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16. Abstract

The Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act) requires states to monitor bacteria levels in recreational coastal waters. High levels of bacteria increase the potential for many illnesses to beach goers, so coastal towns are forced to post advisories or close beaches after many rainfall events, which potentially decrease tourism profits. Stormwater outfalls, common in many coastal towns, empty stormwater from roads, parking lots, etc., contaminated with bacteria and other pollutants, into the ocean or sounds.

The NC Department of Transportation and the Town of Kure Beach wanted to reduce the amount of stormwater from nearby US 421 and other residential and commercial sites from entering ocean recreational areas. Two stormwater Dune Infiltration Systems were designed to divert a portion of the flow into the beach dunes. Sand filters have historically been successful in bacterial removal. The infiltration systems were constructed using commercially available open-bottomed infiltration chambers. Due to limited land area, the systems were designed to infiltrate 0.5 in storms, which comprise approximately 80% of the rainfall events at the site. The watersheds of both sites were small (4.5 ac and 8.1 ac) and of mixed urban and residential land use. Water table measurements indicated a tidal influence, but approximately 7 ft of sand was available for infiltration in the vertical direction.

Overall, the two Dune Infiltration Systems (DIS) captured 96.6% of runoff produced from 25 storm events during March - October 2006. Inflowing stormwater runoff had concentrations of fecal coliform concentrations ranging from 181 CFU/100 ml to 28300 CFU/100 ml with a median of 7600 CFU/100 ml, and enterococcus concentrations from <10 CFU/100 ml to >2005 CFU/100 ml with a median of 1298 CFU/100 ml. The groundwater concentrations were significantly less ($p < 0.001$) than the inflow with fecal coliform concentrations ranging from <1 CFU/100 ml to 214 CFU/100 ml with a median of 1.5 CFU/100 ml. For enterococcus concentrations the range was from <10 CFU/100 ml to 2005 CFU/100 ml with a median of 10 CFU/100 ml. The groundwater enterococcus concentrations at both sites were also significantly ($p<0.01$) less than the stormwater runoff inflow concentration. North Carolina's indicator bacteria standards were exceeded only in Site M's groundwater. Groundwater samples surpassed the limit on 2 of the 25 events for fecal coliform and 6 of the 22 for enterococcus. Based on these results, the DIS has potential as an effective BMP at the remaining ocean outfalls in Kure Beach and elsewhere.

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Kure Beach Dune Infiltration System

Submitted by:
Michael R. Burchell II, Ph.D[1]., William F. Hunt III, Ph.D., P.E.[1]
and Tiffany M. Bright[2]

[1] Assistant Professor [2]Graduate Research Assistant

North Carolina State University
Department of Biological and Agricultural Engineering
Campus Box 7625, Raleigh, NC, 27695

For the North Carolina Department of Transportation
Research and Analysis Group
Raleigh, NC 27699-1549

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Executive Summary

The Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act) requires states to monitor bacteria levels in recreational coastal waters. High levels of bacteria increase the potential for many illnesses to beach goers, so coastal towns are forced to post advisories or close beaches after many rainfall events, which potentially decrease tourism profits. Stormwater outfalls, common in many coastal towns, empty stormwater from roads, parking lots, etc., contaminated with bacteria and other pollutants, into the ocean or sounds.

The NC Department of Transportation and the Town of Kure Beach wanted to reduce the amount of stormwater from nearby US 421 and other residential and commercial sites from entering ocean recreational areas. Two stormwater Dune Infiltration Systems (DISs) were designed to divert a portion of the flow into the beach dunes. Sand filters have historically been successful in bacterial removal. The infiltration systems were constructed using commercially available open-bottomed infiltration chambers. Due to limited land area, the systems were designed to infiltrate 0.5 in storms, which comprise approximately 80% of the rainfall events at the site. The watersheds of both sites were small (4.5 ac and 8.1 ac) and of mixed urban and residential land use. Water table measurements indicated a tidal influence, but approximately 7 ft of sand was available for infiltration in the vertical direction.

Data were collected from twenty-five storms during the months of March through October 2006 to determine the Dune Infiltration System's viability as a BMP. From those 25 storms, Site L's Dune Infiltration System captured total volume of 23,272 ft^3 of stormwater runoff, allowing no runoff to bypass. Site M's Dune Infiltration System capacity was exceeded during only 5 of the storms, capturing a total stormwater runoff volume of 82,486 ft^3 of the total 85,986 ft^3. At both sites, the Dune Infiltration Systems significantly ($p < 0.01$) reduced runoff volume and peak flow discharging directly onto the beach. Overall, the two systems captured 97% of runoff from the two watersheds during the study period. Routing the stormwater runoff through the sand beneath the dune and into groundwater below did not cause a significant increase fluctuations in the groundwater ($p<0.05$).

Bacteria concentrations in the stormwater runoff flowing into the Dune Infiltration System from both outfalls ranged from 181 CFU/100 ml to 28,300 CFU/100 ml with a median of 7600 CFU/100 ml for fecal coliform and from <10 CFU/100 ml to >2005 CFU/100 ml with a median of 1298 CFU/100 ml for enterococcus. The groundwater bacteria concentrations were significantly ($p<0.01$) lower than those of the stormwater inflow, ranging from <1 CFU/100 ml to 214 CFU/100 ml with a median of 1.5 CFU/100 ml for fecal coliform and from <10 CFU/100 ml to 2005 CFU/100 ml with a median of 10 CFU/100 ml for enterococcus. Groundwater bacteria levels at Site L never exceeded North Carolina state's standard; whereas levels were exceeded in 2 of 25 groundwater samples for fecal coliform and 6 of 22 groundwater samples for enterococcus from Site M. The samples that exceeded the standards were towards the end of the study and associated with relatively large runoff volumes.

The Dune Infiltration System's viability as a stormwater BMP requires continued research. However initial results are promising. The Dune Infiltration Systems did reduce the amount and rate of stormwater directly discharging into the ocean, while maintaining groundwater hydrology. Specifically, more research is needed to better understand the Dune Infiltration System's bacteria removal efficiency. The relationship between infiltration rate to bacteria removal needs to be evaluated when designing the Dune Infiltration System and developing a maintenance schedule. In addition, public acceptance and permitting by the NC Division of Coastal Management must be addressed before more systems are installed.

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1.0 INTRODUCTION

Coastal areas, which comprise only 17 percent of the land area in the United States, are host to over 50 percent of the total U.S. population. According to the Natural Resource Defense Council (NRDC), the coastal population grew by 37 million people between 1970 and 2000, and by 2015 is projected to increase by another 21 million (Dorfman, 2004). Urban development increases stormwater runoff, while limiting the amount of available land that can be used to treat the stormwater. Stormwater runoff may contain pollutants such as hydrocarbons, nutrients, metals, bacteria, pathogens, and sediment. To control the amount of bacteria entering the ocean, the US Congress passed the Beach Environment Assessment and Coastal Health Act (BEACH Act), which required states to monitor bacteria levels in recreational coastal waters and to post advisories of closures if a state's bacteria standards are exceeded. The bacteria standard was initially fecal coliform, but many coastal states are now choosing enterococcus per EPA recommendations.

North Carolina spends approximately $550,000 annually to operate the water quality monitoring program for its coastal recreational waters to protect the public safety of its residents and the more than 6.5 million tourists that travel to the state's beaches each year. Although these beaches are being monitored, they are still threatened by pollution from agricultural, septic system, and development runoff (Dorfman 2004).

Baker *et al.* (2005) conducted a study using data from two California beaches, Newport and Huntington, to estimate the economic impact of illnesses associated with polluted recreational waters. It was found that recreational swimming at these two beaches cost the public $3 million per year in health related expenses. Another negative affect of stormwater contamination is the loss of income associated with tourism. According to the U.S Environmental Protection Agency 2000 Liquid Assets Report, $44 billion dollars were spent on coastal tourism in that year (USEPA 2000). National Resource Defense Council's 2004 Testing the Waters Report indicated that there were 2,635 beach closures and advisories in the U.S. due to increased ocean bacterial levels associated with stormwater runoff. In 2004, North Carolina had 555 beach closures or advisories, which equates to twenty percent of the U.S closures (Potts 2005). As North Carolina's coastal population continues to increase, stormwater must be mitigated to reduce the potential of human exposure to bacteria and other pathogens in order to prevent the more serious problems that have been documented on the west coast.

The Town of Kure Beach is located in New Hanover County, south of Wilmington, North Carolina. The North Carolina Department of Transportation (NCDOT) and the Town of Kure Beach sought a technology to reduce the amount of runoff entering Kure Beach's recreational swimming areas. Stormwater outfalls, common in many coastal towns, discharge stormwater and associated bacteria and pollutants directly into the ocean. Greenberg (1956), Carlucci and Pramer (1959) and Mitchell (1968) concluded that die-off of coliforms in marine waters is a fairly rapid event that is controlled by a variety of factors, including toxicity due to high salt concentrations, predation, competition by native microflora, heavy metals, and limited nutrient supply. Typical die-off curves for *Escherichia coli* (*E. coli*) in seawater show an initial lag phase followed by a mortality of up to 90% in 3 to 5 days (Gerba and McLeod 1975). Even though bacteria will eventually die-off, they do pose a threat initially if stormwater discharges into swimming areas. Thus, after rain events if the bacteria count exceeds states' standards, communities must temporarily post advisories or close beaches.

In order to capture stormwater runoff, decreasing the public's contact with bacteria, a Dune Infiltration System (DIS) was designed and implemented to demonstrate and research the potential of the system's technology to treat small to mid-sized rainfall events that frequently occur along the North Carolina coast.

2.0 LITERATURE REVIEW

2.1 GOVERNMENT'S ROLE IN COASTAL WATER QUALITY

The Clean Water Act (CWA) has established regulatory pollutant standards in the United States. The CWA established enforceable water quality standards for contaminants in surface waters and recognized the need to address the problems posed by non-point source pollution. This also gave the EPA the authority to employ pollution control programs (US EPA 2006b).

Beginning in the late 1980s, efforts to address polluted runoff have increased substantially. Evolution of CWA programs over the last decade has also included a shift from a program-by-program, source-by-source, pollutant-by-pollutant approach to more comprehensive watershed-based strategies. In this approach, equal resources are devoted to both protecting healthy waters and restoring impaired ones. A full array of issues are addressed, not just those subject to CWA regulatory authority (US EPA 2003). One example is the safety of coastal waters for swimming and recreational activities. To protect coastal recreation waters, the EPA has published scientifically justified limits for a range of pollutants in coastal waters, known as the protective criteria for coastal waters. Individual states are responsible for writing their own legal standards for pollutants and adopting the protective criteria, pending EPA approval. The states can do this by: (1) adopting the EPA's recommended criteria, (2) modifying the EPA's recommended criteria to reflect site-specific conditions, or (3) adopting criteria that are as protective as the EPA's recommendation based on scientific methods (US EPA 2006a).

As of 2000, many states had not adopted the recommended federal bacteria criteria for monitoring *E. coli* and/or enterococcus bacteria levels. In response, Congress passed the Beach Environment Assessment and Coastal Health (BEACH) Act in October 2000, giving states until April 2004 to adopt protective bacteria criteria into their state standards. For states that did not meet the deadline, Congress required EPA to issue federal standards to ensure national protection (US EPA 2006a). The EPA's published standards include a geometric mean value for multiple samples taken over 30 days and an instantaneous single sample value. Based on these measures, local authorities should issue beach closings or advisories if either standard is exceeded. Many states, only use one measure, either the geometric mean or the single maximum. North Carolina's standard is currently a single maximum of enterococci (Potts 2005).

2.2 Coastal Microorganism Contamination

2.2.1 Pathogens in polluted waters

While the BEACH Act established bacterial concentration standards to protect coastal recreational waters, these standards may not be enough to ensure swimmer safety. A recent study by Griffin *et al.* (2003) concluded, "…a majority of pathogens responsible for outbreaks of human illnesses acquired from marine recreational exposure have not been identified."

Polluted waters may contain several different types of disease causing pathogens, specifically bacteria, virus, and protozoa. According to the Natural Resources Defense Council (NRDC 2004), 88% of beach closing and advisories in 2003 were due to detected bacteria levels that exceed recreational coastal waters standards. Six percent were from precautionary warnings due to rainfall known to carry pollution to swimming water and 4% were in response sewage treatment plant failure and breaks in sewage pipes, both of these causes polluting the water with bacteria and virus pathogens. The last 2% were due to dredging problems and algal blooms.

2.2.1.1 Viral and Bacterial Coastal Pathogens

Research has shown that fecal-oral viral pathogens present various health concerns. Ocean goers exposed to bacteria-enriched recreational waters have symptoms ranging from asymptomatic to severe gastrointestinal, respiratory, and eye, nose, ear, and skin infections. The two most common fecal-oral viral pathogens are adenoviruses and Norwalk viruses. Adenoviruses are commonly found in wastewater-impacted marine environments and can cause acute upper respiratory tract infections as well as ocular and gastrointestinal infections. Norwalk-like viruses (small round structured viruses [SRSV]) are a major cause of shellfish-associated disease and may be the most significant cause of adult viral gastroenteritis (Griffin *et al.,* 2003). Other microbial bacteria diseases that can be contracted by swimmers include salmonellosis, shigellosis, and infection caused by *E. coli* (Dorfman 2005).

One of the primary concerns of public health officials is the relationship between the presence of pathogens and the recreational risk to human health in polluted marine environments. While a number of studies have attempted to address this issue, the relationship is still poorly understood. A contributing factor to the slow progress in the field has been the lack of methods sensitive enough to detect the broad range of both bacterial and viral pathogens (Griffen *et al*. 2003).

2.2.1.2 Other Coastal Pathogens

Phytoplankton are microscopic plants that form the base of the marine food web. Sixty-three of the thousands of species of phytoplankton are known to be toxic to animals. High concentrations of phosphorus and nitrogen that enter the ocean via sewage discharge or stormwater, artificially stimulate phytoplankton population. The result is rampant multiplication with resultant blooms that can last for days or months. Depending on the type of toxic organism, ocean swimmers exposed to the toxic algae can experience illnesses ranging from respiratory problems and eye irritation to neurotoxic poisoning that can cause short-term memory loss, dizziness, muscular aches, peripheral tingling, vomiting, and abdominal pain (Bushaw-Newton and Sellner 1999).

Although the most common consumer health impact of toxic blooms arises from eating contaminated shellfish, there are numerous instances, which such blooms have directly affected fishermen, swimmers and other recreational users of nearshore marine and riverine waters. Toxic outbreaks of such organisms as *Pfiesteria piscicida,* which was first discovered in North Carolina in 1991, have been found to be associated with fish kills and with skin and neurological damage as well as memory loss (Trainer 2002). Red-tide algal blooms of *Gymnodinium brevii* affected beaches of North Carolina in 1987 and 1988 (Tester *et al.* 1991).

2.2.2 INDICATOR BACTERIA

Research studies conducted during the past few decades demonstrate a strong relationship between the amount of indicator bacteria in coastal water and the incidence of swimming-associated illnesses. Common indicator bacteria are total and fecal coliform, enterococcus, and *E. coli*; the latter two being the most common. *E. coli* is defined as "gram-negative, facultative anaerobic, nonspore-forming bacillus commonly found in the intestinal tracts of humans and other warm-blooded animals…*Escherichia coli* is considered the primary indicator of recent fecal pollution" (Symons and Bradley 2001). *Enterococcus* genus is defined by North Carolina Shellfish Sanitation and Recreational Water Quality Section of the North Carolina Department of Environment and Natural Resources (NCDENR) as "a gram-positive coccoid-shaped bacteria that is found in the intestinal tracts of warm-blooded animals that include *Enterococcus faecalis, Enterococcus faecium, Enterococcus avium,* and *Enterococcus gallinarium*" (Potts 2005). *E. coli* is still being used in some states as indicator bacteria, but the EPA recommends enterococci for the indicator bacteria for recreational coastal waters.

Even though indicator bacteria may not be directly harmful to humans, they are relatively easy to test for and are typically found in the presence of more harmful pathogens. However, the effectiveness of bacterial indicators as predictors of viral contamination is questionable (Griffin *et al.* 2003).

Another problem with using microorganisms as indicators of fecal contamination is the 24-hour lag time between sample collections and test results. In the meantime, ocean goers may be exposed to contaminated water. Scientists are researching nonbiological indicators that may eventually replace or supply conventional indicators to provide instantaneous results. This includes testing for caffeine concentration in sewage contamination or using chemical fluorescence techniques to detect fecal contamination on processed meat products (Buerge 2003).

2.3 Causes of Coastal Contamination

Recreational coastal water can be contaminated by polluted storm water runoff, sewer line breaks, sewage spills and overflows, waste from domestic animals, marine mammals and birds, poorly maintained septic systems, boat waste, and oil spills. Since mainly stormwater and sometimes sewage can discharge through ocean outfalls carrying bacteria and pathogens, only those sources are discussed in the next sections.

2.3.1 Sewage

According to Potts (2005) there are no ocean sewage outfalls or combined sewer overflows in coastal North Carolina. Sewage treatment plants in North Carolina typically discharge to rivers which in turn lead to the ocean. But sewage can still contaminate coastal waters through combined sewer overflows, sanitary sewer overflow, sewage line breaks, sewage treatment plant malfunctions, and poorly designed/operated residential septic systems.

2.3.2 Stormwater Runoff

Stormwater runoff is also recognized as an important beach pollutant source, resulting in elevated bacteria levels. Almost every coastal and Great Lakes state reported at least one beach where stormwater drains onto or near bathing beaches. Stormwater is created when rain or snowmelt travels on pervious and impervious areas, dissolving contaminants and carrying them from their origin. Common contaminants include oil, grease, heavy metals, pesticides, litter, fecal matter from pets and other urban animals, and pollutants from vehicles. Even though separate storm sewer systems are designed to carry only stormwater, human sewage can enter through leaks in adjacent sewage pipes or from sewage pipes that are illegally hooked up to the stormdrains (Dorfman 2004).

As reported by the EPA (1998) about a quarter of our nation's polluted estuaries and lakes are fouled by urban stormwater. There are 21 stormdrains in North Carolina that discharge directly into the ocean waters (Potts 2005). Urban stormwater was the number one cause of known beach closings and advisories in 2004 and 2005 (Table 2-1).

Table 2-1. Major pollution sources causing beach closings/advisories in 2005 according to (Dorfman 2005).

Pollution Source	Number of Closings/Advisories
Elevated bacteria levels of unknown origin	14,602 days plus 69 extended and 39 permanent events
Stormwater runoff	5,333 days plus 26 extended and 2 permanent events
Sewage spills and overflows	898 days plus 7 permanent events
Other (algal blooms, dredging, wildlife, etc.)	333 days plus 1 extended and 3 permanent event
Rain or preemptive closing usually due to stormwater or sewer overflows	5,213 days plus 23 extended and 9 permanent events

In March 1999, North Carolina health officials placed warning signs 200 ft (122 m) on each side of stormwater pipes on the beach to warn swimmers of polluted runoff discharge along Kure and Carolina Beach. New Hanover County health officials have recorded high bacteria counts near the outfall pipes and attributed blame to septic tanks (that existed then) leaking into the stormwater system along the oceanfront road (Feagans 1999). However, even without leaking septic systems, bacteria levels are typically elevated in stormwater emptying from the outfalls on to the beaches. The source of this bacteria is typically not quantified and is likely variable.

2.4 North Carolina Beach Monitoring

In June 1997 North Carolina Shellfish Sanitation and Recreational Water Quality Section of NCDENR was delegated the responsibility of monitoring the ocean beaches, sounds, bay and estuarine rivers. North Carolina monitors all 240 of the state's coastal beaches. Of the 240 beaches, there are 92 Tier 1 sites (daily recreational use), 104 Tier 2 sites(average 3 days per week use), and 44 Tier 3 sites (average 4 days per month use). Recreational beach water quality monitoring is performed on the ocean and sound-side weekly from April 1st to September 30th and twice a month in October. Monitoring and testing continues on a monthly basis from November through March (Potts 2005).

If a certain area along the coast has a problem with water quality, the Shellfish Sanitation Branch will recommend people not swim within 200 ft (61 m) of a posted sign, list the area on the local county's website, and notify the local media and county health department. The state health director and local health directors have the authority necessary to close a beach if they deem it an hazard to public health (Potts 2005). Recently, some permanent signs have been posted at exposed ocean outfalls in Kure Beach and other sites, warning swimmers of the potential dangers of swimming near flowing outfalls.

Since imperfections exist in the timing of the monitoring system and the issuance of warnings, there continues to be risks that ocean goers can get sick. These risks can be reduced if the amount of bacteria entering the ocean is reduced through development and implementation of stormwater best management practices in these coastal locations.

2.5 Best Management Practices (BMPs)

2.5.1 Introduction to BMPs

To help minimize the volume and improve the quality of stormwater runoff entering the ocean, Best Management Practices (BMPs) can be implemented. EPA (1999) defines a stormwater BMP as "a technical measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost effective manner." Structural BMPs are engineered, constructed systems. Non-structural BMPs are educational and pollution prevention practices designed to limit the generation of stormwater runoff or reduce the amounts of pollutants contained in the runoff. Structural and non-structural BMPs are used to minimize flooding, erosion, and the amount of metals, nutrients, and bacteria (US EPA 1999a). Some common types of BMPs are stormwater wetlands, bioretention areas, and permeable pavement, and sand filtration/infiltration. All of these can be installed in strategic locations within a watershed to mitigate stormwater. However, sand filtration/infiltration shows the highest potential be used near the lower portions of watersheds that include the beach area to maximize treatment for the entire watershed.

2.5.2 Sand Filtration BMPs

Sand filters are BMPs that have been borrowed from the treatment of wastewater and drinking water. Sand filters consist of self-contained beds of sand that are either underlain with drains or cells, and include baffles at inlets and outlets. Stormwater runoff is filtered through the sand, removing contaminants via physical entrapment and sorption.

The type of media used and its grain size determines the pollutant particle size captured. Coarser sands have larger pore space, allowing for high flow-through rates, but also allowing commensurately larger particles to pass through. Fine sand has smaller pore spaces with accordingly slower flow-through rates and filters out small total suspended solids (TSS) particles (Urbonas 1999).

Sand filters are primarily intended for water quality enhancement. They are preferred over infiltration practices when contamination of the groundwater by suspended solids and high concentrations of fecal coliform are of concern (e.g. when groundwater may be used as drinking water). Sand filters can be highly effective stormwater BMPs since they have high removal rates of sediment and fecal bacteria and require less land then other BMPs. Typical pollutant removal efficiency in sand filters is shown in Table 2-2 (US EPA 1999b). Of note is the high removal rate of fecal coliform bacteria.

Sand filters are typically designed for a drainage area ranging from 0.5-10 ac (0.2-4.0 ha).

Table 2-2. Typical pollutant removal efficiency in sand filters (EPA 1999b).

Pollutant	Percent Removal
Fecal Coliform	76
Biochemical Oxygen Demand (BOD)	70
Total Suspended Solids (TSS)	70
Total Organic Carbon (TOC)	48
Total Nitrogen (TN)	21
Total Kjeldahl Nitrogen (TKN)	46
Total Phosphorus (TP)	33
Iron (Fe)	45
Lead (pb)	45
Zinc (Zn)	45

Grisham (1995) presented the concept of engineers designing for the ‘first flush’ of a storm, describing the first flush as the runoff from the first 15 minutes of a storm generally considered the first 0.5 in (1.3 cm) of stormwater runoff. This ‘first flush’ contains proportionately high levels of pollutants relative to rain thereafter. Thus, sand filters are typically designed to capture (0.5-1.0 in) 1.3-2.5 cm of the storm. Successful utilization of sand filters for stormwater treatment have occurred in Austin, TX and Delaware (Urbonas 1999).

Maintenance is required for sand filters to work properly according to Grisham (1995). When designing sand filters, permeability calculations should be based on the assumption that the filter is 50 % clogged due to the expected clogging and improper maintenance. Accumulated trash, paper, and debris should be removed from sand filters every 6 months, or as necessary. Corrective maintenance of filtration chambers includes removal and replacement of the top layers, 1.0-3.0 in (2.5-7.6 cm) of sand (Hunt 1999).

The main impediment for adoption of this technology is the high construction cost; however, the low amount of land required for filter/basin configurations may reduce the cost substantially. Thus, sand filters are a viable technology for stormwater treatment where low concentrations of sediment and particle-associated, such as bacteria, constituents are desired.

3.0 OBJECTIVES

The literature review established the importance of keeping bacteria counts in coastal waters below government recommended bacteria standards. If bacteria levels in coastal and estuarine waters rise, the risk of illness to ocean goers and those who ingest shellfish and other ocean life increase. Increased bacteria levels also decrease the coastal communities’ economic viability by causing beach closures and advisory days, which hurt local businesses. Stormwater runoff is the number one known cause of beach closures and advisories.

Sand filters are an effective BMP for mitigating flow and removing stormwater constituents where land is limited. As coastal communities develop, the amount of stormwater runoff increases, while land availability decreases. Areas with high quality and highly permeable sand is common to many coastal areas in NC and elsewhere. This is may seem beneficial to the adoption of sand filtration, but urban development pressures make many of these areas unavailable. However, locations that cannot be developed are the beach dunes. Despite the successes of sand filters in other locations, sand filter/infiltration systems have yet to be placed in un-developable coastal land, the beach sand dune.

The overall goal of this research was to test a potential BMP, called a Dune Infiltration System (DIS), which does not consume valuable coastal developable property. The research will establish whether the DIS decreases the potential health dangers associated with stormwater ocean outfalls for local coastal residences, tourists, and coastal wildlife. Decreasing potential health dangers involve treating/removing the bacteria transported in the stormwater ocean outfalls. In order to achieve the overall goal, a field study was designed to answer several objectives.

The objectives of the field study were as follows:

1. Identify a range of fecal coliform and enterococcus concentrations in an urban coastal community's stormwater runoff.
2. Design a Dune Infiltration System that will capture all runoff associated with a rainfall intensity of 0.5 in/hr (12.5 mm/hr) or less.
3. Determine if implementing a DIS decreased the amount and peak rate of stormwater runoff directly discharged on the beach.
4. Determine if routing and discharging stormwater runoff in the dunes elevated the level of the groundwater beneath the dunes.
5. Determine bacteria removal efficiency of the DIS by monitoring the inflowing and outflowing bacteria concentration for 25 storm events.
6. Determine if routing and discharging stormwater runoff into the dunes increased the bacteria level in the groundwater beneath the dunes.

4.0 DUNE INFILTRATION SYSTEM FIELD STUDY

4.1 SITE DESCRIPTION

The Dune Infiltration System (DIS) demonstration project was implemented in the Town of Kure Beach, North Carolina, located at 34°00'11" North latitude and 77°54'21" West longitude according to the North American Datum of 1983 (NAD83). The Town of Kure Beach is located in New Hanover County, as shown in Figure 4.1

4.1.1 LOCATION OF DIS

The Town of Kure Beach has 17 stormwater ocean outfalls. Two of these ocean outfalls draining small watershed areas in Kure Beach were selected for the DIS demonstration and research project. Site L (Figure 4-2 (a)), named after the street it borders, is a 4.5 ac (1.8 ha) mixed urban and residential land use watershed, with a Rational equation runoff coefficient of C = 0.8. Site M (Figure 4-2 (b)), also named after the street it borders, is an 8.1 ac (3.3 ha) predominately dense residential land use watershed, with a C = 0.7. The DIS were designed to be placed under the site's dunes,

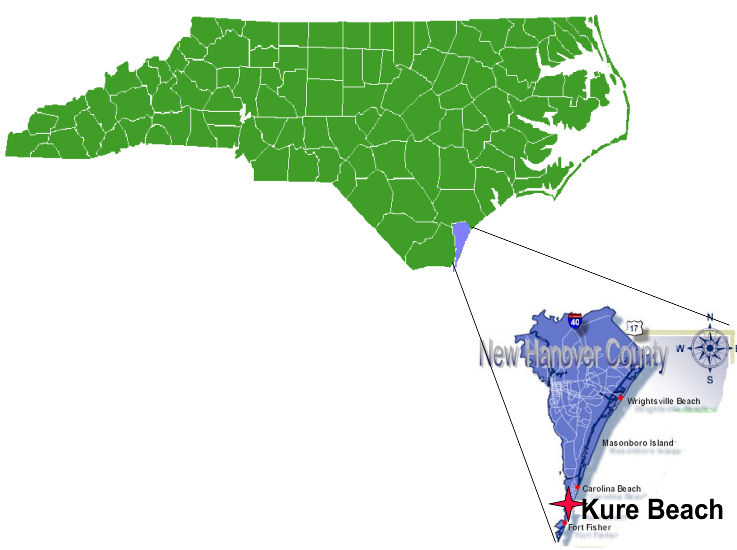

Figure 4-1. Map of NC illustrating the location of New Hanover County and the Town of Kure Beach.

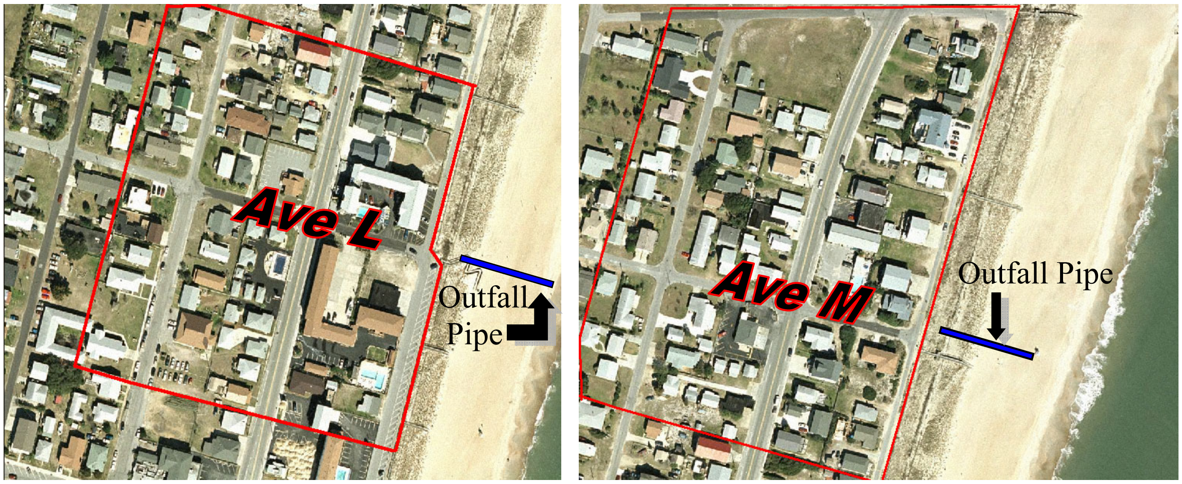

Figure 4-2. (a) Site L watershed area (b) Site M watershed area.

described as a Newhan Fine sand, composed of 99.4 % sand and 0.6% silt (NRCS, 2005). The North Carolina Division of Coastal Management issued a Coastal Area Management Act (CAMA) exemption to permit the work within the dune system. This not only facilitated the logistics of the design but also substantially reduced the cost of the project, since valuable ocean-front real estate was not purchased. Special care was taken not to disturb the dunes during sea-turtle nesting season.

4.2 DIS Design Considerations

4.2.1 DIS Preconstruction Monitoring

Prior to DIS installation, groundwater elevations beneath the dunes, and bacteria concentrations in the stormwater outfalls and groundwater were monitored from June-January 2006 at Sites L and M to establish baseline levels.

In June, 2005, two groundwater monitoring wells and six groundwater bacteria monitoring wells were installed at each site. Preconstruction groundwater monitoring wells were installed to measure groundwater depths, daily tidal influences, and storm-induced fluctuations. Groundwater elevations were measured using an encased

INFINITY[1] continuous water table recorder (INFINITIES USA, Inc., Daytona Beach, FL). The INFINITY's casing was a 14 ft (4.3 m) long, 2 in (5 cm) diameter polyvinyl chloride (PVC) pipe. The bacteria monitoring wells were constructed using 2 in (5 cm) diameter PVC of varying lengths with the last 1 ft (30 cm) screened, as reported in Table 4-1. Figure 4-3, depicts the preconstruction groundwater sampling wells in Site M's dunes.

Table 4-1. Groundwater bacteria monitoring well specifications.

Site L Well ID	Site M Well ID	Depth of Well Screen
L-4	M-4	3-4 ft
L-6	M-6	5-6 ft
L-8	M-8	7-8 ft
L-10	M-10	9-10 ft
L-12	M-12	11-12 ft
L-14	M-14	13-14 ft

Figure 4-3. Pre-construction hydrology and water quality monitoring wells.

[1] The use of trade names does not imply endorsement by North Carolina State University.

Precipitation measurements were necessary to correlate the rise in the water table with the size of the storm. A Davis Rain Collector™ tipping bucket recorder with a 0.01 capacity bucket (Davis Instruments, Hayward CA, Model 7852) along with a HOBO® data logger (Onset Computer Corporation) were installed in site M's dunes. A backup manual gauge was installed near the tipping bucket. Due to a malfunction in the original HOBO tipping bucket, a second one was later installed at Site L.

4.2.2 Preconstruction Sampling Protocol

Fecal coliform samples were collected during the months of July 2005 through September 2005 within 24 hours of a storm event. Stormwater runoff samples were collected from each site's ocean outfall pipes. A total of six groundwater samples were obtained from the following installed monitoring wells: L-10, L-12, L-14, M-12, and M-14. The remaining wells were dry. Before collecting the sample, monitoring wells were purged 2 well volumes using the well's designated bailer. One 200 ml sample was collected from each well in a sterile 250 ml bottle, with a sodium thiosulfate tablet in the bottle as preservative. The samples were put on ice and transported to Oxford Laboratory, Inc., in Wilmington, NC, for fecal coliform analysis (EPA method SM 922D).

Along with bacteria sampling, groundwater and rainfall data was obtained. INFINITY data loggers were downloaded using a Hewlett-Packard™ calculator with INFINITY software. The HOBO® data logger was downloaded using a HOBO® data shuttle (Onset Computer Corporation).

4.2.3 DIS Preconstruction Field Measurements

4.2.3.1 Site Survey

To accurately design the DIS, Site L's and Site M's dune areas were surveyed. These areas were surveyed with a Sokkia Total Station model SET5 30R. Survey points were measured approximately every 10 ft (3 m) apart from the western side of the dune, Atlantic Avenue, to the eastern side of the dune, approximately the mean high tide water line. These points were surveyed within the north and south boundaries of the public beach access boardwalks

Surveying the North Carolina Geodetic Survey Stations ANT and THRID, located near Site L's and M's dune, allowed the conversion of relative elevations, to become actual elevations in the NAD83. The new survey was overlaid onto a 2002, aerial photograph download from New Hanover County website (2006). Figure 4-4 is the Autodesk Land Desktop® drawing of the NAD83 elevations of Site L and M.

Figure 4-4. Actual survey elevations of Site L and M at Kure Beach, NC (feet).

4.2.3.2 Single Ring Infiltrometer Test

From the Nature Resource Conservation Service (NRCS) Soil Data Mart (2006), the site soil was defined as Newhan Fine sand, having a profile with a uniform measured moist bulk density between 0.057 lbs/in^3 (1.60 g/cm^3) to 0.063 lbs/in^3 (1.75 g/cm^3) and uniform saturated hydraulic conductivity of 154 in/hr (392 cm/hr) (NRCS 2006). Single ring infiltrometer tests were preformed in an attempt to verify this saturated hydraulic conductivity. The single ring infiltrometer test measures infiltration rates, rather then saturated hydraulic conductivity values.

ASTM D 3385, the "Standard Test Method for Infiltration Rate in Field Soils Using Double-Ring Infiltrometer" was the procedural basis for measuring surface infiltration rates. This test measures infiltration rates for soils with a hydraulic conductivity between 3.9×10^{-7} in/s and 3.9×10^{-3} in/s. The double ring infiltrometer test was modified to a single ring infiltrometer test, due to the NRCS reporting the saturated hydraulic conductivity greater than the standard's range.

The single-ring infiltrometer used consisted of 16 gauge galvanized steel rings with inner diameter of 12 in (30.5 cm). Six single infiltrometer tests were performed at three separate locations at each site in the dunes after a 24-hour dry period. The locations of the tests were at least 30 ft (8.1 m) apart on a level dune surface with no vegetation located inside the ring. The ring was hammered 6 in (15 cm) into the ground with a sledge and a wooden block. The test was done according to the ASTM 3385 standard, with one exception. The test was designed to run until the water can no longer infiltrate. This was deemed impossible due to the high infiltration rate of Newhan sand, so the test was run until the water source ran dry.

Data were plotted as cumulative infiltration versus infiltration time (Figure 4-5). Since the infiltration rate is equivalent to the maximum-steady state or average incremental infiltration velocity, the slope of the least squares line for each test was determined to be equal to the surface infiltration rate of the tested surface. The surface infiltration rate for each site was determined by averaging the results from the three tests. The average surface infiltration rate was measured to be 130 in/hr (329 cm/hr) for Site L and 165 in/hr (419 cm/hr) for Site M. The overall average of the test was 147 in/hr (372 cm/hr), which was close to the saturated hydraulic conductivity, 154 in/hr (392 cm/hr), measured by NRCS (2005).

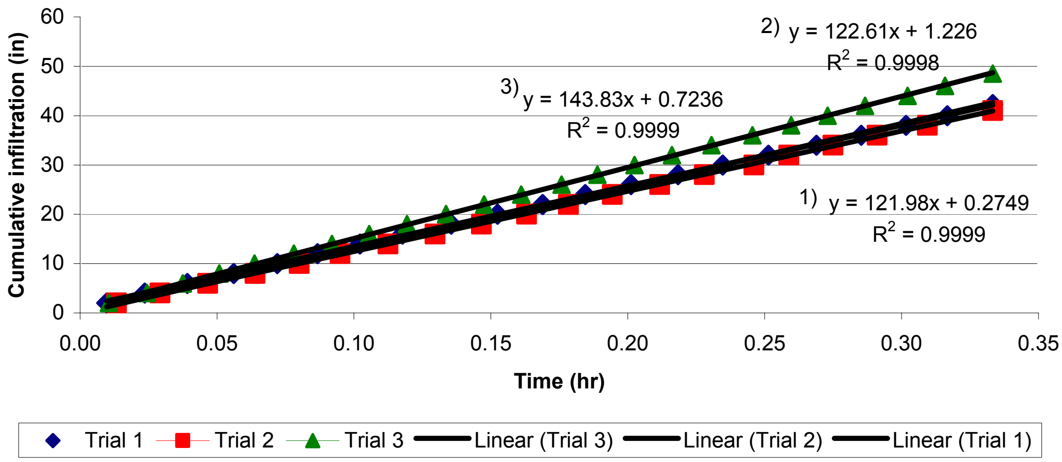

Figure 4-5. Site L's cumulative infiltration versus time for three single ring infiltrometer tests.

4.3 DIS Design

Pre-construction monitoring from July 2005 until January 2006 indicated that water table depths below the dune surface were on average 3.5 m (11.5 ft) at Site L and 4.0 m (13.1 ft) for Site M. This provided sufficient depth to allow for vertical infiltration of stormwater runoff, so design of the system could then proceed.

4.3.1 Hydrologic Calculations

The DIS was designed to capture the amount of stormwater runoff produced by a 0.5 in (12.5 mm) per hour storm, a conservative choice for the first design of this type of system. Using previously measured watershed characteristics and a given design storm, the system was designed based on the Rational Method as well as the NRCS Method.

4.3.1.1 Rational and Natural Resources Conservation Service Method (NRCS) Calculations

The Rational Equation, (EQN 4-1) was used to calculate peak discharge of each site's drainage area (Schwab *et al.* 1993).

$$q = C * i * A \qquad (4\text{-}1)$$

Where: q = peak discharge (cfs),
C = Rational method runoff coefficient (0.8 Site L, 0.7 Site M),

i = rainfall intensity (in/hr),
A = Watershed Drainage area (ac).

The peak discharge based on the design storm, area of the watershed, and C values, that was calculated to be diverted to the Dune Infiltration System was 1.88 cfs (0.05 m^3/s) for Site L and 2.69 cfs (0.07 m^3/s) for Site M. The method of calculating the time of concentration, T_c, was the Kirpich/Ramser (EQN 4-2) (Schwab *et al.* 1993).

$$t_c = \left[\frac{L^3}{H}\right]^{0.385} * 128 \qquad (4\text{-}2)$$

Where: t_c = time of concentration (min)
L = hydraulic watershed length (ft)
H = elevation change along hydraulic length (ft)

S was calculated from the survey data, equaling 0.02 ft/ft, which yielded an estimated T_c value of 12 minutes for Site L and 16 minutes for Site M.

Two other relevant empirical formulae for determining the quantity of runoff were the NRCS Equations used to calculate a Unit Hydrograph. This method estimated the time to peak and the peak discharge, remembering that:

1) Weighted CN must be over 40.
2) The CN procedure is less accurate when runoff is less than 13 mm/hr (0.5 in/hr).

First, surface storage and runoff depth were calculated using equations 4-3 and 4-4 (Schwab *et al.* 1993)

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad (4\text{-}3)$$

$$Q^* = \frac{(I - 0.2S)^2}{(I + 0.8S)} \qquad (4\text{-}4)$$

Where: S = maximum potential differences of rainfall and runoff (in)
CN = curve number
I = storm rainfall (in)

$Q*$ = direct surface runoff depth (in)

The CN used was a composite CN, using CN=98 for impervious area and CN= 50 for pervious surfaces, based on the value determined for Kure Beach's soil. The composite CN was estimated to be 88 for Site L and 69 for Site M. Next, total runoff volume (EQN 4-5) was calculated so that time of peak runoff could be calculated (EQN 4-6) (Malcom 1989).

$$Vol = 3630 * Q * A \tag{4-5}$$

$$T_p = \frac{Vol}{1.39 * Q_p} \tag{4-6}$$

Where: Vol = volume of water under hydrograph (ft^3)
Q = direct surface runoff depth (in)
A = watershed Drainage area (ac)
Tp = time to peak of the design hydrograph (sec)
Qp = peak discharge (cfs)

Equation 4-7 was used to graph each site's unit hydrograph (Figure 6) as derived by Malcom (1989).

$$\begin{aligned} &0 \le t \le 1.25 * T_p \rightarrow Q = \frac{Q_p}{2}\left(\frac{1-\cos(\pi t)}{T_p}\right) \\ &t > 1.25 * T_p \rightarrow 4.34 * Q_p * e^{\left(\frac{-1.3t}{Tp}\right)} \end{aligned} \tag{4-7}$$

Where:
Q = Watershed Inflow (cfs)
Tp = Time to peak of the design hydrograph (sec)
Qp = peak discharge (cfs)

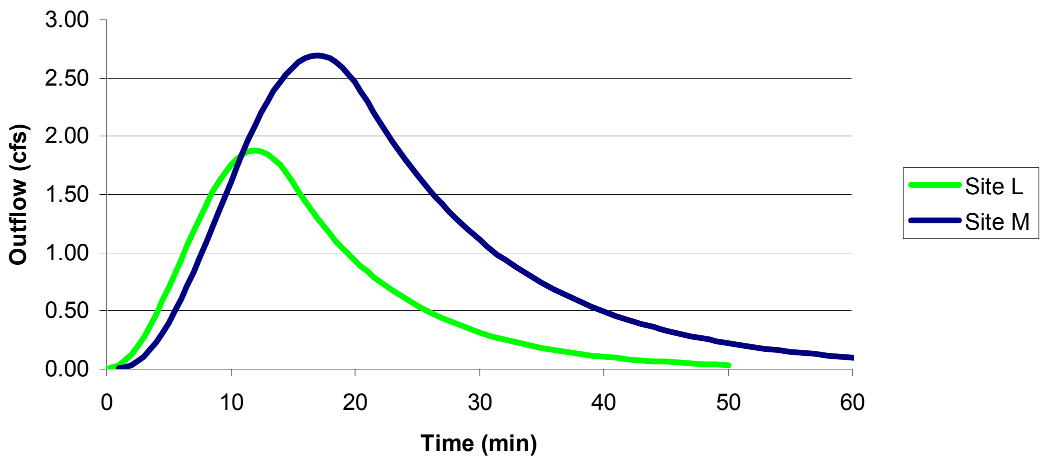

Figure 4-6. Sites L's and M's estimated inflow hydrograph for a 0.5 in/hr (12.5 mm/hr) storm.

4.3.1.2 Stormwater infiltration

The DIS was designed using commercially-available open bottomed, high density polyethylene (HDPE) infiltration chambers sold as StormChambers™ , produced by HydroLogic Solutions, Incorporated, Occoquan, VA. The chambers were 3.5 ft (1.07 m) high, 5 ft (1.52 m) wide, and 8.2 ft (2.5 m) long (Figure 4-7).

The number of StormChambers™ necessary to infiltrate stormwater into the dunes was calculated by combining the hydrologic calculations previously described with Darcy's equation (equation 4-8).

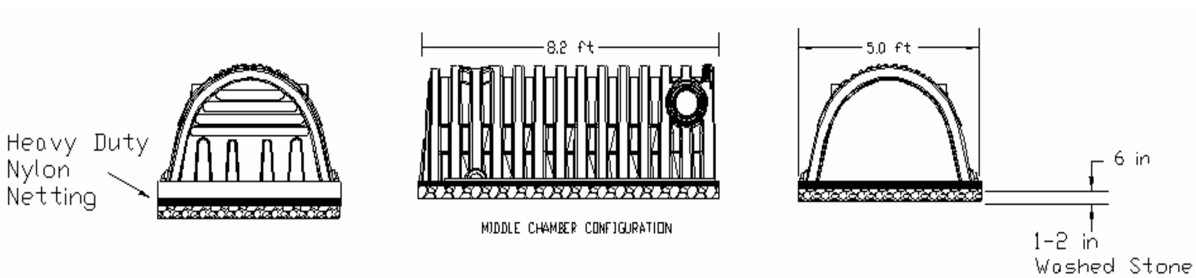

Figure 4-7. StormChambers™ schematic (courtesy Hydrologic Solutions).

$$Q = AK\frac{\Delta h}{L} \tag{4-8}$$

Where: Q = volumetric flowrate (ft^3/s or m^3/s),
A = flow area perpendicular to L (ft^2 or m^2),
K = hydraulic conductivity (ft/s or m/s),
L = flow path length (ft or m),
Δh = change in hydraulic head (ft or m)

Darcy's equation was used to conservatively estimate the number of chambers required to accommodate stormwater infiltrate into the dunes. The use of this equation assumed only vertical flow. Since this was a demonstration of an untested coastal BMP, ignoring lateral flow during design provided a conservative design to help ensure dune protection.

The vertical hydraulic conductivity, K, used in Darcy's equation was the single ring infiltrometer test result, which averaged to a value of 0.003 ft/s (372 cm/min). The flow path, L, was the depth of the sand to the water table, which ranged from 6.6-8.5 ft (2.0-2.6 m). The area perpendicular to the flow, A, was equal to the open area of the bottom of an individual chamber, 36.5 ft^2 (3.4 m^2). The change in hydraulic head, h, ranged from 11 ft (3.4 m), (the height of the chamber, 3.5 ft (1.1 m), full of stormwater plus the average depth of sand) to approximately zero meters at the water table. Using the maximum and minimum change in hydraulic head, the volumetric flow rate, Q, at its maximum and minimum can be calculated based on the number of chambers in the system. The combination of the hydrologic calculations and Darcy's equation yielded that twelve chambers total were needed at Site L and 22 chambers total at Site M to divert a rain event of intensity 0.5 in (12.5 mm) per hour.

4.3.2 DIS Design

The DIS was designed to connect to a pre-existing stormwater outfall, by installing a concrete vault in-line with the outfall to divert stormwater into the infiltration system, and serve as a monitoring station (design of the vault is shown under section 4.3.4.1 Monitoring Equipment). The depth of burial of the vault and the infiltration chambers was not predetermined; rather it dependant on the invert elevation of each original outfall. Site L's system was installed deeper beneath the dunes than at Site M because the outfall was at a lower elevation as it passed beneath Atlantic Avenue. The invert elevations of the StormChambers™ allowed an average of 6.5 ft (2.0 m) for Site L and 8.5 ft (2.6 m) for Site M of sand for the stormwater runoff to infiltrate through before reaching the groundwater. This also allowed the 3.5 ft (1.07 m) StormChambers™ to be buried 2.5 ft (0.8 m) at Site L and 1.5 ft (0.5 m) at Site M under the dunes, which added protection to the DIS systems. A 1 ft (0.3 m) diameter pipe, sloping less than 0.01 ft/ft, lead from the diversion vault to the StormChambers™. The StormChambers™ inflow pipe inverts were 2 ft (0.6 m) higher than the StormChambers™ invert elevation to allow for a gravity flow system. As seen in Figure 4-8, stormwater from the outfall is diverted within a buried concrete vault into a "T" intersection, allowing for two separate laterals of StormChambers™ for flexibility if stormwater runoff debris clogged one of the entrances or in the event routine maintenance was performed. Clean-out pipes were designed and installed at the beginning and end of each StormChamber™ row, to facilitate maintenance, which the Town of Kure Beach Department of Public Works agreed to perform.

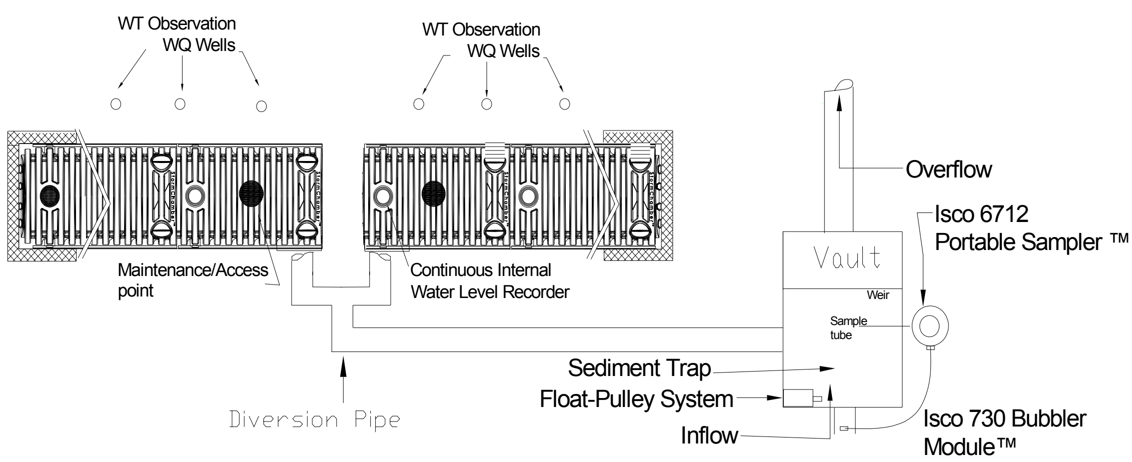

Figure 4-8. Top view of DIS layout.

4.3.3 DIS INSTALLATION

The Town of Kure Beach Public Works Department, under the supervision of North Carolina State University, installed the Dune Infiltration System in February 2006. In order to install the chambers in the dunes, a trench 9 ft (2.7 m) wide by 6 ft (1.8 m) deep by 96 ft (29 m) long for Site L and 9 ft (2.7 m) wide by 5 ft (1.5 m) deep by 176 ft (54 m) long for Site M was constructed. Banks were stabilized with a geotextile fabric. Then, 6 to 12 in (15 to 31 cm) of 1 to 2 in (2.5 to 5.1 cm) washed stone was placed on top of the sand at the bottom of the trench to achieve uniform grade. Heavy duty nylon netting was placed on top of the stones to secure them during future maintenance (i.e. sediment removal) of the chambers. The chambers were placed on top of the netting, and the trench and chambers were filled midway with washed stone (Figure 4-9 (a)). The 12 in (30.5 cm) pipe from the diversion vault was attached to the start chambers and sealed.

Access points for chamber maintenance were installed at the beginning and end of the chambers (Figure 4-9b). Internal chamber water level monitoring points, 4 in (10 cm) in diameter, were also installed near these locations to accommodate an INFINITY™ water level recorder.

(a) (b)

Figure 4-9. Installation of a StormChamber™.

Upon completion of installation, American beach grass (*Ammophila breviligulata)* was replanted on the dunes at Site L and Site M in March 2006 to help initially stabilize the dunes. Fertilizer was broadcast in May 2006, then sea oats (*Uniola paniculata*) a native North Carolina plant, were planted June 2006 as directed by the New Hanover County Cooperative Extension dune restoration specialist (David Nash), to more effectively vegetate and stabilize the dunes. Figure 4-10 shows Kure Beach volunteers planting sea oats.

Figure 4-10. Planting Sea oats in Site M's dunes.

4.3.4 DIS Monitoring

4.3.4.1 Monitoring Equipment

The amount of stormwater diverted into the chambers was calculated from measurements recorded in the monitoring vault. Figure 4-11 shows the design schematic of the two diversion vaults.

An ISCO 730 Bubbler Module™ was attached to the bottom of the existing stormwater outflow pipe. Manning's equation (equation 4-9), with a maximum Manning's n for corrugated metal pipe, flowing full, near a manhole, of 0.024 was used to program the ISCO Bubbler to calculate inflow rate of stormwater runoff into the vault.

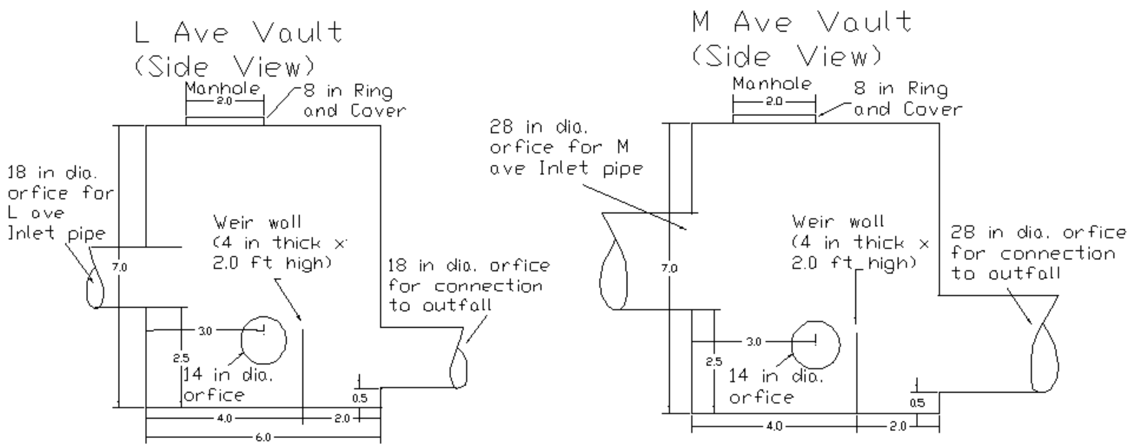

Figure 4-11. AutoCAD drawing of Site L and Site M vault (feet unless otherwise noted).

$$Q = \frac{1.49 * R^{2/3} S^{1/2}}{n} \tag{4-9}$$

Where: Q= Discharge (cfs)
R= Hydraulic Radius (ft)
S = Friction Slope (ft/ft)

Since this was a demonstration of a new concept in coastal stormwater management the Dune Infiltration Systems were designed to capture only the amount of stormwater runoff produced by a 0.5 in (1.3 cm) 1-hour storm. For storms greater then 0.5 in/hr (1.3 cm/hr) design intensity, overflow was expected. The overflow was designed to overflow a rectangular weir in the vault and discharge through the original stormwater outflow pipe onto the beach. To calculate the volume of overflow, a 2 ft (0.6 m) high, 4 ft (1.2 m) wide, and 2.5 ft (0.8 m) rectangular concrete weir without end contractions was constructed as part of the vault (Figure 4-11). The weir was positioned 2 ft (0.6 m) from the connection with original outflow stormwater pipe. A 2.5 ft (0.8 m) metal plate was drilled onto the concrete weir, giving the weir a total height of 2.5 ft (0.8 m). With the known type and height of the weir, the overflow rate was calculated using the weir equation below (Grant & Dawson 2001).

$$Q = 13.32 * H^{1.5} \tag{4-10}$$

Where :Q = Discharge (cfs)
H = Head Over Weir (ft)

The head over the weir during a storm event was measured and recorded using a datalogger (SGT Engineering, Champaign, Illinois) connected to a float-pulley system which was constructed and installed in a stilling well in the vault near the inflow stormwater pipe (Figure 4-12). The float-pulley system included a 5-turn pulley connecting a float with a matching counterweight, which was attached to a 10-KΩ Newark™ potentiometer.

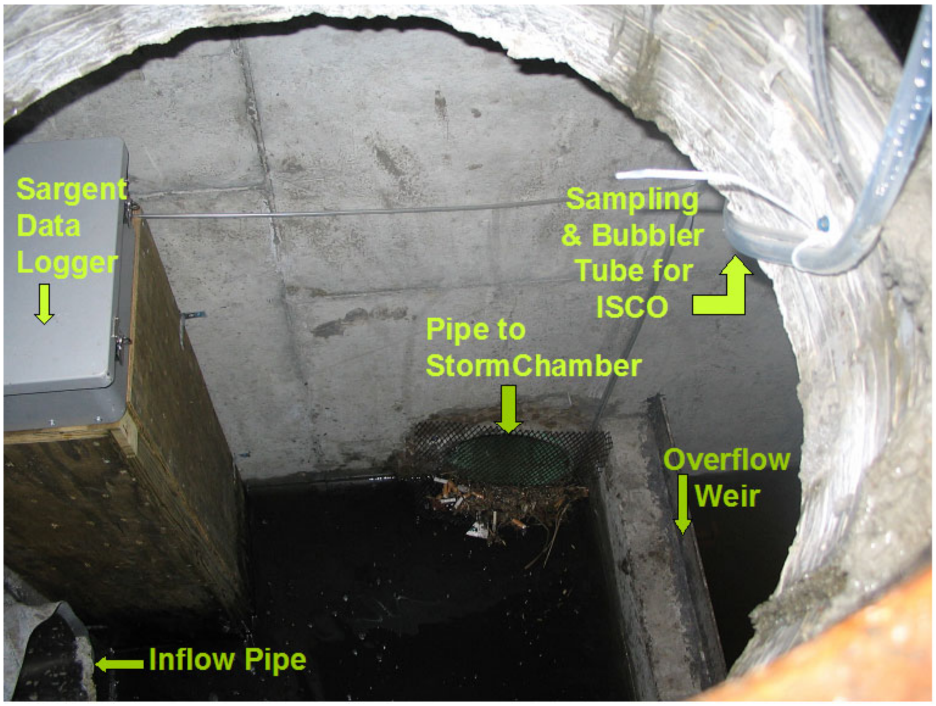

Figure 4-12. View of monitoring vault from manhole.

In instances when the system was overwhelmed with stormwater runoff, the calculated overflow volume was subtracted from the total measured inflow, obtaining the volume treated in the DIS. If no flow was recorded over the weir, then the flow into the chambers was reasonably assumed to be equal to that measured from the inflow pipe.

The bacteria concentration entering the system was measured by water quality grab samples captured during a storm. At Site L and Site M an ISCO 6712 Portable Sampler™ was programmed using Manning's equation to capture stormwater runoff at flow weighted points along the inflow hydrograph. Site L's ISCO was programmed to capture a 200 ml sample for every 85 ft^3 (2.4 m^3) of stormwater runoff that entered the vault. Site M's ISCO was set to capture a 200 ml sample for every 137 ft^3 (3.9 m^3) of stormwater that entered the vault. Samples were pulled from the ISCO Sampler located in the vault 6 in (15 cm) below the pipe that leads to the StormChambers™. The ISCO samplers were each powered with a 12-volt battery that was recharged by a 15 W Solarex Solar™ Panel. Figure 4-13 depicts the final DIS and monitoring equipment.

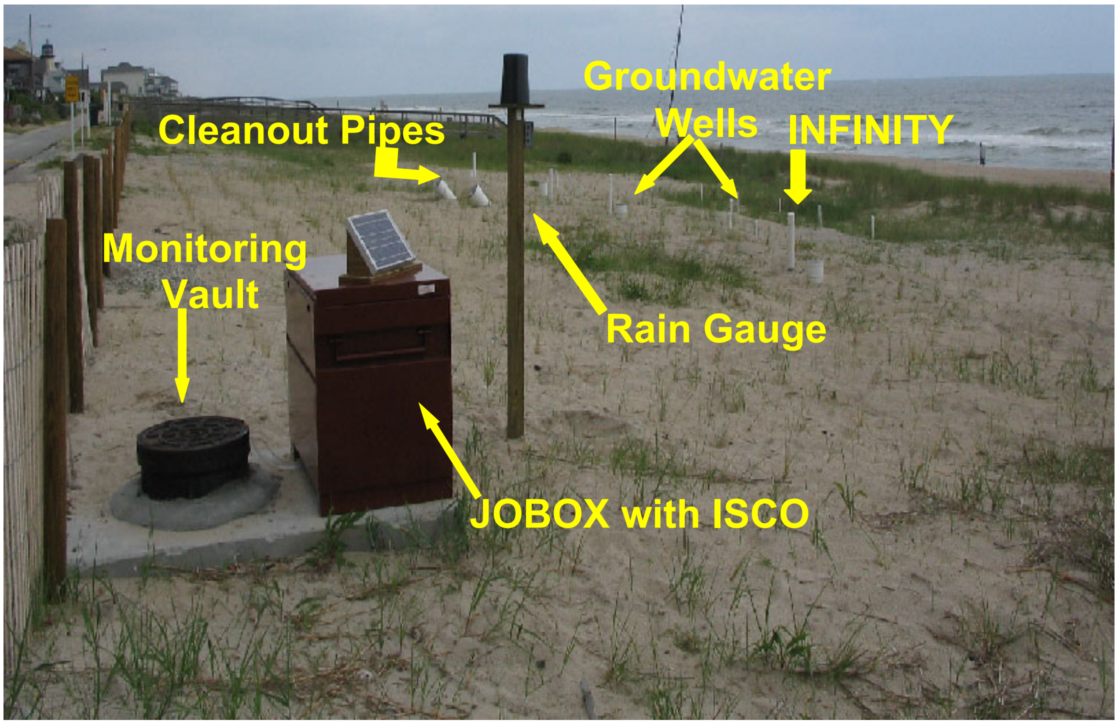

Figure 4-13. DIS system at Site L after installation.

4.3.4.2 Sampling Collection Protocol

Stormwater and groundwater samples were collected during the months of March 2006 through October 2006, within 24 hours of a storm event. Stormwater runoff bacteria samples were collected from the ISCO automatic samplers at each site. Depending on the storm size and intensity, stormwater was stored in one or more 1 liter bottles inside the ISCO, and a composite sample was collected for analysis using equal volumes from each . Groundwater samples were obtained from L-12 and M-12, as described in the preconstruction sampling protocol, since the other groundwater wells installed at more shallow depths remained dry during the study period.

Duplicate samples were collected from each sampling location in order to analyze for both fecal coliform and enterococcus. Fecal coliform samples were taken to Oxford

Laboratory, Inc., Wilmington, NC, as described in the preconstruction sampling protocol. Enterococcus samples were collected in a 60 ml sterile bottle and taken to the NCDENR Division of Shellfish Sanitation Laboratory located in Wrightsville Beach, NC, who analyzed water samples using the IDEXX Laboratories Inc. developed method, Enterolert™ (ASTM method D6503-99).

4.4 DIS Results and Discussion

4.4.1 Preconstruction Monitoring

From July, 2005, through September, 2005, bacteria samples were collected from the groundwater wells. The groundwater samples were collected after five rain events; three from groundwater wells at Site L: L-10, L-12, and L-14 and two from Site M: M-12 and M-14. Site M surface elevation was higher than Site L, so the M-10 monitoring well remained dry and no groundwater bacteria samples could be collected.

Site L's groundwater fecal coliform colony forming units (CFU) ranged from less than 1 CFU/100 ml to 190 CFU/100 ml; whereas, Site M's ranged from less than 1 CFU/100 ml to 200 CFU/100 ml. All groundwater fecal coliform levels remained equal to or less than North Carolina's standard of 200 CFU/100 ml. Table 4-2 shows the groundwater bacteria concentrations for the five storms. Oxford Laboratory bottles were not used on July 12, 2005, which may explain the increased bacteria counts.

Runoff from four storms was sampled directly from ocean outfall pipes at Site L and Site M. Site L's stormwater fecal coliform levels ranged from 1,300 to 22,300 CFU/100 ml, where as Site M's ranged from 1,820 to 6,000 CFU/100 ml. All stormwater inflow rates exceeded the state's standard for human contact waters. Table 4-3 shows the stormwater runoff bacteria concentrations.

Groundwater hydrology was monitored at the site to provide baseline profile of the water table response before installation of the DIS. It was also used to verify the invert elevation at which the system was to be installed was above the range of water table fluctuations due to tidal and rainfall influences.

Table 4-2. Preconstruction groundwater fecal coliform levels.

	L-10 CFU/100ml	L-12 CFU/100ml	L-14 CFU/100ml	M-12 CFU/100ml	M-14 CFU/100ml
7/12/2005	115	110	190	200	54
7/24/2005	<1	<1	11	1	66
8/10/2005	15	23	<1	12	11
8/24/2005	<1	<1	<1	<1	29
9/21/2005	<1	22	<1	<1	29

Table 4-3. Preconstruction stormwater runoff bacteria levels.

	Site L CFU/100 ml	Site M CFU/100 ml
7/12/2005	5320	6000
8/10/2005	7240	1820
8/23/2005	22300	3000
10/24/2005	1300	2200

Groundwater elevations at Site L and Site M ranged from approximately 6 ft (1.8 m) below the surface elevation of the dunes to 13 ft (3.6 m) below the dune surface. This data confirmed that the elevation that each DIS would have to be installed (dictated by the outfall elevations at Atlantic Ave.) was feasible (Figure 4-14 and Figure 4-15). When installed at the target elevations, the invert of the DIS would be 8-9 ft above the average water table elevation measured during this period. Data collection was missed at Site M from September 22, 2005 until October 16, 2005 due to equipment malfunction.

The large peaks in water table elevation at Site L and M shown in Figure 4-14 and 4-15 were fluctuations in the groundwater caused by tropical systems. The largest peak in the groundwater occurred on September 14, 2005 during Hurricane Ophelia. This storm's rainfall total was approximately 17 in (43 cm), which caused the groundwater at Site L and Site M to rise 4.9 ft (1.5 m) and 6.6 ft (2 m) respectively. Next was Tropical Storm Tammy on October 6, 2005, shown only in the Site L groundwater data. Around 5 in (13 cm) of rain caused the water table to rise 3.3 ft (1.0 m). On October 23, 2005 remnants of Hurricane Wilma produced a rainfall total of about 3 in (8 cm) with a corresponding rise of 2.3 ft (0.7 m) in the groundwater at Site L. At both site locations we were fortunate to collect this data during the preconstruction phase, as it showed that the water table during these events was still 3-4 ft (0.9-1.2 m) below the design invert elevation of the DIS systems.

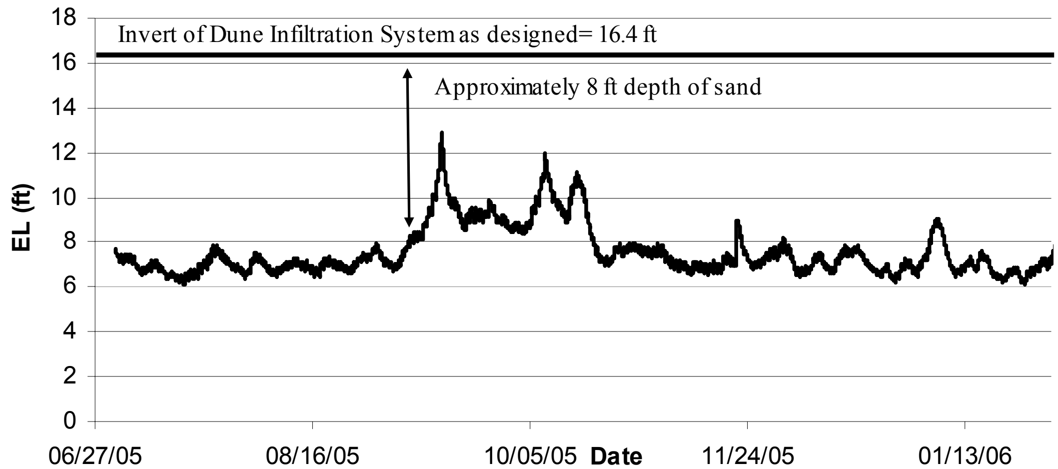

Figure 4-14. Preconstruction groundwater elevations at Site L.

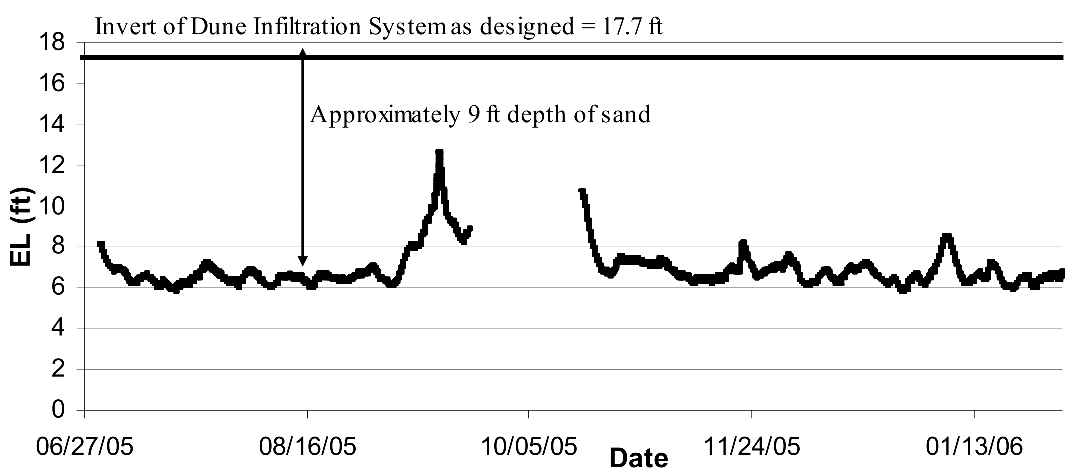

Figure 4-15. Preconstruction groundwater elevations at Site M.

4.4.2 Post Construction Hydraulic Data

4.4.2.1 Summary of Storm Events

Twenty-five storm events were captured during the months of March through October, 2006 (Table 4-4 and Table 4-5).

Table 4-4. Site L Storm Characteristics.

Storm Date	Rainfall Amount (in)	Duration (hr)	Peak Intensity* (in/hr)	Peak Flow (cfs)	Runoff Watershed Depth* (in)	Total Runoff Volume Captured (cf)	Total Runoff Volume Bypass* (cf)
3/21/2006	0.47	10.33	0.11	0.08	0.02	365	0
4/16/2006	0.76	No data	No data	0.90	0.04	612	0
4/26/2006	1.04	No data	No data	0.44	0.12	1993	0
5/7/2006	0.51	2.00	1.32	0.38	0.03	453	0
5/14/2006	0.81	3.25	1.20	0.20	0.04	683	0
5/15/2006	0.15	0.27	0.56	0.16	0.02	261	0
5/20/2006	0.92	19.10	0.40	0.14	0.07	1068	0
6/5/2006	0.36	5.93	1.62	0.40	0.07	1154	0
6/12/2006	0.31	11.62	0.20	0.06	0.03	559	0
6/14/2006	0.67	4.02	1.56	0.56	0.04	724	0
6/25/2006	0.33	2.40	2.88	0.29	0.02	270	0
6/26/2006	0.26	3.52	0.60	0.19	0.02	277	0
6/27/2006	0.22	6.12	0.44	0.09	0.02	321	0
7/6/2006	0.46	4.82	1.10	0.11	0.02	254	0
7/16/2006	0.18	1.77	0.72	0.20	0.01	180	0
7/23/2006	1.58	24.32	2.00	0.61	0.08	1384	0
7/25/2006	1.14	23.27	1.72	0.67	0.08	1290	0
7/30/2006	0.16	8.22	0.05	0.02	0.02	330	0
8/21/2006	0.42	0.68	0.76	0.15	0.01	208	0
8/22/2006	1.92	6.38	3.50	0.50	0.05	773	0
9/1/2006	4.14	21.80	0.90	0.44	0.26	4244	0
9/6/2006	0.34	13.07	0.48	0.11	0.03	453	0
9/13/2006	1.96	10.77	0.24	0.48	0.11	1845	0
10/8/2006	3.00	15.33	3.50	1.38	0.19	3078	0
10/17/2006	0.26	18.93	0.17	0.08	0.03	500	0
					Total=	**23278**	**0**

*Indicates calculated values, the rest were directly measured.

Table 4-5. Site M Storm Characteristics.

Storm Date	Rainfall Amount (in)	Duration (hr)	Peak Intensity* (in/hr)	Peak Flow (cfs)	Runoff Watershed Depth* (in)	Total Runoff Volume (cf)	Total Runoff Volume Bypass* (cf)
3/21/2006	0.47	10.33	0.11	0.09	0.03	806	0
4/16/2006	0.76	No data	No data	1.68	0.05	1564	0
4/26/2006	1.04	No data	No data	1.53	0.23	6680	0
5/7/2006	0.51	2.00	1.32	0.99	0.05	1360	0
5/14/2006	0.81	3.25	1.20	0.46	0.05	1597	0
5/15/2006	0.15	0.27	0.56	0.34	0.02	471	0
5/20/2006	0.92	19.10	0.40	0.60	0.08	2385	0
6/5/2006	0.36	5.93	1.62	1.06	0.13	3765	0
6/12/2006	0.31	11.62	0.20	0.09	0.05	1333	0
6/14/2006	0.67	4.02	1.56	1.87	0.09	2566	74
6/25/2006	0.33	2.40	2.88	0.83	0.03	832	0
6/26/2006	0.26	3.52	0.60	0.48	0.02	616	0
6/27/2006	0.22	6.12	0.44	0.18	0.02	612	0
7/6/2006	0.46	4.82	1.10	0.68	0.04	1039	0
7/16/2006	0.18	1.77	0.72	0.55	0.02	477	0
7/23/2006	1.58	24.32	2.00	2.09	0.22	6208	222
7/25/2006	1.14	23.27	1.72	2.20	0.20	5758	170
7/30/2006	0.16	8.22	0.05	0.05	0.02	678	0
8/21/2006	0.42	0.68	0.76	0.54	0.03	798	0
8/22/2006	1.92	6.38	3.50	1.96	0.11	3102	92
9/1/2006	4.14	21.80	0.90	1.67	0.67	19660	0
9/6/2006	0.34	13.07	0.48	0.33	0.06	1848	0
9/13/2006	1.96	10.77	0.24	1.89	0.26	7664	0
10/8/2006	3.00	15.33	3.50	6.36	0.44	9895	2942
10/17/2006	0.26	18.93	0.17	0.13	0.03	773	0
					Total=	**82486**	**3500**

*Indicates calculated values, the rest were directly measured

A storm event was defined as rainfall separated from another by an inter-event dry period of at least 6 hours. Storm intensity was calculated using the US EPA procedure for 2-yr-15-minute storms (U.S. EPA, 2002b). Appendix A lists the statistical tests for field hydrology data.

Seventeen of the 23 storms peak rainfall intensity exceeded the design intensity of 0.5 in (12.5 mm), averaging 1.14 in/hr (28.9 mm/hr). Figure 4-16 is a graph of peak rainfall intensity versus rainfall amount, showing the variety of storms captured. The peak intensity ranged from 0.05 in/hr (1.27 mm/hr) on July 30, 2006, to 3.5 in/hr (89 mm/hr) on July 23, 2006 and October 8, 2006. Rainfall amount averaged 0.89 in (22.7

mm) and ranged from 0.15 in (3.81 mm) occurring May 15, 2006 to 4.14 in (105.2 mm), occurring September 1, 2006 during Tropical Storm Ernesto.

The majority of these storms are categorized as Type III storms, with relative short durations of peak intensity occurring at the beginning of the storms. Type III storms are typical in the Gulf of Mexico and Atlantic coastal areas where tropical storms bring large 24-hour rainfall amounts (Schwab *et al.* 1993). The months of March through October 2006, were of average rainfall relatively to the last decade of rainfall events measured at nearby New Hanover County Airport in Wilmington, North Carolina (State Climate Office of North Carolina 2006).

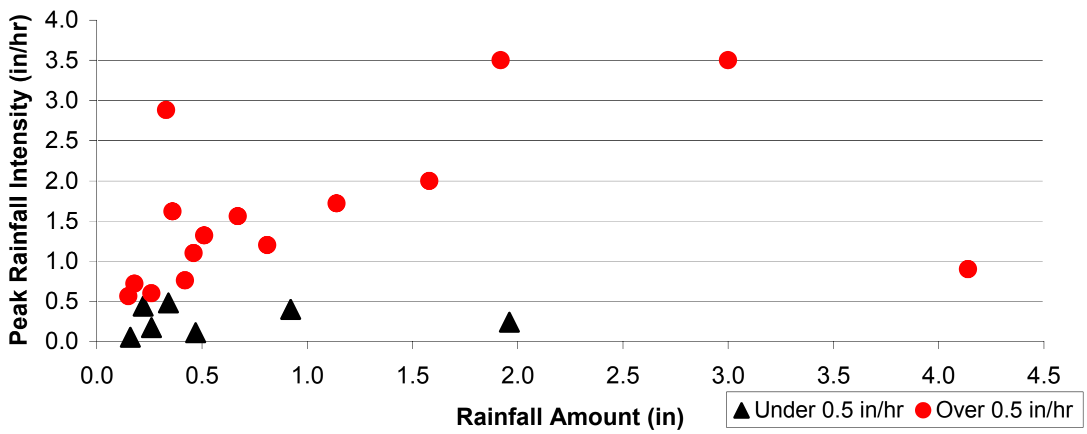

Figure 4-16. Rainfall intensity versus rainfall amount.

4.4.2.2 Groundwater Results and Discussion

Figures 4-17 and 4-18 show the variation of groundwater elevations for Site L between the months of July through October, both before (2005) and after (2006) the DIS was implemented.

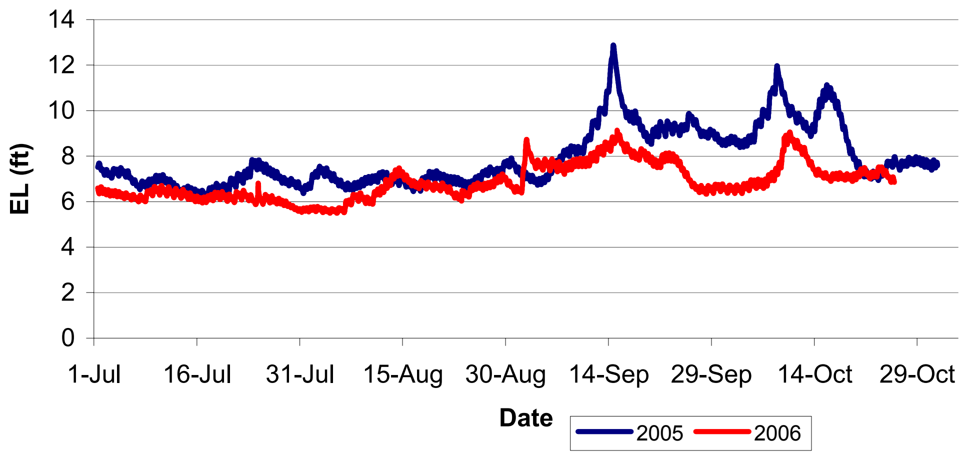

Figure 4-17. Site L groundwater fluctuations from July to October 2005 and 2006.

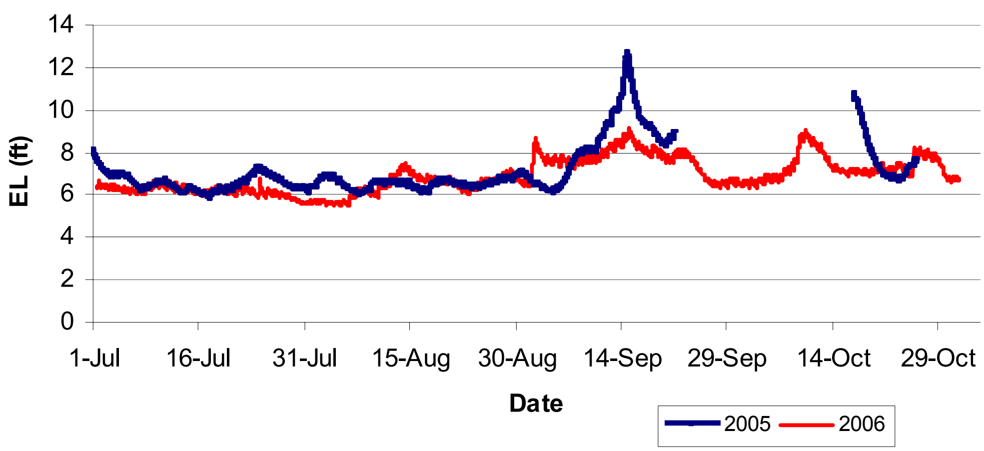

Figure 4-18. Site M groundwater fluctuations from July to October 2005 and 2006.

The water table elevations for July through October, 2006, are similar to the water table elevations for July through October 2005. As previously discussed, in 2005 there were 3 large storms, Hurricane Ophelia, Tropical Storm Tammy, and Hurricane Wilma. In 2006 there was only one large storm event, Tropical Storm Ernesto. The statistical analysis did not take into account rainfall variation in the two years. The amount of rainfall affects the level of groundwater, since the rainfall amount established the volume of water available to runoff and recharge the shallow groundwater.

The tide also influenced the water table elevation. Figure 4-19 shows the effect of tidal fluctuations on the water table elevation of Site L and Site M. Tidal data were obtained from a NOAA station located in Wrightsville Beach, located about 20 miles north of Kure Beach (NOAA 2006). The datum for the tidal data was taken from the mean lower low water (MLLW), which is defined as the average height of the lower low waters at a location over a 19-year period. (IHO 2001).

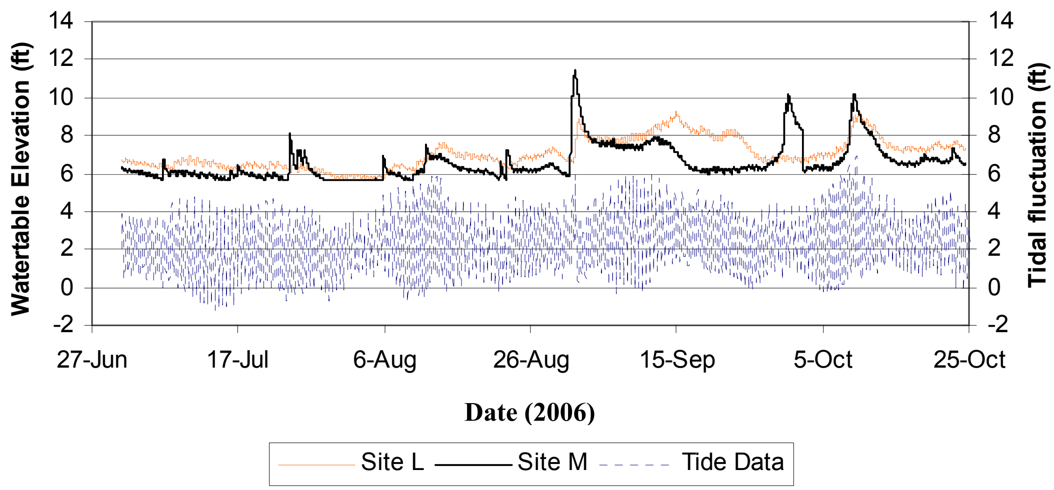

Figure 4-19. Wrightsville Beach tidal influences on groundwater elevations in Kure Beach, NC.

Tide elevations varied from -1.18 ft (-0.36 m) to 6.92 ft (2.11 m), yielding a 8.1 ft (2.5 m) difference. Of course these ranges were influenced by lunar phase, wind and storm surge. The water table elevation range at Site L was 6.30 ft (1.92 m) to 13 ft (4.0 m) in 2005 and 5.68 (1.73 m) to 9.3 ft (2.84 m) in 2006. Site M's water table elevation range was 5.81 ft (1.77 m) to 12.7 ft (3.88 m) in 2005 and 5.61 ft (1.71 m) to 11.5 ft (3.50 m) in 2006. These ranges were heavily influenced by precipitation at the site and in the contributing watershed. Closer inspection of the data revealed a daily water table fluctuation that was on average < 1 ft. Therefore, the proximity of the system to the intertidal zone resulted in daily water table elevation ranges that were influenced by tide, but were of less magnitude than the tidal fluctuations measured at the NOAA station, due to the dampening effects of the sand in the subsurface system.

Routing large the amounts of stormwater runoff through the dunes does not appear to have a strong effect on water table elevations when 2005 and 2006 data is compared. Thus for a watershed less than 8.1 ac (3.3 ha) with groundwater elevation greater than 8.1ft (2.5 m), a DIS designed to capture storms with an intensity of 0.5 in/hr (13 mm/hr) or less should not hydraulically overload the subsurface system.

4.4.2.3 Flow Mitigation Results and Discussion

4.4.2.3.1 Site L Results and Discussion

As hypothesized, at Site L, the volume of stormwater runoff captured in the DIS was significantly greater than the volume of stormwater runoff bypassed by the DIS ($p<0.01$). None of the storms caused overflow within Site L's DIS system. Figure 4-20 depicts the volume of stormwater runoff captured per storm. The 25 storms produced a total of 23, 278 ft^3 (659 m^3) of runoff, ranging from 180 ft^3 (5.1 m^3) to 4,244 ft^3 (120 m^3), and averaging 932 ft^3 (26.4 m^3). No incidents of system overflow were observed. The largest runoff volume captured occurred on September 1, 2006, Tropical Storm Ernesto. The peak intensity of Ernesto at Kure Beach was 0.89 in/hr (23 mm/hr), resulting in a

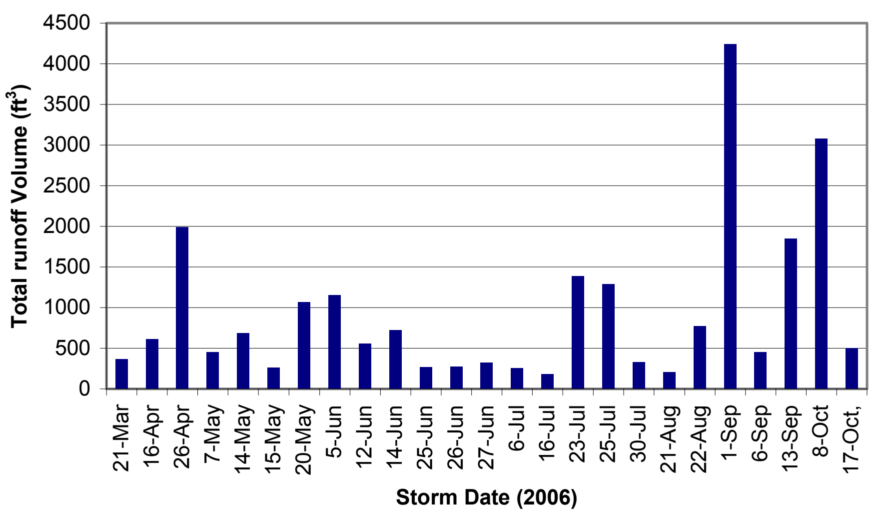

Figure 4-20. Volume of runoff captured Site L.

peak runoff rate of 0.424 cfs (0.012 m^3/s). This rate was substantially less than the infiltration rate of the soil. The water level rise in the beginning chambers was 0.55 ft (0.17 m) out of the possible 3.34 ft (1.01m) of storage height.

The peak inflow rate of stormwater runoff entering the DIS for Site L was significantly greater than the peak rate bypassing the DIS ($p<0.01$). Peak flow into the system ranged from 0.0247 cfs (0.0007 m^3/s) to 1.380 cfs (0.0391 m^3/s), averaging 0.3461 cfs (0.0098 m^3/s). The maximum peak intensity occurred during an October 8, 2006 storm event, which caused the stage in the monitoring vault to rise within 0.14 in (4.2 mm) of the overflow weir. Figure 4-21 shows the various peak flow inflow rates per storm.

Figure 4-22 shows the inflow hydrograph of both Tropical Storm Ernesto and the October 8, 2006, storm. As noted in Figures 4-20 and 4-21, the runoff volume and peak runoff rates for Tropical Storm Ernesto were 4237 ft^3 (120 m^3) and 0.424 cfs (0.012 m^3/s), and 3079 ft^3 (87.2 m^3) at 1.380 cfs (0.0391 m^3/s) for the October 8, 2006, storm. During Tropical Storm Ernesto, the maximum stage in the vault was 1.64 ft (0.50 m). In comparison, the October 8th storm maximum stage reached 2.36 ft (0.72 m), almost overflowing the bypass weir. This may be attributed to the October 8, 2006 storm's peak inflow rate exceeding Tropical Storm Ernesto's by more than a factor of three.

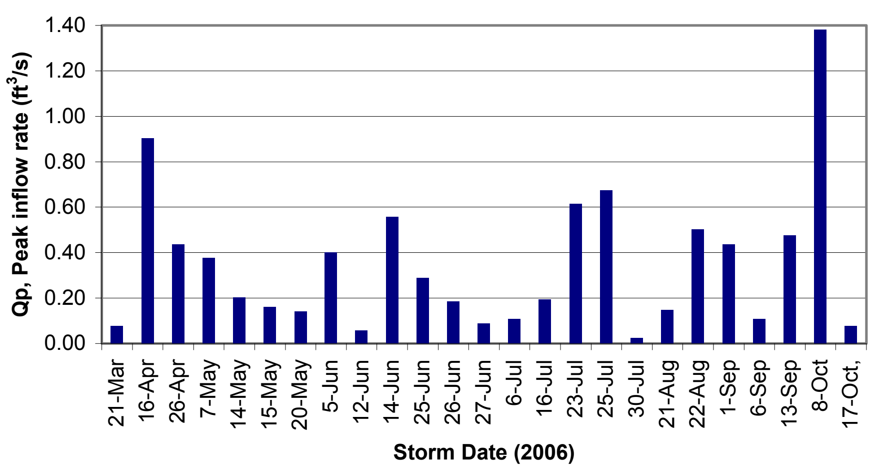

Figure 4-21. Site L peak inflow per storm.

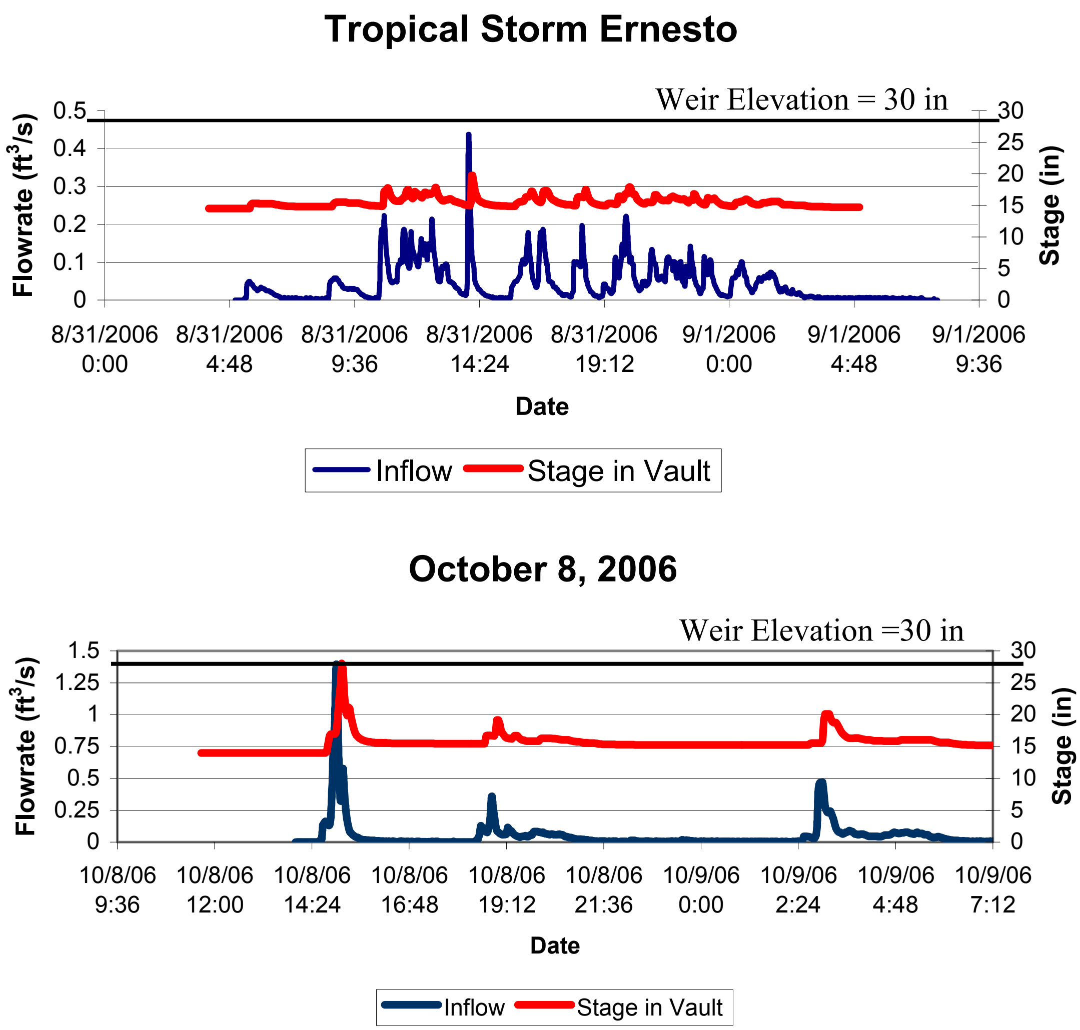

Figure 4-22. Site L Tropical Storm Ernesto and October 8, 2006, inflow hydrographs.

4.4.2.3.2 Site M Results and Discussion

The volume of stormwater runoff captured in the DIS at Site M was significantly greater than the volume of stormwater runoff that bypassed by the DIS ($p<0.001$). Five of the 25 storms caused overflow of Site M's DIS system, capturing 96% of the measured inflow volume (Figure 4-23).

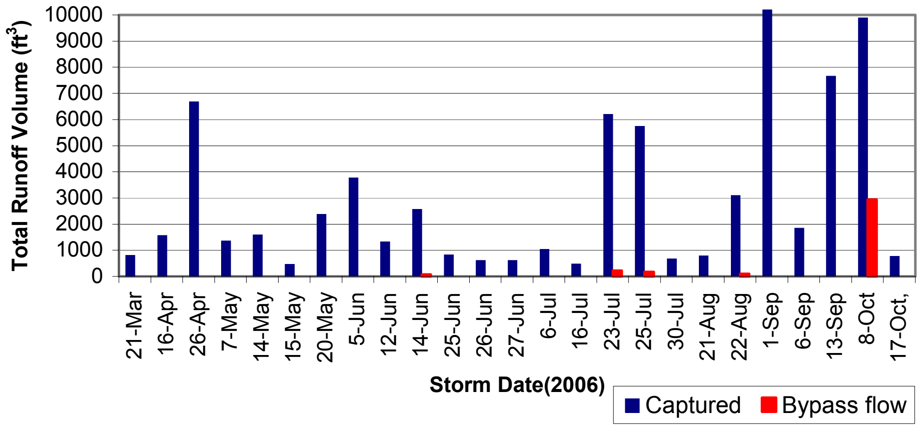

Figure 4-23. Volume of runoff captured versus overflow per storm at Site M.

The volume of the 20 storms completely captured ranged from 471 ft^3 (13.3 m^3) to 19,660 ft^3 (557 m^3), averaging 2,747 ft^3 (77.8 m^3). The 5 bypassing storms, the total runoff volume (including volume captured and volume passed) ranged from 2,642 ft^3 (74.8 m^3) to 12,855 ft^3 (364 m^3), averaging 6,215 ft^3 (176 m^3). Table 4-6 summarizes the volume of bypassed storm's runoff that was either captured or bypassed.

The largest runoff volume was from September 1, 2006, Tropical Storm Ernesto, shown in Figure 4-24. The captured runoff volume from this storm almost doubled the maximum bypassing storm's runoff volume, but the stage in the beginning chambers only rose to 1.26 ft (0.39 m) out of the possible 3.34 ft (1.01m) of storage height. This was due to the relatively low peak inflow rate of Tropical Storm Ernesto, 1.66 cfs (0.047 m^3/s). The water in the monitoring vault rose to a stage of 2.33 ft (0.71 m), less than the 2.5 ft (0.76 m) that allowed bypass. As shown is the flow rate response of the graph, Tropical Storm Ernesto lasted almost 24 hours, but exhibited staged rainfall. This

Table 4-6. Site M summary result of bypassing storms.

Storm date	Rainfall Amount (in)	Peak Intensity (in/hr)	Rainfall Duration (hr)	Peak Runoff Rate (cfs)	Stormwater entering vault* (ft^3)	Bypass Volume (ft^3)
6/14/2006	0.67	1.1	4.02	1.87	2640	74
7/23/2006	1.58	3.50	24.32	2.09	6431	222
7/25/2006	1.14	1.1	23.27	2.20	5927	170
8/22/2006	1.92	2.05	6.38	1.96	3194	92
10/8/2006	3	3.5	15.33	4.04	12837	2942

*Note: From Outfall Leading form Watershed M

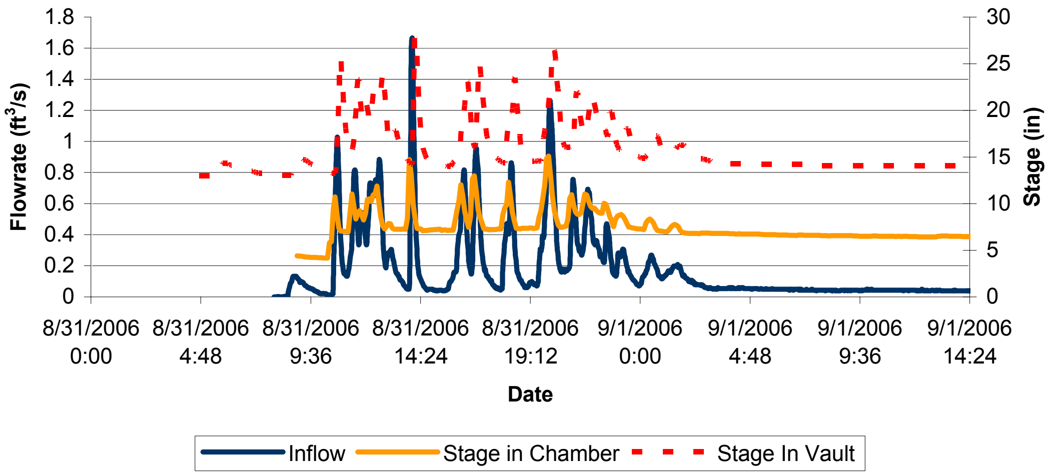

Figure 4-24. Site M inflow hydrograph, stage in vault and stage in StormChambers during Tropical Storm Ernesto (8/31/06-9/01/06).

allowed the previous runoff to infiltrate into the system before the next relatively high intensity part of the storm.

As hypothesized for Site M the peak inflow rate of stormwater runoff entering the DIS was significantly greater than the peak flow rate bypassing the DIS ($p<0.01$). Peak flow into the system ranged from 0.071 cfs (0.002 m^3/s) to 4.026 cfs (0.114 m^3/s), averaging 1.059 cfs (0.030 m^3/s). Peak inflow rates exceeding 1.80 cfs (0.051 m^3/s) caused bypass. The bypass flow rate ranged from 0.328 cfs (0.009 m^3/s) to 5.513 cfs (0.156 m^3/s), averaging 1.589 cfs (0.045 m^3/s), Figure 4-25.

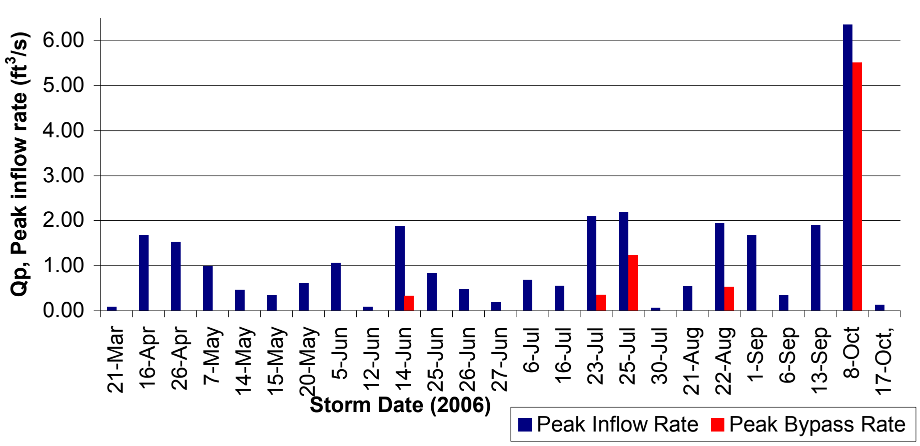

Figure 4-25. Peak inflow rate versus peak outflow rate per storm at Site M.

The storm's rainfall intensity can be used to predict if a storm will overflow the system. Rainfall intensity is significantly ($p<0.05$) predictive of bypass at Site M. Figure 4-26, shows the rainfall intensity versus rainfall amount for captured storms. In 5 of 7 rainfall events with intensity greater than 1.5 in/hr (40 mm/hr), some stormwater flow bypassed the DIS and overflowed into the existing outfall.

One storm occurred on May 7, 2006 (circled in Figure 4-26), was an example of a storm with high rainfall intensity, but low total rainfall amount that did not bypass the system.. This May storm was a 2 hour event with a rainfall amount of 0.5 in (13 mm) and peak intensity of 3.10 in/hr (78.7 mm/hr). Five days prior to this storm, there was no rain. It was speculated that this lead to greater infiltration capacity due to the antecedent conditions in the watershed, resulting in a maximum peak flow rate of only 0.989 cfs (0.028m^3/s).

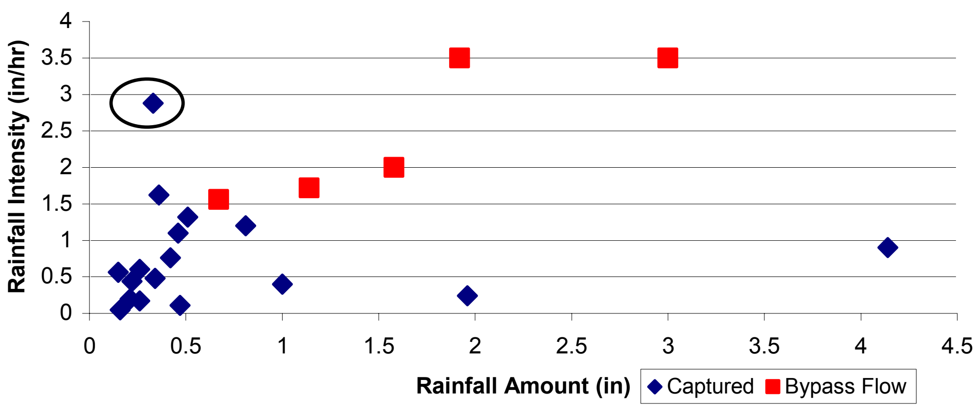

Figure 4-26. Peak rainfall intensity versus rainfall amount for captured and bypassed storms for Site M.

4.4.2.4 Design Discussion

Figures 4-27 and 4-28 shows the difference in runoff volume and peak inflow rate for storms at Site L and Site M. A difference in runoff volume and peak discharge was expected for Site L and Site M. Site L was a 4.5 ac (1.8 ha) watershed with CN = 88, while Site M was a 8.1 ac (3.3 ha) watershed with CN = 69. The NRCS method predicted a runoff volume of 530 ft^3 (15 m^3) for Site L and 1,098 ft^3 (31 m^3) for Site M

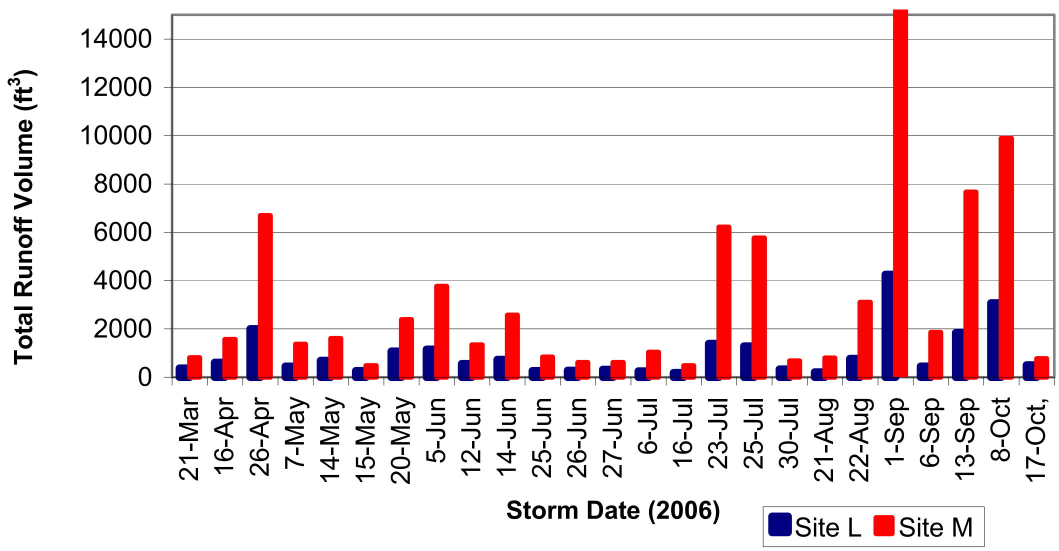

Figure 4-27. Variation in stormwater runoff volume measured at the diversion vault at Site L and Site M.

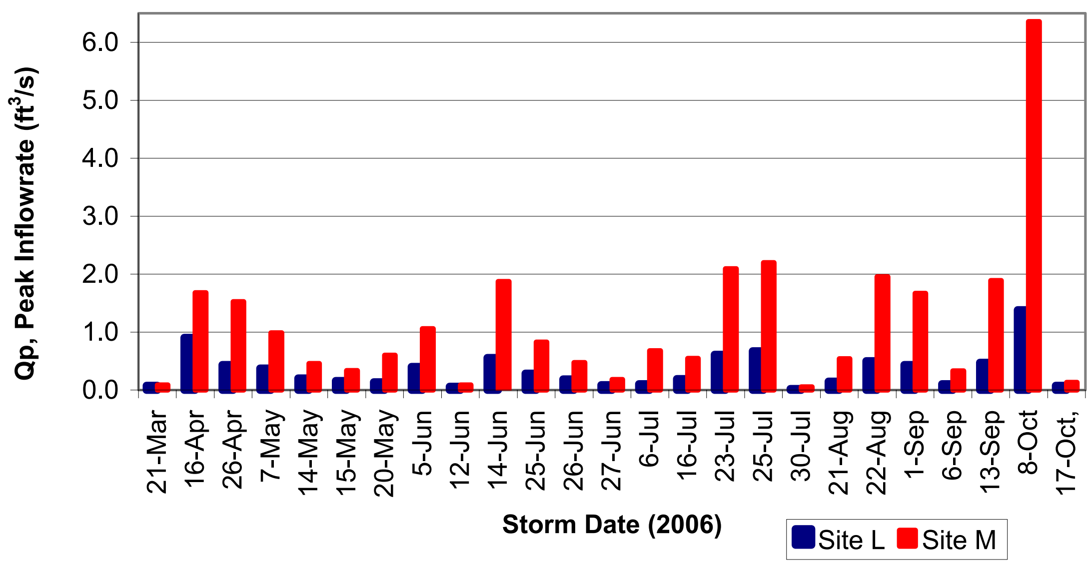

Figure 4-28. Variation in peak stormwater inflow rate measured at the diversion vault at Site L and Site M.

for a 0.50 in/hr (12.7 mm/hr) size storm. The May 7, 2006, storm produced 0.51 in (13 mm) of rain, which translated into runoff volumes of 424 ft^3 (12 m^3) for Site L and 1,377 ft^3 (39 m^3) for Site M. This slight disparity between predicted and measured values can be due to an inaccurate estimate of CN or watershed delineation for each site. When back calculating CN for the monitored storms using the NRCS method, it appears that these watersheds exhibit a different CN for storms less than 1 in (25.4 mm) when compared to storms greater than that amount. Based on observed flow data at Site L, CN for storms less than 25.4 mm (1 in) was calculated as 92, while CN for storms greater than 1 in (25.4 mm) was 74, resulting in an average CN of 83. The CN calculated for Site M was 89 and 59 for storms less than and greater than 1 in (25.4 mm) respectively, with an average CN=74. As storm sizes increase, CN more accurately characterizes the watershed (Schwab 1993). The DIS was designed to capture relatively small storms. Thus the average CN is most applicable when designing the DIS using the NRCS method. Perhaps, the Rational Method should be used when designing the system with smaller watersheds.

It also should be noted that a majority of street curb storm drains in the watershed of Site L were partially clogged with sand. This could have caused runoff from this watershed to be diverted into the storm drains flowing to Site M. This may also help explain why flow from the Site L watershed was somewhat less than predicted, and why runoff from the Site M watershed was a larger than predicted. Also, there was continuous flow during the study from the stormwater outflow pipe at Site M, most likely indicating shallow groundwater intrusion which further added to flow measured at this outfall that would have been difficult to predict.

4.4.3 Bacteria Data Results and Discussion

4.4.3.1 Summary Results

The 25 storm events captured during the months of March through October 2006, were analyzed for fecal coliform concentrations while 22 were analyzed for enterococcus concentrations. Fewer were measured for enterococcus counts due to NCDENR's laboratory schedule. Appendix B lists the statistical tests for field bacteria data.

Table 4-7 lists fecal bacteria concentrations for each storm at Site L and Site M. It is noteworthy that a North Carolina Tier 1 coastal beach (such as Kure Beach) will have to post an advisory if fecal coliform levels exceed 200 CFU/100 ml in the surf zone. Inflow fecal coliform levels ranged from 181 CFU/100 ml to 28,300 CFU/100 ml with a

Table 4-7. Summary of Fecal Coliform levels for the 25 storms.

Date	Site L Stormwater Runoff CFU/100 ml	Site L Groundwater CFU/100 ml	Site M Stormwater Runoff CFU/100 ml	Site M Groundwater CFU/100 ml
3/21/2006	3800*	<1	2280*	3
4/16/2006	2300*	<1	17200*	3
4/26/2006	181	<1	19400*	3
5/7/2006	2700*	1	3000*	<1
5/14/2006	358*	<1	760*	8
5/15/2006	570*	<1	940*	8
5/20/2006	2000*	<1	5000*	2
6/5/2006	2900*	1	5100*	2
6/12/2006	5800*	4	4700*	1
6/14/2006	820*	<1	3100*	1
6/25/2006	TNTC**	1	TNTC**	<1
6/26/2006	19000*	<1	15000*	<1
6/27/2006	4100*	1	3300*	<1
7/6/2006	10000*	1	9000*	4
7/16/2006	4762*	<1	6800*	43
7/23/2006	8200*	<1	TNTC**	18
7/25/2006	TNTC**	<1	TNTC**	86
7/30/2006	7100*	2	8000*	3
8/21/2006	TNTC**	2	TNTC**	66
8/22/2006	TNTC**	54	TNTC**	214*
9/1/2006	TNTC**	4	TNTC**	TNTC**
9/6/2006	TNTC**	<1	TNTC**	4
9/13/2006	TNTC**	4	TNTC**	18
10/8/2006	4800*	1	16600*	<1
10/17/2006	28300*	1	6500*	37

*Exceeded North Carolina State Standard of 200 CFU/100 ml
**TNTC=To Numerous to Count

median of 7,600 CFU/100 ml for Site L and ranged from 760 CFU/100 ml to 19,400 CFU/100 ml with a median of 9,000 CFU/100 ml for Site M.

All stormwater runoff bacteria concentrations exceeded the state's standard for swimmable waters except for the minimum value measured at Site L. The ground water bacteria levels ranged from <1 CFU/100 ml to 54 CFU/100 ml with a median of 1 CFU/100 ml for Site L, and ranged from <1 CFU/100 ml to TNTC ((12,000 CFU/100 ml for statistical purposes) with a median of 3 CFU/100 ml for Site M. None of the groundwater samples measured at Site L exceeded the state standard, but two samples from Site M's groundwater did. For statistical purposes, when the upper limit value was reached, (i.e. too numerous to count (TNTC)), the maximum number measured by the analysis, 6000, was multiplied by two. Also when the lower limit was reached, 1, the lowest test value allowed was divided by two (Spooner 1991).

Enterococcus concentrations per storm for Site L and M are shown in Table 4-8. For Site L, stormwater runoff enterococcus levels ranged from <10 CFU/100 ml to >2005 CFU/100 ml (4,010 CFU/100 ml for statistical purposes) with a median of 1,013 CFU/100 ml and ranged from <10 CFU/100 ml to >2005 CFU/100 ml (4,010 CFU/100 ml for statistical purposes) with a median of 1,725 CFU/100 ml for Site M. One storm event from Site L and two events from Site M did not exceed the state standard. The groundwater bacteria levels ranged from 5 CFU/100 ml to 64 CFU/100 ml with a median of 5 CFU/100 ml for Site L and ranged from 5 CFU/100 ml to 2,005 CFU/100 ml with a median of 26 CFU/100 ml for Site M. None of Site L's groundwater samples exceeded the state threshold for swimmable water standards, but six samples from Site M's groundwater did.

Table 4-8. Summary of Enterococcus levels for 22 storms.

Date	Site L Stormwater Runoff CFU/100 ml	Site L Groundwater CFU/100 ml	Site M Stormwater Runoff CFU/100 ml	Site M Groundwater CFU/100 ml
4/16/2006	344*	<10	>2005*	<10
4/26/2006	306*	<10	2005*	<10
5/7/2006	334*	10	>2005*	31
5/14/2006	1652*	64	1445*	31
5/15/2006	945*	64	>2005*	31
5/20/2006	870*	<10	334*	10
6/5/2006	1013*	<10	504*	10
6/13/2006	>2005*	<10	504*	64
6/14/2006	2005*	<10	1184*	31
6/25/2006	>2005*	<10	>2005*	10
6/26/2006	>2005*	<10	1298*	20
6/27/2006	1013*	<10	478*	<10
7/16/2006	453*	40	1298*	10
7/23/2006	2005*	<10	>2005*	429*
7/25/2006	>2005*	10	>2005*	406*
7/30/2006	10	31	<10*	<10
8/21/2006	42	<10	271*	10
8/22/2006	738*	<10	1184*	137*
9/6/2006	>2005*	31	>2005*	2005*
9/14/2006	1013*	42	>2005*	150*
10/8/2006	1091*	10	>2005*	124*
10/17/2006	>2005*	<10	>2005*	20

*Exceeded North Carolina State Standard of 104 CFU/100ml

As with the fecal coliform data, for statistical analysis, when the upper limit value was reached, >2005, the maximum number allowed by the test was multiplied by two. Also when the lower limit was reached, >10, the lowest test value allowed was divided by two (Spooner 1991).

4.4.3.2 Statistical Analysis and Discussion

Statistical analysis indicated that the concentration of fecal coliform flowing into the system was significantly greater than the concentration of fecal coliform in the groundwater for both Site L and Site M ($p<0.01$). The same was also true for enterococcus. When all storms were considered at both sites, the groundwater bacterial concentrations were 99% less than the stormwater.

At Site M, the two storms that resulted in groundwater fecal coliform concentrations that exceeded state standards were August 22, 2006, and September 1, 2006. The August 22, 2006 event also caused groundwater enterococcus levels (137 CFU/100 ml) to exceed the standards. This storm was one of the large events, allowing 3,087 ft^3 (87.4 m^3) of stormwater to infiltrate into the dunes, with an average concentration of TNTC (12,000 CFU/100 ml for statistical purposes). Groundwater concentration following Tropical Storm Ernesto had a groundwater concentration of 214 CFU/100 ml and inflow concentration of TNTC. Enterococcus analysis could not be performed for Tropical Storm Ernesto sample because the NCDENR Shellfish Sanitation lab was closed. It is interesting to note that the largest volume of stormwater routed into the dune, 19,670 ft^3 (557 m^3) with an average concentration of TNTC (12,000 CFU/100 ml for statistical purposes), caused the largest rise in groundwater fecal concentration.

The DIS at Site M, with a watershed approximately 2 times larger than Site L, captured a total runoff of 82,486 ft^3 (2,336 m^3), 3.5 times that of the total runoff infiltrated at Site L, 23,278 ft^3(659 m^3). In addition, Site M's stormwater runoff had a median bacteria concentration greater than Site L. Therefore, Site M was infiltrating more stormwater runoff with higher bacteria concentrations than Site L. This may have influenced the increased groundwater bacteria concentrations observed at Site M and not at Site L during large summer storm events.

Site L did not appear to experience bacteria overloading, as neither bacteria indicators in the groundwater beneath that DIS exceeded state standards. Site L groundwater remained under the limit during summer months, when concentrations are potentially the highest (Whitlock *et al.* 2002). The concentration of bacteria in the stormwater runoff entering the system should be as higher in the summer due to the increased temperature and of fecal coliform sources. The bacteria beneath the DIS system would tend to die off during North Carolina's drier months of October and December (Van Donsel *et al.* 1967).

Figures 4-29 and Figure 4-30 show the enterococcus concentration and stormwater runoff volume per storm. As noted earlier, groundwater concentrations did not exceed the state standard during the study, but the highest concentrations were measured during the summer and following T.S. Ernesto. The six storms that exceeded the enterococcus standard at Site M did not occur until five months after the systems had been implemented. Two peaks of note followed two storms on July 23 and 25, 2006. It is difficult to determine at this time if the system was overloaded with bacteria from previous storms or a result of several large storms occurring close together in the warmest months of the study.

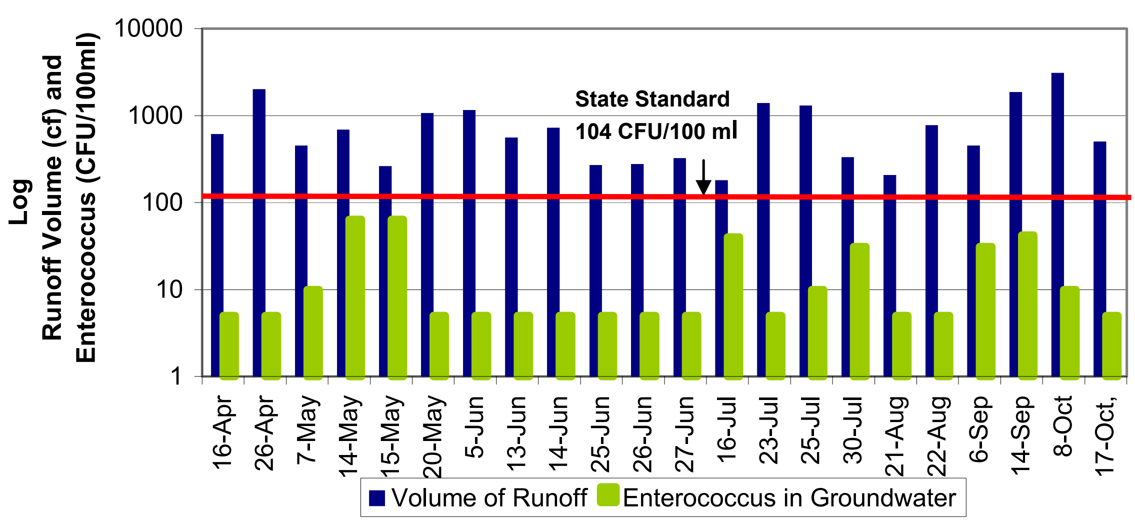

Figure 4-29. Semi-log comparison of groundwater enterococcus concentration and volume of runoff per storm event at Site L

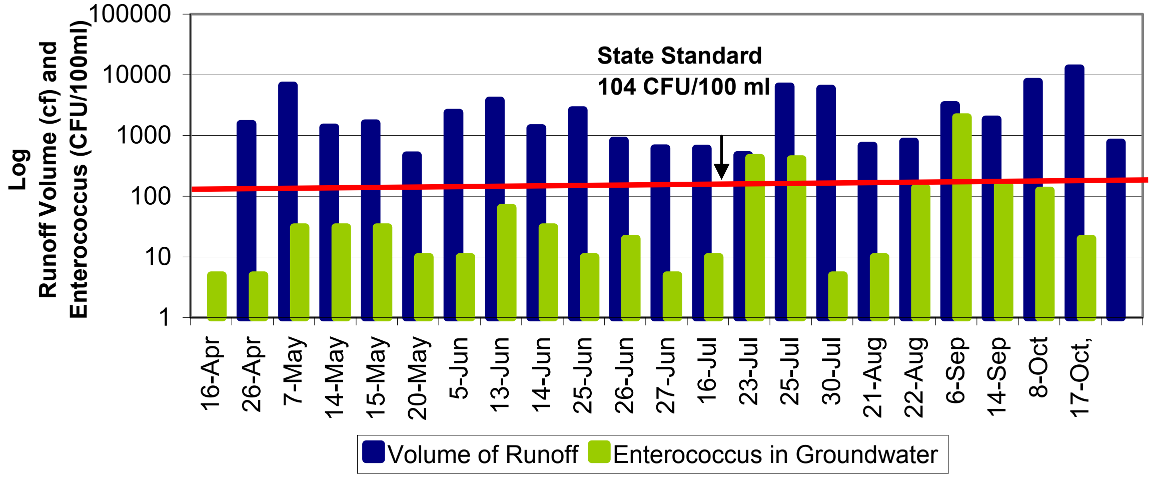

Figure 4-30. Semi-log comparison of groundwater enterococcus concentration and volume of runoff per storm event at Site M

After those two storms, the concentration of enterococcus in the groundwater at Site M the surpassed state standards on August 22, September 6, September 14, and October 8. All of these storms infiltrated at least 1,847 ft^3 (52.3 m^3). For Site L, only the volume for the October 8 event (3,087ft^3 (87.4 m^3)) exceeded the runoff volume of 1,847 ft^3 (52.3 m^3), which was substantially less than 12,819 ft^3 (363 m^3) of runoff at Site M, for the same event.

The groundwater fecal coliform bacteria concentrations at both Site L and M, after the implementation of the DIS, were significantly similar ($p < 0.05$) to the groundwater fecal coliform bacteria concentrations before the DIS was installed. Figures 4-31 and 4-32 are SAS generated graphs that show log probability plots for groundwater bacteria concentration before and after DIS installation at for Site L and Site M. Unfortunately, this comparison could not be made for enterococcus since the preconstruction sampling regime did not include enterococcus. Preconstruction sampling was completed before the agreement with the Shellfish Sanitation and Recreation Water Quality Laboratory in Wrightsville Beach to analyze our samples was finalized.

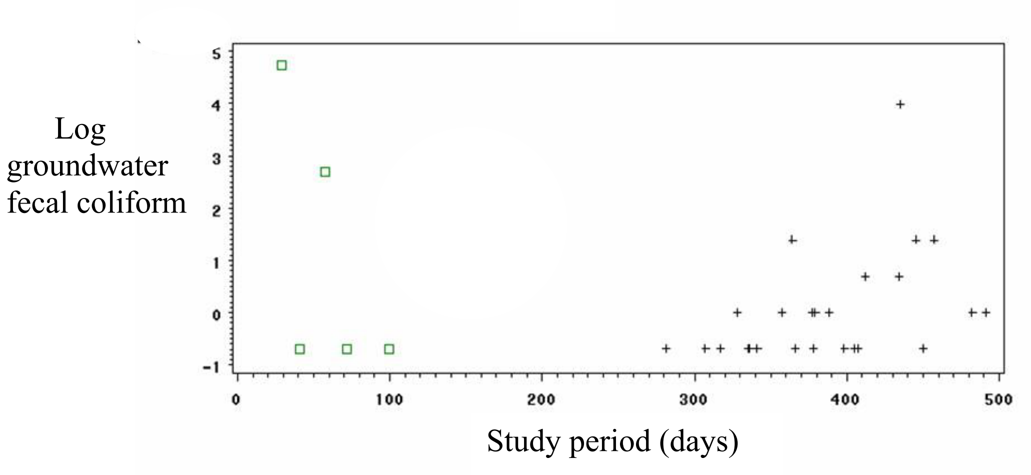

Figure 4-31. SAS output for Site L of fecal coliform groundwater concentration before DIS (square symbol) and after (plus symbol).

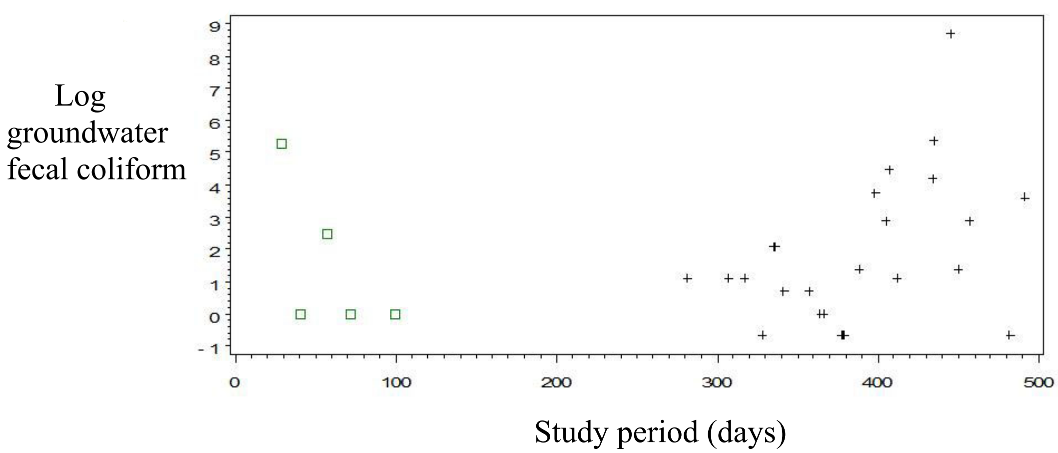

Figure 4-32. SAS output for Site M of fecal coliform groundwater concentration before DIS (square symbol) and after (plus symbol).

It should be noted that there were a limited number of groundwater bacteria samples collected before the DIS was installed. Also, it was difficult to determine if there was a seasonal variation in the groundwater bacteria data. Whitlock *et al.* (2002) and Van Donsel *et al.* (1967) have reported seasonal variations in survival of indicator bacteria. Another consideration is the constituents found in stormwater runoff. Anderson and Rounds (2003) reported *E. coli* concentrations, at a mixture of urban and agricultural sites, to be statistically correlated with concentrations of suspended sediment, TP, and NO_3-N. Anderson and Rounds found that *E. coli* concentrations were not statistically correlated to temperature, but found the largest *E.coli* concentration amount occurring during the warmest water temperature. Since inflow nutrient and sediment levels are not known in this study (since including those constituents would have exceeded the water quality budget for this grant), a comparison cannot be made, but it is important to keep these correlations in mind when analyzing the data.

Even without analyzing stormwater constituents, the data indicated increased bacteria loading of the groundwater at Site M towards the end of the study. The fact that Site L infiltrated less stormwater runoff and never exceeded the enterococcus state standard, and Site M only started to surpass the standards near the conclusion of measurement, indicates the potential of increased bacteria loading in the system at Site M. Bacteria colonies may have been stabilizing and growing using organic matter deposited from the sediment in stormwater runoff. Gerba and McLeod (1975) reported a longer survival of *E. coli* colonies in marine waters when a greater content of organic matter was present. If data collection would have extended into the winter months, it would have interesting to observe if the groundwater concentrations would have decreased to near background levels.

In must be noted, all groundwater samples discussed were collected within 30 ft (10 m) of the DIS and approximately 150 ft (50 m) from the surf zone. Therefore these samples should represent the most conservative bacterial counts. Further reduction in groundwater concentration would possibly be observed closer to the surf zone.

5.0 CONCLUSIONS

The main objective of this study was to design and analyze an innovative coastal stormwater BMP - the Dune Infiltration System. If the system worked as designed, stormwater runoff that would have normally been directly discharged onto the beach or into the ocean would be routed into the dunes, and infiltrate the underlying sand. The objectives outlined in Chapter 3 were used as guidelines to analyze the DIS.

The Dune Infiltration System captured all runoff associated with the designed rainfall intensity of 0.5 in/hr (12.5 mm/hr) or less, thus, reducing the volume of stormwater that transports potential pathogenic microorganisms through the ocean outfalls towards the recreational areas. The DIS implemented at Site L never overflowed into its associated outfall, capturing storms with intensity up to 3.5 in/hr (90 mm/hr). The DIS at Site M captured all storms with intensities up to 1.1 in/hr (28 mm/hr) and only overflowed 5 times out of 25 measured storms. Both DIS systems captured a measured total of 105,764 ft^3 (2,995 m^3) and bypassed 3,500 ft^3 (99 m^3), therefore routing 97% of the stormwater runoff from both watersheds (12.6 acres) into the dunes.

One objective was to determine if routing and discharging stormwater runoff in the dunes elevated the level of the groundwater beneath the dunes. Routing the stormwater into the dunes did not substantially change the elevation of the water table. The largest storm-induced fluctuation, 4.9 ft (1.5 m) occurred at Site M during Tropical Storm Ernesto. Pre-construction groundwater data shows a greater groundwater elevation increase during 2005 with Hurricane Ophelia. During Ophelia maximum tidal fluctuations caused groundwater to elevate 8.1 ft (2.5 m). Thus, there appears to be limited and short-lived groundwater mounding phenomenon beneath the DIS system at Site L and Site M.

Another objective was to determine if routing and discharging stormwater runoff into the dunes increased the bacteria level in the groundwater beneath the dunes. This was tested by identifying a range of fecal coliform and enterococcus concentrations in an urban coastal community's stormwater runoff. Inflowing stormwater runoff had concentrations of fecal coliform concentrations ranging from 181 CFU/100 ml to 28300 CFU/100 ml with a median of 7600 CFU/100 ml and from <10 CFU/100 ml to >2005 CFU/100 ml with a median of 1298 CFU/100 ml for enterococcus. The groundwater concentrations were significantly less ($p < 0.001$) than the inflow with fecal coliform concentrations ranging from <1 CFU/100 ml to 214 CFU/100 ml with a median of 1.5 CFU/100 ml. For enterococcus concentrations the range was from <10 CFU/100 ml to 2005 CFU/100 ml with a median of 10 CFU/100 ml. The groundwater enterococcus concentrations at both sites were significantly ($p<0.01$) less than the stormwater runoff inflow concentration. In addition, the groundwater fecal coliform bacteria concentrations at both Site L and M, after the implementation of the DIS, were significantly similar (p

<0.05) to the groundwater fecal coliform bacteria concentrations before the DIS was installed.

North Carolina's indicator bacteria standards were exceeded only in Site M's groundwater. Groundwater samples surpassed the limit on 2 of the 25 events for fecal coliform and 6 of the 22 for enterococcus. These incidents occurred five months after the system was implemented and during large storm events. Further groundwater samples at the site would help determine whether these increased trends were seasonal or due to bacterial overloading. In must be noted, these samples were collected approximately 150 ft (50 m) from the surf zone, so further reduction in groundwater concentration would possibly be observed closer to the surf zone.

Because this system significantly reduced the discharge frequency and volume of stormwater flowing from these ocean outfalls, the Dune Infiltration System has successfully decreased potential health dangers for local coastal residents and tourists at these two locations in Kure Beach. Based on the results of this relatively short study, the Dune Infiltration System has the potential to become an effective BMP at the remaining ocean outfalls in Kure Beach and elsewhere. The DIS implementation at ocean outfalls in other coastal towns is dependent upon the dune elevation, distance to the surf zone, site hydrology, and watershed characteristics. In addition, public acceptance and permitting by the NC Division of Coastal Management must be addressed before more systems are installed.

6.0 DIS RECOMMENDATIONS

The following is a list of recommendations to consider for the Dune Infiltration System:

1. Continue monitoring of the existing Dune Infiltration Systems to better understand the hydrology and the fate and transport of bacteria in the dune system surrounding the DIS. A small, 1-year grant has been secured by NCSU-BAE from the Water Resources Research Institute (WRRI) to perform a more detailed monitoring study at the site which will include a more intense measurement and analysis of the site hydrology and bacteria concentrations residing in the dunes.

2. Yearly inspection of debris build-up within the start chambers of the DIS. The Town of Kure Beach Public Works Department will perform this task with a vacuum truck.
3. A more rigorous design process may be investigated for the DIS. Infiltration equations such as Green-Ampt may provide a more accurate sizing criteria when land is limited. The Darcy equation method provided a conservative estimate of the number of chambers needed to design each DIS.
4. Further implementation based on this data should be only at sites with watersheds less than 10 acres and with NRCS Curve Numbers of around 80. Further research may verify that these systems can be used on larger watersheds or ones that are less permeable.

7.0 IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

Presentations relating to the Dune Infiltration System have been given to several local and state organizations. Research presentations have been given and conference proceedings papers have been submitted for several national/international conferences. Kure Beach Dune Infiltration System's implementation and findings have been presented in the August 2006 American Society of Agricultural and Biological Engineers (ASABE) International Conference, July 2006 StormCon Conference, and March 2007 International Low Impact Development (LID) Conference. In addition, the site has been a tour stop on three coastal stormwater related tours. Below is a list of presentations and conference proceedings papers generated from this research grant. Further implementation of another Dune Infiltration System is planned for 2-3 more outfalls near the Kure Beach Pier. NCDOT, the Town of Kure Beach and NCSU-BAE are currently planning this collaborative endeavor. Presentations at conferences, and at local and state meetings will continue through this new phase of the project.

Conferences
Bright, T.M., M.R. Burchell II, W.F. Hunt III. 2007. An examination of a Dune Infiltration System's Impact on Coastal Hydrology and Bacterial Removal 2nd International Low Impact Development Conference, Wilmington, NC. March 11-14, 2007.

Bright, T.M., M.R. Burchell II, W.F. Hunt III. 2006. Stormwater dune infiltration system for reducing pollutant loads from ocean outfalls. Paper number 062308 ASABE International Meeting, Portland, OR. July 9-12, 2006.

Burchell, MR, WF Hunt, JT Smith and T. Bright. 2005. Stormwater Dune Infiltration System – Kure Beach, NC. ASAE Joint Section Meeting – SC, GA, and NC. Charleston, SC June 2 - 3, 2005.

Wright, J.D., T.M Bright, W.F Hunt III, and M.R Burchell. 2006. Innovative Stormwater Retrofits for Barrier Island Applications. StormCon National Conference, Denver, CO. July 24-27.

Professional Meetings
Bright, T.M., M.R. Burchell II, W.F. Hunt III. 2007. An examination of a Dune Infiltration System's Impact on Coastal Hydrology and Bacterial Removal. North Carolina Division of Water Quality Stormwater Workshop. February 13, 2007.

Burchell, M.R. and W.F. Hunt III. Coastal Stormwater Infiltration Systems. 2006. NC Coastal Resources Commission Meeting. November 17. Atlantic Beach, NC.

Burchell, M.R., W.F. Hunt, and T. Bright. 2006. Kure Beach Stormwater Infiltration system. NCDOT Stormwater Program Researchers Review Session. May 23. Raleigh, NC.

Local Meetings
Burchell, M.R. Kure Beach Town Council Meeting - Discussion of Dune Infiltration System. September 19, 2006.

Burchell M.R. Kure Beach - Beach Information Night - Discussion of Dune Infiltration System. October 23, 2006.

Popular Press
"New Storm Chambers to Reduce Stormwater Discharge to the Ocean" by W.H. Killough III in *The Island Gazette* Carolina Beach, NC. February 9, 2006.

"Kure Beach Stromwater Outfall Experiment Shows Good Results" by W.H. Killough III in *The Island Gazette* Carolina Beach, NC. October 5, 2006.

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A.0 APPENDIX A-FIELD STUDY HYDROLOGY STATISTICS

A.1 Flow Mitigation-Volume

- SAS Data Input

Storm Date	Site L captured (m^3)	Site L overflow (m^3)	Site M captured (m^3)	Site M overflow (m^3)
03/21/06	10.33	0	22.943	0
04/16/06	17.34	0	44.291	0
04/26/06	56.44	0	189.149	0
05/07/06	12.83	0	38.520	0
05/14/06	19.35	0	45.215	0
05/15/06	7.38	0	13.326	0
05/20/06	30.23	0	67.547	0
06/05/06	32.67	0	106.611	0
06/12/06	15.82	0	37.745	0
06/14/06	20.50	0	72.667	2.1
06/25/06	7.63	0	23.557	0
06/26/06	7.85	0	17.430	0
06/27/06	9.10	0	17.329	0
07/06/06	7.20	0	29.408	0
07/16/06	5.09	0	13.496	0
07/23/06	39.19	0	175.794	6.3
07/25/06	36.53	0	163.047	4.8
07/30/06	9.35	0	19.188	0
08/21/06	5.89	0	22.586	0
08/22/06	21.90	0	87.850	2.6
09/01/06	120.18	0	556.712	0
09/06/06	12.82	0	52.328	0
09/13/06	52.24	0	217.021	0
10/08/06	87.15	0	280.194	83.3
10/17/06	14.15	0	21.891	0

- SAS Analysis

The data in not normally distributed, thus a non-parametric analysis was performed. Since the data being compared are numerically very different (0 versus 30-550), univariate test was performed. The volume treated was statistically different from the volume bypassed for both Site L and Site M ($p<0.0001$).

--------------------------- site=L ----------------------

The UNIVARIATE Procedure
Variable: scordat

Moments

N	25	Sum Weights	25
Mean	26.3664	Sum Observations	659.16
Std Deviation	27.6456359	Variance	764.281182
Skewness	2.2070484	Kurtosis	5.16639951
Uncorrected SS	35722.4246	Corrected SS	18342.7484
Coeff Variation	104.851765	Std Error Mean	5.52912717

Basic Statistical Measures

Location		Variability	
Mean	26.36640	Std Deviation	27.64564
Median	15.82000	Variance	764.28118
Mode	.	Range	115.09000
		Interquartile Range	23.57000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	4.768637	Pr > |t|	<.0001
Sign	M	12.5	Pr >= |M|	<.0001
Signed Rank	S	162.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	120.18
99%	120.18
95%	87.15
90%	56.44
75% Q3	32.67
50% Median	15.82
25% Q1	9.10
10%	7.20
5%	5.89
1%	5.09
0% Min	5.09

------------------------ site=M ---------------------

The UNIVARIATE Procedure
Variable: scordat

Moments

N	25	Sum Weights	25
Mean	89.4698	Sum Observations	2236.745
Std Deviation	116.782597	Variance	13638.1749
Skewness	2.93612618	Kurtosis	10.5368611
Uncorrected SS	527437.326	Corrected SS	327316.199
Coeff Variation	130.527392	Std Error Mean	23.3565194

Basic Statistical Measures

Location		Variability	
Mean	89.46980	Std Deviation	116.78260
Median	44.29100	Variance	13638
Mode	.	Range	543.38600
		Interquartile Range	84.02500

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	3.830614	Pr > |t|	0.0008
Sign	M	12.5	Pr >= |M|	<.0001
Signed Rank	S	162.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	556.712
99%	556.712
95%	217.021
90%	196.894
75% Q3	106.611
50% Median	44.291
25% Q1	22.586
10%	17.329
5%	13.496
1%	13.326
0% Min	13.326

A.2 Flow Mitigation-Peak Flow Rate

- SAS Data Input

Storm Date	Site L Peak Flow captured (m^3/s)	Site L Peak Flow bypassed (m^3/s)	Site M Peak Flow captured (m^3/s)	Site M Peak Flow bypassed (m^3/s)
03/21/06	0.0022	0.0000	0.0025	0.0000
04/16/06	0.0256	0.0000	0.0475	0.0000
04/26/06	0.0124	0.0000	0.0432	0.0000
05/07/06	0.0107	0.0000	0.0280	0.0000
05/14/06	0.0058	0.0000	0.0130	0.0000
05/15/06	0.0046	0.0000	0.0096	0.0000
05/20/06	0.0040	0.0000	0.0170	0.0000
06/05/06	0.0113	0.0000	0.0301	0.0000
06/12/06	0.0016	0.0000	0.0025	0.0000
06/14/06	0.0158	0.0000	0.0530	0.0093
06/25/06	0.0082	0.0000	0.0234	0.0000
06/26/06	0.0053	0.0000	0.0135	0.0000
06/27/06	0.0025	0.0000	0.0051	0.0000
07/06/06	0.0030	0.0000	0.0192	0.0000
07/16/06	0.0055	0.0000	0.0155	0.0000
07/23/06	0.0174	0.0000	0.0593	0.0099
07/25/06	0.0191	0.0000	0.0622	0.0346
07/30/06	0.0007	0.0000	0.0015	0.0000
08/21/06	0.0042	0.0000	0.0153	0.0000
08/22/06	0.0142	0.0000	0.0554	0.0151
09/01/06	0.0124	0.0000	0.0472	0.0000
09/06/06	0.0030	0.0000	0.0094	0.0000
09/13/06	0.0135	0.0000	0.0535	0.0000
10/08/06	0.0391	0.0000	0.1800	0.1561
10/17/06	0.0022	0.0000	0.0037	0.0000

- SAS Analysis

The same univariate test was performed as mentioned in Section B.2. The peak rate of inflow was statistically different from the peak rate that bypassed in both Site L and Site M ($p<0.0001$).

--------------------- site=L ---------------------

The UNIVARIATE Procedure
Variable: scordat

Moments

N	25	Sum Weights	25
Mean	0.009772	Sum Observations	0.2443
Std Deviation	0.00889445	Variance	0.00007911
Skewness	1.73404163	Kurtosis	3.80413241
Uncorrected SS	0.00428597	Corrected SS	0.00189867
Coeff Variation	91.0197652	Std Error Mean	0.00177889

Basic Statistical Measures

Location		Variability	
Mean	0.009772	Std Deviation	0.00889
Median	0.005800	Variance	0.0000791
Mode	0.002200	Range	0.03840
		Interquartile Range	0.01050

NOTE: The mode displayed is the smallest of 3 modes with a count of 2.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	5.493312	Pr > |t|	<.0001
Sign	M	12.5	Pr >= |M|	<.0001
Signed Rank	S	162.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	0.0391
99%	0.0391
95%	0.0256
90%	0.0191
75% Q3	0.0135
50% Median	0.0058
25% Q1	0.0030
10%	0.0022
5%	0.0016
1%	0.0007
0% Min	0.0007

------------------------- site=M -----------------------

The UNIVARIATE Procedure

Variable: scordat

Moments

N	25	Sum Weights	25
Mean	0.023424	Sum Observations	0.5856
Std Deviation	0.0167809	Variance	0.0002816
Skewness	0.40159763	Kurtosis	-1.1738085
Uncorrected SS	0.02047546	Corrected SS	0.00675837
Coeff Variation	71.6397663	Std Error Mean	0.00335618

Basic Statistical Measures

Location		Variability	
Mean	0.023424	Std Deviation	0.01678
Median	0.019200	Variance	0.0002816
Mode	0.002500	Range	0.05200
		Interquartile Range	0.03070

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	6.979364	Pr > |t|	<.0001
Sign	M	12.5	Pr >= |M|	<.0001
Signed Rank	S	162.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	0.0535
99%	0.0535
95%	0.0494
90%	0.0475
75% Q3	0.0403
50% Median	0.0192
25% Q1	0.0096
10%	0.0025
5%	0.0025
1%	0.0015
0% Min	0.0015

A.3 Correlation Between Rainfall Intensity and Bypass Storms

- SAS Data Input

Success (0) or Failure (1) Success = Captured	Rainfall Amount (mm)	Rainfall Intensity (mm/hr)
0	4.064	1.27
0	7.9	1.524
0	11.938	2.794
0	11.684	27.94
0	5.588	4.064
0	6.604	4.318
0	25.4	5.334
0	8.636	9.652
0	6.604	38.1
0	4.572	13.462
0	3.81	14.2875
0	10.668	15.61171
0	105.156	22.86
0	31.2	41.148
0	8.382	73.152
0	12.954	78.74
0	76.2	88.9
0	49.784	3.556
0	20.574	12.446
1	17.018	27.94
1	28.956	27.94
1	40.132	88.9
1	48.768	52.07
1	76.2	88.9

- SAS Analysis

A logistic test was used to determine if overflow could be predicted based on the rainfall intensity and amount. A logistic test is a binary test that tests for the probability of success. It was found that there was no significant evidence ($p>0.05$) of using a storm's rainfall amount to predict the probability of bypass, but there was significant evidence ($p<0.05$) of using a storm's rainfall intensity to predict the probability of bypass.

The LOGISTIC Procedure with Amount and Intensity

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	3.5409	1.2939	7.4893	0.0062
intensity	1	-0.0415	0.0218	3.6280	0.0568
amount	1	-0.0260	0.0207	1.5824	0.2084

The LOGISTIC Procedure-Intensity Only

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	2.6865	0.9860	7.4241	0.0064
intensity	1	-0.0343	0.0174	3.8908	0.0486

A.4 Correlation Between Peak Inflow Intensity and Bypass Storms

- SAS Data Input

Success (0) or Failure (1) Success = Captured	Peak Runoff rate (m^3/s)
0	0.00248
0	0.047544
0	0.043231
0	0.02797
0	0.013045
0	0.009595
0	0.017035
0	0.030053
0	0.00248
1	0.052976
0	0.023398
0	0.013514
0	0.005142
0	0.019232
0	0.015475
1	0.05927
1	0.06224
0	0.001538
0	0.015273
1	0.055416
0	0.047191
0	0.009436
0	0.053535
0	0.18
1	0.00371

- SAS Analysis

A logistic test was used to determine if overflow could be predicted peak inflow rate (See B.4). It was found that there was no significant evidence ($p>0.05$) of using a storm's peak inflow rate to predict the probability of bypass.

The LOGISTIC Procedure

Analysis of Maximum Likelihood Estimates

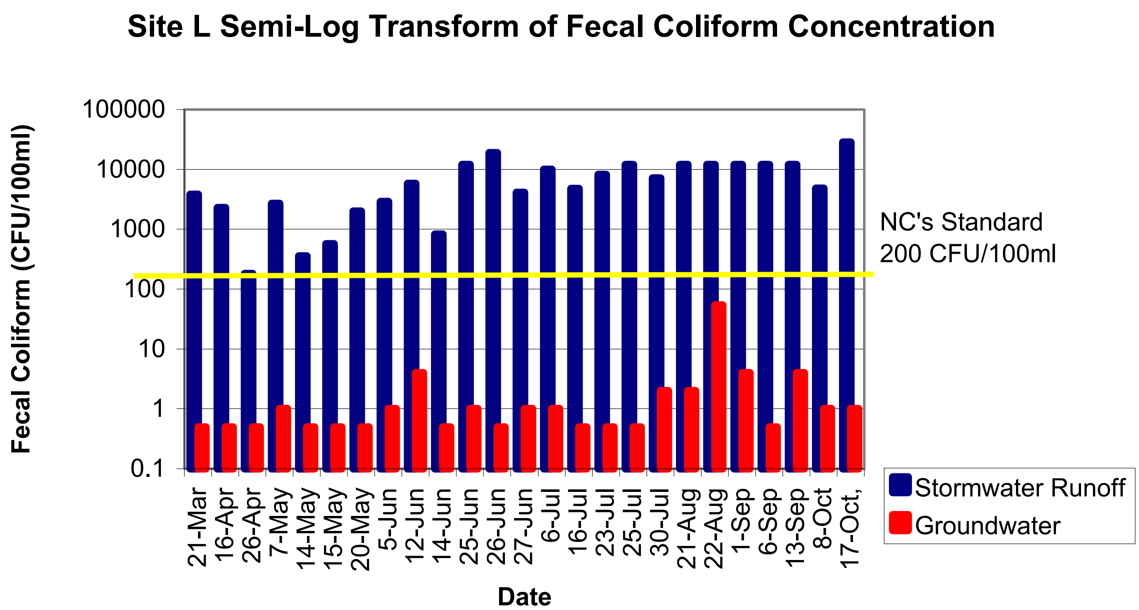
Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	2.0794	1.0607	3.8436	0.0499
intensity	1	9.4570	184.7	0.0026	0.9592

B.0 APPENDIX B-FIELD STUDY BACTERIA STATISTICS

B.1 Inflow/Groundwater Fecal Coliform Concentration

- SAS Data Input

Date	Site L Stormwater Runoff CFU/100 ml	Site L Groundwater CFU/100 ml	Site M Stormwater Runoff CFU/100 ml	Site M Groundwater CFU/100 ml
3/21/06	3800	0.5	2280	3
4/16/06	2300	0.5	17200	3
4/26/06	181	0.5	19400	3
5/7/06	2700	1	3000	0.5
5/14/06	358	0.5	760	8
5/15/06	570	0.5	940	8
5/20/06	2000	0.5	5000	2
6/5/06	2900	1	5100	2
6/12/06	5800	4	4700	1
6/14/06	820	0.5	3100	1
6/25/06	12000	1	12000	0.5
6/26/06	19000	0.5	15000	0.5
6/27/06	4100	1	3300	0.5
7/6/06	10000	1	9000	4
7/16/06	47662	0.5	6800	43
7/23/06	8200	0.5	12000	18
7/25/06	12000	0.5	12000	86
7/30/06	7100	2	8000	3
8/21/06	12000	2	12000	66
8/22/06	12000	54	12000	214
9/1/06	12000	4	12000	12000
9/6/06	12000	0.5	12000	4
9/13/06	12000	4	12000	18
10/8/06	4800	1	16600	0.5
10/17/06	28300	1	6500	37



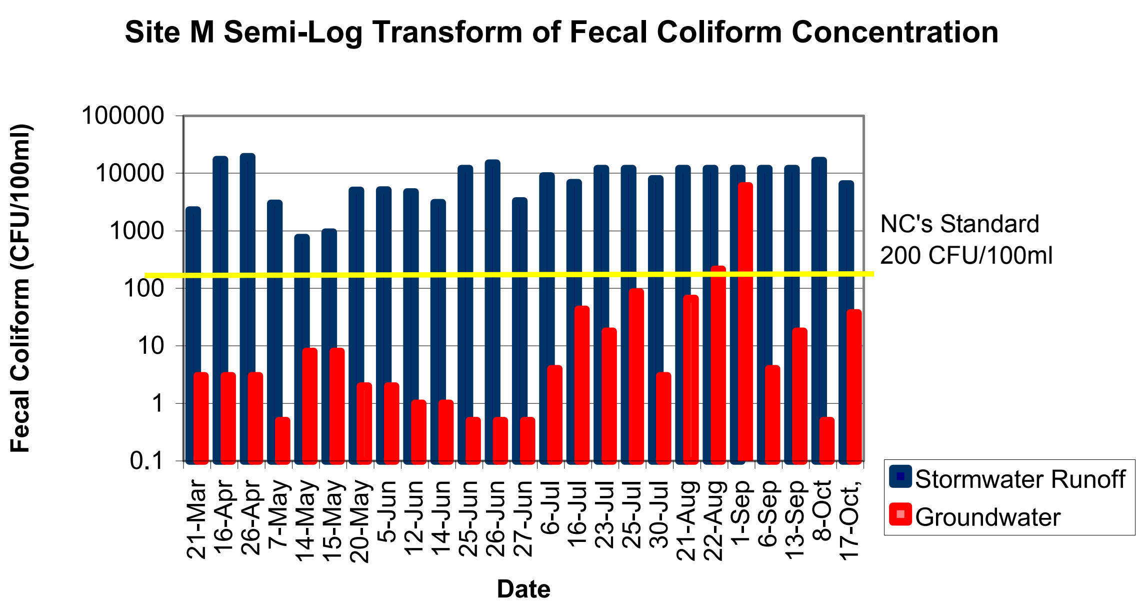


Figure B1. Fecal coliform concentrations in stormwater and groundwater during 2006

- SAS Analysis

Since the data was slightly skewed, the natural log of the bacteria concentrations were taken. Proc Mixed was run in SAS, since the data was normalized and dependant. A significant difference was found ($p < 0.001$) between the runoff fecal coliform concentration and the groundwater bacteria concentration for both sites.

---------------------- site=L ----------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
SP(POW)	0.9000
Residual	2.0941

Null Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
1	0.00	1.0000

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Intercept	1	24	854.85	<.0001

---------------------- site=M ----------------------

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
SP(POW)	0.9000
Residual	5.2414

Null Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
1	0.00	1.0000

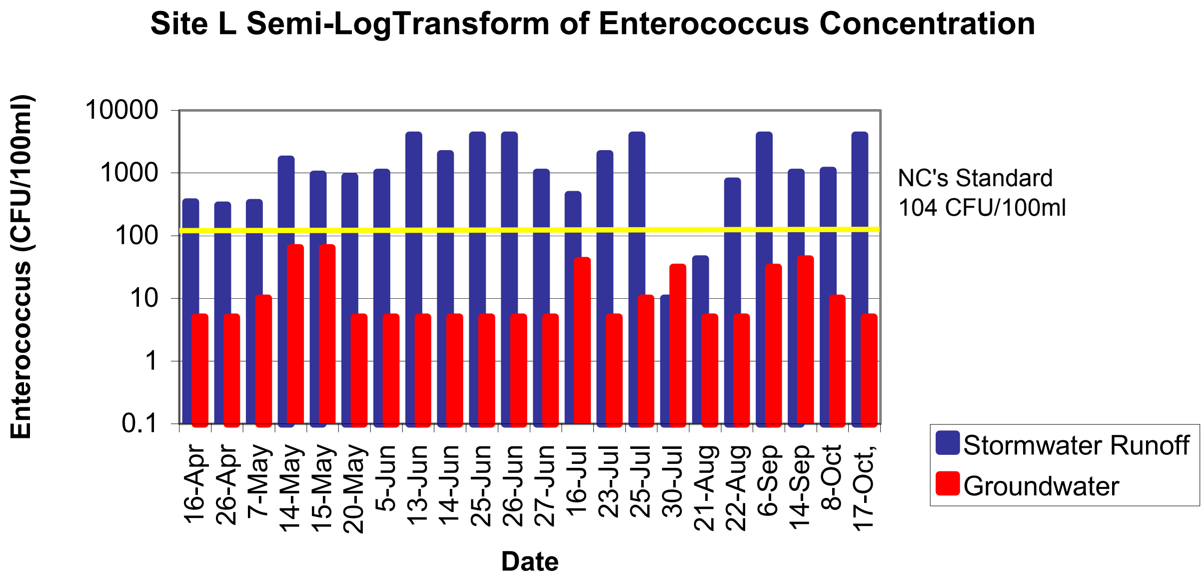
Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Intercept	1	24	235.20	<.0001

B.2 Inflow/Groundwater Enterococcus Concentration

- SAS Data Input

Date	Site L Stormwater Runoff CFU/100 ml	Site L Groundwater CFU/100 ml	Site M Stormwater Runoff CFU/100 ml	Site M Groundwater CFU/100 ml
4/16/2006	344	5	4010	5
4/26/2006	306	5	2005	5
5/7/2006	334	10	4010	31
5/14/2006	1652	64	1445	31
5/15/2006	945	64	4010	31
5/20/2006	870	5	334	10
6/5/2006	1013	5	504	10
6/13/2006	4010	5	504	64
6/14/2006	2005	5	1184	31
6/25/2006	4010	5	4010	10
6/26/2006	4010	5	1298	20
6/27/2006	1013	5	478	5
7/16/2006	453	40	1298	10
7/23/2006	2005	5	4010	429
7/25/2006	4010	10	4010	406
7/30/2006	10	31	5	5
8/21/2006	42	5	271	10
8/22/2006	738	5	1184	137
9/6/2006	4010	31	4010	2005
9/14/2006	1013	42	4010	150
10/8/2006	1091	10	4010	124
10/17/2006	4010	5	4010	20



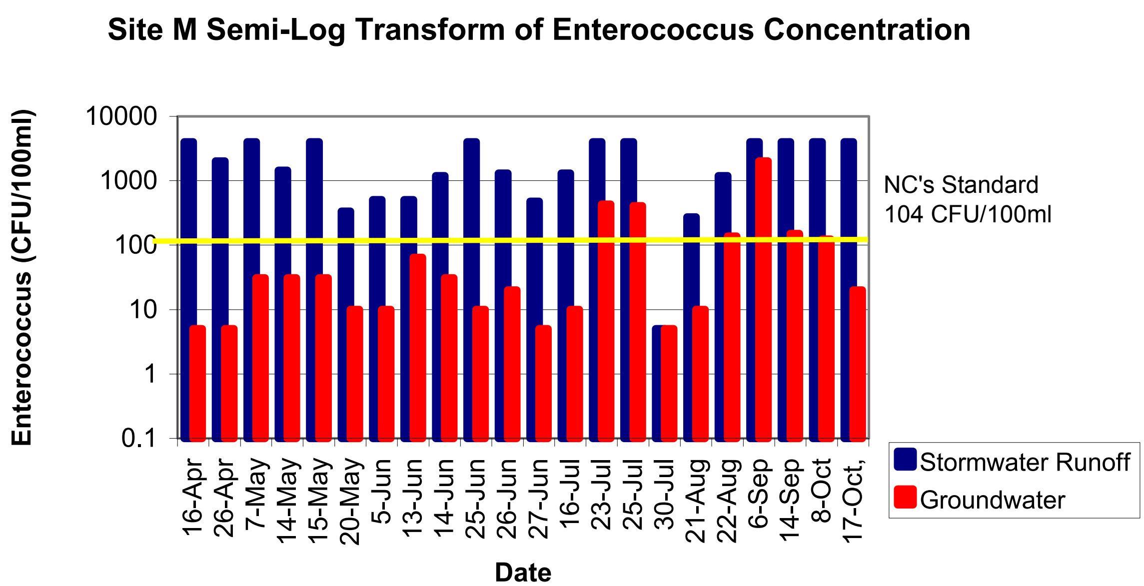


Figure B2. Enterococcus concentrations in stormwater and groundwater during 2006

- SAS Analysis

Since the data was slightly skewed, the natural log of the bacteria concentrations were taken. Proc Mixed was run in SAS, since the data was normalized and dependant. A significant difference was found ($p < 0.001$) between the runoff enterococcus concentration and the groundwater bacteria concentration for both sites.

```
----------------------- site=L ---------------------

                The Mixed Procedure

              Covariance Parameter
                    Estimates

              Cov Parm      Estimate

              SP(POW)         0.9000
              Residual        3.6850


        Null Model Likelihood Ratio Test

        DF     Chi-Square       Pr > ChiSq

        1            0.00            1.0000

          Type 3 Tests of Fixed Effects

                  Num      Den
 Effect            DF       DF     F Value     Pr > F

 Intercept          1       21      122.03     <.0001
------------------- site=M ---------------------

                The Mixed Procedure

              Covariance Parameter
                    Estimates

              Cov Parm      Estimate

              SP(POW)         0.9000
              Residual        2.8308



        Null Model Likelihood Ratio Test

        DF     Chi-Square       Pr > ChiSq

        1            0.00            1.0000

          Type 3 Tests of Fixed Effects

                  Num      Den
 Effect            DF       DF     F Value     Pr > F

 Intercept          1       21      107.22     <.0001
```

B.3 Groundwater Fecal Concentration Before and After DIS

- SAS Data Input

Used data entered in C.1 along with table below

	L-12 CFU/100ml	M-12 CFU/100ml
7/12/2005	110	200
7/24/2005	0.5	1
8/10/2005	23	12
8/24/2005	0.5	1
9/21/2005	22	0.5

- SAS Analysis

Since the data was slightly skewed, the natural log of the bacteria concentrations were taken. Proc Mixed was run in SAS, since the data was normalized and dependant. No significant difference was found at Site L or Site M ($p > 0.05$) between bacteria concentrations in the groundwater before and after the system was implemented.

```
--------------------- site=L ----------------------
               The Mixed Procedure

            Convergence criteria met.


          Covariance Parameter Estimates

         Cov Parm      Subject     Estimate

         SP(POW)       system        0.3092
         Residual                    1.9191

         Null Model Likelihood Ratio Test

         DF     Chi-Square       Pr > ChiSq

          1           0.58           0.4464


          Type 3 Tests of Fixed Effects

                  Num       Den
Effect             DF        DF     F Value     Pr > F

system              1      26.5        2.30     0.1410
```

---------------------- site=M ----------------------

The Mixed Procedure

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
SP(POW)	system	0.8618
Residual		5.3049

Null Model Likelihood Ratio Test

DF	Chi-Square	Pr > ChiSq
1	9.35	0.0022

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
system	1	9.62	0.05	0.8330