *and*
  - The Total Turf treated is at least equal to the site turf area, *and*
  - The Total Impervious Cover treated is at least equal to the site impervious cover.

Channel and Flood Protection

This sheet assists with calculation of Adjusted Curve Numbers that can be used to calculate peak flows associated with the 2-year storm, 10-year storm, or other storm events.

1. Indicate the appropriate depths for the 2-year, 10-year, 25-year, and 100-year 24-hour storms (or other storms as needed) on **line 5**.
2. The Total Site Area (from the **Site Data** Tab), is reported in **Cell C7**.
3. Detention Storage Volume (cf) is calculated in **Cell C8**, and refers to the total storage provided in all LID practices using the following equation:

$$V_{DS} = \sum_{LID\ BMPs} Sv_{BMP} \times IRD_{BMP}$$

where:

V_{DS} = Volume in Site Detention Storage (cf)

Sv_{BMP} = Storage Volume Provided in Each BMP (cf)

(from **Column D** of the **BMPs** Tab)

IRD_{BMP} = Infiltration, Retention or Detention Credit for Each BMP

(from **Column J** of the **BMPs** Tab)

Note that, while other practices such as ponds provide detention, it is assumed that design engineers will explicitly account for this detention in a Pond Routing program.

4. As indicated in the Site Data sheet, each cover type is associated with a NRCS curve number. **Cells D15–G20** show the pre-development land cover areas and curve numbers that were indicated on the Site Data Sheet. Using these curve numbers, a weighted curve number is calculated in **cell G22**.
5. **Cells D27–G32** show the post-development land cover areas and curve numbers that were indicated on the Site Data Sheet. Using these curve numbers, a weighted curve number is calculated in **cell G39**.
6. Using NRCS methodology, **line 38** calculates the pre-development runoff volume (inches) for the various storm events.

Potential Abstraction:

$$S = \frac{1{,}000}{(CN - 10)}$$

where:

S = potential abstraction (inches)

CN = weighted curve number

Runoff Volume:

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

where:

Q	=	runoff volume (in.)
P	=	precipitation depth for a given 24-hour storm (in.)
S	=	potential abstraction (in.)

7. Line 39 calculates the post-development runoff volume based solely on land cover (without regard to the BMPs selected on the BMP sheet). **Line 40** then subtracts the runoff reduction volume provided by BMPs, from **Cell C8**.
8. Based upon the reduced runoff volumes calculated in line 40, the spreadsheet then calculates corresponding reduced curve numbers for each storm event. This Adjusted Curve Number is reported on **line 41**.
9. Line 42 compares the pre-development runoff volume in line 38 with the post-development (with BMPs) runoff volume in line 40. If the post-development volume (with BMPs) is less than or equal to the pre-development volume for a given storm event, then it is assumed that detention will not be required. If the post-development volume (with BMPs) is greater than the pre-development volume for a given storm event, then detention will be necessary, and the Adjusted Curve Numbers from line 41 should be used to calculate the post-development peak runoff rates.

Appendix B. Infiltration Testing

B.1 General Notes Pertinent to All Geotechnical Testing

A geotechnical report is recommended for all underground BMPs, including infiltration-based practices, filtering systems, ponds and wetlands. The following should be taken into account when producing this report:

- ✧ Testing should be conducted by a qualified professional such as a professional engineer, soils scientist, or geologist.
- ✧ Soil boring or test pit information should be obtained from at least one location on the site. However, the location, number, and depth of borings or test pits should be determined by a qualified professional, and be sufficient to accurately characterize the site soil conditions.
- ✧ Depth to the ground water table and estimated depth to the seasonally high ground water table should be included in the boring logs/geotechnical report.
- ✧ The geotechnical report should include soil descriptions from each boring or test pit. Based upon the proposed development, the geotechnical report also may include evaluation of settlement, bearing capacity, and slope stability of the proposed structures.
- ✧ All soil profile descriptions should provide enough detail to identify the boundary and elevations of any problem (boundary/restrictions) conditions such as fills and seepage zones, type and depth of rock, etc.
- ✧ In addition to the testing recommendations described above, infiltration tests should be performed for all BMPs which rely upon infiltration, including permeable pavement systems, bioretention, infiltration, and dry swales. Specific recommendations for infiltration testing are discussed below.

B.2 Initial Feasibility Assessment

The feasibility assessment is conducted to determine whether full-scale infiltration testing is necessary, screen unsuitable sites, and reduce testing costs. However, a designer or landowner may opt to skip the initial feasibility assessment at his or her discretion, and begin with soil borings.

The initial feasibility assessment typically involves existing data, such as the following:

- ✧ On-site septic percolation testing, which can establish initial rate, water table, and/or depth to bedrock
- ✧ Previous geotechnical reports prepared for the site or adjacent properties
- ✧ Natural Resources Conservation Service (NRCS) Soil Mapping

If the results of initial feasibility assessment show that a suitable infiltration rate (greater than 0.3 inches per hour) is possible or probable, then test pits should be dug or soil borings drilled to verify the infiltration rate.

B.3 Test Pit/Boring Recommendations for Infiltration Tests

1. Excavate a test pit or drill a standard soil boring to a depth of 2 feet below the proposed facility bottom.
2. Determine depth to groundwater table (if within 2 feet of proposed bottom), and the estimated seasonally high groundwater table.
3. Determine Unified Soil Classification (USC) System textures at the proposed bottom and 2 feet below the bottom of the BMP.
4. The soil description should include all soil horizons. If any of the soil horizons below the proposed bottom of the infiltration practice appear to be a confining layer, additional infiltration tests should be performed on this layer (or layers), following the procedure described below.
5. The location of the test pits or borings shall correspond to the proposed BMP locations.

At least one test pit should be dug or encased soil boring drilled for each proposed infiltration-based BMP. For larger practices, additional test pits or soil borings are recommended for infiltration testing, as described in Table B.3-1.

Table B.3-1. Number of Infiltration Tests Required per BMP

Area of Practice (ft^2)	Minimum Number of Test Pits/Soil Borings
< 1,000	1
1,000–1,999	2
2,000–9,999	3
≥ 10,000	Add 1 test pit/soil boring for each additional 5,000 ft^2 of BMP.

When more than one test pit or boring is necessary for a single BMP, the pit or boring locations should be equally spaced throughout the proposed area of the practice, as directed by the qualified professional. The reported infiltration rate for a BMP should be the median or geometric mean of the observed results from the soil boring/test pit locations.

B.4 Infiltration Testing Requirements

The following tests are acceptable for use in determining soil infiltration rates. The geotechnical report should include a detailed description of the test method and published source references:

- Well Permeameter Method (USBR 7300-89)
- Tube Permeameter Method (ASTM D 2434);
- Double-Ring Infiltrometer (ASTM D 3385);
- Other constant head permeability tests that utilize in-situ conditions and are accompanied by a recognized published source reference.
- Falling head tests may be substituted for constant head tests at the discretion of the qualified professional overseeing the infiltration testing. If a falling head test is used, the measured rate must be adjusted, as appropriate, based on the depth of water each time a measurement is taken during head depth used in the test.

Appendix C. Soil Compost Amendment

C.1 Description

Soil restoration is a practice applied after construction, to deeply till compacted soils and restore their porosity by amending them with compost. These soil amendments can reduce runoff from compacted urban landscapes and also may be used to enhance the runoff reduction performance of areas that receive runoff, such as downspout disconnections, grass channels, and filter strips (Table C.3-1).

Figure C.1-1. Soil with compost amendment (Photo: Center for Watershed Protection)

C.2 Physical Feasibility and Design Applications

Compost amended soils are suitable for any pervious area where soils have been or are proposed to be compacted by the grading and construction process. They are particularly well suited when existing soils have low infiltration rates (HSG C and D) and when the pervious area will be used to filter runoff (downspout disconnections and grass channels). The area or strip of amended soils should be connected hydraulically to the stormwater conveyance system. Soil restoration is recommended for sites that will experience mass grading: the removal and stockpiling of existing topsoil (the A horizon) and replacing over top of the newly graded landscape.

Compost amendments are not recommended where:

- ✧ Existing soils have high infiltration rates (e.g., HSG A and B), although compost amendments may be needed at mass-graded B soils in order to maintain runoff reduction rates.
- ✧ The bedrock or at any time of the year the water table is located within 2 feet of the soil surface.
- ✧ Slopes exceed 10%.
- ✧ Existing soils are saturated or seasonally wet.
- ✧ Application would harm roots of existing trees (keep amendments outside the tree drip line).
- ✧ The downhill slope runs toward an existing or proposed building foundation.
- ✧ The contributing impervious surface area exceeds the surface area of the amended soils.

Compost amendments can be applied to the entire pervious area of a development or be applied only to select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include:

- ✧ Reduce runoff from compacted landscapes (while also enhancing the long term viability of the turf and other plant materials included in the amended area).
- ✧ Increase runoff reduction credit of impervious cover disconnections on poor soils.
- ✧ Increase runoff reduction credit within a grass channel.
- ✧ Increase runoff reduction credit within a vegetated filter strip.
- ✧ Reduced runoff from a tree cluster or reforested area of the site.

Considerations in the Coastal Plain. Designers should evaluate drainage and water table elevations to ensure the entire depth of soil amendment will not become saturated (i.e., a minimum separation depth of 2 feet from groundwater) at its highest point during the year. Compost amendments are most cost effective when used to boost the runoff reduction capability of grass vegetated filter strips, grass channels, and rooftop disconnections.

C.3 Design Criteria

Performance When Used in Conjunction with Other Practices. Soil compost amendments can be used to enhance the runoff reduction capabilities of allied practices. The specifications for each of these practices contain design criteria for how compost amendments can be incorporated into those designs:

- ✧ Impervious Surface Disconnection – see Section 4.7.
- ✧ Grass Channels – see Section 4.8.

Soil Testing. Soil chemical and physical tests are required to be conducted by a reputable laboratory during two stages of the compost amendment process. The first testing is done to ascertain preconstruction soil properties at proposed amendment areas. This initial testing is used to determine soil properties to a depth 1 foot below the proposed amendment area, with respect to bulk density, saturated hydraulic conductivity, organic matter content, pH, salts, and soil nutrients. These tests should be conducted every 5,000 square feet, and are used to characterize potential drainage problems and determine what, if any, further soil amendments are needed.

The second soil test is taken at least one week after the compost has been incorporated into the soils. This soil analysis should be conducted to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth. It should be done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths.

Determining Depth of Compost Incorporation. The depth of compost amendment is based on the relationship of the surface area of the soil amendment to the contributing area of impervious cover that it receives. Table C.3-1 presents some general guidance derived from soil modeling by Holman-Dodds (2004) that evaluates the incorporation depth for compost. Some adjustments to the recommended incorporation depth were made to reflect alternative recommendations of Roa Espinosa (2006), Balousek (2003), Chollak and Rosenfeld (1998), and others.

Table C.3-1. Short-Cut Method to Determine Compost and Incorporation Depths				
	Contributing Impervious Cover to Soil Amendment Area Ratio [1]			
	IC/SA = 0 [2]	IC/SA = 0.5	IC/SA = 0.75	IC/SA = 1.0 [3]
Compost (in) [4]	2 to 4 [5]	3 to 6 [5]	4 to 8 [5]	6 to 10 [5]
Incorporation Depth (in)	6 to 10 [5]	8 to 12 [5]	15 to 18 [5]	18 to 24 [5]
Incorporation Method	Rototiller	Tiller	Subsoiler	Subsoiler

Notes:
[1] IC = contributing impervious cover (ft^2) and SA = surface area of compost amendment (ft^2)
[2] For amendment of compacted lawns that do not receive off-site runoff
[3] In general, IC/SA ratios greater than 1 should be avoided, unless applied to simple rooftop disconnection
[4] Average depth of compost added
[5] Lower end for B soils, higher end for C/D soils

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed, using an estimator developed by The Composting Council (TCC, 1997):

$$C = A \times D \times 0.0031$$

where:

C = compost needed (yd^3)

A = area of soil amended (ft^2)

D = depth of compost added (in)

Compost Specifications

✧ Compost shall be derived from plant material and meet the general criteria set forth by the U.S. Composting Seal of Testing Assurance (STA) program. See www.compostingcouncil.org for a list of local providers.

✧ The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost should have a moisture content that results in no visible free water or dust produced when handling the material. It should meet the following criteria, as reported by the U.S. Composting Council STA Compost Technical Data Sheet provided by the vendor:

- 100% of the material should pass through a half inch screen.
- The pH of the material should be between 5.5 and 8.5.
- Manufactured inert material (plastic, concrete, ceramics, metal, etc.) should be less than 1.0% by weight.
- The organic matter content should be >35%.

- Soluble salt content should be less than 6.0 mmhos/cm.
- Should be mature and stable per the appropriate test(s) as specified by STA.
- Carbon/nitrogen ratio should be less than 25:1.
- Must meet the Standards for the Use or Disposal of Sewage Sludge (2014) levels for heavy metals.
- The compost should have an optimum dry bulk density ranging from 40 to 50 lbs/ ft^3. However, certain fully mature coarse textured composts may be lower.

In general, fresh manure should not be used for compost because of high bacteria and nutrient levels. If manure is used, it should be aged (composed) and meet the criteria listed above.

C.4 Construction

Construction Sequence. The construction sequence for compost amendments differs depending whether the practice will be applied to a large area or a narrow filter strip, such as in a rooftop disconnection or grass channel. For larger areas (where IC/SA < 0.5, Table C.3-1), a typical construction sequence is as follows:

Step 1. After the area has been cleared of construction activity, the area should be deep tilled to a depth of 2 to 3 feet using a tractor and sub-soiler with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow. This establishes a vertical pathway for the compost to influence microbial activity into the adjacent soil. (This step may be omitted when compost is used for narrower filter strips.)

Step 2. Spread the specified compost depth in accordance with Table C.3-1 across the surface and incorporate into the soil using a rototiller, tiller, or subsoiler as specified. It is important to have dry conditions at the site prior to incorporating compost.

Step 3. The site should be leveled and seed or sod used to establish a vigorous grass cover. Other amendments such as lime or gypsum and/or irrigation may initially be needed to help the grass grow quickly.

Step 4. Areas of compost amendments exceeding 2,500 square feet should employ simple erosion control measures, such as silt fence, to reduce the potential for erosion and trap sediment. See the South Carolina DHEC's Storm Water Management BMP Handbook (https://www.scdhec.gov/environment/water/swater/docs/BMP-handbook.pdf) for examples of erosion and sediment control.

Construction Inspection. Construction inspection involves digging a test pit to verify the depth of amended soil and scarification. A rod penetrometer should be used to establish the depth of uncompacted soil at one location per 10,000 square feet.

C.5 Maintenance During Establishment

First Year Maintenance Operations. In order to ensure the success of soil compost amendments, the following tasks are necessary in the first year following soil restoration:

✧ ***Initial Inspections.*** For the first six months following the incorporation of soil amendments, the site should be inspected for erosion at least once after each storm event that exceeds ½-inch of rainfall.

- ✧ ***Spot Reseeding.*** Inspections should note bare or eroding areas in the contributing drainage area or around the soil restoration area and ensure that they are immediately stabilized with grass cover.
- ✧ ***Fertilization.*** Depending on the findings of a soils test of the amended area, a one-time, spot fertilization may be needed in the fall after the first growing season to increase plant vigor. Fertilization rates and fertilizer source should follow soil test recommendations for the appropriate plant cover.
- ✧ ***Watering.*** Water once every three days for the first month (or more often, if signs of drought stress appear), and then weekly during the first year (March-November), accounting for effective rainfall.

C.6 Ongoing Maintenance

There are no major on-going maintenance needs associated with soil compost amendments, although the owners may want to de-thatch the turf every few years to increase permeability. Example maintenance inspection checklists for various BMPs can be found in *Appendix F*.

C.7 Soil Compost Amendment References and Additional Resources

1. Balusek. 2003. *Quantifying decreases in stormwater runoff from deep-tilling, chisel-planting and compost amendments*. Dane County Land Conservation Department. Madison, Wisconsin.
2. Chollak, T. and P. Rosenfeld. 1998. *Guidelines for Landscaping with Compost-Amended Soils.* City of Redmond Public Works. Redmond, WA. Available online at: http://www.compostingvermont.org/pdf/compostamendedsoils.pdf
3. City of Portland. 2008. "Soil Specification for Vegetated Stormwater Facilities." *Portland Stormwater Management Manual*. Portland, Oregon.
4. Composting Council (TCC). 1997. *Development of a Landscape Architect Specification for Compost Utilization*. Alexandria, VA. http://www.cwc.org/organics/org972rpt.pdf
5. Holman-Dodds, L. 2004. *Chapter 6. Assessing Infiltration-Based Stormwater Practices*. PhD Dissertation. Department of Hydroscience and Engineering. University of Iowa. Iowa City, IA.
6. Lenhart, J. 2007. "Compost as a Soil Amendment for Water Quality Treatment Facilities." *Proceedings: 2007 LID Conference*. Wilmington, NC.
7. Low Impact Development Center. *Guideline for Soil Amendments*. Available online at: http://www.lowimpactdevelopment.org/epa03/soilamend.htm
8. Roa-Espinosa. 2006. *An Introduction to Soil Compaction and the Subsoiling Practice. Technical Note.* Dane County Land Conservation Department. Madison, Wisconsin.
9. Soils for Salmon. 2003. *Soil Restoration and Compost Amendments*. Available online at: http://www.soilsforsalmon.org/pdf/SoilsforSalmonLIDrev9-16-04.pdf
10. Standards for the Use or Disposal of Sewage Sludge. Title 40 *Code of Federal Regulations*, **§503.13**. 2014. Available online at: http://www.ecfr.gov/cgi-bin/text-idx?SID=b65d61df344d5dcbf0b5976ed7d5def1&node=40:31.0.1.2.42.2.13.4&rgn=div8

Appendix D. Water Quality Volume Peak Discharge

The peak rate of discharge for individual design storms may be required for several different components of water quality BMP design. While the primary design and sizing factor for most stormwater runoff reduction BMPs is the design Water Quality Volume (WQV), several design elements will require a peak rate of discharge for specified design storms. The design and sizing of pretreatment cells, level spreaders, by-pass diversion structures, overflow riser structures, grass swales, and filters all require a peak rate of discharge in order to ensure non-erosive conditions and flow capacity.

The peak rate of discharge from a drainage area can be calculated from any one of several calculation methods. The NRCS TR-55 Curve Number (CN) methods (NRCS TR-55, 1986) are very useful for characterizing complex sub-watersheds and drainage areas and estimating the peak discharge from large storms (greater than two inches), but can significantly underestimate the discharge from small storm events (Claytor and Schueler, 1996). Since the WQV is based on a half-inch or one-inch rainfall, depending upon the best management practice (BMP), this underestimation of peak discharge can lead to undersized diversion and overflow structures, potentially bypassing a significant volume of the design WQV around the BMP. Undersized overflow structures and outlet channels can cause erosion of the BMP conveyance features which can lead to costly and frequent maintenance.

Rather than the CN Method, the method recommended here is based on the approach used by the South Carolina Department of Transportation (SC DOT) for determining peak flow designs for Manufactured Treatment Devices (MTDs). SC DOT specifies that the 1.8-inch, 1-year, 24-hour storm event be used to size water quality devices (as pollutant removal effectiveness for this storm event equates roughly to annual performance). 1.8-inch, 1-year, 24-hour storm event is known as the Water Quality Event (WQE). The following provides a step by step procedure for calculating the WQE peak rate of discharge (Q_{pWQE}):

Step 1: Estimate peak rainfall intensity using South Carolina Department of Transportation (SC-DOT) Designation SC-M-815-13 (8/11) using:

$$i = \frac{a}{(b + t_c)^c}$$

where

i = the rainfall intensity (inches per hour)

t_c = the time of concentration (minutes)

a = water quality event coefficient = 135.65

b = water quality event coefficient = 40.2

c = water quality event coefficient = 1.0863

Step 2: Use the resulting rainfall intensity from Step 1 in the Rational Formula.

$$Q_{pWQE} = C \times i \times A$$

where

Q_{pWQE} = the WQE peak rate of discharge (ft^3/s),

C = the rational method runoff coefficient (not to be confused with the *c* value from Step 1)

i = the rainfall intensity from Step 1 (in/hr)

A = the contributing drainage area (acres)

The resulting *Q* from the Rational Formula represents the peak discharge for the WQE, and should be used when a peak rate of discharge is needed instead of a volume for sizing water quality practices and components.

Water Quality Volume and Peak Discharge References and Additional Resources

1. Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. http://www.sciencetime.org/ConstructedClimates/wp-content/uploads/2013/01/ClaytorSchueler1996.pdf
2. Pitt, R., 1994, Small Storm Hydrology. University of Alabama - Birmingham. Unpublished manuscript. Presented at design of stormwater quality management practices. Madison, WI, May 17-19 1994.
3. SCDOT, 2011. Supplemental Technical Specification for Stormwater Manufactured Treatment Devices (MTDs). SCDOT Designation: SC-M-815-13 (8/11).
4. United States Department of Agriculture Natural Resources Conservation Service *Urban Hydrology for Small* Watersheds *TR-55.* June 1986.

Appendix E. Coordinating Erosion and Sediment Control With Low-Impact Development Planning

E.1 Introduction

It is essential to coordinate post-construction stormwater planning with the design and implementation of erosion and sediment control plans. This appendix provides general guidance on this coordination.

Before proceeding, it may be helpful to provide some simple definitions in order to distinguish what is meant by "erosion and sediment control" and "post-construction stormwater" in the context of this section:

EROSION AND SEDIMENT (E&S) CONTROL: The application of planning approaches and practices during the construction phase in accordance with the Stormwater Management and Sediment Reduction Act of 1991 and the *South Carolina Stormwater Management and Sediment Control Handbook for Land Disturbance Activities.* These practices generally apply during the active construction phase of a land disturbing activity, including land clearing, filling, excavation, soil movement, construction, and other activities defined in the Act. It should be noted that construction phase plans and practices also must be coordinated with other applicable permits, such the NPDES General Permit for Discharge from Construction Activities and, for MS4 communities, minimum measure #4.

POST-CONSTRUCTION STORMWATER: The term post-construction stormwater is used to distinguish stormwater practices used during the active construction phase (sometimes referred to as "construction stormwater") from those that are used on a permanent basis to control runoff once construction is complete ("post-construction stormwater"). Post-construction stormwater includes site planning and structural and non-structural practices such as Low-Impact Development features that intercept, treat, and often reduce the volume of runoff from land development sites. Collectively, these practices are referred to as "post-construction BMPs (best management practices)". As with construction, other permits may apply, such as MS4 minimum measure #5.

Recent trends in post-construction stormwater management make erosion and sediment control coordination all the more important. These include:

- **The use of low impact development and green infrastructure techniques to help satisfy post-construction stormwater requirements.** These approaches involve the use of open space, vegetated areas, impervious cover disconnection, and other site planning and design techniques. For an E&S control plan, this can mean more "do not disturb" zones and the need to avoid disturbing and compacting soils in dispersed areas around a development site.
- **The use of small-scale, distributed (low impact development) practices that treat runoff closer to its source.** Many of these practices rely on the underlying soil to infiltrate at least part of the runoff. Some may be on individual lots, within community open space, or within drainage easements. For the erosion and sediment control plan, this means a finer level of control for the limits of disturbance so that the performance of the ultimate post-construction practices is not compromised during the construction phase.

- **More elaborate design parameters for stormwater ponds and wetlands that may begin their lives as sediment basins.** Often, the post-construction configuration will involve pretreatment forebays, flowpath and geometry requirements, multi-stage riser structures, and other features that the designer must consider when designing the initial sediment basin. A detailed conversion plan is needed for the practice to successfully meet both E&S control and post-construction needs.

All of these trends make it essential for a higher level of coordination during site planning and implementation of erosion and sediment control in the field.

There are several key principles that apply to the coordination between E&S control and post-construction stormwater, as outlined below:

Principle #1: Limits on the Limits of Disturbance (LOD): The limits of disturbance on the E&S control plan must respect natural areas, open spaces, undisturbed vegetated areas, and the footprints of certain BMPs that are part of the post-construction stormwater plan. Limits of disturbance that make sense for the construction phase only can compromise the integrity of the post-construction approach. Also, LOD boundaries may need more careful fencing and signage during construction.

Principle #2: Soil Structure as a Post-Construction Stormwater Tool: Many post-construction practices rely on the underlying soil structure to allow the BMPs to function properly. This obviously is true for practices designed to infiltrate runoff, but also applies to post-construction BMPs that have an underdrain (e.g., some bioretention, dry swale, and porous pavement designs). Care must be taken during the construction phase not to compact soils in the vicinity of post-construction BMP installations.

Principle #3: Diversions: In many cases, construction runoff can seriously compromise post-construction BMPs, even before they are installed. Sediment-laden construction runoff can damage soils intended for infiltration or filtration and can clog rock and other materials intended for use in the post-construction BMP. As such, the E&S control plan should include diversions to prevent construction runoff from entering certain areas associated with post-construction BMP implementation.

Principle #4: Conversion Details: In many cases, E&S control practices and post-construction practices can be co-located. This has advantages in terms of the efficiency of the design, and also can help the post-construction BMP because the conversion cannot take place until the erosion control function is complete (thus avoiding premature installation of the post-construction features). However, given the increasingly sophisticated nature of post-construction BMP design, a detailed conversion plan is needed as part of the E&S control plan to make sure that post-construction volumes, BMP geometry, riser configuration, access, and other features adhere to the design. Also, the conversion plan should be very specific about the timing and sequencing of conversion activities with ongoing land disturbance and stabilization.

Principle #5: Communication & Coordination: In order to coordinate erosion and sediment control with post-construction stormwater, the local government authority should strive to integrate activities such as plan review, site inspections, administration of performance bonds, adoption of technical standards and policies, and training and communication for the regulated community.

Figure E.1-1 shows several typical points of coordination between E&S control and post-construction stormwater.

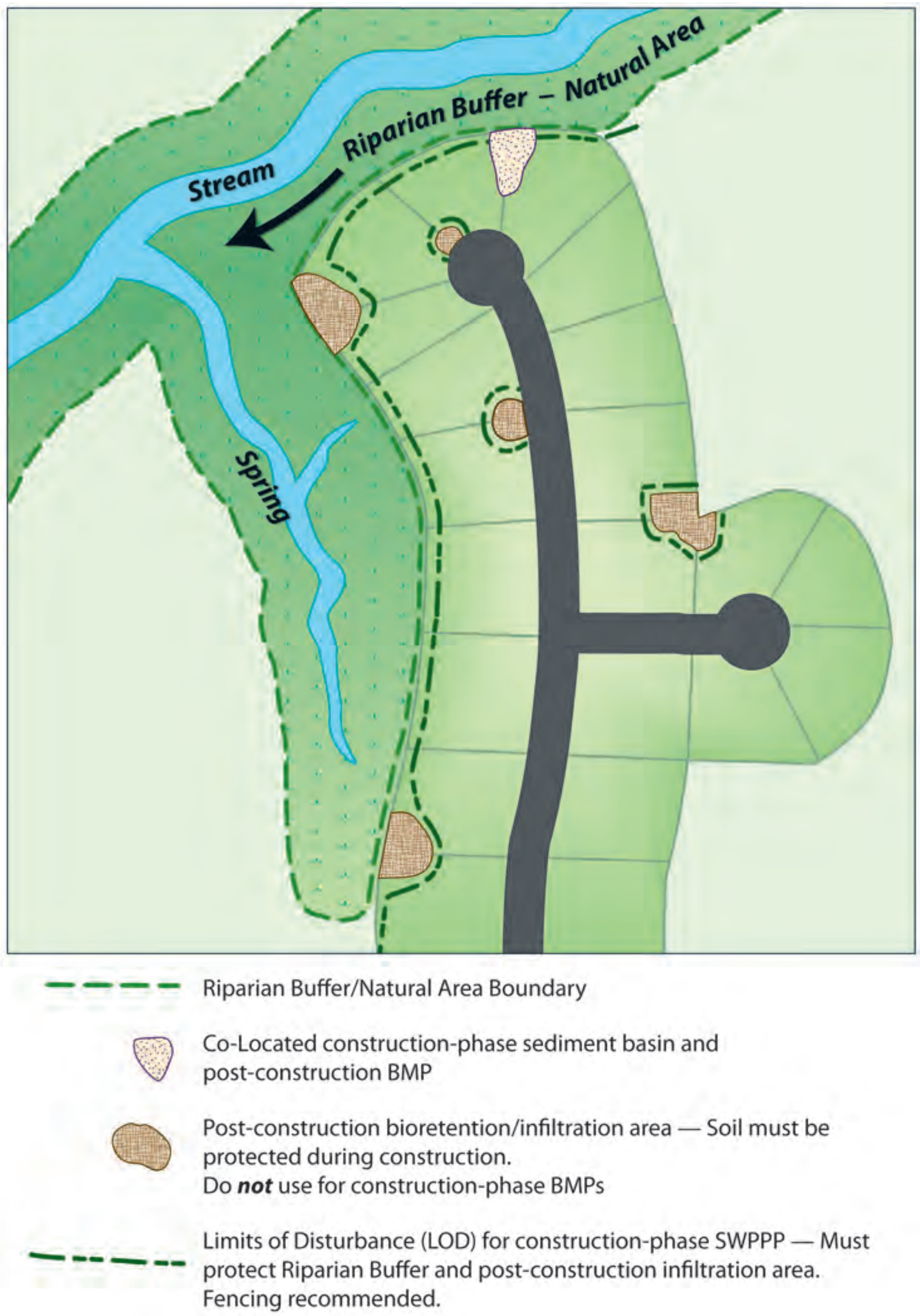

Figure E.1-1. Typical coordination points between E&S control and post-construction stormwater management. (Source: CWP, 2008)

E.2 E&S Control Considerations when Using Post-Construction Practices

Tables E.2-1 and E.2-2 provide more specific guidance on E&S control considerations for practices and BMPs contained in *Low Impact Development in Coastal South Carolina: A Planning and Design Guide*. Table E.2-1 provides E&S control considerations for post-construction practices related to natural resources protection, low impact design, and other site planning practices.

Table E.2-1. E&S Control Considerations for Natural Resource Protection and Site Planning Practices

Practice	E&S Control Considerations
Natural Area Conservation: Protect floodplains, slopes, porous/erodible soils, aquatic resources, groundwater recharge zones.	♦ Clearly identify all natural resources area boundaries on E&S control plans as being outside of the limits of disturbance (LOD). ♦ Specify use of temporary construction fencing at LOD. ♦ Diversions or other measures may be needed to divert construction runoff away from the area. ♦ Install temporary fencing and signage at the beginning of land disturbing activities. ♦ Monitor construction activities to ensure that heavy equipment does not enter natural resource areas.
Stream/Riparian Buffers: Protect or restore vegetated area adjacent to streams and aquatic resources.	♦ Clearly identify all stream buffer boundaries on E&S control plans as being outside of the LOD. ♦ See above for other guidelines under "Natural Area Conservation."
Disconnection of Post-Construction Impervious Surface: Direct impervious cover to down-gradient pervious areas as sheet flow or overland flow filter paths.	♦ Identify on E&S plans all pervious areas that will receive runoff from upgradient impervious or developed areas. ♦ Avoid compaction of pervious areas with heavy equipment during construction; use temporary fencing as necessary. ♦ Diversions or other measures may be needed to divert construction runoff away from the pervious areas. ♦ Make sure that all subcontractors know about the areas. ♦ It may not be practical to prevent disturbance or compaction of ALL of these pervious receiving areas on a site (e.g., small areas on individual lots). Pervious receiving areas that ARE compacted during construction should be restored by tilling and adding compost, as per the Impervious Surface Disconnection section in this manual or similar guidance.
Grass/Vegetated Channels: Direct runoff from developed areas to vegetated channels instead of storm sewer systems.	♦ Similar to Impervious Surface Disconnection, vegetated/grass channels and drainageways should be identified on E&S control plans and marked in the field to avoid disturbance and compaction as much as possible. ♦ Roadside channels will be disturbed during construction; soil restoration should follow post-construction plans.
Other LID Practices: Reduce limits of clearing, reduce impervious cover, more compact development design.	♦ Ensure that reduced development footprint translates to E&S control plan by matching limits of disturbance with post-construction design and layout. ♦ Clearly mark limits of disturbance; use temporary construction fencing as necessary.

Table E.2-2 lists similar considerations for structural post-construction BMPs, such as bioretention, porous pavement, vegetated swales, infiltration trenches, and stormwater ponds and wetlands.

Table E.2-2. E&S Control Considerations for Structural Post-Construction BMPs

Post-Construction BMP	E&S Control Considerations
Bioretention, Infiltration, Permeable Pavement WITHOUT an underdrain system (designed for infiltration into underlying soils)	♦ Clearly show post-construction practice footprints on E&S control plan. Usually, these areas should be outside of the limits of disturbance (with the exception of permeable pavement), unless they are used as small, temporary sediment traps. ♦ Mark practice footprint areas in the field with temporary fencing and signage. ♦ Monitor construction activities to ensure that heavy equipment does not enter practice footprint areas. ♦ All contributing drainage areas (CDAs) to the practice MUST be fully stabilized and vegetated prior to installation of post-construction BMP. ♦ In addition, runoff from the CDA can be diverted around the post-construction BMP footprint and supplemental E&S control measures (e.g., silt fence/barriers around the perimeter of the practice) can be used to prevent erosion into the practice from the CDA or practice side slopes as they are being graded.
Bioretention, Dry Swale, Permeable Pavement WITH an underdrain system (designed for underdrain to discharge to storm sewer)	♦ Clearly show post-construction practice footprints on E&S control plan. Usually, these areas should be outside of the limits of disturbance (with the exception of permeable pavement), unless they are used as small, temporary sediment traps. ♦ If outside of the LOD, mark practice footprint areas in the field with temporary fencing and signage. ♦ Monitor construction activities to ensure that heavy equipment does not enter practice footprint areas. ♦ Similar to practices without underdrains, the CDA must be stabilized and supplemental E&S control measures (e.g., silt fence/barriers around the perimeter of the practice) can be used to prevent sediment from entering the post-construction BMP.
Conversions from temporary E&S practice to post-construction BMP	♦ For post-construction stormwater designs that include stormwater ponds or wetlands, it is likely that the practice will be installed initially as a temporary E&S basin. ♦ E&S control plans should incorporate the design considerations outlined in the following section on co-locating and converting E&S practices to post-construction BMPs. ♦ The timing of conversion from temporary to permanent practices depends on exposed areas and continued land disturbance in the CDA. The E&S control plan should have a detailed phasing plan that clearly explains this sequence.

E.3 Co-Locating & Converting E&S Practices to Post-Construction BMPs

Previous sections discussed the prospect of co-locating E&S control and post-construction practices. While this cannot be done in all cases, it is an acceptable approach as long as certain guidelines are followed to ensure the integrity of the post-construction BMP. In addition, there are some notable advantages to co-locating practices, the chief one being that the post-construction conversion cannot take place until the construction-phase E&S control function is complete. This is important because one of the chief causes of failure for post-construction BMPs is premature installation and the introduction of construction sediments into the practice. There are many bioretention, infiltration, and other practices where this has been a serious concern (see Figure E.3-1). The other advantage for co-location is that it is straight-forward, can be implemented easily by the contractor, and may lead to cost savings.

Despite these advantages to co-location, there are circumstances where it should not be done, including:

- ✧ Post-construction BMPs that have too small of a drainage area and/or are in a location that is not conducive for an E&S control trap.
- ✧ Post-construction BMPs where the local plan reviewer deems that construction activity will compact and damage underlying soils to an extent that performance of the post-construction BMP will be compromised.
- ✧ Post-construction BMPs where timing and sequencing of construction phases will not allow the conversion to take place in the proper sequence so that the practice cannot fulfill its post-construction treatment objectives.
- ✧ Other situations where the local authority, plan reviewer, designer, and/or contractor believes that co-location will compromise the E&S control and/or post-construction plan implementation.

Where co-location is a viable option, there are generally two types of practices where conversion from E&S control to post-construction can take place:

1. Smaller-scale sediment traps (generally with drainage areas less than 3 acres) that can be converted to bioretention, dry swales, or surface sand filter BMPs. See Table E.3-1 for specific conversion guidance.
2. Larger-scale sediment basins with larger drainage areas that can be converted to post-construction stormwater ponds or wetlands. See Table E.3-2.

In addition, Figure E.3-1 shows examples of E&S control practice conversions to post-construction BMPs, as well as some of the pitfalls of the conversion process.

Table E.3-1. Conversion of Smaller-Scale Sediment Traps to Bioretention, Dry Swales, or Surface Sand Filter BMPs (generally with drainage areas less than 3 acres).

Topic	Conversion Guidance
Drainage Areas	Drainage areas should be limited by the appropriate post-construction BMP design specifications, even if construction phase drainage areas could be larger. This means that sites may have to be divided into smaller drainage areas with use of multiple sediment traps and other E&S control measures.
Grading to Blend into Topography	Some temporary E&S practices are installed on slopes, have steep embankments or side slopes, and otherwise don't blend into the surrounding topography. These types of practices are not good candidates to convert to post-construction BMPs, unless re-grading is part of the conversion plan. A sounder approach is to design the temporary E&S control practice so that this type of re-grading is not necessary, which may include changing the footprint, grading, slopes, and other features of the E&S practice.
Stabilizing the Drainage Area	Make sure the contributing drainage area (CDA) is stabilized prior to conversion. This is a good thing about using sediment traps, since they cannot be taken out until their erosion control function is complete. Therefore, the tendency to prematurely install post-construction practices is lessened. The conversion can proceed when site inspectors indicate that the CDA is properly stabilized. In addition to CDA stabilization, other supplemental E&S control measures may be warranted, such as diverting flow around the practice during the conversion process and using silt fence or matting/sod on side slopes of the practice.
Remove Construction Sediments	All construction sediments should be removed as the first step in the conversion process. This may also involve de-watering the practice with an approved de-watering and sediment capture method (e.g., dirt bags, sediment traps).
Excavate Below the E&S Practice Bottom Elevation	The bottom of the post-construction practice should be at least one foot lower than the temporary ES&PC bottom elevation. This is so that the bottom of the post-construction BMP will be in undisturbed soils that are not impacted by construction activities. During excavation to the post-construction design elevation, scarify or rip the underlying soil to promote infiltration.
Installing Underdrains	If the post-construction practice design has an underdrain, decide when to install the underdrain. Usually this will be done as part of the conversion (at end of the construction phase). However, if the underdrain goes through an impounding structure or berm that will stay in place with the post-construction BMP, it may be best to install the underdrain with the initial E&S practice, cover it with heavy gage plastic, and then fill on top to reach the desired bottom elevation of the E&S practice. This will prevent having to breach the impounding structure or berm to install an underdrain system during the conversion process. At the time of conversion, the overlying soil and plastic can be removed, exposing the underdrain system, at which point the desired soil or filter layers can be placed on top of the underdrain.
Proceed to Install Post-Construction BMP	Install the practice as per the approved post-construction plans. Some minor grading or adjustments to the footprint may be needed to meet the post-construction design.
Be Aware of Easement & Post-Construction Practice Location	If the post-construction BMP is supposed to be located within a drainage easement or in another specific location (e.g., common area in a subdivision), it is very important to make sure that the final practice is within the specified area in order to avoid costly relocation of the practice.

Table E.3-2. Conversion of Larger Sediment Basins to Post-Construction Stormwater Ponds & Wetlands

Topic	Conversion Guidance
Timing/ Sequencing	Generally, E&S basins cannot be converted to a post-construction configuration until the contributing drainage area (CDA) is fully developed and stabilized. However, phasing plans can incorporate additional upgradient E&S control practices if certain portions of the CDA will be disturbed subsequent to the conversion. This is likely the case with multi-phase development projects, commercial subdivisions, etc.
Sediment Removal	Construction sediment will have to be removed from the basin before conversion to a post-construction BMP. Once de-watered, the sediment can be used as fill on the site. Additional grading may be needed to meet the design standards for the post-construction configuration.
Volume & Design Elevations	Sizing rules are different for E&S basins and post-construction BMPs. The E&S basin may be larger or smaller than the post-construction practice, so additional grading is likely needed for the conversion. A common problem with conversions is that not all of the construction sediment is removed so that the post-construction elevations are incorrect. Contractors should always check design elevations for the post-construction BMP.
Pond Geometry	Compared to an E&S control basin, a post-construction practice may have a longer flow path, multiple cells, larger surface area, shallower side slopes (e.g., 3:1), deeper or shallower pool depths, safety benches around permanent pools, and other design features. The E&S basin should at least consider the overall footprint and general depth of the post-construction pond so that major grading can be avoided in the conversion process.
Pre-Treatment	Most post-construction ponds will incorporate one or more forebays for pretreatment. The forebays can be constructed as part of the E&S basin, but it may be preferable to install them as part of the conversion to avoid the cost of cleaning them out, repairing or replacing rock spillways, etc. In either case, the footprint of the forebay should be incorporated into the E&S basin footprint.
Risers & Spillways	The post-construction practice design will adhere to certain safety features and riser designs (likely multi-stage risers to address water quality, channel protection, and flood protection). The designer should consider constructing the post-construction design as part of the E&S basin, and then modifying it for the construction phase. For instance, risers can be perforated during construction, and then the perforations plugged as part of the conversion. Certain orifices will likely need to be temporarily plugged during construction. In addition, the spillway and freeboard requirements may be different for the post-construction pond, and relevant design elevations should be used for the temporary E&S basin, unless this is specifically addressed otherwise in the conversion plan.
De-watering Drains	Certain post-construction pond or wetland designs may call for de-watering drains so that pools can be drained to remove sediment or for maintenance. With regard to constructability, it may be best to install drains in the original E&S basin, and make sure they do not get clogged during construction.
Rock Weirs, Spillways, Outlet Protection	Rock features may be part of the E&S and/or post-construction practice. However, it is likely that they will get filled with sediment during construction, so they will have to be replaced or rebuilt as part of the conversion.
Maintenance Access	While temporary E&S basins only need to be accessed during the construction phase, post-construction ponds require permanent maintenance access. Plan for this access during construction.
Landscaping	Most post-construction ponds will have a landscaping plan. The landscaping should be installed during the conversion, and not during the active construction phase.

Conversion of a small-scale sediment trap to bioretention. The photo shows adding an underdrain system.

Conversion of a sediment basin to a bioretention area. The original riser acts as the overflow structure for the bioretention practice.

Post-construction conversion called for the creation of sediment forebay in this larger scale pond.

A major issue with conversions is timing. Premature installation of the post-construction practice can result in damage from construction sediments.

Figure E.3-1. Examples of E&S control practice conversions to post-construction BMPs (Photos: Center for Watershed Protection)

E.4 Conclusion

Increasingly, it is important to coordinate E&S control planning and implementation with post-construction stormwater plans. A coordinated plan will help both phases (construction and post-construction) to proceed in a logical, well thought-out way that avoids costly redesigns and work delays.

The principles of adjusting the limits of disturbance, protecting soil structure associated with post-construction BMPs, diverting construction runoff around important post-construction areas, developing detailed conversion plans for E&S to post-construction BMPs, and coordination and communication among plan reviewers, design professionals, inspectors, and contractors will help achieve this integration of E&S control and post-construction stormwater.

E.5 Coordinating Erosion and Sediment Control with LID Planning References

1. CWP. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*. Center for Watershed Protection, Ellicott City, MD. EPA Publication No.: 833-R-08-001.

Appendix F. Maintenance Checklists

Infiltration/Filtration/Bioretention/Dry Swale Practices

Party Responsible for Maintenance: ____________________

Practice ID: ____________________

Location: ____________________

Contact: ____________________

GPS Coordinates: ____________________

Phone Number: ____________________

E-mail: ____________________

Inspector(s): ____________________

Mailing Address: ____________________

Date: __________ **Time:** __________

Key Questions			
Item		**X**	**Comments**
1.	Type of practice (check all that apply)		
	a. Bioretention		
	b. Dry Swale		
	d. Residential Rain Garden		
	e. Infiltration Practice		
	f. Filtration Practice		
2.	For Bioretention		
	a. Standard Design		
	b. Enhanced Design		
3.	Practice Location		
	a. Open to Surface		
	b. Underground		
4.	Filtration Media		
	a. No filtration media (e.g., stone reservoir only)		
	b. Sand		
	c. Bioretention Soil Mix		
	d. Peat		
	e. Other		
5.	Hydraulic configuration		
	a. On-line		
	b. Off-line		
6.	Type of pretreatment		
	a. Separate pretreatment cell		
	b. Sedimentation chamber/manhole		
	c. Grass channel		
	d. Grass filter strip		
	e. Gravel or stone flow spreader		
	f. Gravel diaphragm		
	g. Other		Type of pretreatment:
7.	If designed for infiltration (i.e., no underdrain OR infiltration sump below underdrain):		
	a. Soil boring logs and infiltration testing report provided		
	b. Field-measured infiltration rate of at least 0.5 in/hr (preferred 1-4 in/hr)		Field-measured rate:

Infiltration/Filtration/Bioretention/Dry Swale Practices

A. Contributing Drainage Area

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Excessive trash/debris	0	1	2	3	N/A	
2.	Bare/exposed soil	0	1	2	3	N/A	
3.	Evidence of erosion	0	1	2	3	N/A	
4.	Excessive landscape waste/yard clippings	0	1	2	3	N/A	

B. Pretreatment

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Maintenance access to pretreatment facility	0	1	2	3	N/A	
2.	Excessive trash/debris/sediment	0	1	2	3	N/A	
3.	Evidence of standing water	0	1	2	3	N/A	
	a. Ponding	☐					
	b. Noticeable odors	☐					
	c. Water stains	☐					
	d. Presence of algae or floating aquatic vegetation	☐					
4.	Evidence of clogging	0	1	2	3	N/A	
5.	Dead vegetation/exposed soil	0	1	2	3	N/A	
6.	Evidence of erosion	0	1	2	3	N/A	

C. Inlets

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Inlets provide stable conveyance into practice	0	1	2	3	N/A	
2.	Excessive trash/debris/sediment accumulation at inlet	0	1	2	3	N/A	
3.	Evidence of erosion at/around inlet	0	1	2	3	N/A	

Infiltration/Filtration/Bioretention/Dry Swale Practices

D. Practice							
0 = Good condition. Well maintained, no action required.							
1 = Moderate condition. Adequately maintained, routine maintenance needed.							
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.							
3 = Serious condition. Immediate need for repair or replacement.							
☐ Inspected							
☐ Not Inspected							
Item							**Comments**
1. Maintenance access		0	1	2	3	N/A	
2. Condition of structural components		0	1	2	3	N/A	
3. Condition of hydraulic control components		0	1	2	3	N/A	
4. Excessive trash/debris/sediment		0	1	2	3	N/A	
5. Evidence of erosion		0	1	2	3	N/A	
6. Evidence of oil/chemical accumulation		0	1	2	3	N/A	
7. Evidence of standing water:		0	1	2	3	N/A	
a.	Ponding	☐					
b.	Noticeable odors	☐					
c.	Water stains	☐					
d.	Presence of algae or floating aquatic vegetation	☐					
8. Underdrain system (if equipped)		0	1	2	3	N/A	
a.	Broken	☐					
b.	Clogged	☐					
9. Vegetation		0	1	2	3	N/A	
a.	Plant composition consistent with approved plans	☐					
b.	Presence of invasive species/weeds	☐					
c.	Dead vegetation/exposed soil	☐					

E. Outlets						
0 = Good condition. Well maintained, no action required.						
1 = Moderate condition. Adequately maintained, routine maintenance needed.						
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
3 = Serious condition. Immediate need for repair or replacement.						
☐ Inspected						
☐ Not Inspected						
Item						**Comments**
1. Outlets provide stable conveyance out of practice	0	1	2	3	N/A	
2. Excessive trash/debris/sediment accumulation at outlet	0	1	2	3	N/A	
3. Evidence of erosion at/around outlet	0	1	2	3	N/A	
☐ Inspected						
☐ Not Inspected						

Infiltration/Filtration/Bioretention/Dry Swale Practices

F. Miscellaneous

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

	Item						Comments
1.	Complaints from local residents	0	1	2	3	N/A	
2.	Mosquito proliferation	0	1	2	3	N/A	
3.	Encroachment on practice or easement by buildings or other structures	0	1	2	3	N/A	

Inspector's Summary:

Photographs

Photo ID	Description
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

Infiltration/Filtration/Bioretention/Dry Swale Practices

Sketch of Practice
(note problem areas)

Permeable Pavement

Party Responsible for Maintenance:	**Practice ID:**
	Location:
Contact:	**GPS Coordinates:**
Phone Number:	
E-mail:	**Inspector(s):**
Mailing Address:	
	Date: **Time:**

Key Questions

	Item	X	Comments
1.	Type of practice (check all that apply)		
	a. Standard design		
	b. Infiltration design		
	c. Infiltration sump design		
2.	Pavement Type		
	a. Pervious concrete		
	b. Porous asphalt		
	c. Concrete grid pavers		
	d. Permeable interlocking concrete pavers		
	e. Other:		
3.	External drainage area?		
	a. Yes		Ratio:
	b. No		
4.	Pretreatment (if landscaped/turf areas in drainage area)		
	a. Yes		Type:
	b. No		
5.	If designed for infiltration (e.g., no underdrain OR infiltration sump below underdrain):		
	b. Soil boring logs and infiltration testing report provided		
	c. Field-measured infiltration rate indicated		Field-measured rate:

A. Contributing Drainage Area

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Excessive trash/debris	0	1	2	3	N/A	
2.	Bare/exposed soil	0	1	2	3	N/A	
3.	Evidence of erosion	0	1	2	3	N/A	
4.	Excessive landscape waste/yard clippings	0	1	2	3	N/A	
5	Excessive grit, sand, or other clogging agents on upgradient pavement that drains onto permeable pavement	0	1	2	3	N/A	

Permeable Pavement

B. Pretreatment (if applicable to landscaped/turf drainage area) 0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.							
Inspected							
Not Inspected							
Item							**Comments**
1. Maintenance access to pretreatment	0	1	2	3	N/A		
2. Excessive trash/debris/sediment	0	1	2	3	N/A		
3. Evidence of standing water							
a. Ponding	0	1	2	3	N/A		
b. Noticeable odors	0	1	2	3	N/A		
c. Water stains	0	1	2	3	N/A		
d. Presence of algae or floating aquatic vegetation	0	1	2	3	N/A		
4. Evidence of clogging	0	1	2	3	N/A		
5. Dead vegetation/exposed soil	0	1	2	3	N/A		
6. Evidence of erosion	0	1	2	3	N/A		

C. Evidence of Materials Storage or Resurfacing of Permeable Pavement 0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.							
Inspected							
Not Inspected							
Item							**Comments**
1. Evidence of storage of sand, mulch, soil, construction staging, power washing, or other activities that can clog pavement	0	1	2	3	N/A		
2. Evidence of resealing or resurfacing of permeable pavement surface	0	1	2	3	N/A		

Permeable Pavement

D.	***Practice***						
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Maintenance access to practice	0	1	2	3	N/A	
2.	Condition of structural components	0	1	2	3	N/A	
3.	Condition of hydraulic control components	0	1	2	3	N/A	
4.	Excessive trash/debris/sediment on pavement surface	0	1	2	3	N/A	
5.	Evidence of damaged pavers and/or cracked/broken surface	0	1	2	3	N/A	
6.	Evidence of oil/chemical accumulation	0	1	2	3	N/A	
7.	Evidence of clogging:						
	a. Ponding/water standing in observation wells	0	1	2	3	N/A	
	b. Noticeable odors	0	1	2	3	N/A	
	c. Water stains	0	1	2	3	N/A	
8.	Underdrain system (if equipped)	0	1	2	3	N/A	
	a. Broken	0	1	2	3	N/A	
	b. Clogged	0	1	2	3	N/A	
9.	Vegetation (e.g., grass in grid pavers) if present	0	1	2	3	N/A	
	a. Grass or vegetation needs mowing or maintenance	0	1	2	3	N/A	
	b. Excessive growth of weeds	0	1	2	3	N/A	
	c. Dead vegetation	0	1	2	3	N/A	

E.	***Miscellaneous***						
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Complaints from local residents	0	1	2	3	N/A	
2.	Spring clean-up conducted?	0	1	2	3	N/A	
3.	Vacuum sweeping without water spray (2 -- 4 time annually)	0	1	2	3	N/A	
4.	Encroachment on practice or easement by buildings or other structures	0	1	2	3	N/A	

Permeable Pavement

Inspector's Summary:

Photographs

Photo ID	Description
1.	
2.	
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Permeable Pavement

Sketch of Practice

(note problem areas)

Green Roof Practices

Party Responsible for Maintenance: ____________	**Practice ID:** ____________
	Location: ____________
Contact: ____________	**GPS Coordinates:** ____________
Phone Number: ____________	
E-mail: ____________	**Inspector(s):** ____________
Mailing Address: ____________	____________
____________	**Date:** ______ **Time:** ______

Key Questions

	Item	X	Comments
1.	Type of vegetated roof (check all that apply)		
	a. Extensive - shallow soil		
	b. Intensive - deep soil		
	c. Other		Type:
2.	Type of plant cover (check all that apply)		
	a. Sedums		
	b. Shrubs		
	c. Trees		
	d. Other		Type:

A. Practice

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Maintenance access to practice	0	1	2	3	N/A	
2.	Condition of structural components	0	1	2	3	N/A	
3.	Condition of hydraulic control components	0	1	2	3	N/A	
4.	Excessive trash/debris/sediment	0	1	2	3	N/A	
5.	Evidence of leaking in waterproof membrane	0	1	2	3	N/A	
6.	Evidence of perforated root barrier	0	1	2	3	N/A	
7.	Evidence of standing water:	0	1	2	3	N/A	
	a. Ponding						
	b. Noticeable odors						
	c. Water stains						
	d. Presence of algae						
8.	Roof drain system	0	1	2	3	N/A	
	a. Broken						
	b. Clogged						
9.	Vegetation	0	1	2	3	N/A	
	a. Plant composition consistent with approved plans						
	b. Presence of invasive species/weeds						
	c. Plants appear nutrient deficient						
	d. Evidence of birds/pests removing plants						
	e. Dead/sparse vegetation soil						

Green Roof Practices

B. Outlets

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

Item						Comments
1. Roof drain conveyance is clogged	0	1	2	3	N/A	
2. Excessive trash/debris/sediment accumulation at roof drain outlets	0	1	2	3	N/A	
3. Evidence of erosion at/around outlet	0	1	2	3	N/A	

C. Miscellaneous

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

Item						Comments
1. Complaints from local residents	0	1	2	3	N/A	
2. Mosquito proliferation	0	1	2	3	N/A	

Inspector's Summary:

Photographs

Photo ID	Description
1.	
2.	
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Green Roof Practices

Sketch of Practice
(note problem areas)

Rainwater Harvesting

Party Responsible for Maintenance: ____________________

Contact: ____________________

Phone Number: ____________________

E-mail: ____________________

Mailing Address: ____________________

____

Practice ID: ____________________

Location: ____________________

GPS Coordinates: ____________________

Inspector(s): ____________________

____

Date: __________ **Time:** __________

A. Contributing Drainage Area (Roof Area)

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Excessive leaves and debris in gutters/downspouts	0	1	2	3	N/A	
2.	Other materials/debris on roof surface (e.g., excessive bird droppings)	0	1	2	3	N/A	
3.	Clear overhanging trees/vegetation over roof surface	0	1	2	3	N/A	

B. Pretreatment

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Maintenance access to pretreatment	0	1	2	3	N/A	
2.	Check first flush diverters/filters for proper functioning (e.g., not bypassing too much water). Clean debris from filter screens.	0	1	2	3	N/A	Sediment marker reading:

C. Inlets

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Check all conveyances into tank; remove debris; check for clogging	0	1	2	3	N/A	
2.	Patch any holes or gaps.	0	1	2	3	N/A	

Rainwater Harvesting

D. Tank or Cistern

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐	Inspected							
☐	Not Inspected							
	Item							**Comments**
1.	Maintenance access to practice	0	1	2	3	N/A		
2.	Check storage tank lids	0	1	2	3	N/A		
	a. Vents and screens on inflow/outflow spigots	0	1	2	3	N/A		
	b. Lids in place, properly secured	0	1	2	3	N/A		
3.	Overflow pipes & downstream flow path	0	1	2	3	N/A	Cause:	
	a. Debris/clogging in overflow pipes	0	1	2	3	N/A	Cause:	
	b. Erosion, excessive debris, clogging of flow path	0	1	2	3	N/A	Cause:	
	c. Condition of downstream secondary runoff reduction practice (see applicable checklist)	0	1	2	3	N/A	Cause:	
4.	Sediment build-up in tank	0	1	2	3	N/A		
5.	Backflow preventer	0	1	2	3	N/A		
6.	Structural integrity	0	1	2	3	N/A		
	a. Tank and foundation	0	1	2	3	N/A		
	b. Pump and pump housing	0	1	2	3	N/A		
	c. Pipes	0	1	2	3	N/A		
	d. Electrical system and housing	0	1	2	3	N/A		
7.	Water Quality Devices	0	1	2	3	N/A		
8.	Mosquitos	0	1	2	3	N/A		
	a. Mosquito screens; check gaps and holes	0	1	2	3	N/A		
	b. Evidence of mosquito larvae in tank or manholes	0	1	2	3	N/A		

E. Miscellaneous

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐	Inspected						
☐	Not Inspected						
	Item						**Comments**
1.	Complaints from local residents	0	1	2	3	N/A	
2.	Mosquito proliferation	0	1	2	3	N/A	
3.	Encroachment on practice or easement by buildings or other structures	0	1	2	3	N/A	
4.	Adequate safety signage	0	1	2	3	N/A	

Rainwater Harvesting

Inspector's Summary:

Photographs	
Photo ID	**Description**
1.	
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Rainwater Harvesting

Sketch of Practice
(note problem areas)

Impervious Surface Disconnection

Party Responsible for Maintenance: ________	**Practice ID:** ________
Contact: ________	**Location:** ________
Phone Number: ________	**GPS Coordinates:** ________
E-mail: ________	**Inspector(s):** ________
Mailing Address: ________	
________	**Date:** ________ **Time:** ________

Key Questions

Item	X	Comments
1. Type of impervious area disconnected		
a. Rooftop		
b. Parking		
c. Other		
2. Type of disconnection surface		
a. Managed turf areas		
b. Forest cover or preserved open space		
c. Soil compost amended filter path		
3. Type of forest cover or open space (if applicable)		
a. Forest		
b. Meadow/Brush		
c. Other		
4. Vegetative Cover Condition		
a. Good		
b. Average		
c. Poor		
5. Meets width/length requirement		

A. Contributing Drainage Area

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

Item						Comments
1. Excessive trash/debris	0	1	2	3	N/A	
2. Excessive landscape waste/yard clippings	0	1	2	3	N/A	

Impervious Surface Disconnection

							Comments
B. Inflow Points							
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Inflow points (e.g. downspouts, curb cuts, edge of pavement, level spreader) provide stable conveyance into practice	0	1	2	3	N/A	
2.	Runoff enters pervious area as sheet flow	0	1	2	3	N/A	
3.	Excessive trash/debris/sediment	0	1	2	3	N/A	
4.	Evidence of erosion at/around inflow points	0	1	2	3	N/A	
5.	Level spreader functional, if applicable	0	1	2	3	N/A	

C. Practice (Pervious Area Receiving Runoff)							
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Maintenance access to area	0	1	2	3	N/A	
2.	Downspouts or surface impervious area drains to the receiving pervious area (doesn't bypass)	0	1	2	3	N/A	
3.	Receiving pervious areas retain dimensions as shown on plans and are in	0	1	2	3	N/A	
4.	Excessive trash/debris/sediment	0	1	2	3	N/A	
5.	Evidence of standing water:	0	1	2	3	N/A	
	a. Ponding						
	b. Noticeable odors						
	c. Water stains						
	d. Presence of algae or floating aquatic vegetation						
6.	Evidence of erosion	0	1	2	3	N/A	
7	Evidence of oil/chemical accumulation	0	1	2	3	N/A	
8.	Vegetation	0	1	2	3	N/A	
	a. Plant composition consistent with approved plans	0	1	2	3	N/A	
	b. Presence of invasive species/weeds	0	1	2	3	N/A	
	c. Dead vegetation/exposed soil	0	1	2	3	N/A	
	d. Disturbance to natural vegetation or excessive maintenance (e.g. mowing, tree cutting)	0	1	2	3	N/A	
	e. Restoration planting survival, if	0	1	2	3	N/A	
9.	Conservation area signs (if applicable)	0	1	2	3	N/A	
10.	Level spreader (if applicable)	0	1	2	3	N/A	

Impervious Surface Disconnection

D. Miscellaneous

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

	Inspected
	Not Inspected

	Item						Comments
1.	Complaints from local residents	0	1	2	3	N/A	
2.	Mosquito proliferation	0	1	2	3	N/A	
3.	Encroachment on pervious area or easement by buildings or other structures	0	1	2	3	N/A	

Inspector's Summary:

Photographs

	Photo ID	Description
1.		
2.		
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Impervious Surface Disconnection

Sketch of Practice
(note problem areas)

Dry Detention Practices

Party Responsible for Maintenance:	**Practice ID:**
	Location:
Contact:	
	GPS Coordinates:
Phone Number:	
E-mail:	**Inspector(s):**
Mailing Address:	
	Date: **Time:**

Key Questions		
Item	**X**	**Comments**
1. Type of detention practice		
a. Dry Pond		
b. Underground Detetention Vault and/or Tank		
c. Other		Type:

A. Contributing Drainage Area

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

Item						**Comments**
1. Excessive trash/debris	0	1	2	3	N/A	
2. Bare/exposed soil	0	1	2	3	N/A	
3. Evidence of erosion	0	1	2	3	N/A	
4. Excessive landscape waste/yard clippings	0	1	2	3	N/A	
5. Oils, greases, paints and other harmful substances disposed of in drainage area.	0	1	2	3	N/A	

B. Forebay/Pretreatment

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

Item						**Comments**
1. Maintenance access to pretreatment facility	0	1	2	3	N/A	
2. Excessive trash/debris accumulation	0	1	2	3	N/A	
3. Excessive sediment accumulation	0	1	2	3	N/A	Sediment marker reading:
4. Evidence of clogging	0	1	2	3	N/A	
5. Dead vegetation/exposed soil	0	1	2	3	N/A	
6. Evidence of erosion	0	1	2	3	N/A	

Dry Detention Practices

C.	***Inlets***						
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Inlets provide stable conveyance into	0	1	2	3	N/A	
2.	Excessive trash/debris/sediment accumulation at inlet	0	1	2	3	N/A	
3.	Evidence of erosion at/around inlet	0	1	2	3	N/A	
4.	Damaged pipes or components	0	1	2	3	N/A	
5.	Inflow hindered by soil height, build up of sediment and/or grass	0	1	2	3	N/A	

D.	***Practice***						
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Maintenance access to practice	0	1	2	3	N/A	
2.	Sediment accumulation	0	1	2	3	N/A	
3.	Abnormally high or low water levels	0	1	2	3	N/A	Cause:
4.	Evidence of pollution/hotspot runoff	0	1	2	3	N/A	Cause:
5.	Berm(s)/embankment(s)	0	1	2	3	N/A	
	a. Cracking, bulging, or sloughing	0	1	2	3	N/A	
	b. Soft spots or sinkholes	0	1	2	3	N/A	
	c. Evidence of erosion/bare spots	0	1	2	3	N/A	
	d. Evidence of animal burrows	0	1	2	3	N/A	
	e. Presence of woody vegetation	0	1	2	3	N/A	
6.	Riser/outlet	0	1	2	3	N/A	Type of riser:
	a. Maintenance access to riser	0	1	2	3	N/A	
	b. Structural condition of riser	0	1	2	3	N/A	
	c. Condition of joints	0	1	2	3	N/A	
	d. Trash/debris accumulation	0	1	2	3	N/A	
	e. Woody growth within 5 ft. of outlet	0	1	2	3	N/A	
	f. Emergency spillway eroding or failing	0	1	2	3	N/A	
7.	Low flow orifice	0	1	2	3	N/A	
	a. Trash/debris accumulation	0	1	2	3	N/A	
	b. Adjustable control valve accessible and operational	0	1	2	3	N/A	
9.	Vegetation	0	1	2	3	N/A	
	a. Plant composition consistent with approved plans	0	1	2	3	N/A	
	b. Presence of invasive species/weeds	0	1	2	3	N/A	
	c. Dead vegetation/exposed soil	0	1	2	3	N/A	
	d. Reinforcement planting recommended						

Dry Detention Practices

E. Outlets						
0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.						
☐ Inspected						
☐ Not Inspected						
Item						**Comments**
1. Outlets provide stable conveyance out of practice	0	1	2	3	N/A	
2. Excessive trash/debris/sediment accumulation at outlet	0	1	2	3	N/A	
3. Evidence of erosion at/around outlet/outfall	0	1	2	3	N/A	
4. Evidence of leaking/clogging of trash racks or reversed slope pipes	0	1	2	3	N/A	

F. Miscellaneous						
0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.						
☐ Inspected						
☐ Not Inspected						
Item						**Comments**
1. Complaints from local residents	0	1	2	3	N/A	
2. Mosquito proliferation	0	1	2	3	N/A	
3. Encroachment on practice or easement by buildings or other structures	0	1	2	3	N/A	
4. Adequate safety signage	0	1	2	3	N/A	

Inspector's Summary:

Dry Detention Practices

Photographs	
Photo ID	**Description**
1.	
2.	
3.	
4.	
5.	
6.	
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Sketch of practice
(note problem areas)

Stormwater Wet Pond/Wetland

Party Responsible for Maintenance:	**Practice ID:**
Contact:	**Location:**
Phone Number:	**GPS Coordinates:**
E-mail:	**Inspector(s):**
Mailing Address:	
	Date: **Time:**

Key Questions

	Item	X	Comments
1.	Type of stormwater practice (check all that apply)		
	a. Stormwater wetland basin		
	b. Stormwater multi-cell wetland or pond/wetland combination		
	c. Subsurface gravel wetland		
	d. Wet pond		
	d. Other		Type:
2.	Type of pretreatment facility (check all that apply)		*Pretreatment must be provided*
	a. Sediment forebay		
	b. Other		Type:

A. Contributing Drainage Area

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

	Item						Comments
1.	Excessive trash/debris	0	1	2	3	N/A	
2.	Bare/exposed soil	0	1	2	3	N/A	
3.	Evidence of erosion	0	1	2	3	N/A	
4.	Excessive landscape waste/yard clippings	0	1	2	3	N/A	
5.	Oils, greases, paints and other harmful substances disposed of in drainage area.	0	1	2	3	N/A	

Stormwater Wet Pond/Wetland

B.	***Pretreatment***						
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Maintenance access to pretreatment facility	0	1	2	3	N/A	
2.	Excessive trash/debris accumulation	0	1	2	3	N/A	
3.	Excessive sediment accumulation	0	1	2	3	N/A	Sediment marker reading:
4.	Evidence of clogging	0	1	2	3	N/A	
5.	Dead vegetation/exposed soil	0	1	2	3	N/A	
6.	Evidence of erosion	0	1	2	3	N/A	

C.	***Inlets***						
	0 = Good condition. Well maintained, no action required.						
	1 = Moderate condition. Adequately maintained, routine maintenance needed.						
	2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.						
	3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Inlets provide stable conveyance into	0	1	2	3	N/A	
2.	Excessive trash/debris/sediment accumulation at inlet	0	1	2	3	N/A	
3.	Evidence of erosion at/around inlet	0	1	2	3	N/A	
4.	Damaged pipes or components	0	1	2	3	N/A	
5.	Inflow hindered by soil height, build up of sediment and/or grass	0	1	2	3	N/A	
6.	Asphalt/concrete crumbling at inlets	0	1	2	3	N/A	

Stormwater Wet Pond/Wetland

D. Practice

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐	Inspected							
☐	Not Inspected							
	Item							**Comments**
1.	Maintenance access to practice	0	1	2	3	N/A		
2.	Sediment accumulation	0	1	2	3	N/A		
	Bathymetric study recommended	☐						
3.	Abnormally high or low water levels	0	1	2	3	N/A	Cause:	
4.	Evidence of pollution/hotspot runoff	0	1	2	3	N/A	Cause:	
5.	Berm(s)/embankment(s)	0	1	2	3	N/A		
	a. Cracking, bulging, or sloughing	0	1	2	3	N/A		
	b. Soft spots or sinkholes	0	1	2	3	N/A		
	c. Evidence of erosion/bare spots	0	1	2	3	N/A		
	d. Evidence of animal burrows	0	1	2	3	N/A		
	e. Presence of woody vegetation	0	1	2	3	N/A		
6.	Riser/outlet	0	1	2	3	N/A	Type of riser:	
	a. Maintenance access to riser	0	1	2	3	N/A		
	b. Structural condition of riser	0	1	2	3	N/A		
	c. Condition of joints	0	1	2	3	N/A		
	d. Trash/debris accumulation	0	1	2	3	N/A		
	e. Woody growth within 5 ft. of outlet	0	1	2	3	N/A		
	f. Emergency spillway eroding, or failing	0	1	2	3	N/A		
7.	Low flow orifice	0	1	2	3	N/A		
	a. Trash/debris accumulation	0	1	2	3	N/A		
	b. Adjustable control valve accessible and operational	0	1	2	3	N/A		
8.	Pond drain (underdrain) system (if applicable)	0	1	2	3	N/A		
	a. Broken	0	1	2	3	N/A		
	b. Clogged	0	1	2	3	N/A		
	c. Adjustable control valve accessible and operational	0	1	2	3	N/A		
9.	Vegetation	0	1	2	3	N/A		
	a. Plant composition consistent with approved plans	0	1	2	3	N/A		
	b. Presence of invasive species/weeds	0	1	2	3	N/A		
	c. Dead vegetation/exposed soil	0	1	2	3	N/A		
	d. Reinforcement planting recommended	☐						

Stormwater Wet Pond/Wetland

E. Outlets						
0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.						
☐ Inspected						
☐ Not Inspected						
Item						**Comments**
1. Outlets provide stable conveyance out of practice	0	1	2	3	N/A	
2. Excessive trash/debris/sediment accumulation at outlet	0	1	2	3	N/A	
3. Evidence of erosion at/around outlet/outfall	0	1	2	3	N/A	
4. Evidence of polluted water being released – discoloration, odor, staining, etc.	0	1	2	3	N/A	

F. Miscellaneous						
0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.						
☐ Inspected						
☐ Not Inspected						
Item						**Comments**
1. Complaints from local residents	0	1	2	3	N/A	
2. Mosquito proliferation	0	1	2	3	N/A	
3. Encroachment on practice or easement by buildings or other structures	0	1	2	3	N/A	
4. Adequate safety signage	0	1	2	3	N/A	

Inspector's Summary:

Stormwater Wet Pond/Wetland

Photographs	
Photo ID	**Description**
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

Sketch of practice
(note problem areas)

Grass Swale

Party Responsible for Maintenance: ____________________

Contact: ____________________

Phone Number: ____________________

E-mail: ____________________

Mailing Address: ____________________

Practice ID: ____________________

Location: ____________________

GPS Coordinates: ____________________

Inspector(s): ____________________

Date: __________ **Time:** __________

A. Contributing Drainage Area

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

Item						Comments
1. Excessive trash/debris	0	1	2	3	N/A	
2. Bare/exposed soil	0	1	2	3	N/A	
3. Evidence of erosion	0	1	2	3	N/A	
4. Excessive landscape waste/yard clippings	0	1	2	3	N/A	
5. Impervious area added	0	1	2	3	N/A	

B. Inflow Points

0 = Good condition. Well maintained, no action required.
1 = Moderate condition. Adequately maintained, routine maintenance needed.
2 = Degraded condition. Poorly maintained, routine maintenance and repair needed.
3 = Serious condition. Immediate need for repair or replacement.

☐ Inspected
☐ Not Inspected

Item						Comments
1. Inflow points (e.g. curb cuts, edge of pavement, pipes) provide stable conveyance into the channel	0	1	2	3	N/A	
2. Excessive trash/debris/sediment accumulation at inflow points	0	1	2	3	N/A	
3. Evidence of erosion at/around inflow points	0	1	2	3	N/A	

Grass Swale

C.	***Practice (Grass Swale)*** 0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Swale remains vegetated; no concrete, rip-rap, or other lining has been added	0	1	2	3	N/A	
2.	Grade ensures positive flow	0	1	2	3	N/A	
3.	Evidence of erosion	0	1	2	3	N/A	
4.	Sediment accumulation	0	1	2	3	N/A	
5.	Excessive trash/debris accumulation	0	1	2	3	N/A	
6.	Evidence of oil/chemical accumulation	0	1	2	3	N/A	
7.	Vegetation condition	0	1	2	3	N/A	
	a. Mowing as needed to maintain 4"-6" grass height.	0	1	2	3	N/A	
	b. 90% turf cover in practice.	0	1	2	3	N/A	
8.	Check dams in place	0	1	2	3	N/A	
9.	Signs of erosion around or under check dams	0	1	2	3	N/A	

D.	***Miscellaneous*** 0 = Good condition. Well maintained, no action required. 1 = Moderate condition. Adequately maintained, routine maintenance needed. 2 = Degraded condition. Poorly maintained, routine maintenance and repair needed. 3 = Serious condition. Immediate need for repair or replacement.						
	Inspected						
	Not Inspected						
	Item						**Comments**
1.	Complaints from local residents	0	1	2	3	N/A	
2.	Mosquito breeding	0	1	2	3	N/A	
3.	Encroachments (e.g. filling, fences, obstructions, etc.)	0	1	2	3	N/A	

Inspector's Summary:

Appendix G. Adapting Stormwater Management for Climate Change*

Climate change has the potential to affect South Carolina's coast, with impacts including sea level rise and potentially more devastating and intense storm events. However, the exact nature and timeline of these impacts is almost impossible to predict with accuracy. Revising stormwater design parameters such as rainfall depth, intensity, and frequency; initial abstraction; and pollutant loading rates is a fairly straightforward exercise. However, whether these factors change by 3% or 40% creates a dramatically different outcome in terms of conveyance, storage, and treatment capacity. At present, the degree of uncertainty in climate change models, as well as region-specific considerations, make it necessary to consider various scenarios of change in stormwater design factors (Shaw et al. 2005).

Consequently, coastal communities need to adapt to the potential for climate change, but should seek low-cost solutions that can be adjusted over time as more is learned about potential impacts of climate change. This Appendix outlines some cost-effective, adaptable approaches to modify stormwater management techniques in the face of potential climate change.

G.1 Impacts of Climate Change

Some potential impacts of climate change include Sea Level Rise, Increased Storm Intensity, Drought, and Shift in Plant Communities.

Sea Level Rise

The International Panel on Climate Change (Christensen et al., 2007) predicts sea level rises ranging from 6 inches to 2 feet over the next century.[1] In the flat coastal plain of South Carolina, even the low range of this potential sea level rise would be significant. Regional research (Morris et al., 2002) predicted that for the southeastern US, relative sea level rise (RSLR) could be at most 1.2 centimeters per year. Locally, the RSLR was measured to be approximately 1 to 1.5 feet per century at the observing stations at Springmaid Pier (in Myrtle Beach, SC) and Charleston Harbor. Charleston Harbor's RSLR was 10 inches over 80 years, which Tibbetts (2011) reports was 50% faster than NOAA's reported global average.

Climate and sea level change result in the slow and systematic reshaping of the coast by individual hurricanes and storms. South Carolina's coasts are net erosional and the impacts of coastal storms are likely to increase as SLR accelerates (SCDHEC-OCRM, 2010). Increased rates of SLR accelerate rates of coastal erosion and land loss; impair urban infrastructure; and facilitate depletion of coastal habitats, including critical estuarine wetlands that help buffer storm surges. Impacts from higher water levels can include salt water intrusion for drinking water sources and greater extent for storm surge (NRC, 2010).

For stormwater management, some key impacts of sea level rise include:

1. volume in stormwater BMPs lost to sea water;
2. flushing of pollutants from stormwater BMPs during storm surge

* content based on Hirschman et al., 2011

[1] Reflects range of most likely outcomes across a variety of future scenarios.

3. stormwater conveyance during storm surge
4. effects of salt water intrusion on plants and soil media in stormwater BMPs

Larger, More Intense Storm Events

Over the last century, we have begun to experience more intense storm events, and infrequent storms (e.g., the 100-year storm event) have been occurring more frequently. Climate change models predict that this trend will continue. However, it is uncertain exactly how storm events will change, and over what time period. More frequent above-normal rain events are anticipated in the southeast. Heavy downpours that normally occur once every 20 years are projected to occur every 4 to 15 years by 2100. Increased hurricanes are projected to add 6-18% more rainfall for every 1.8°F increase in tropical sea surface temperature (USGCRP, 2009). After coming off of a 12-year drought, South Carolina's annual precipitation in 2013 was the second heaviest on record on an annual basis, and the wettest summer recorded (Mizzell, 2013). Across the SC, NC, and GA region, there is an increasing trend in fall precipitation. The number of days with precipitation greater than or equal to one inch (as measured at Charleston Airport), shows a slight increasing trend from 1939 to present; similar results were observed by Dai et al. (2013) in their analysis of 60 years of precipitation data from the Santee Experimental Forest in coastal South Carolina. Although precipitation changes seasonally and future predictions are variable (Carbone, 2013), most models indicate that there will be a 5-10% increase in precipitation in the next 40 years.

Some specific concerns for stormwater management include

1. safely conveying stormwater during more intense events
2. potential bypass of some practices, such as filter strips, during higher intensity storms
3. practice sizing for both water quality and water quantity

Potential Drought and Shift in Plant Communities

Under the most likely scenario (the A1B scenario)[2] predicted by the IPCC, most of the planet will experience a shift in annual precipitation. In Coastal South Carolina, the annual temperature is predicted to increase between three and six degrees Farenheit over the next century. Higher temperatures increase evaporation and increase the intensity and duration of droughts (USGCRP, 2009). These changes will result in a shift in plant communities, and also create a greater need for irrigation and water reuse.

G.2 Stormwater Strategies to Adapt to Climate Change

Effectively responding to climate change will require broad-based, adaptive approaches. Some measures that can help Coastal South Carolina effectively adapt to climate change include:

1. implementing LID practices at the site scale
2. modifying practices to prevent bypass during intense storm events

[2] This scenario assumes: 1) Rapid economic growth; 2) A global population that reaches 9 billion in 2050 and then gradually declines; 3) The quick spread of new and efficient technologies; 4) A convergent world - income and way of life converge between regions. Extensive social and cultural interactions worldwide; and 5) Reliance on a mix of fossil fuels and other energy sources.

3. periodically revisiting design storms and mapped floodplains
4. creating adaptable planting plans
5. using stormwater as a resource

Implement LID Practices at the Site Scale

Since the level of uncertainty in predicting climate change is high, making it difficult to recommend specific design standards, the design community should focus on broader design principles that build system resiliency for climate change. Designers should rely on approaches that:

1. enhance storage and treatment in natural areas
2. use small-scale storage and treatment
3. provide conveyances that allow for a margin of safety for flood conveyance and water quaity treatment

These design principles reflect current thinking in stormwater design and the low-impact development (LID) design framework.

Taken together, an LID design approach can reduce runoff volumes, thus minimizing the impacts of climate change. For example, in one study in New Hampshire (Ballestero, 2009), LID practices were found to retain 15-22% of design storm runoff on-site, so that resulting runoff volumes were similar to conditions before predicted climate change.

Modify Practices to Prevent Bypass During Intense Storm Events.

Design modifications of individual stormwater practices may also be necessary in response to the climate change factors noted above. Since our understanding of design storms may change, the design community may want to focus on fairly modest modifications of existing designs to better accommodate more intense rainfall events. The following examples provide two illustrations of how individual practices could be modified at relatively low cost.

Example 1: Reallocating Storage in Bioretention

The Issue: Increasing rainfall depths and intensities may force a rethinking about how storage is allocated to the various layers within a bioretention facility. More frequent high-intensity rainfall will lead to increased bypassing of the treatment mechanism, resulting in lower overall performance. The most vulnerable flow path element may be the rate at which water stored on the surface of the filter can effectively percolate down and fill the void spaces within the soil media.

Possible Adaptation: Increasing the surface area allocated for storage above the soil media can create a “holding zone” for water to move down through the soil voids. Importantly, this does not necessarily mean that the surface area (or volume) of engineered soil media needs to increase, as this change could have profound cost implications. The solution may be to have a surface ponding area that is not underlain by soil media, as shown in Figure G.2-1. In fact, this method has already been adopted in existing specifications, such as those on the Virginia Stormwater Best Management Practice (BMP) Clearinghouse, albeit not as a climate change adaptation (Virginia Department of Conservation and Recreation [VADCR], 2013a).

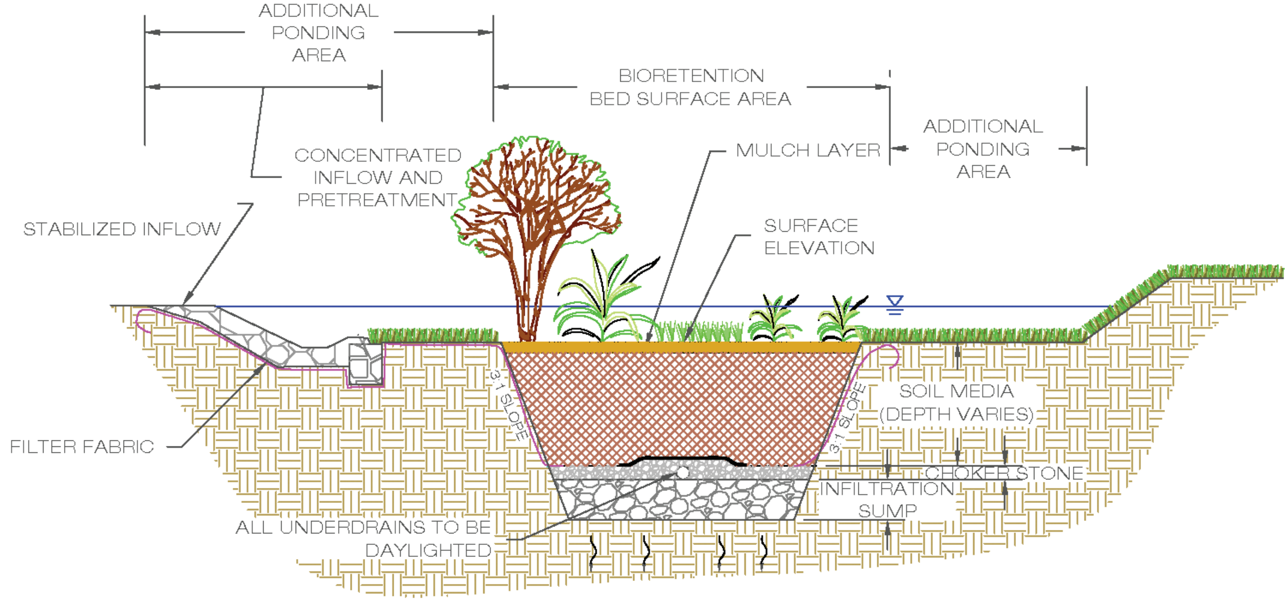

Figure G.2-1. Adaptation of a bioretention facility. Additional surface ponding area has been incorporated while the surface area and volume of soil media remains the same. (Source: VADCR 2013a, figure 9.5 excerpt).

Example 2: Pretreatment for Rainwater Harvesting

The Issue: Rainwater harvesting systems are designed to capture a target amount of water. However, both ends of the spectrum feature designed bypasses—first-flush diverters, vortex filters, and additional pretreatment devices to keep leaves and gross solids out of the storage tank (Figure G.2-2) and bypasses for higher flows once the storage device fills to capacity. With changing rainfall depths and intensities, it is possible that more water than desired will bypass at the front end, resulting in a loss of precious water that could be stored for future use, and overflow at the back end, creating downstream problems.

Possible Adaptation: The efficiencies of vortex filters and other pretreatment devices can be increased so that higher-intensity rainfall events will not lead to excessive bypassing of the storage tank. For instance, some current specifications call for a filter efficiency of 95% for a storm intensity of 25 mm (1 in) per hour (VADCR 2013b). The assumed intensity could be increased to 38 or 51 mm (1.5 or 2 in) per hour. To address more frequent overflows from the tank itself, on-site or off-site downstream infiltration or filtering practices can be coupled with the rainwater harvesting system (Figure G.2-3).

Periodically Revisit Design Storms and Mapped Floodplains

Due to the uncertainty in climate change modeling, it is not clear how, or if, practices need to be sized differently to account for potential larger storm events. Similarly, predicted sea level rise and storm events will likely change the location of mapped floodplains, but we are currently unable to predict the future floodplain or depth to groundwater with any accuracy. Consequently, an Adaptive Management approach, which periodically evaluates storm event data. as well as sea level and groundwater elevation, will allow for gradual readjustment over time. By using this approach, practices would have a useful life before changes occurred, but "new generation" BMPs would be sized and located to consider the effects of climate change as they are learned.

Figure G.2-2. A vortex filter is an example of a pretreatment device for rainwater harvesting. The vortex filter diverts the first amount of rainfall, which tends to have a lot of solids and vegetative debris. Vortex filters come in different sizes based on efficiency curves for rooftop area treated and rainfall intensity. (Source: VADCR 2011, Figure 6.11)

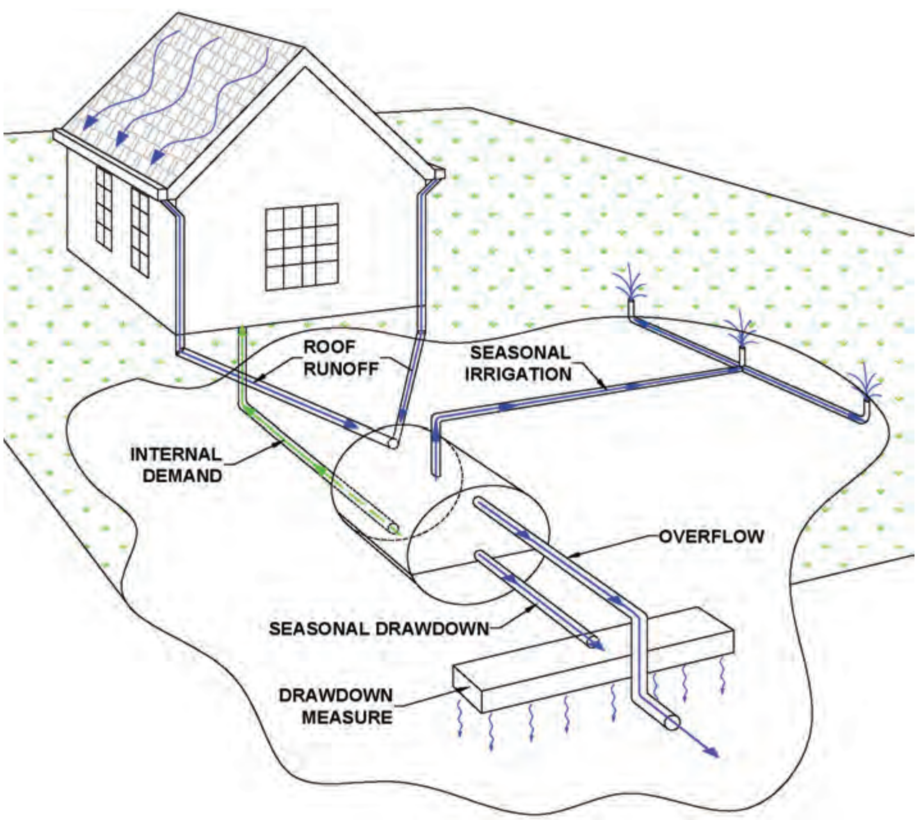

Figure G.2-3. Schematic of a rain-water harvesting system designed for internal use, seasonal irrigation, and treatment in a downstream filtration or infiltration practice during non-irrigation or rainy season months when the tank overflows routinely. (Source: VADCR 2013b, figure 6.3.)

Create Adaptable Planting Plans

Changes in temperature and rainfall patterns will likely combine to change plant communities. The plant lists included in this manual focus on native plants. In the long term, though, these plants may struggle to survive in a changing climate. Consequently, planting plans should be adapted over time so that, as practices are maintained, replacement plants are able to survive in a changing climate. In addition, plant lists in this manual should be reviewed and updated periodically to ensure that they include only plants that continue to thrive in coastal South Carolina.

Use Stormwater As a Resource

If hotter, drier conditions result from climate change, supplying coastal communities with sufficient water to meet both drinking water and irrigation demands may be a challenge. Stormwater management can play an important role in mitigating this problem, either by reducing water demand, or actively storing stormwater for future use. By concentrating ornamental vegetation in stormwater practices such as bioretention, the irrigation demand is far less than it would be in traditional landscaped islands since stormwater directed to these practices provides frequent inundation. Another option is to expand the use of stormwater harvesting practices. By using these practices to provide landscape irrigation and some interior water uses, water demand can be reduced substantially.

G.3 Conclusion

Climate change has the potential to impact Coastal South Carolina, with potential impacts including sea level rise, frequent and more intense storms, and drought and consequent shift in plant communities. However, it is difficult to predict the precise timing and magnitude of these changes. Consequently, the approach recommended in this appendix is a measured one that highlights low-cost solutions and adaptation over time as more is learned about climate change. The elements of this approach include: implementing LID practices at the site scale; modifying practices to prevent bypass during intense storm events; periodically revisiting design storms and mapped floodplains; creating adaptable planting plans; and using stormwater as a resource.

G.4 Adapting Stormwater Management for Climate Change References

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14. Virginia Department of Conservation and Recreation (VADCR). 2013a. Design specification no. 9: Bioretention. Version 2. Richmond, VA: Virginia Department of Conservation and Recreation.
15. Virginia Department of Conservation and Recreation (VADCR). 2013b. Design specification no. 6: Rainwater harvesting. Version 2.0. Richmond, VA: Virginia Department of Conservation and Recreation.

Appendix H. Stormwater Statutes and Regulations

This appendix is not legal advice and is provided for informational purposes only. Anyone interested in which, if any, statutes and/or regulations apply to a particular project should consult an attorney licensed in South Carolina. (Information provided by Andrew Wurley, Esq., Charleston Waterkeeper)

H.1 FEDERAL:

Clean Water Act

In General - All point source discharges are illegal, unless authorized by and in compliance with an NPDES permit

- ✧ ***National Pollutant Discharge Elimination System (NPDES)***
  - In general - Many stormwater discharges are considered point sources and operators are required to receive an NPDES permit before they can discharge stormwater.
  - NPDES permits - Contain numerical or narrative effluent limitations on the types and amounts of pollutants and require the use of Best Management Practices (BMPs) and/or stormwater treatment.
  - Note - Permits are either general (issued to a class of discharges) or individual (issued to a single discharger)
- ✧ ***CWA Section 402(p)*** - Provides a phased approach for regulating stormwater discharges under NPDES program
  - Phase I (1990) - NPDES permits required for:
    - Construction activity disturbing 5 acres or more
    - Industrial activity in the 11 categories listed here: http://www.scdhec.gov/Environment/WaterQuality/NPDES/Classifications/
    - Large and Medium Municipal Separate Stormwater Sewer Systems (population equal to or greater than 100,000)
  - Phase II (2003) - NPDES permit required for:
    - Construction activity disturbing between 1 and 5 acres
    - Industrial activity (added 1 category to list of 11)
    - Small MS4s (population between 10,000 and 100,000)
- ✧ CWA Section 401 - Requires that the DHEC issue a certification for any activity which requires a Federal permit and may result in a discharge to State waters. This certification must state that applicable effluent limits and water quality standards will not be violated. See R.61-101 Water Quality Certification available at http://www.scstatehouse.gov/coderegs/c061e.php

Endangered Species Act (ESA)

In general - May affect stormwater management designs when dealing with downstream habitats of endangered species or habitats of endangered species currently residing onsite.

Note - The Fact sheet to the Industrial Stormwater General Permit SCR000000 indicates DHEC removed and reserved the ESA requirement from the permit. DHEC considers this a Federal program and believes it should be administrated as such. See SCR000000 Fact Sheet (page 5) available at http://www.scdhec.gov/Environment/docs/sw_PNFSIGP.pdf

National Environmental Policy Act (NEPA)

In general - If a new or expanded industrial discharge is established, environmental impact reviews must be conducted and approved before an NPDES permit is granted.

Note - A New Source Determination (NSD) determines whether the proposed source is subject to environmental assessment under NEPA.

National Historic Preservation Act (NHPA)

In general - May affect stormwater management design when historical places are located onsite.

Note - The Fact sheet to the Industrial Stormwater General Permit SCR000000 indicates DHEC removed and reserved the NHPA requirement from the permit. DHEC considers this a Federal program and believes it should be administrated as such. See SCR000000 Fact Sheet (page 5), available at http://www.scdhec.gov/Environment/docs/sw_PNFSIGP.pdf

Coastal Zone Management Act (CZMA)

In general - Prohibits the issuance of NPDES permits for activities affecting land or water use in the coastal zone unless the permit applicant certifies that the proposed activity complies with the State CZM Program.

H.2 STATE:

Pollution Control Act (PCA)

In general - "It is unlawful for a person, directly or indirectly, to throw, drain, run, allow to seep, or otherwise discharge into the environment of the State organic or inorganic matter, including sewage, industrial wastes, and other wastes, except in compliance with a permit issued by [DHEC]." See ***S.C. Code Ann 48-1-90(A)(1)*** available at http://www.scstatehouse.gov/code/t48c001.php

Note - The PCA grants DHEC authority to promulgate regulations to implement the requirements of the PCA

- ***Water Pollution Control Permits*** - R.61-9 122.26 Storm water discharges implement South Carolina's stormwater NPDES permit program. The program is implemented via general and individual permits that require the use of stormwater controls. Information is available at http://www.scdhec.gov/environment/water/regs/r61-9.pdf

- ✧ ***General Permits***
  - SCR00000 - Industrial Stormwater General Permit
    - http://www.scdhec.gov/Environment/docs/scr000000.pdf
  - SCR10000 - Construction General Permit
    - http://www.scdhec.gov/Environment/docs/CGP-permit.pdf
  - SCR03000 - Small Municipal Separate Stormwater Sewer Systems
    - http://www.scdhec.gov/Environment/docs/Final_SMS4_Permit.pdf
- ✧ ***Individual Permits***
  - Large & Medium MS4s - SC Department of Transportation, City of Columbia, Greenville County, Lexington County, and Richland County
  - Some Industrial Sites
  - Some Construction Activities

Erosion and Sediment Reduction and Stormwater Management

In general - Sets forth requirements for erosion and sediment control and stormwater management measures to be used on land owned by the state of South Carolina to prevent damage to land, water, and property from erosion, sediment and stormwater.

Note - R.72-106(E) provides a set of minimum standards and specifications that must be used to control erosion and stormwater for projects on state property. More information available at http://www.scdhec.gov/environment/water/regs/r72-101.pdf

Standards of Stormwater Management and Sediment Reduction Act (SMSRA)

In general - The SMSRA contains a set of design criteria and minimum standards and specifications based upon the number of acres to be disturbed.

Categorical Exceptions - many activities are excepted from the SMSRA. These include land disturbing for agriculture, timber harvesting, and improvement of a single family residence. Full list of exceptions and variances available at:

- ✧ R.72-302: http://www.scdhec.gov/environment/water/regs/r72-300.pdf
- ✧ S.C. Code Ann 48-14-40: http://www.scstatehouse.gov/code/t48c014.php

Note 1 - SMSRA requirements based on acres disturbed:

Table H.2-1. SMSRA Requirements	
Acres	**Minimum Standards***
Less than 2 acres (not part of ager common plan)	R.72-307(H)
Between 2 and 5 acres (not part of a larger common plan)	R.72-307(I)
More than 5 acres	R.72-305(H) and (I)
**Available online at http://www.scdhec.gov/environment/water/regs/r72-300.pdf*	

Note 2 - Land disturbing activities on land owned by the South Carolina Department of Transportation are regulated under R.72-405: http://www.scdhec.gov/environment/water/regs/r72-405.pdf

Coastal Zone Consistency Permits

In general - Activities affecting land and water in the coastal zone may require a DHEC-OCRM Consistency Determination before coverage is granted under an NPDES permit. A consistency determination establishes that all land and water uses within the coastal zone are consistent with both the State's Coastal Zone Management Plan and the South Carolina Coastal Zone Management Act.

In the eight coastal counties - Consistency Determinations are required as a precondition to NPDES permit coverage if:

- The project will disturbs more than 0.5 acre in one of the eight coastal counties (Charleston, Berkeley, Dorchester, Georgetown, Horry, Jasper, Beaufort, and Colleton), or
- (1) hazardous chemicals are stored, (2) the project is a residential subdivision directly adjacent to saltwater, or (3) the project impacts a Geographic Area of Particular Concern as defined in R.30-1(D)(24), available at http://www.scstatehouse.gov/coderegs/c030.php

Note - these are general rules, DHEC provides helpful guidance which is available at http://www.scdhec.gov/environment/WaterQuality/Stormwater/ConstructionActivities/

Federal permits - Some federal permits (CWA Section 404 dredge and fill) may require both a 401 Water Quality Certification and a Consistency Determination. In this case the 401 Certification serves as the Consistency Determination.