STATE OF THE KNOWLEDGE REPORT:

STORMWATER PONDS IN THE COASTAL ZONE

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Resource Management

State of Knowledge Report: Stormwater Ponds in the Coastal Zone

Prepared by the South Carolina Dept. of Health and Environmental Control,
Office of Ocean and Coastal Resource Management

in cooperation with the

South Carolina Sea Grant Consortium

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EXECUTIVE SUMMARY

The South Carolina Department of Health and Environmental Control's Office of Ocean and Coastal Resource Management (SCDHEC-OCRM) is responsible for stormwater management in the eight coastal counties of South Carolina. Within this region, detention and retention ponds are the most commonly employed stormwater management practices. Stormwater ponds can reduce localized flooding and capture sediments that would otherwise be carried by surface runoff into receiving waters. However, their effectiveness in treating other pollutants associated with stormwater runoff is unclear. This report identifies continuing research and information needs, and outlines potential management implications. The "State of the Knowledge" of stormwater ponds is still evolving through the collective research efforts of state and federal agencies, academic institutions, and non-profit organizations.

In June 2006, a Stormwater Pond Research Initiative was launched through a partnership between the SC Sea Grant Consortium, SCDHEC-OCRM, University of South Carolina, Coastal Carolina University, SC Algal Ecology Laboratory (SCDNR), Clemson University, and others. The first meeting of this collaboration resulted in a call for developing a "State of the Knowledge" report to synthesize existing research and identify future research priorities related to stormwater ponds. To date, independent stormwater pond research efforts have tended to focus on a small number of ponds and/or ponds with suspected performance failures. There have been no large-scale, comprehensive analyses of stormwater pond performance in coastal areas of the southeastern U.S. Therefore, our ability to determine factors that may lead to poor pond performance, or to assess potential ecological impacts, is currently limited.

Existing Stormwater Pond Research

In preparing this report, numerous research projects were reviewed, and findings related to water quality, sediment quality, hydrology, and other studies were synthesized into corresponding sections. In particular, a large number of studies have focused on water quality aspects of stormwater ponds in South Carolina's coastal zone over the past ten years. This research has demonstrated that stormwater pond surface waters often have poor water quality conditions. Stormwater ponds often accumulate large masses of algae – sometimes consisting of harmful algal species. In addition, they are often the sites of fish kills, accumulate debris and trash, and often exhibit high concentrations of nutrients, chlorophyll *a*, chemicals, pesticides, fecal coliform bacteria (FCB), and have low dissolved oxygen (DO) concentrations. These conditions are not necessarily problematic, especially when a stormwater pond is considered to be a water treatment facility rather than an amenity. Regardless of their intended use, ponds attract humans and wildlife, and understanding the water quality conditions of stormwater ponds in our region is therefore important. Further, ponds may be ineffective in treating some pollutants prior to discharging into receiving waters. Other sections of the report examine the sediment quality of stormwater ponds, hydrology models, and socioeconomic considerations of stormwater management.

Research and Information Needs

Stormwater pond research efforts in South Carolina have begun to answer a number of important questions; however, key research issues remain. During the first meeting of the Stormwater Pond Research Initiative, data gaps and research priorities were identified as follows:

- How many stormwater ponds exist in the SC coastal zone, what is their cumulative volume/coverage, and at what rate are they expanding?
  - Is there a need to classify stormwater ponds according to size, land use, type, etc.?
- What stormwater pretreatment procedures are most effective?
- What are common pond maintenance practices, and how do they affect pond structure and function?
- What are the impacts to receiving waters from stormwater pond discharges?
- How fast are stormwater ponds "filling in," and what is the level of sediment contamination? How often is sediment removed from ponds? Where is the removed sediment placed/disposed?
- What water quality indicators and levels may indicate impaired pond conditions, or potential pollution sources for receiving waters?
- Would other stormwater pond design criteria (i.e., other than 2-year and 10-year rain events) better protect water quality and control water quantity (flooding)?
  - Are designed storm events (2- and 10-year rain events) reducing peak rates of flow to pre-development conditions? Are pre-development runoff rates accurate for SC's low topography?
  - What is the performance of stormwater ponds during small, frequent rain events versus large, infrequent rain events?
- Which stormwater hydrologic model is most applicable in coastal SC?
  - Which of the commonly used models have been validated for coastal SC?
- What public and environmental health risks might stormwater ponds pose?
- How can education and outreach to local governments and homeowners be improved?
- What are the economic costs and benefits of a stormwater pond? What are the comparative costs and benefits of more innovative stormwater management practices?

Management Implications

Stormwater management is of increasing concern in the coastal counties of South Carolina. The Council on Coastal Futures, a group composed of diverse membership representing environmental, scientific, government and business interests, was tasked by the SC Board of Health and Environmental Control to document priority issues and concerns relating to coastal zone management. The Council agreed on a list of the "highest priorities," which included improving local and state stormwater management. The following are a list of specific stormwater-related recommendations (SCDHEC, 2004b):

- Improve water quality by managing stormwater on a watershed basis.
- Allow and encourage innovative stormwater management practices and standards.
    - Provide allowances for innovative stormwater approaches beyond the stated performance standards.
    - Develop a process to allow and encourage installing innovative stormwater management practices as well as research into their efficiency.
    - In order to minimize stormwater infrastructure installation and repair costs, encourage vegetative options for conveyance and treatment where possible.
    - SCDHEC-OCRM should require new detention ponds to be designed and constructed with vegetated areas unless other non-vegetative methods prove to be more effective at removing pollutants.
- SCDHEC-OCRM should research the current use, feasibility, economic impact and projected effectiveness of implementing a pollutant (i.e., nutrients, bacteria) removal efficiency standard for new stormwater management systems.
- Develop a strategy and guidance to maintain, monitor, inspect, and provide education for stormwater management practices.
- Establish formal partnerships between SCDHEC-OCRM and state research institutions.

As the South Carolina coastal zone experiences increasing development pressures, improved stormwater management will prove to be an integral tool in addressing the associated ecological impacts. The "State of the Knowledge" of stormwater ponds is still evolving through the joint research and outreach efforts of SCDHEC-OCRM, SC Sea Grant, and other state and federal agencies, academic institutions, and non-profit organizations. Based on existing research, stormwater ponds are known to reduce local flooding and protect receiving waters from pollution in stormwater runoff; however, they can also accumulate nutrients, bacteria, and chemical contaminants resulting in poor pond water quality and potential threats to receiving waters. The pollution extent and impacts to receiving waters is largely unknown and future studies should assess this management concern. The influences of pond designs and other characteristics on performance also remain unclear. As development pressures increase, LID practices could prove to be an essential component of stormwater management; however, their functionality in this state's low-lying areas with high water tables must be addressed, and since these practices rely on infiltration, their effects on groundwater should also be studied. While stormwater ponds are successful stormwater management practices in many locations, they may not be ideal for every situation.

ISSUE STATEMENT

The South Carolina Department of Health and Environmental Control's Office of Ocean and Coastal Resource Management (SCDHEC-OCRM) is responsible for stormwater management in the eight coastal counties of South Carolina (i.e., the coastal zone). Within this region, detention and retention ponds are the most commonly employed stormwater management practices. Stormwater ponds can reduce localized flooding and capture sediments that would otherwise be carried by surface runoff into receiving waters. However, their effectiveness in treating other pollutants associated with stormwater runoff is unclear. This report identifies continuing research and information needs, and outlines potential management implications. The "State of the Knowledge" of stormwater ponds is still evolving through the collective research efforts of state and federal agencies, academic institutions, and non-profit organizations.

Overview

In June 2006, a Stormwater Pond Research Initiative was launched through a partnership between the SC Sea Grant Consortium, SCDHEC-OCRM, University of South Carolina, Coastal Carolina University, SC Algal Ecology Laboratory (SCDNR), Clemson University, and others. The first meeting of this collaboration resulted in a call for developing a "State of the Knowledge" report to synthesize existing research and identify future research priorities related to stormwater ponds. To date, independent stormwater pond research efforts have tended to focus on a small number of ponds and/or ponds with suspected performance failures. Additionally, there have been no large-scale, comprehensive analyses of stormwater pond performance in coastal areas of the southeastern U.S. Therefore, our ability to determine factors that may cause poor pond performance, or to assess related ecological impacts, is currently limited.

Background

During the past two decades, southeastern coastal counties have experienced rapid growth, much of which has occurred in the form of sprawling residential development that has consumed land at a rate nearly six times higher than population growth (Beach, 2002). For example, between 1974 and 1994 the urban area of Charleston increased by 250 percent while the population increased only 40 percent (Allen & Lu, 2003). Because of the high levels of impervious cover associated with this type of development (roofs, parking lots, roads, etc.), non-point source pollution is now the most significant threat to coastal waters and habitats in the region (Holland et al., 2004). Although a variety of stormwater reduction and treatment practices have been developed, the use of stormwater ponds is by far the most common practice utilized to address non-point source pollution in the coastal zone. Stormwater permit applications have increased from just above sixty in 1992 to over 1,300 in 2006. In fact, recent estimates place the increasing number of stormwater ponds in coastal South Carolina at over 8,000 (Seiwicki et al., 2007), making these waterbodies an increasingly significant feature of the coastal landscape. Many stormwater ponds discharge directly into tidal waters and marshes; however, the cumulative impacts on the receiving waters, habitats, and associated fisheries are unknown. Estuaries along the South Carolina coast serve as critical nursery habitats for many important fisheries species (Sanger et al., 1999 a, b; Lerberg et al., 2000; Mallin et al., 2000; Holland et al., 2004).

Stormwater ponds, including detention ponds (water gradually released through an outlet structure to adjacent surface waters) and retention ponds (water gradually released through infiltration and evaporation) were originally intended to manage localized flooding. Over the past two decades stormwater ponds have been increasingly expected to (or in some cases required to) address water quality concerns for receiving waters, by removing sediments as well as other pollutants (i.e., nutrients and bacteria) through physical, chemical, and biological processes in the water column. Stormwater ponds are also being used to irrigate golf courses and residential landscaping, enhance aesthetics, provide a natural environment for wildlife and vegetation, and support recreational uses (Urbonas and Stahre, 1993; Figures 1 and 2). Regardless of flood control, water quality, and recreational benefits, stormwater ponds will continue to be constructed because they also provide an important source of fill material for development in low-lying areas, like coastal South Carolina.

Figures 1 and 2: Stormwater ponds used for irrigation in Myrtle Beach, and recreation/aesthetics in Charleston, SC.

The research summarized in this report found that some ponds protect receiving waters from pollution and protect communities from flooding during storms, while other studies found that ponds were polluted, can impact receiving waters, and are not controlling stormwater runoff as they were designed and permitted. Because stormwater ponds have diverse designs and characteristics, determining a common denominator for pond performance is difficult. These structural designs (Appendix A) and other factors such as age, location within the watershed, and linkages with other ponds play an important, albeit not well understood, role in their functioning and performance. A variety of research on stormwater ponds addresses their functionality, water and sediment quality, and surface and groundwater impacts. If not properly maintained, ponds can accumulate sediment and debris and have slope and/or outlet failures, resulting in high sediment and pollutant loadings to receiving waters. When sediment is removed from ponds as part of routine maintenance, contaminated sediments could require disposal at certified landfills.

It is clear that while we have gained much needed information about stormwater ponds, there is no “one-size-fits-all” stormwater management solution. For some projects, stormwater ponds are the best option; in other cases, more innovative management practices may be preferable (i.e., “Low Impact Development” practices). Additional research is needed to improve current stormwater plans and designs, and to inform decision-makers and stakeholders on the tradeoffs associated with various alternatives.

South Carolina's Stormwater Management

In South Carolina, stormwater ponds are designed as water quantity and quality control structures and are the most common stormwater management practice. The three basic pond types are: 1) wet detention ponds that have a permanent pool of water designed to temporarily store stormwater before being discharged downstream; 2) dry detention ponds that are designed to temporarily store stormwater before being discharged downstream; and 3) retention ponds that have a permanent pool of water and discharge runoff only through infiltration and/or evapotranspiration (SCDHEC, 2005). The laws and regulations that resulted in SC's Coastal Zone Management Program that are used to regulate land disturbing projects in the eight coastal counties under state and federal legislation are detailed in Appendix B.

SCDHEC-OCRM implements the Phase II Construction General Permit (CGP) in the state's eight coastal counties. These permits address water quality and quantity using thresholds based on the project's land disturbance footprint, distance to receiving water, and proximity to sensitive areas. Generally, permits are required if a land disturbing project is ≥ 1 acre and not within ½ mile of a receiving water **<u>or</u>** if a project is > ½ acre and within ½ mile of a receiving water. However, a permit could be required even if the project is ≤ ½ acre and within ½ mile of a receiving water if it meets defined criteria that are outlined in the regulations. For certain acreages of disturbance the regulations require that peak post-development discharge rates from the basin shall be at or below pre-development rates for the 2- and 10-year 24-hour storm events (4.5 and 6 inches, respectively). Stormwater ponds (wet detention ponds) for projects that disturb ≥ 5 acres and are not within ½ mile of a receiving water should catch and store onsite the first ½ inch of runoff and release that quantity over 24 hours. Typically, projects within ½ mile of a receiving waterbody should catch and store onsite the first ½ inch of runoff from the site or the first 1 inch of runoff from the built upon area, whichever is greater. During construction, the stormwater management plan should demonstrate an 80% sediment trapping efficiency for the 10-year 24-hour storm event if the project disturbs > 10 acres and drains to a common point (SCDHEC, 2002; 2003; 2006).

Coastal Stormwater Maintenance Program

A SCDHEC-OCRM Stormwater Maintenance Program performed site inspections for 511 developments with stormwater permits from 2001 through 2006. Stormwater inspectors reported an 86% compliance rate (meaning that the majority of the ponds were functioning properly). Some type of maintenance (i.e., non-compliance) was required for 73 permits. Non-compliance was greatest in commercial land uses, and common violations included: 1) sedimentation in the inflow and/or outflow pipes; 2) slope erosion; and 3) excess pond vegetation that limited the ponds' storage capacity (Lopez, 2003; Wahl, 2007). Wet detention ponds were the most frequently used stormwater management practice, and were often found in conjunction with swales. The stormwater permit sites that were inspected contained stormwater ponds that varied in number, age, land use, and maintenance practices. It is important to note that these inspections were carried out from the shore, so no pond depths (sedimentation accumulations) were assessed.

The stormwater maintenance program resulted in the following recommendations for consideration by SCDHEC-OCRM:

- Continue pond maintenance inspections;
- Develop maintenance inspection procedures for emerging stormwater management practices;
- Track stormwater system transitions from construction phase (owner and developers) to operational phase (i.e., Home Owner Associations (HOAs));
- Develop policies and guidance procedures for sediment removal;
- Incorporate stormwater maintenance information into SCDHEC-OCRM's Realtor Workshops;
- Provide stormwater maintenance education to HOAs, developers, municipal planners and leaders, and other community groups; and
- Add sampling for sediment contaminants (Lopez, 2003; Wahl, 2007).

Stormwater Management in Other Coastal States

North Carolina

The State Stormwater Management regulations for NC also apply to land disturbing projects. These projects must develop an Erosion and Sedimentation Control Plan that complies with the Coastal Area Management Act's major development permit that is issued by the Division of Land Resources or the Division of Coastal Management. There are three permit types, 1) low density permits (≤ 30% impervious surfaces); 2) high density permits (> 30% impervious surfaces); and 3) general permits (covering activities such as construction of single-family homes and bulkheads). The State advocates low and high-density development permits to protect receiving waters. Generally, stormwater management practices must control 1 to 1.5 inches of rainfall and remove 85% of the total suspended solids (TSS) (NC Division of Water Quality, 2007). As of 1995, ponds were required to have a forebay (a small pool to catch the initial pulse of heavy pollutants before water enters the larger stormwater pond) and an aquatic shelf (located below the pond upper banks at a 6:1 slope to sustain aquatic plans and further reduce TSS). Prior to 1995, pond design was simpler and consisted of a basin, a 3:1 grass covered slopes, and an outlet structure located away from the stormwater entry point (NC Division of Water Quality, 2005)

In order to determine non-compliance trends and improve future stormwater management, the NC State Stormwater Program examined a systematic, random sample of 3,648 facilities permitted from 1988 through 2002 in five of the 20 coastal counties. Approximately 15% (524 projects) of the low-density and high-density permitted projects were investigated. Of these, a total of only 30.7% were in full compliance. High-density permits with detention ponds (249 projects) had a 27% full compliance rate. The most common non-compliance issues for detention ponds were reporting violations (51%) followed by maintenance violations (33%). (NC Division of Water Quality, 2005)

A major finding of this coastal stormwater compliance study was that the total area of impervious surface coverage for projects permitted as low-density was greater than the high density permits. Therefore, low-density development may be having a greater impact on receiving waters than high-density projects. This study identified compliance of low density projects as a high priority and the following compliance efforts were proposed: 1) increase the number of compliance evaluation inspections; 2) enhance design certifications and deed restriction compliance; and 3) increase maintenance education (NC Division of Water Quality, 2005).

Georgia

The Georgia Coastal Management Program oversees urban stormwater management under the GA Sediment and Erosion Control Act (Georgia Stormwater Management Manual, 2001a). Stormwater management is administered to control stormwater quantity and quality. This means that the stormwater ponds will reduce pollutants to the Maximum Extent Possible to protect water quality, reduce storm event volume, and meet federal Clean Water Act guidelines (Risse and Tanner, 2004).

The following components are required for stormwater ponds in Georgia: 1) a length to width ratio minimum of 1.5 to 1; 2) a maximum depth of 8 feet; 3) pond slopes should not exceed 3:1; and a forebay should be included. The Georgia Stormwater Management Manual (2001a) suggests eleven minimum stormwater management standards that local jurisdictions can use as a guide. Examples of these standards include the following better management practices: 1) protecting water quality by removing 80% of the TSS annual pollutant load; 2) sizing the stormwater pond to capture and treat runoff volumes from 1.2 inch rain events; 3) protecting stream channels by detaining stormwater for 24 hours from a 1-year, 24 hour storm event, providing erosion control, and preserving stream buffers; and 4) providing flood protection by controlling the 2 through 25 year storm event post-development peak discharge rates to the respective predevelopment rates. Projects can gain stormwater management credits for natural area conservation, buffers, vegetated channels, and areas that decrease the effects of impervious surfaces and promote infiltration/filtration (Georgia Stormwater Management Manual, 2001a; Georgia Stormwater Management Manual, 2001b).

Stormwater Pond Research

Water Quality

Stormwater pond surface waters are documented to have poor water quality indicators and other unintended, negative consequences. These ponds can accumulate large masses of algae, including some harmful algal species. They can be the sites of fish kills, accumulate debris and trash, and exhibit high concentrations of nutrients, chlorophyll *a*, chemicals, pesticides, fecal coliform bacteria (FCB), and have low dissolved oxygen (DO) concentrations. These conditions are not necessarily problematic, especially when a pond is considered a water treatment facility rather than an amenity. However, an opportunity may exist to improve pond water quality through changes in design and maintenance of ponds. Furthermore, regardless of their intended use, ponds attract humans and wildlife, as well as serving as a source of freshwater to estuarine systems. It is therefore important to understand the water quality conditions of stormwater ponds in our region. There are presently no standards for stormwater pond water quality, efficiency or pollutant treatment standards except for the calculation of an 80% sediment removal for the construction phase of development; however SCDHEC, National Ocean and Atmospheric Administration (NOAA), SC Estuarine and Coastal Assessment Program (SCECAP), and US Environmental Protection Agency (USEPA) standards for similar freshwater bodies could be used as guidelines.

In conjunction with the 2006 Stormwater Pond Initiative, SCDHEC-OCRM conducted two stormwater pond studies: 1) a baseline study of the water quality conditions in coastal stormwater ponds and 2) a hydrology and efficiency study of two stormwater ponds in coastal South Carolina (Drescher et al., 2007; Messersmith, 2007). The baseline study examined 112 stormwater ponds representing varying ages, land use types and designs.

The Center for Watershed Protection (CWP) identified pollution sources and strategies for the town of Edisto Island in 2005. The study identified stormwater "hot spots," performed site inspections, and provided follow-up actions such as retrofitting, corrective management, site clean up, and education (CWP, 2005). In Myrtle Beach, stormwater ponds feeding the Wither's Swash area could impact nearshore waters; therefore, Coastal Carolina University and SCDHEC-EQC Region 6 will begin monitoring this year (Davis et al., 2005; Ambrose and Pearson, pers. comm.). In Bluffton, SC, community concern about stormwater runoff led to a city ordinance that: 1) requires FCB, TN, and TP monitoring; 2) outlines maintenance practices; and 3) holds an owner financially responsible for negligent stormwater management (Town of Bluffton, SC, 2007).

Nutrients

Nutrient concentrations within stormwater ponds are a concern because of their ability to enhance eutrophication and facilitate algae growth. The SCDHEC-OCRM stormwater baseline study, found that 71% of ponds had low total nitrogen (TN) (TN < 0.95 mg L^{-1}) and 69% of ponds had low total phosphorus (TP) (TP < 0.09 mg L^{-1}). However, these nutrients could be depleted due to rapid uptake by phytoplankton or macroalgae. In a second study, Serrano (2005) found that 47% of the monthly mean dissolved nitrogen concentrations of a pond that functions for stormwater control and is known as Lake Edmunds (James Island, SC) were greater than the USEPA standard for lakes of 0.37 mg L^{-1} and 100% of the monthly mean dissolved phosphorus levels were above the standard of 0.036 mg L^{-1} (USEPA, 2001). In a third study, Brock (2007) reported that six ponds analyzed for five years on Kiawah Island, SC, showed signs of eutrophication based on multiple chemical and biological parameters such as chlorophyll *a*, DO, and nutrients. Brock (2007) reported that nutrients were seasonally variable, and highly available to phytoplankton communities when in the inorganic form (i.e., NO_x, NH_4).

While these studies demonstrate the variability of nutrient concentrations within stormwater ponds, excess nutrients have the potential to breed algal species in high density as well as harmful algal species (i.e., algal species containing known toxins). Brock (2007) documented persistent algal blooms, such as a four-month long *Mycrosystis* bloom, and found that salinity ranges selected for the dominant phytoplankton communities. The SCDHEC-OCRM baseline study found that although nutrients tended to be low and DO tended to be high (DO > 4 mg L^{-1} in 79% of the ponds), chlorophyll *a* concentrations were high (≥ 40 µg L^{-1} in approximately 32% of the ponds). In fact, an analysis of the 25 samples with chlorophyll *a* concentrations >60 µg L^{-1} found that 80% contained algal blooms, including HABs. In 2001, *Pfiesteria* like organisms were also found in brackish detention ponds on Kiawah Island, SC, and Hilton Head Island, SC (Lewitus and Holland, 2003). In 2002, a brackish detention pond fish kill located in Mount Pleasant, SC, was linked to a *Karlodinium micrum* bloom, by either the toxicity of the dinoflagellates, or the bloom persistence and subsequent low DO conditions (Kempton et al., 2002). In response to stormwater pond HABs, the SC Task Group on Harmful Algae (www.scseagrant.org/oldsite/schab.htm) was formed in 1997, to monitor HAB events and inform the public of HAB risks. SCDHEC also responds to fish kills through their Emergency Response toll-free hotline (http://www.scdhec.gov/eqc/lwm/).

Bacteria

FCB concentrations in stormwater ponds are indicators of fecal matter bacteria, they can be temporally and spatially variable, and the sources (i.e., wildlife, pets, septic tanks, etc.) are often unknown. As development patterns decrease vegetative habitats, the wildlife concentration increases in these shrinking areas that are often adjacent to sensitive waterways, such as shellfish beds. A common bacteria model for wet detention ponds is shown in Appendix C. Siewicki et al. (2007) found that FCB in stormwater ponds on Kiawah Island were higher after rain events, increased winds, and decreases in landscaped areas. Using a long-term dataset at Kiawah Island and Hilton Head, models were developed to predict FCB loading from ponds to estuaries and predict the ecological impact of development scenarios. Serrano (2005) found that monthly averages of FCB were ≥ 200 colony forming units (CFUs) 100 mL^{-1} for five out of fifteen months and the SCDHEC-OCRM baseline study found FCB ≥ 400 CFUs 100 mL^{-1} in approximately 23% of the ponds and a weak, positive correlation with rainfall prior to sampling. Variability in FCB concentrations could be related to antecedent rainfall conditions and to land use in the drainage basin. In the SCDHEC-OCRM stormwater pond efficiency study, Messersmith (2007) found that 24 hours after a rain event, FCB concentrations were elevated by about 5000% from the pre rain event concentrations. These concentrations were still significantly elevated 48 hours after the event. At Lake Edmunds source tracking found that the majority of FCB could be attributed to pet waste (Serrano, 2005). In Hilton Head, where “lagoon systems” (i.e., stormwater ponds) are common, sixteen waterbodies were monitored from 1999 to 2005 on a bi-weekly basis to identify local “hot spots.” FCB at two reporting Sea Pines Plantation sites had FCB concentrations > 1600 CFU 100 mL^{-1} 11% and 20% of the time (Skigen, 2005a; Skigen, 2005b). In Palmetto Bluff, SC, alligator FCB will be isolated to determine if there is a public health threat from these stormwater pond inhabitants. Potential human pathogens have been identified during the preliminary results of this study (Johnston, pers. comm.). Source tracking and antibiotic resistance studies in Beaufort County indicate that wildlife was a major contributor to fecal bacteria in ponds and antibiotic resistance (human source indication) was related to land cover rather than environmental factors. Both bacteria and antibiotic resistance were related to development and impervious surfaces, while rainfall effects were variable. Hydrologic models were developed and found suitable to predict stormwater pond FCB and nutrient loading to estuarine waterways. Finally, this Beaufort County study also concluded that current stormwater management practices (ponds) work well to reduce bacteria and nutrient loading except when heavy rainfall coincides with ebbing tides (Porter et al., 2005). Seiwicki et al. (2007) reported that 90% of pond and creek FCB isolates showed no antibiotic resistance and were likely from wildlife. To decrease bacterial contamination from a pond to Murrells Inlet, SC, an ultra violet (UV) treatment system was used and decreases in FCB were recorded for the two rain events measured, however more testing is needed to confirm these initial results (PBS&J, 2007).

Chemical Contaminants

In addition to nutrients, algae, and FCB, chemical contaminants are of increasing concern within stormwater ponds. Persistent concentrations of pesticides and herbicides can bioaccumulate and biomagnify, which can significantly impact organisms within the ponds and potentially organisms within the receiving waters (Serrano, 2005). Surface waters of a stormwater pond on James Island, SC, contained the pesticide contaminants atrazine, chlorothalonil, and 2,4-D (Serrano, 2005). There is a potential for contaminant loading to the receiving waters because this pond discharges directly to Kushiwah Creek and an adjacent estuary. On Kiawah Island, SC, the surface waters of ten ponds were sampled for six pesticides and herbicides every six weeks. During the spring and summer months, when application would be greatest, the concentrations were higher and were more frequently detected (USES, 2006). Common pesticides found in stormwater ponds, such as atrazine, 2,4-D, chlorothalonil, and chlorpyrifios are the most frequently used herbicides, fungicides, and insecticides for lawn care and are subsequently the most commonly found in stormwater ponds (Serrano, 2005). Also, Lee (2007) includes fipronil among common GA stormwater pond pesticides.

The ability of stormwater ponds to detain contaminants prior to stormwater discharge can be beneficial to the receiving water bodies. Daehler-Wilking (2000) reported that locating a pond between an agricultural field and marsh decreased the three-year total chemical transport to the marsh by 30%. Additionally, Cooper (2007) found that pharmaceutical concentrations decreased from the sewage treatment plant to the stormwater pond and ultimately the Kiawah River and the detected concentrations were below toxicity thresholds. Also, this study produced a database to assess the risk of pharmaceuticals and is available online at: http://www.chbr.noaa.gov/peiar (Cooper, 2007).

Hydrology

In the coastal zone, where the water table is high and the soils and sediments are sandy, it is likely that stormwater ponds influence, and are influenced by, groundwater. However, few studies have measured the hydrology of stormwater ponds, and most models have not included a hydrologic component (Elliott and Trowsdale, 2007). On Kiawah Island, SC, two stormwater ponds were studied and groundwater was found to be a potential source of high nutrient loading from detention ponds to surrounding areas. Additionally, rain events were found to have six times more runoff from a more developed site than a less developed site, indicating that the volume of runoff from more intensive development could be substantially greater (Bunker, 2004). Using this information, Strosnider (2005) designed a stormwater wetland for a golf course influenced pond, and models predicted nitrate and ammonium removal from effluent to be 92% and 74%, respectively. This model will be tested after construction. Stormwater discharge might also be related to the design configuration of the pond system and conveyance of the stormwater. On Daniel Island, SC, Messersmith (2007) reported that discharge from a single pond draining a residential area was faster than discharge from a series of five interconnected ponds. Daehler-Wilking (2000) studied groundwater flow for irrigation ponds on Wadmalaw Island and recommended separating the marsh from the pond by a groundwater divide, reducing groundwater head differences by orienting the long axis of the pond parallel to the nearest marsh, and placing drainage ditches perpendicular to ponds to reduce three year chemical transport by half.

Pollutant Removal Efficiencies

The ability of a stormwater management practice to remove pollutants before entry to receiving waters is called pollutant removal efficiency. In South Carolina, studies of this kind are lacking; however studies have been performed nationally, and the reported efficiencies are variable (Lindsey et al., 1992; Wu et al., 1996; Harper 1999; Pettersson et al., 1999, Comings et al., 2000; Mallin et al., 2002; Jeng et al., 2005). Differences can be attributed to varying pond design, sample design, land use, and how the efficiency is measured and/or calculated. For example, Mallin (2002) reported both significant increases as well as decreases in bacteria, nutrients, and chlorophyll *a* at three detention ponds with varied land use in NC. In this study, causes of event variability were found to be from differing storm dynamics and pond water conditions, and/or resuspension of sediments. Many types of birds and waterfowl utilize these ponds as a source of food and/or refuge, which could also contribute to variability in efficiencies (Mallin et al., 2002). The SCDHEC-OCRM efficiency study found that ponds could exhibit rain event variability of pollutant removal efficiencies (Messersmith, 2007). This study also found that pollutant removal efficiencies varied by rain event and pond site, with rain event removal of nutrients (–208% to 95%), FCB (–477% to 99%), and TSS (–79% to 91%) The negative removals represent higher concentrations at the pond outflow compared to the inflow and are indicative of poor pond performance. In summary, this study found that a single pond removed pollutants less effectively and had higher rain event variability than the terminal pond in a series of interconnected ponds (Messersmith 2007).

In Conway, SC, a stormwater dry pond was retrofitted with a forebay and wetland system to improve water quality in a Planned Unit Development (PUD). The pond wetland system (PWS) experienced a "first flush" response after rain events pre and post retrofit. Removal efficiencies were significantly higher following retrofit although the wetland plants had been installed for only two years. Due to a historic drought during the project period, pollutant removal efficiencies were determined for three low-volume rain events (2, 3, and 4 cm). The PWS exhibited removal of all pollutants: TSS (75 to 90%), BOD_5 (19 to 93%), nitrate plus nitrite (42 to 96%), ammonium (62 to 95%), phosphate (23 to 97%), enterococci (28 to 98%) and FCB (80 to 98%). Multiple antibiotic resistance testing indicated a mixture of pathogen sources including wildlife, pet dogs, and humans. (Libes and Bennett, 2003). This study demonstrated the effectiveness of utilizing a PWS.

Using a large number of studies (n=139) that sampled at least five rain events, employed automated flow or time based composite sampling, and documented the efficiency calculation, Schueler and Holland (2000) found the mean removal efficiencies for TN, TP, TSS, NO_x, and soluble P were 33%, 51%, 80%, 43%, 66%, respectively. As shown, the pollutant removal efficiency of stormwater ponds is highly variable. In fact, research has shown that stormwater ponds may also exhibit seasonal variations in pollutant removal efficiencies related to thermal stratification and fall turnover (Borden et al., 1998). Certain pond design factors have the potential to increase pond pollutant removal capability. Some of these factors include slowing down the rate of inflow to the pond, pipe location and angle within the pond, amount of controlled aquatic vegetation, maximizing the vegetative buffers around the pond, increasing the length to width ratio between inflow and outflow pipes, and increasing the pond area to drainage area ratio. While these factors might improve pond performance, they certainly do not guarantee success.

Sediments

Increasingly urbanized areas with greater coverage of impervious surfaces can lead to faster transport of pond sediment to the receiving waterbodies. Stormwater ponds are designed to capture, retain, and accumulate suspended sediments over time. Due to the high affinity of certain pollutants to adhere to sediment, pond sediments could contain high levels of contaminants. Some common sediment contaminants include:

- Polyaromatic hydrocarbons (PAHs)
    - Petrogenic PAHs have 2 and 3 aromatic rings and indicate a petroleum source (i.e., naphthalenes and phenanthrenes)
    - Pyrogenic PAHs have 4 and 5 aromatic rings and some can have mutagenic and carcinogenic properties (i.e., dibenz[a,h]anthracene and benzo(a)pyrene)
- Heavy metals
    - Cr, Cu, Pb, Zn, Cd, Fe, Ni, Mn
- FCB
- Algae cysts
- Pesticides/herbicides

Many animals live in and around stormwater ponds, which increases the potential for acute and sublethal toxicity effects to these organisms. The inevitable sedimentation in stormwater ponds also reduces the pond volume, pollutant residence time, and clogs inflow and outflow pipes. Failing pond embankments can allow additional sediment to enter the ponds. In the SCDHEC-OCRM efficiency study, Messersmith (2007) found a 15% and 36% decrease in pond volume in two systems that were approximately 6 and 7 years old. Pond sedimentation removal is recommended about every 10 years (Reynolds, 2005). Hazardous sediments should be disposed of at an appropriate landfill or disposal area, but if sediments are not hazardous, they can be used onsite for fill material (Hicks, pers. comm.). However, stormwater pond sediments can potentially remove more nitrogen from the system than soils on the landscape via denitrification (Drescher, 2005).

There are limited studies on stormwater pond sediment contamination in South Carolina; however, a study on Kiawah Island, SC, found that PAH levels in pond sediments and stormwater were below background levels and that concentrations did not decrease from input to output.While this appears to be positive, it is not representative of all situations. Kiawah Island's land use is primarily residential or golf, has low traffic, and a low percent of impervious cover (Flemming, 2006). Additionally, stormwater ponds draining commercial, industrial or highway sites have higher levels of contaminants than those draining primarily residential areas. While initial concentrations might be relatively low, as ponds age they can accumulate sediment. Bishop et al. (2000) found that Pb, Zn, Cu, and total PAHs increased in sediments with increasing pond age.

Contaminated pond sediments can have adverse biological impacts as well. At Kiawah Island, SC, the brackish water mussel, *M. leucophaeata*, was identified as a promising indicator organism because the PAH concentrations bioaccumulate within the mussel, thereby providing a better indicator for long-term toxicity (Flemming, 2006). In one study in Ontario, Canada, sediment toxicity negatively affected hatching success and survival of northern leopard frog eggs and larvae (Bishop et al., 2000). In Florida, red ear sunfish (bottom-feeding), largemouth bass (predators) and bluegill sunfish (omnivores) in stormwater ponds had higher metal levels than controls (Campbell, 1994). In Maryland, aquatic invertebrates from ponds in recently developed urban areas contained higher levels of zinc and copper contamination than those from commercial areas; however, concentrations were below levels that were reported to be harmful to fish (Karouna-Renier and Sparling, 2001). Marsalek et al. (2002) found that while pond sediments were contaminated with PAHs and metals, benthic toxicity tests indicated that there was a low impact to the nearby river. However, Van Dolah et al. (2004) reported degraded water quality in creeks containing suburban detention ponds in their watershed.

Regionally, an ongoing study in Georgia is investigating organic and inorganic sediment contaminants from thirty coastal ponds to determine the potential biological effects in ponds and nearby estuaries as related to land use (Lee, 2007). Also, SCDHEC-OCRM is partnering with SC Sea Grant Consortium to determine the sediment contamination levels in 16 of SCDHEC-OCRM's baseline study stormwater ponds and quantify the associated risks to wildlife and human health. This study will provide researchers and stormwater managers with data to more effectively understand pond sediment contamination (Weinstein and Crawford, 2007).

Modeling

In accordance with regulatory measures, engineers and planners use models to predict stormwater movement on site and plan stormwater conveyance and control measures so that flooding is minimized and downstream water quality is protected. The following is a list of commonly used software modeling programs:

- Storm Water Management Model (SWMM) (http://www.ccee.orst.edu/swmm/)
- Hydrologic Simulation Program-Fortran (HSPF) (http://water.usgs.gov/software/hspf.html)

- Water Quality Analysis Simulation Program (WASP5) (http://www.epa.gov/athens/wwqtsc/WASP.pdf)
- Source Loading and Management Model (SLAMM) (http://rpitt.eng.ua.edu/Publications/Stormwater%20Management%20and%20Modeling/SLAMM%20chapter%20Pitt%20and%20Voorhees%202002.pdf)
- winDETPOND (www.winslamm.com)
- Advanced Interconnected Channel and Pond Routing (AdICPR) (Streamline Technologies, Inc.)
- Integrated Design and Evaluation Assessment of Loadings (IDEAL) (http://www.forester.net/sw_0309_model.html)
- Hydraflow (Intelisolve)
- PondPack (Bentley Systems, Inc.)
- SedCAD (Civil Software Design)

These models can serve as strong predictive and quantitative tools for managers and researchers. However, model validations are often lacking and should be carried out to determine their applicability. Standard practices for modeling of detention ponds focus on sedimentation as the primary means for pollutant removal. However, Borden et al. (1998) demonstrated that many pollutants were not closely correlated with sediment concentrations, and that a process other than sedimentation was the primary pollutant removal mechanism. Furthermore, a shift from a water quantity focus to a water quality focus will help protect our economically and ecologically viable estuaries and can be accomplished through use of models that focus on nutrient and sediment removal instead of water volume alone (Messersmith, 2007). The current focus of stormwater management is on a site-by-site basis; however, there is extensive research that recommends managing runoff on a watershed-scale basis.

A project that tested the pond design and performance using *Drain:Hydro 2.0* to compare simulated results with accepted professional programs found that current practices were not sufficient to control flooding and protect channel erosion. The study recommendation to focus on more frequent, shorter duration storm events because they are major annual runoff and sediment load contributors compared to larger, infrequent events and supported recommendations from the SCDHEC-OCRM efficiency study (Huda, 2007). Specifically, Huda (2007) suggests designing ponds based around the 1-year 24-hour stormwater control.

Next Generation Radar (NEXRAD) is a Doppler-based estimation of rainfall and wind available from NOAA (National Weather Service, Radar Operations Center). The NEXRAD predicted rainfall information has proven to be a reliable and useful tool to estimate rain events for stormwater ponds at Palmetto Bluff, SC (White et al., 2004). This technology in conjunction with historical monitoring data, automated stormwater sampling, and water quality indicator measurements show promise for increasing real-time prediction and effective management of stormwater detention ponds (White et al., 2004).

Social Sciences

Few studies have examined human uses, economic implications, or perceptions regarding stormwater ponds and other stormwater management practices in this region. However, an ongoing study has begun to examine differing perceptions of cost (construction and maintenance), effectiveness, and regulatory challenges related to a range of stormwater management practices and across three general groups: the management community, developers, and other stakeholders (Martin, 2006). Initial results suggest that professionals from all groups believe there is a strong need for more applied research on the efficiency and performance of various stormwater practices. In addition, most developers, engineers, and other private sector stormwater professionals were either undecided or did not feel that there was enough research and information available to know whether innovative technologies and/or Low Impact Development practices were more effective and more cost effective than more traditional approaches, including stormwater ponds, in the long term. Many regulators and managers indicated that barriers to implementing LID technologies included a lack of research and the inability of many LID practices to meet the stormwater regulations (i.e., the first-flush test and pre- and post-development discharge rates). Study participants also identified difficulties in implementing innovative stormwater practices due to the time it takes to get new practices permitted. However, most participants interviewed agreed that there is a need for new approaches to stormwater management.

In addition to water quality and quantity treatment, stormwater ponds can increase property values and attract or provide for a variety of alternative uses such as:

- Recreational activities
    - Boating
    - Fishing
    - Crabbing
    - Swimming;
- Enhanced aesthetics;
- Wildlife habitat; and
- Irrigation for golf courses and residential landscaping (Figures 1 and 2).

In fact, many residential ponds have landscaped areas, trails, benches, gazebos, and/or bridges to promote their use, and real estate listings often refer to stormwater ponds as "lagoons" and adjacent properties as "waterfront." However, in some areas, signs prohibit recreational activities such as swimming and fishing. Overall, public knowledge of the intended functions and maintenance histories of stormwater ponds is poor (personal observations). However, in areas where stormwater ponds have been considered nuisances (i.e., fish kills, algae blooms, bank erosion, and "filling in"), homeowners, business owners, and other responsible parties are often unsure how to appropriately manage existing ponds.

Some studies have included surveys to assess community awareness, such as a study of a residential subdivision pond in Charleston, SC, where intensive monitoring was coupled with education and outreach that included: 1) awareness of water quality conditions; 2) management strategy recommendations; and 3) mitigation activities (Serrano, 2005). Serrano (2005) determined that the majority of residents use the lake for boating and fishing and that only 23% of the homeowners were aware that algal blooms develop within the lake. Only 11% of the properties surrounding the lake possessed vegetative buffers between the backyard and the lake; however, almost half the residents were conscientious of water quality issues and willing to change their land-use practices. Many groups (i.e., HOAs, the Cub Scouts, and high school students) were included in outreach and education programs focused on water quality and the benefits of vegetative buffers (Serrano, 2005).

Highlighted Future Projects

- In North Charleston, SC, a project will test LID stormwater management BMPs of a new LID (Oak Terrace Preserve), where before-and-after data will determine if the design BMPs are efficient at maintaining pre-development flow rates and effectively filtering/removing NPS pollutants at the small watershed scale. This project will also analyze the non-technical aspects of LID practices (design criteria, economic comparison, regulatory conflicts, maintenance through homeowner education) (SC Sea Grant Consortium, 2007; Vandiver, pers. comm.).
- This year, SCDHEC-OCRM and the SC Sea Grant Consortium will sponsor sediment contamination work in a subset of the ponds sampled in the water quality baseline study (Weinstein and Crawford, 2007).
- Another study this year will focus on stormwater pond's potential public and environmental health risks in Beaufort and Charleston counties by using models that include chemical contaminant and biological loadings as well as existing data sets (Porter, pers. comm.).
- Pond morphology and vertical water quality are being investigated to determine characteristics that contribute to poor water quality and fish and benthic animal kills in stormwater ponds located in Kiawah Island, SC (Joe Kelley, pers. comm.).
- Historic storm event data analysis and runoff modeling using Soil Conservation Service-Curve Number (SCS-CN) are being conducted and compared to long term observed event flow data from the Turkey Creek Watershed at the USDA Forest Service Santee Experimental Forest in SC, to determine the accuracy of the model in predicting event outflow and peak flow rates (Amatya and La Torre-Torres, and Callahan pers. comm.).
- The hydrologic interaction between surface and groundwater, the feasibility of SCS-CN for rainfall-runoff estimates in shallow water table landscapes, and the feasibility of using LID stormwater management practices in these areas will be studied at a proposed development site, Bannockburn Plantation, near Georgetown, SC. Related research is anticipated to aid in the development of stormwater management recommendations and tools for coastal watersheds that are undergoing significant land-use change (Hitchcock and Williams, 2007).

Education and Outreach Activities

The following are examples of stormwater outreach/extension programs in coastal SC:

1) South Carolina Home-A-Syst (Homestead Assessment System) - helps homeowners identify ways to improve their practices;
2) Clemson's Carolina Clear Program – a broad water quality program;
3) National Estuarine Research Reserve System (NERRS) Coastal Training Programs – host training sessions;
4) SC's Non-point Education for Municipal Officials program (SC NEMO) – an in-depth training for local decision-makers to understand the impacts of stormwater and ways to manage those impacts (SCDHEC, 2007);
5) Coastal Waccamaw Stormwater Education Consortium - a regional group of education providers and community representatives that "aims to help citizens understand stormwater issues and preserve the quality of the water resources in coastal northeastern SC" (Coastal Carolina University, 2007); and
6) Public outreach and education programs have been developed in select Municipal Separate Storm Sewer Systems (MS4) communities to comply with the National Pollution Discharge Elimination (NPDES) Phase II requirements.

Research and Information Needs

Stormwater pond research efforts in South Carolina have begun to answer a number of important questions; however, key research issues remain. During the first meeting of the Stormwater Pond Research Initiative (described p. 4), data gaps and research priorities were identified as follows:

- How many stormwater ponds exist in the SC coastal zone, what is their cumulative volume/coverage, and at what rate are they expanding?
  - Is there a need to classify stormwater ponds according to size, land use, type, etc.?
- What stormwater pretreatment procedures are most effective?
- What are common pond maintenance practices, and how do they affect pond structure and function?
- What are the impacts to receiving waters from stormwater pond discharges?
- How fast are stormwater ponds "filling in," and what is the level of sediment contamination? How often is sediment removed from ponds? Where is the removed sediment placed/disposed?
- What water quality indicators and levels may indicate impaired pond conditions, or potential pollution sources for receiving waters?

- Would other stormwater pond design criteria (i.e., other than 2-year and 10-year rain events) better protect water quality and control water quantity (flooding)?
    - Are designed storm events (2- and 10-year rain events) reducing peak rates of flow to pre-development conditions? Are pre-development runoff rates accurate for SC's low topography?
    - What is the performance of stormwater ponds during small, frequent rain events versus large, infrequent rain events?
- Which stormwater hydrologic model is most applicable in coastal SC?
    - Which of the commonly used models have been validated for coastal SC?
- What public and environmental health risks might stormwater ponds pose?
- How can education and outreach to local governments and homeowners be improved?
- What are the economic costs and benefits of a stormwater pond? What are the comparative costs and benefits of more innovative stormwater management practices?

Management Implications

Stormwater ponds are an increasingly prominent feature on South Carolina's coastal landscape and there is a need to better understand cumulative impacts of this stormwater management practice. Continuing inspections of stormwater systems should be a priority, as ponds that are not maintained are not likely to provide intended water quality and flood reduction services (Lopez, 2003; Wahl, 2007). The extent and significance of failing stormwater systems is largely unknown and should be investigated.

While stormwater ponds are not specifically required, they are the most prominent tools used in stormwater management. Table 1 (next page) lists examples of structural (associated physical structures) and non-structural (no associated physical structures) management practices that control pollutant movement, prevent degradation of soil and water resources, and are compatible with land use (SCDHEC, 2005; SCDHEC-OCRM, 2007). SCDHEC encourages development and testing of innovative (i.e., LID) stormwater management practices. The USEPA (http://www.epa.gov/waterscience/guide/stormwater/), International Stormwater Best Management Practices Database (http://www.bmpdatabase.org/), and the University of New Hampshire Stormwater Center 2005 Data Report (http://ciceet.unh.edu/news/releases/stormwater_report_05/) have additional information on alternative stormwater management approaches.

Stormwater Management Practices	
Structural	**Non-Structural**
Wet Detention Ponds	Vegetative conveyance systems
Dry Detention Ponds	Stream buffers
Underground Detention Systems	Disconnected rooftops to pervious areas
Stormwater Wetlands	Cluster development
Bioretention Areas	Natural infiltration
Infiltration Trench	
Enhanced Grassed Swales	
Pre-Fabricated Control Devices	
Vegetated Filter Strips	
Grass Paving and Porous Paving Surfaces	

Table 1. Structural and non-structural better stormwater management practices (SCDHEC, 2005).

All of these stormwater management practices (Table 1) reduce or store runoff, promote pollutant removal through biological uptake, and/or remove sediments (SCDHEC, 2003). Since some stormwater ponds may have unintended negative effects, innovative management practices should be emphasized and encouraged, or incentives should be developed through future permits or regulations. Further study is needed to assess the viability and effectiveness of innovative stormwater management practices such as LID practices. Additionally, education and outreach programs (i.e., SC NEMO and Clemson Extension Program) should be supported, because one of the best ways to control pollution is to limit it at its source. Finally, the general public should be educated so that these stormwater ponds are not considered natural lakes and are known to collect polluted stormwater runoff.

The Council on Coastal Futures, a group composed of diverse membership representing environmental, scientific, government and business interests, was tasked by the Board of Health and Environmental Control to document priority issues and concerns relating to coastal zone management. The council agreed on a list of the "highest priorities," which included improving local and state stormwater management. The following are a list of specific stormwater-related recommendations (SCDHEC, 2004b):

- Improve water quality by managing stormwater on a watershed basis.
- Allow and encourage innovative stormwater management practices and standards.
    - Provide allowances for innovative stormwater approaches beyond the stated performance standards.
    - Develop a process to allow and encourage installing innovative stormwater management practices as well as research into their efficiency.

    - In order to minimize stormwater infrastructure installation and repair costs, encourage vegetative options for conveyance and treatment where possible.
    - SCDHEC-OCRM should require new detention ponds to be designed and constructed with vegetated areas unless other non-vegetative methods prove to be more effective at removing pollutants.

- SCDHEC-OCRM should research the current use, feasibility, economic impact and projected effectiveness of implementing a pollutant (i.e., nutrients and bacteria) removal efficiency standard for new stormwater management systems.
- Develop a strategy and guidance to maintain, monitor, inspect, and provide education for stormwater management practices.
- Establish formal partnerships between SCDHEC-OCRM and state research institutions.

As the South Carolina coastal zone experiences increasing development pressures, improved stormwater management will prove to be an integral tool in addressing the associated ecological impacts. The "State of the Knowledge" of stormwater ponds is still evolving through the joint research and outreach efforts of SCDHEC-OCRM, SC Sea Grant, and other state and federal agencies, academic institutions, and non-profit organizations. Based on existing research, stormwater ponds are known to reduce local flooding and protect receiving waters from pollution in stormwater runoff; however, they can also accumulate nutrients, bacteria, and chemical contaminants resulting in poor pond water quality and potential threats to receiving waters. The pollution extent and impacts to receiving waters is largely unknown and future studies should assess this management concern. The influences of pond designs and other characteristics on performance also remain unclear. As development pressures increase, LID practices could prove to be an essential component of stormwater management; however, their functionality in this state's low-lying areas with high water tables must be addressed, and since these practices rely on infiltration, their effects on groundwater should also be studied. While stormwater ponds are successful stormwater management practices in many locations, they may not be ideal for every situation.

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Appendix A

Design criteria for wet detention ponds (SCDHEC, 2005).

Wet detention design criteria that increase pollutant removal efficiency include the following:

1. **Permanent wet pool** – A permanent wet pool is a design criterion that has the greatest effect on water quality. To achieve moderate to high runoff pollutant rates, the permanent pool volume is equal to 1-inch of runoff per impervious acre on the site. For water quality treatment, the recommended average depth is 4 to 6 feet, which decreases the amount of sediment re-suspension when runoff enters the pond.
2. **Temporary pool or overlaying zone** – A temporary pool is located above the stormwater pond and controls water quality volume. Detention time can be increased by releasing water through a low flow orifice.
3. **Aquatic bench** – An aquatic bench is a vegetated area inside the stormwater pond that serves to improve water quality and stabilize side slopes.
4. **Forebay** – A forebay is upstream and separate from the stormwater pond. Forebays trap the coarse fraction of suspended solids in runoff before entering the stormwater pond.
5. **Flow length** – Maximum stormwater pond water quality benefits are achieved when the flow length to flow width is 3:1 and a minimum ratio of 1.5:1 is suggested.
6. **Low flow orifice** – A low flow orifice is a structure that slowly releases runoff over time for water quality volume control.
7. **Emergency spillway** - Emergency spillways are designed to pass the post-development 100-year 24-hour storm event without topping dam structures. The 100-year water surface elevation should be at least 1 foot below the embankment top.

Appendix B

South Carolina's Coastal Zone Management Program: Laws and Regulations

By the late 1980s and early 1990s, amendments to the federal Clean Water Act (CWA) (33 U.S.C.1251 et seq.) and Coastal Zone Management Act (16 U.S.C. §1451 et seq.) symbolized a shift in regulatory focus from "point source," industry-related pollution discharges, to "non-point source" pollution associated with runoff from expanding agricultural and residential areas (Boesch et al., 2001). The Federal Coastal Zone Management Act (CZMA) in 1972, and subsequent SC Coastal Zone Management Act in 1977, resulted in the formation of SC's Coastal Zone Management Program with the authority to regulate land-disturbing projects in the Coastal Zone (eight coastal counties) under the following state and federal legislation:

1. <u>Clean Water Act (33 U.S.C. 1251 et seq.) and the SC Pollution Control Act (S.C. Code Ann. 48-1-10 et. seq.)</u>
   SC regulatory provisions contained in R.61-9.122 and 124 implement the National Pollutant Discharge Elimination System (NPDES) Program under sections 318, 402, and 405 of the federal CWA and the SC Pollution Control Act (1987) and established SCDHEC as the state agency responsible for protecting SC's environment where S.C. Code Ann. 48-1-10, et seq. requires permits for sediment runoff into state waters.

2. <u>SC Coastal Management Program (SCCMP), 1979, and Program Refinements, 1993</u>
   Established more stringent requirements for development projects near receiving waterbodies and shellfish beds, bridge runoff, golf course runoff, mines, landfills, and other activities with potential for significant impact.

3. <u>Stormwater Management and Sediment Reduction Act of 1991</u>
   - SC Code Ann. Section 48-14-10 *et seq.* (supp. 2001), enacted the SC Stormwater Management and Sediment Control Act and provided penalties for violations
   - SC Code Ann. Regulations 72-300 *et seq.* (supp. 2001)
     - Erosion and Sediment Reduction and Stormwater Management Regulations (R.72-101): *"These regulations set forth requirements for erosion and sediment control and stormwater management measures to be used on state land to prevent damage to land, water and property from erosion, sediment and stormwater*."
     - Standards for Stormwater Management and Sediment Reduction Act of 1991 (R.72-300): "*Stormwater runoff is a source of pollution of waters of the State, and may add to existing flooding problems. The implementation of a statewide stormwater management and sediment control program will help prevent additional water quantity and quality problems and may reduce existing problems."*
     - Amendment to 48-18-70, Standards for Stormwater Management and Sediment Reduction (R. 72-405): "*Apply to activities by the SC Department of Transportation that relate to highway construction, encroachment permit or easement, or right-of-way work."*

Appendix B Continued

South Carolina's Coastal Zone Management Program: Laws and Regulations

4. <u>The National Pollutant Discharge Elimination System (NPDES)</u>
   The Phase I stormwater program was established under the Clean Water Act (1990) and included the Phase I Construction General Permit (CGP) and Phase I municipal separate storm sewer systems (MS4s), which encompasses populations ≥ 100,000. In 2006, implementation of NPDES Phase II (including Phase II CGP and Phase II MS4s) merged state and federal permit guidelines. The NPDES Phase II program extends permit coverage to smaller MS4 communities and public entities. The NPDES Phase II CGP addresses impacts to navigable waterways and impaired waterbodies (i.e., 303d listed waters). Furthermore, the permit requires a stormwater pollution prevention plan (SWPPP) and a notice of intent (NOI), which is followed by a review period and SC Regulation 61-9 conditions are applied to all NPDES permits (SCDHEC, 2004a; SCDHEC, 2006; SCDHEC, Retrieved 2007).

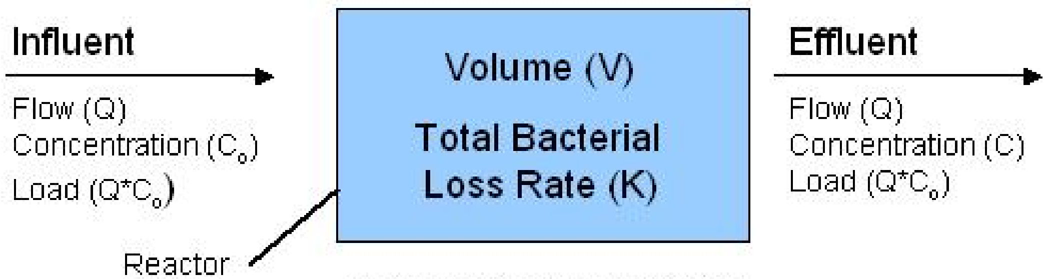
"The NPDES program requires permits for the discharge of 'pollutants' from any 'point source' and into 'waters of the United States'" and has provisions used by to determine what requirements must be placed in permits, if issued (SCDHEC, 2004a).

Appendix C

Bacteria model for wet detention ponds taken from Thomas & Hutton Engineering Co., 2001.

Bacteria Model for Wet Detention Ponds

Thomas & Hutton Engineering Co, Ralph A. Lopez, PE, DEE — January 2001



<u>Materials-Balance Equation</u>

Steady-State Solution to the Materials-Balance Equation for a Complete-Mix Reactor

$$\boxed{C = Q*C_o/(Q+K*V)}$$

Average daily effluent concentration (C) is a function of:
- Average daily influent load ($Q*C_o$)
- Reactor (permanent pool) volume (V)
- Reactor total bacterial loss rate (K)

$Q*C_o$ — Average daily influent load $Q*C_o$ is a function of:
- Average influent bacteria concentration Co
- Average daily flow Q, which is a function of:
  - Total 3-month precipitation per 90 days
  - Drainage area
  - Seasonal runoff coefficient

V — Reactor (permanent pool) volume (V) is a function of:
- Surface area at normal water level
- Average water depth

K — Total bacterial loss rate K is composed of three separate mechanisms such that $K = k_1 + k_2 + k_3$ (see Note).

k_1 — Base mortality rate k_1 is a function of:
- Salinity
- Water temperature

k_2 — Loss rate due to solar radiation k_2 is a function of:
- Average daily solar radiation
- Suspended solids concentration in reactor
- Average water depth

k_3 — Settling loss rate k_3 is a function of:
- Fraction of bacteria attached to suspended solids
- Settling velocity of suspended solids
- Average water depth

Note — For computation of bacterial loss rates, see "Chapra, S.C. 1997 <u>Surface Water-Quality Modeling</u>. McGraw-Hill, New York."