STORMWATER PILOT PROJECT FOR NCDOT MAINTAINED OCEAN OUTFALLS AND ASSOCIATED OUTLETS

OCEAN OUTFALL MASTER PLAN

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Introduction and Objectives

Stormwater outfalls in coastal NC are a cause for concern given the patterns and magnitude of precipitation, altered local landscapes (Line et al. 2000; Napton et al. 2010; Mallin et al. 2001), and the potential for delivery of significant loads of contaminants during hurricanes and Nor'easters (Parker et al. 2010, Converse et al. 2010, Stumpf et al. 2010). The North Carolina (NC) Shellfish Sanitation and Recreational Water Quality Section (NCSSRWQ) routinely monitor over 200 coastal beach and estuarine sites for the fecal indicator bacteria (FIB) group, *Enterococcus* spp. North Carolina ranks 6th in the country in beach-related tourism and beaches contribute significantly to the State's economy. Beach water quality is generally good in North Carolina during dry weather periods, but storms, and the resulting stormwater, lead to significant numbers of beach swimming advisories (Coulliette et al. 2009, Converse et al. 2010, Dorfman and Roselot 2011, Gonzalez et al. 2012). Storms produce overland runoff and increases in groundwater levels in shallow coastal systems, potentially delivering feces from dogs (and other pets), wildlife, livestock, and birds as well as human fecal contamination from overburdened sewage and septic systems as is relevant to the respective transport vector and into receiving waters.

To address the challenges and potential economic impacts to beach –related tourism noted above, the objectives of this study were to: 1) characterize the watersheds and stormwater outfalls that contribute to nine NC Department of Transportation outfalls, including, but not limited to, land-use, groundwater, FIB and fecal sources, and flow assessments, 2) use the information to prioritize for pilot BMP implementation the nine outfalls based on pollutant load, discharge volumes, watershed characteristics, and fecal contamination patterns, 3) install and assess the performance of a pilot BMP, 4) conduct assessments of the distribution of FIB and fecal source markers by storm size and transport distance along receiving water beaches, and 5) develop preliminary BMP plans and designs to mitigate the remaining outfalls using results from the pilot project as well as other systems. An additional and vital component to this project was an engaged stakeholder and project team process which was conducted throughout project.

Characterization of Watersheds

A significant data collection effort was completed for the project consisting of topographic and existing stormwater infrastructure surveys, geotechnical investigations (hydraulic conductivity testing as well as groundwater monitoring), and surface water quality sampling. In the project report, the data are organized by watershed. The watersheds are characterized by size, which ranges from 61 to 488 acres, and levels of imperviousness from 11 to 34%. Watersheds were also characterized for density of on-site septic systems, the numbers of new septic systems, and septic system repairs from 2006-2012. Data collected show that all watersheds have significant areas where groundwater routinely and consistently interacts with drainage ditches and other storm drain pipe systems. This interaction has a major influence on water quality and the factors affecting BMP performance and effectiveness. The level of connectivity of impervious surfaces to existing drainage infrastructure is also a key factor in the hydraulic behavior of the watersheds. These factors as well as those noted above were used to develop complex models to quantify the hydrologic and hydraulic behavior of the watersheds.

Existing Stormwater Management Programs

Both the Towns of Kill Devil Hills and Nags Head have updated their stormwater ordinances in recent years to require that new developments capture and treat the stormwater runoff from the 10-year, 24-hour storm event (approximately 4.3 inches of rainfall), which is more rigorous than the NCDEQ requirement for coastal counties to capture and treat the first 1.5 inches of rainfall. Both towns have also instituted measures to facilitate and encourage low impact development (LID) techniques, with Nags Head having developed an LID Design Manual and Kill Devil Hills having developed a GIS-based Stormwater Decision Support System to target stormwater management measures and evaluate their performance. In addition to the Town's efforts, NCDOT has a Highway Stormwater Program which includes efforts to retrofit stormwater BMPs to treat runoff from DOT facilities and existing roadways where appropriate, and DOT has developed a BMP Toolbox which includes design and implementation guidance for structural treatment practices in the linear environment.

Hydrologic/Hydraulic Modeling

Based upon past experience, a coupled surface water/groundwater model was selected and developed for each outfall watershed. This tool is used to more accurately predict the range of water quantity loadings expected at each outfall. This model is the Danish Hydraulic Institute's (DHI) MIKESHE model which links surface water and groundwater behaviors in the same model. The model was locally calibrated and verified using a number of storm events, particularly those capturing extreme conditions (e.g. Tropical Storms Ernesto and Barry) and then was further developed over a series of synthetic storm events as well (which ranged from more frequent events such as a 1- and 2-inch rainfall to less frequent events such as the 50-yr and 100-yr events). The modeling analysis predicted that the peak outfall discharges would range from 0.3 to 8.7 cfs during a 1-inch rainfall event and from 3.9 to 37 cfs during a storm event with a 2-year recurrence interval, based on median groundwater levels at the onset of the storm event. For the 100-yr event, the peak discharges ranged from 18 to 76 cfs. Peak flows for all outfalls were also generated for the full range of storm events based on 90th percentile groundwater levels at onset in order to evaluate the importance of antecedent soil moisture conditions as well as for even more extreme events. A detailed discussion of the modeling results is presented in Section 2.5 of the document. It is interesting to note that the estimates for peak discharges from the model are significantly less than peak discharges that would be estimated using normal techniques such as the Rational Method and TR-55. The lack of stormwater infrastructure such as curb and gutter, which delivers flows more quickly, as well as the level of infiltration and groundwater transmission in these systems are likely the main reasons for this behavior as well as the fact that most hydrologic techniques were developed in hydrographic settings much different than coastal barrier islands.

Outfall Bacteria Monitoring

The extensive flow measurements, the advanced surface/groundwater modeling effort, coupled with novel molecular microbial source tracking (MST) tools to assess fecal contamination made this project a seminal advancement in the field of stormwater research. During the initial prioritization (2006-2008), Fecal *Bacteroides* spp. concentrations were measured to provide additional information on the presence of fecally-associated indicator bacteria (e.g. Converse et al. 2010). The qPCR assay for Fecal *Bacteroides* spp. specifically targets and quantifies the most common human Bacteroides spp. While the assay has been shown to quantify concentrations of bacteria that can be human-associated, the assay is not specific to only human fecal contamination. The assay is not currently utilized alone for monitoring of fecal contamination sources, but it has been demonstrated over an array of studies to improve existing FIB monitoring programs when added to standard indicator monitoring. This is important given that swimmers exposed to contaminated waters with high concentrations of this marker have exhibited human health impacts. In addition, when the fecal Bacteroides spp. marker is paired with a highly specific human fecal contamination marker, such as "HF183", the two have provided a more definitive indicator of the presence of human fecal contamination in stormwater. For this effort, during the upcoast/downcoast fecal source assessments, molecular markers specific to human and seagull fecal contamination were employed (e.g. Layton et al. 2013, marker referred to as "HF183", and Sinigalliano et al. 2013, referred to as "gull marker").

From 2006-2008, stormwater outfalls were characterized during storm events using a state-of-the art flow assessment and FIB/source marker study design. During any given storm, rates of discharge (reported in gallons per minute, gpm) were measured in real-time, along with environmental parameters including temperature, salinity, rainfall, and turbidity. The storm event sampling response was highly adaptive, with a grab sampling approach utilized for all nine outfalls. Therefore, depending on storm intensity and duration, a minimum of two grab samples were taken, with a maximum of seven grab samples collected over the duration of an event**.**

Rainfall totals for the storms characterized over the duration of the study ranged from 1.19 to 3.89 inches, sometimes with multiple individual rainfall events within a longer total storm event period (up to 3 or 4 days total). Microbial contaminant concentrations in outfall discharges during storm events from all nine stormwater monitoring locations exceeded existing recreational beach water quality standards in nearly all samples collected (NC State Standard: *Enterococcus* 104 MPN or CFU per 100 ml), sometimes exceeding the standard by two orders of magnitude (e.g. >24,196 MPN per 100 ml). For example, the mean Enterococcus value exceeded the single sample recreational water quality standard across all but two storm sampling events shown on **Table 34** (exceeded 95% of the time). Additionally, even though the State of NC does not utilize *E. coli* active management of marine recreational water quality, *E. coli* concentrations demonstrated similar patterns for all outfalls during all storms. Loading of *Enterococcus* spp. and *E. coli* was assessed using the combined flow and grab sample concentration data.

During longer storm events (>24 hours), loading of *Enterococcus* and *E. coli* ranged from 10^{10} - 10^{12} cells per hour (flows in exceedance of ca. 1,000 gpm or 2.2 cfs). During shorter or less intense storms, loading of *Enterococcus* spp. and *E. coli* was lower, generally ranging from 10^{7}-10^{9} cells per hour (e.g. Gallery Row, December 2007 storm, maximum flow of 227 gpm or 0.5 cfs). Rainfall events were captured over all four seasons and over a range of conditions, permitting an examination of a wide range of conditions where groundwater levels were strongly influenced by the intensity and duration of precipitation. The fact that concentrations of FIB, in particular *Enterococcus* spp., were very high (>10,000 MPN per 100 ml) at all outfalls for almost all of the storms measured, given the range of conditions assessed, is important. To that end, there are four essential points to be drawn from this study that are important for future consideration of this issue.

- An isolated "first flush" dynamic of FIB was not observed. "First flush" type delivery was not observed for concentrations or for loading patterns of FIB. At the onset of storms, FIB concentrations in outfall discharges were generally above the state standard, and either remained similar, or increased over the course of the storm. For example, at the South Nags Head outfall, during the storm from September 5-11, 2008, 2.4 inches of rain fell. Over the duration of this prolonged storm event, flows reached a maximum of nearly 3,700 gpm (8.2 cfs), with five total grab sampling events occurring over the duration of the storm. At the onset of this storm, *Enterococcus* and *E. coli* concentrations were ca. 15,000 and 4,000 MPN per 100 ml respectively. The concentrations of Enterococcus sp. over the course of these five samples collected over the duration of the storm ranged from 15,531-51,720 MPN per 100 ml. These values are over 100 times the state standard for recreational water quality use. The total loading observed for this single storm was 9.88×10^{12} *Enterococcus* cells.
- Fecal *Bacteroides* spp. levels and measurements of HF183 human specific marker (where conducted) indicate the potential for human fecal contamination to be present in outfall discharges. Taken together, the observed FIB and Fecal *Bacteroides* spp. indicate a potential risk to human health from the stormwater outfalls studied, even during some of the smaller storm events.
- Extensive groundwater, septic system, and antecedent rainfall analyses have not yet been completed. However, initial information appears to indicate that specific watersheds (for example Martin Street, Baum Street, and Gallery Row) appear to be impacted by groundwater/surface water interactions that are exacerbated during larger storms. In these specific systems, groundwater levels increase rapidly during the rising limb of the hydrograph, and stay high throughout the storm sampling periods and into the tail of the hydrograph. This indicates a likely connection with the groundwater until late in the storm event, and also possibly compromising the functionality of septic systems particularly in watersheds with high septic system densities. To this point, notably, in Gallery Row, during the period of study, the groundwater level at one of the monitoring locations was above the ditch invert level for 90% of the study. Moving forward, it will be important for these groundwater/septic system/drainage systems' interactions to be quantitatively and thoroughly assessed.
- This study was focused entirely on monitoring *during storm events* and as a result the FIB data should be considered in this context. When it is dry, 95-98% of the time, water quality conditions are excellent. North Carolina is ranked 5th in the Natural Resources Defense

Council's current publication on beach water quality conditions, *Testing the Waters* (http://www.nrdc.org/water/oceans/ttw/nc.asp?loc=North%20Carolina).

The combination of grab sampling and flow information collected throughout the prioritization period of the study supported a ranking of the outfall systems based upon attributes such as; 1) *Enterococcus* sp. concentrations observed in discharge; 2) *Enterococcus* loading; and 3) hydrological characteristics. The prioritization allowed the research team to focus on these sites for BMP assessment, look at specific problem areas for a more thorough evaluation, and for the upcoast/downcoast transport assessment.

Regional and Outfall-Specific Findings

Potential relationships amongst the data collected over the duration of this project along with key watershed characteristics were examined (See **Table 1).** Some important indications can be drawn from the aggregated data:

- Baum and Martin Street Outfalls appear to behave similarly in hydrology and microbiological contaminant delivery. Baum Street watershed regularly exhibits FIB at high concentrations for both FIB parameters, with high Fecal *Bacteroides* spp. concentrations. However, the watershed has peak hydraulic flows that are consistently among the *lowest* of all watersheds for any given storm event. The flow rate is surprising, given that it is the *second largest* watershed, with fairly high imperviousness coupled with extensively developed artificial drainage network. The low flows may very well result from incidental diversion of flow through the Martin Street outfall due to the connection between the two. Martin Street consistently ranks in the high range for both flow and FIB concentrations and across all FIB indicator types, especially for Fecal *Bacteroides* spp. This outfall also consistently ranks among the highest of all outfalls for both total loading of FIB and FIB loading *rates per hour* (not shown in **Table 1**). Baum and Martin Street watersheds are the 3rd and 4th largest watersheds. Both have high numbers of built structures. They have extensive drainage systems with partially open channels. The two watersheds also have a record of the greatest number of septic repairs as well as for new septic systems.
- Gallery Row is the largest watershed, with the highest total number of impervious acres in the study. With the exception of one storm (November 2008), hydraulic flows from Gallery Row tended to be low for such a large watershed. In this watershed, low topography and saturated groundwater well data indicate the greatest potential for groundwater-septic system interaction. This watershed has the greatest number of septic systems and the highest number of septic system repairs. This outfall also consistently exhibited the highest Fecal *Bacteroides* spp. concentrations. High Fecal *Bacteroides* spp. concentrations can be indicative of human fecal sources, and high fecal Bacteroides spp. concentrations have been significantly related to human health outcomes with potential public health risks for swimmers exposed to waters with high levels of these anaerobic organisms.
- Curlew and Soundside watersheds are very small, while Conch Street was the second largest in the study. All three of these watersheds are close in proximity to one another (all three together are located within a span of 5000 linear feet of beach (less than a mile). All

three watersheds deliver high concentrations of *Enterococcus* and *E. Coli*. Given the relative concentrations of FIB, these three outfalls also appear to convey relatively lower concentrations of Fecal *Bacteroides* spp. For example, mean fecal *Bacteroides* spp. concentrations tended to remain in the tens of thousands per 100 ml. As expected, given the smaller watershed size and relatively low impervious coverage, hydraulic flows from these three watersheds tended to be on the lower side relative to other outfalls.

- The patterns of FIB delivery and flows at the South Nags Head (Old Oregon Inlet Road) watershed indicate that surface water dynamics are more important. This location is characterized by an extensive open ditch system that runs both parallel and perpendicular to the beach receiving waters. This can be observed by comparing the lengths of the open channel to the piped drainage, which equal one another. This location is characterized by vegetated ditches, which receive tidal influx in some locations, are heavily populated by birds, and other forms of wildlife. This location tends to exhibit very high *Enterococcus* concentrations, but relatively low *E. coli* and *Bacteroides* spp. This is the pattern of contamination that would be expected from fecal material from wildlife and birds. Furthermore, the delivery of this material to the ocean receiving waters confirms the relationship between build-up and wash-off mechanisms of FIB delivery. Hydraulic flows from South Nags Head are also consistently among the highest for all outfalls. This was the case for any given storm and for flows associated with open ditch systems. It is possible, given the characteristics of this location, that *Enterococcus* sp. are living and growing in the ditch soils and stagnant waters. Therefore, it may be that a "legacy population" of *Enterococcus* sp., not related to recent fecal contamination, is a prominent feature at this site. This has been observed for similar conditions in other studies in eastern NC (Lauer et al. 2015).
- Whalebone Junction watershed exhibits moderate to low concentrations for all FIB indicators, but at the same time has unusually high flows for a very small watershed. The hydraulic flows may owe to somewhat dense patterns of development close to the outfall discharge location, along with a highly connected artificial drainage network. However, only limited analyses of the Whalebone watershed was conducted for microbial contaminants in comparison to some of the other watersheds studied. In addition, limited mapping data is available to accurately characterize the drainage network.

Conch Street BMP Implementation and Monitoring

Using project data, combined with information on land availability, watershed size, and tractability, the project team determined a candidate location for the installation of a new BMP for stormwater treatment. Due to high flows, high FIB concentrations, and loads at all outfalls, the BMP site selection focused on sites exhibiting ranges of flows that a single BMP could be reasonably expected to attenuate, which resulted in choosing the Conch Street Outfall for the pilot BMP site. Other criteria affecting the siting decision included beach gradient, construction logistics, and the potential for easements or land acquisition. After a thorough literature search of existing innovative and filtering technologies as well as stakeholder interaction, as stated in the original law authorizing the project, the proprietary AbTech SmartSponge system was selected for installation and testing. The pilot BMP then designed to work within the existing site constraints to the maximum extent practicable and was installed in late 2009/early 2010.

Following installation, a FIB monitoring/reduction study was initiated at the site. Over the duration of two years, six storm events were evaluated for total coliform, E. coli, and Enterococcus concentrations upstream of the BMP, in the BMP, and at the end of the Conch Street Outfall pipe. The storm event assessments were conducted over all four seasons, and covered a range of flow regimes and storm types. There were some instances in which some FIB reduction was observed. For example during two storms (August, September 2010) FIB reductions were observed for concentrations of both Enterococcus and E. coli at the end of pipe. However, the pilot BMP did not perform consistently as a remedial tool. Likely challenges to the efficacy of the system included: 1) tides preventing consistent unidirectional flow through the BMP, 2) close proximity to the groundwater table, 3) the inability of tide gates to completely seal the vault leading to a persistent condition of standing water in the BMP, which may have encouraged FIB growth, and, 4) "blinding" of the front faces of the treatment sponges due to fine sands and other debris present in the runoff rendering the antimicrobial compounds ineffective.

Upcoast/Downcoast Ocean Monitoring

One of the final objectives of this project was an "upcoast/downcoast" stormwater outfall storm assessments. This effort was to address concerns about the persistence of the bacterial survival in the stormwater discharge and the extent to which existing signage (placed only at the outfall pipe) bracketed the affected swimming contact areas. Assessing the spatial and temporal distribution of FIB both up - and down - coast of the stormwater outfalls would better inform the location and content of signage on beaches. The goal was to conduct monitoring over the course of a range of storm events for both FIB and molecular MST markers to determine the dispersion of fecal contamination during storms. We studied three stormwater outfalls, Curlew Street, Conch Street, and Soundside outfalls, which are at high-use beaches to determine the extent and magnitude of areal impact during storms of varying sizes and durations. Both culture based (FIB enumeration of *E. coli* and *Enterococcus*) and molecular methods (quantification of Fecal *Bacteroides* spp., HF183 human specific marker, and gull marker) were utilized to assess the impacts of the discharge during storm events at the three locations. Plume dispersion sampling was conducted in a subset of storms by sampling at the storm drain, as well as transects in each direction at increments of 25m up to 200m, north and south of the pipe. At Conch Street, eight storms were studied. At Curlew, three storm events, and at Soundside four storm events were studied. Three summer swimming season storm event samplings were common to all sites, Conch, Curlew, and Soundside. These three outfalls are in close proximity to one another, permitting analysis of spatial resolution of the indicator levels. For all storms and for all samples collected at the end of the pipe of the three outfalls, *Enterococcus* and *E. coli* concentrations exceeded recommended standards, sometimes by more than 2 orders of magnitude (n=44). Of additional concern is that during almost all storms, *Enterococcus* concentrations at distances 200 m from the outfall pipe remained in exceedance of the State standard of 104 MPN per 100 ml over the duration of storms. Fecal Bacteroides concentrations during storm events, were observed to be very high (10^4-10^6 at the end of pipe during several storms. Furthermore, HF183, the human specific marker of fecal contamination was detected at both the outfall and in samples along the beach, indicating the presence of human fecal contamination that could pose possible serious public health risk. While the molecular MST marker for gull contamination was not measured for all storms, when it was quantified, the contribution of sea gull fecal contamination was strong and consistently found in high concentrations at both the outfalls and at distances in the beach waters both north and south from the outfall pipes in excess of 200 m in each direction. Furthermore, the gull fecal contamination signal was not observed to decrease from the outfall location up and down the coast, making it likely that additional beach - and ditch - based sources of bird fecal contamination were being contributed to the system during periods of overland runoff.

Analysis of Management Alternatives

Because this study revealed both significant concentrations and loads of FIB during storm events and because the pilot BMP was not found to consistently significantly reduce the loading, the project team looked at other BMP systems and management strategies to consider in future efforts. Given the significant role of groundwater behavior in contaminant loading, high-rate infiltration sand filters were investigated (for areas with adequate groundwater separation) as well as groundwater lowering systems, which have recently been installed in other beach communities during the course of this study. Combining adjacent outfalls, and developing them into deepwater ocean outfalls was also considered, as well as increased signage, presumptive closures, and installation of sewer systems. The analysis of treatment and management alternatives showed that the costs of retrofitting high-rate infiltration sand filters into the already built landscapes ranged in costs from slightly more than $250,000 in the smallest watershed (Soundside Road) to over $5.3 million in the largest (Gallery Row). High-rate infiltration sand filters offer advantages for this application because they are relatively compact and comparable in cost to conventional rain gardens. However, high-rate infiltration sand filters have been demonstrated to have highly variable bacterial removal rates. High-rate infiltration sand filters also present constraints in that they will only treat up to about 1 acre per installation and they require almost three feet of separation between the groundwater table and the surface for effective performance. This last constraint results in significant portions of the ocean outfall watersheds as untreatable ranging from 24% of the developed portion of the Conch Street watershed as unsuitable for infiltration treatment to 100% of the Old Oregon Inlet Road and Curlew Street watersheds. Importantly, surface BMPs offer little or no capacity to reduce bacterial pollutant loads delivered via groundwater pathways. Groundwater drawdown systems are projected to vary in cost from $2.3 million for Old Oregon Inlet Road to $7.5 million for a combined system to serve Baum and Martin Street watersheds. Relative to surface BMPs, groundwater lowering systems have the capacity to impact bacterial pollutant loads from both surface and groundwater sources, and they offer and added benefit of reducing the degree and frequency of nuisance flooding events. Monitoring results from similar existing systems in Emerald Isle and Corolla have shown them to have very low effluent levels of fecal coliforms. Despite the current legal constraint associated with the extension of outfalls to 2000 feet offshore, this alternative was examined in some detail. The projected costs for outfall extensions range from $13-18 million each for outfalls with lower flow regimes to $19 million for those with high flow regimes. Based on recent experience with other coastal towns of similar size, the installation of sewer systems is expected to exceed well over

$150M. However, installation of sewer systems would allow the on-site septic tanks to be possibly used as stormwater treatment devices.

Given the costs of the number of BMPs needed for high-rate infiltration as well as the increased risk of flooding if not properly maintained, high-rate infiltration systems are not recommended to be implemented on a wide scale. Deepwater ocean outfalls are currently illegal in North Carolina and our results from the upcoast/downcoast monitoring provide strong evidence that outfalls would have to be placed a considerable distance offshore to limit risks to human health from fecal contamination. Installation of watershed wide sewer systems was also found to be cost prohibitive and local stakeholders have expressed serious concerns that installation of widespread sewer systems would allow development densities in the watersheds to reach unacceptable levels. It is clear that any path forward will need to be developed by the local stakeholders and regulatory agencies to reach a consensus.

Given the high costs projected for each of these alternatives, the Master Plan explores potential funding alternatives in Section 4.5. To varying degrees they all require acquisition and/or use of significant areas of land and implementation of substantive new infrastructure. Many of these approaches will require public funding resources beyond those available within the local communities most impacted by these ocean outfalls. Effective solutions are likely require assistance in the form of state and federal grant and loan funding for implementation.

RECOMMENDATIONS

This project was both spatially and temporally intensive and yielded tremendous quantities of valuable data. Here we attempt to distill our technical findings into recommendations. Conclusions from the findings presented in Chapters 2 and 3 directly impact recommendations stated here.

Improve Stormwater Infrastructure Asset Inventories

Stormwater BMP retrofitting is a primary avenue through which FIB loads can be reduced in ocean outfall watersheds. In addition, stormwater BMP retrofits can reduce pollutant loads for a wide array of other pollutants, and reduce stormwater quantities to address nuisance flooding, if sited and designed for those objectives. However, identifying opportunities to site stormwater BMPs in already-built landscapes can be challenging, particularly in beach communities where available land for implementation is scarce and costly. Asset inventories will allow for effective optimization of drainage areas and hydraulic treatment volumes for BMP retrofits.

Analyze Existing Data to Better Understand Shallow Groundwater Delivery of Bacterial Contamination

The results from this project indicate that there is a potential for human fecal contamination to be present in stormwater runoff from ocean outfalls. In addition, the groundwater well monitoring data show that during storms of higher total precipitation and longer duration, there is a high frequency of interaction between groundwater and septic system drain fields. The tide also plays an important role in the delivery of microbial contaminants over the duration of longer storms due to pooling of contaminated water and subsequent release during falling tides. Together, these watershed and coastal hydrologic factors have increased the potential for delivery of human-derived bacterial contamination to the surf.

Utilize Proactive Groundwater Drawdown

As discussed in Section 4.2 of the full report, the Town of Emerald Isle, NC and the Whalehead Community on the Outer Banks of Currituck County, NC have experienced success in controlling excessive stormwater volumes and reducing the frequency, magnitude and duration of flooding events though the use of engineered groundwater drawdown systems. Monitoring data have indicated that such systems have very low levels of FIB present in their discharge. Given the similarity of context to the areas of this study, drawdown systems show promise as a means to reduce the levels of bacteria currently discharged from ocean outfalls. This is achieved by treating the floodwater as it filters through the soil column made available by drawdown (essentially utilizing the *in situ* soils as a sand filter). Based on the positive experience in Currituck County, the potential for improved storm water management warrants the installation of such a system on one outfall on a pilot basis to closely evaluate performance.

Recommendations for Towns and NCDOT

Results from this project provide detailed information regarding water volumes in storms, loading of FIB, timing of delivery of FIB within storms, and fate of FIB in receiving waters that can be effectively utilized to guide the towns through improvements in stormwater management plans. Additionally, watershed assessments including land cover and stormwater infrastructure allow the stormwater data to be analyzed in a site-specific context for each of the storm drains in this study. This information is a tremendous asset that can be used to conduct feasibility assessments in each watershed and, where tenable, design watershed-specific stormwater plans. At the outset, a major goal of this study was providing empirical information to improve stormwater management. Data and information generated by this study are well suited for application in a variety of efforts to enhance the efficacy of stormwater pollution mitigation efforts. The watershed boundaries break neatly along the border between the Towns of Nags Head and Kill Devil Hills, with the northernmost three watersheds, Baum Street, Martin Street and East Lake Drive, located entirely or predominantly (East Lake Drive) Kill Devil Hills, and the remaining watersheds located within the bounds of Nags Head. The sometimes distinct geographic settings and some observations from the vast array of data and assessments lend themselves to some recommendation for town-specific strategies as follows:

In terms of watershed priorities, there is a case to be made for focusing management efforts on the Martin Street watershed. Of all the ocean outfalls in this study, for any given storm Martin Street most consistently delivers among the highest three in terms of hydraulic flow and FIB loads, and this holds true in terms of total storm load and load rates per hour for both *Enterococcus* spp. and *E. coli*. Partly by virtue of being large watershed, but also due to fairly high levels of urbanization, the Martin Street watershed has the most developed system of artificial drainage. Any efforts to reduce, interrupt, infiltrate or divert the storm flows moving through that system will likely have positive impact on pollutant loads. Martin Street offers diverse management opportunities, including the potential for development of a combined groundwater drawdown system in conjunction with the Baum Street outfall, and the potential for a regional stormwater BMP retrofit.

Upcoast/downcoast monitoring data have indicated that there is likely some interaction between the outfalls at Soundside Road, Conch Street, and Curlew Street in terms of the transport and dispersion of their bacterial pollutant loads along the shore. While there are merits to focusing efforts on Martin Street, it would be advantageous to keep in mind that three outfalls within Kill Devil Hills are spread over a distance similar in scale to those three Nags Head outfalls. Given that they are collectively a larger set outfalls in terms of combined flow and bacterial loading, and that they serve a more urbanized landscape than the other outfalls, they should be viewed as having as strong a potential for interaction of their pollutant loads in the surf.

The Town of Nags Head has clearly experienced some success with the Septic Health Initiative by increasing awareness and facilitating higher rates of repair and improvement of on-site septic systems. There is obvious merit to increasing the resources devoted to this program and to exploring potential mechanisms to cause on-site systems to move more rapidly and in greater numbers to higher level of technology and performance among on-site systems within the jurisdiction. The analysis of potential groundwater-septic system interaction herein has point to a high potential for such interaction in the South Nags Head watershed, and especially Gallery Row. Efforts aimed at moving onsite septic systems in these watershed over to new mounded systems could be of obvious benefit. Establishment of proactive on-site wastewater treatment initiative would likely produce similar benefits in Kill Devil Hills.

As mentioned above, upcoast/downcoast monitoring data have indicated that there is likely some interaction between the outfalls at Soundside Road, Conch Street, and Curlew Street in terms of the transport and dispersion of their bacterial pollutant loads along the shore. In that light, these three outfalls should be viewed and managed in a comprehensive fashion. Should groundwater drawdown system be proven to be effective for managing bacterial loads from the ocean outfalls, these outfalls readily lend themselves to opportunities to capitalize on economies of scale by implementing a combined drawdown system. Should any single phase or portion of that system be implemented, there is obvious advantage in designing and implementing it so as to account for subsequent phases.

Given the investment already made and the lessons learned at Conch Street, The Town of Nags Head may wish to consider entering into a more deliberate partnership with NCDOT to affect recommended improvements and regular maintenance of the Conch Street BMP. Since the time the BMP was envisioned and implemented, more cost-effective treatment technologies have advanced and expanded, and designers and practitioners have learned a great deal regarding the operation, maintenance, and performance of such devices. Any efforts to improve the operation and performance of the BMP should be accompanied with sufficient monitoring efforts to gage effectiveness and support an ongoing cycle of adaptive management.

Unlike the Town of Nags Head and Kill Devil Hills, whose jurisdictions each include the watersheds for some of the outfalls, NCDOT has jurisdiction over roadways and other facilities which generate runoff that flows to all of the Dare County Ocean Outfalls. In addition, a considerable amount of the drainage infrastructure connected to the outfalls is located within NCDOT right-of ways and is under their domain. As such, effective management of stormwater and the related infrastructure will require active cooperation between the towns and NCDOT. Any efforts to retrofit green infrastructure BMPs to capture and treat stormwater from already built landscapes would offer obvious opportunities for partnerships. Groundwater drawdown systems, should they be used, will require portions of that infrastructure to be installed within NCDOT right-of-ways as well.

The most obvious opportunity for partnership would be to engage the effort to make improvements to the Conch Street BMP, or to work together in the effort to decommission it if that is the path chosen. It should be noted that both the Town of Nags Head and NCDOT contributed personnel and equipment in the collaborative effort to perform the maintenance that has occurred on the Conch Street BMP.

Consider Limited Applicability of End-Of-Pipe Solutions In Challenging Settings

The monitoring results for the pilot BMP study at Conch Street have shown that limited levels of success were achieved with the device. There was with some level of reduction in FIB concentrations during ideal conditions, predominantly occurring during periods with measurable advective flow through the device and tides low enough to eliminate tail water interference on the downstream end. Unfortunately, such conditions do not occur frequently along the northeastern NC Outer Banks. The very limited amount of topographic relief places severe hydraulic limits on such devices. The change in elevation from the lowest point of drainage system on the upstream side to the outlet below sea level on the downstream side does not always allow for sufficient head pressure to effectively move water through the device. Large structural BMP retrofit devices of this nature are more likely suitable for treating portions of outfall watersheds where space is available and hydraulic conditions are suitable, such as in the large BMP retrofit example presented in Section 4.2 of the full report.

Improve Public Education Regarding Recreational Water Quality

Given the significant FIB delivery during storms, finding an appropriate method to communicate the significance of the findings to stakeholders is essential. Public education approaches could include incentive-based programs for septic system pump-out and system improvements, educational efforts on issues related to FIB, programs describing the connections between FIB and human health, demonstrations of the limitations and sensitivities of FIB based water quality management, programs outlining remedial options ranging from watershed management to end of pipe BMPs, presentations detailing what individuals can do to help prevent stormwater pollution, and educational programs on the economic value of clean recreational waters.

Two specific examples of areas where water quality management and public education intersect are public education regarding feeding of wild birds (seagulls) and proactive pet waste pickup and disposal practices. While a dog waste pickup program is in place in Dare County, NC, there is a need to formalize this program, and provide specific locations for bags for dog waste, and enforcement of dog waste pickup practices. In the case of seagulls, while a program is very generally in place in coastal NC, it may be necessary to incentivize and to put in place a system to more specifically enforce rules and regulations regarding this issue, including the feeding of birds at restaurants and parking lots, and proper covers and closures to all trash receptacles and dumpsters.

Consider Development of Proactive Rainfall-Based Advisories for Beaches

Prior to this study, many local stakeholders were uncertain that Dare County beaches had stormwater-driven FIB issues. This study clearly demonstrated the presence of stormwater delivery of FIB and provides detailed information to craft protective rainfall-based advisories. It is clear from the upcoast/downcoast monitoring portion of this study that even short duration, small storms can result in stormwater contamination in swimming waters. The results from this study indicate that rainfall/FIB relationships exist. Other recent studies in coastal North Carolina have identified significant relationships between rainfall and *Enterococcus* sp. concentrations. To develop a presumptive rainfall advisory, it will be necessary for stakeholder interaction with the project team, to participate in full data analyses that would determine timing and geographic extent of affected areas, and then that would determine whether any rainfall advisories would be best for towns, regions, or states to issue. These preliminary decisions will also determine what data that are included in the analyses.

Rainfall-based advisories are used in many coastal states to effectively manage water quality. Rainfall-based thresholds are derived by simply relating the FIB contamination observed at the beach of interest relative to either the total amount of rainfall or rainfall related parameters such as rainfall per hour. Rainfall-based advisories are one of the most established water quality management techniques used for recreational waters, and they are also part of the most recent (2012) and a new version of EPA-based guidance on the development of real-time predictive tools for water quality management. They are based on the assumption that as rainfall increases FIB concentrations (and therefore public health risk associated with water contact) in beach waters and loading of FIB from stormwater runoff also increases. Many states develop their rainfall-based advisories using the single sample thresholds that are already in place for their beaches (e.g. Enterococcus sp. concentrations of 104 MPN or CFU/100 ml would be the established threshold of interest for NC beaches). By identifying a beach notification threshold or target FIB concentration, managers can predict exceedances of the threshold using cumulative precipitation amount, and/or storm duration and/or intensity.

Should presumptive rainfall-based advisories be implemented for affected Dare County beaches, in the event that an advisory were issued, rapid and frequent sampling could be utilized to enhance public safety and reopen beaches for recreational swimming again, as soon as possible. For instance, the Town of Wrightsville Beach has considered a system of rainfall-based advisories, under which, when an advisory was issued, FIB sampling would just six hours after the rainfall event ceases, and would occur again every six hours until the advisory was lifted, in the interest of minimizing the period of time under the advisory.

As an alternative to a pre-determined presumptive rainfall triggers and advisories, more detailed predictive modeling could be utilized, such as the multiple linear regression tool called “Virtual Beach” that is an EPA product. National guidance is available from the USEPA for the use of predictive models in the form of the new document entitled “Five Key Steps for Developing and Using a Predictive Model at Your Beach”, to be released shortly.

Consider Improved Signage at Major Outfalls

Alerting the public to the extent of stormwater runoff based contamination at the beach may require review of location and number of signs. Currently, permanent signs are placed at the stormwater outfalls and alert the public to contamination that extends to 200 feet from the stormwater outfalls. These signs are typically placed at the outfall pipe itself. The upcoast/downcoast monitoring results from this study, conducted over a wide range of storm events, clearly indicate that *Enterococcus* sp. levels along beaches impacted by outfall discharge consistently exceed water quality standards throughout and well after a storm event. Furthermore, the impact of the Enterococcus sp. contamination appears to extend to distances in exceedance of 100 meters up and down the beach from outfall pipes. In the summer, it has been noted that these events are relatively short in duration and while contamination along the beach appears to extend further than previously speculated, that the pulse of contamination is likely relatively short lived. A previous experiment conducted with a team of water quality managers in 1999 in southern California indicated that signs are not visible to the public at distances in exceedance of 25 feet (Noble et al. unpublished data). This means that, beyond a distance of 25 feet from the outfall pipe, the public are neither aware of, nor responding to signage that exists at the outfall pipe. As indicated previously some states are using rainfall-based advisories in order to alert the public to issues related to stormwater contamination at beaches. Many of those states are also implementing rapid resampling efforts following storms so as to quickly reopen beaches because contamination events can be short lived. Rapid molecular methods such as those approved by EPA for *Enterococcus* sp. can offer an avenue to provide results within 2 hours from sampling, providing a mechanism to rapidly reopen high use beach areas that were impacted by short-lived rainfall events. The levels of FIB measured in these study beaches indicate that human health risks exist in NC recreational waters at distances far from the outfall pipe and perhaps in areas not currently indicated by existing signs. To improve in the protection of public health at recreational beaches in NC that are impacted by major outfalls, it is recommended that the State water quality management agencies utilize the data collected as part of this project to develop an improved approach. An example of a possible outcome might be that the public be alerted using a web-based map tool based on precipitation. However, since summer storm events, during the height of the beach season, are often short in duration, it is likely that no one measure or solution will offer the promise of addressing this matter effectively. It is far more likely that an array of management efforts and engineered solutions, including those presented here, will be required to effectively manage the issues arising from bacterial contamination related to the discharge from the ocean outfalls.

Given this, the major recommendations include the following, scaled in order of short-term to long-term priority:

a. Consider, on the permanent signage, increasing the indicated distance of caution to the public when stormwater is actively discharging from pipes, along with improved placement of signs to promote visibility to the public. Our data indicate that a warning extending to 300-400 feet from the outfall pipe is warranted.

b. For storms of short duration, consider implementation of improved permanent signage continuously along more visible beach locations, including the usage of a web based notification system for rainfall-based advisories.

c. Consider a combination of rainfall-based advisory and rapid resampling of recreational waters using available USEPA-approved rapid methods following storm events to improve protection of public health while minimizing adverse impacts on beach visitation and economies.

Table 1. Watershed Summary Comparison

Watershed	Total Acres	Impervious Acres	Impervious Percent	Total Buildings (total)	Septic Density (per acre)	Hydric soils (acres)	Hydric Soils Percent	Forested vegetation (acres)	Forested Vegetation Percent	Total open channel length (ft)	Total length of drainage piping (ft)	Total Septic Repairs 2006-2012	Total Septic New 2006-2012	Percent Time Groundwater within 3' of Surface	Storm Date	Peak Flow	E. Coli Mean	E. Coli Range	Enterococcus Mean	Enterococcus Range	Bacteroides Mean	Bacteroides Range
																(cubic ft/second)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)
Baum Street	435	131.4	30.2	546	1.26	435	100	40	9.2	16,020	40,997	35	20	76.8	12/15/2007 - 12/16/2007	0.93	13,290	200 - 68,670	475	52 - 2,110	110,597	30,182 - 303,340
															4/20/2008 - 4/23/2008	2.38	3,625	771 - 9,208	3,240	318 - 14,136	73,704	43,908 - 91,724
															9/5/2008 - 9/11/2008	2.34	325	121 - 481	7,475	1,201 - 17,329	132,813	53,353 - 199,292
															11/4/2008 - 11/7/2008	5.15	2,730	52 - 12,997	1,648	155 - 3,873	48,164	36,690 - 64,030
Martin Street	394	103.6	26.3	861	2.19	392	99.5	149	37.8	9,821	60,598	63	31	39.8	06/03/2007 - 06/04/2007	6.38	3,386	2,382 - 5,172	13,901	5,475 - 24,196	3,321	801 - 8,081
															12/15/2007 - 12/16/2007	7.02	3,833	1,529 - 11,120	96	10 - 168	101,221	31,176 - 286,294
															04/20/2008 - 04/23/2008	4.03	854	121-2,098	1,868	460 - 5,475	59,598	55,317 - 63,571
															9/5/2008 - 9/11/2008	6.75	4,169	1,145 - 7,270	7,253	691 - 12,033	114,292	5 - 380,699
															11/4/2008 - 11/7/2008	9.78	2,753	987 - 4,106	5,942	959 - 19,863	51,604	4,867 - 168,605
E Lake Drive "Ocean House"	196	95.1	48.5	355	2.82	193	98.5	15	7.7	633	24,247	18	8	39.5								
Gallery Row "Carolinian"	488	155.7	31.9	857	1.76	481	98.6	105	21.5	12,618	11,799	104	23	89.6	06/03/2007 - 06/04/2007	2.77	3,506	323 - 5,475	15,825	888 - 24,196	11,376	10,896 - 12,065
															12/15/2007 - 12/16/2007	0.51	3,870	10 - 14,136	9,586	226 - 24,196	330,515	82,106 - 441,060
															04/20/2008 - 04/23/2008	4.03	665	318 - 1,076	986	160 - 1,968	137,631	77,072 - 255,098
															11/4/2008 - 11/7/2008	18.16	1,464	228 - 6,867	2,582	364 - 7,270	121,384	82,028 - 208,946
Curlew Street	161	34.3	21.3	345	2.14	52	32	32	19.9	6,413	3,063	35	27	76	06/03/2007 - 06/04/2007	5.18	13,571	2,382 - 24,196	19,399	9,804 - 24,196	-	-
															12/15/2007 - 12/16/2007	2.03	2,996	250 - 6,867	4,329	206 - 24,196	47,475	12,921 - 113,443
															04/20/2008 - 04/23/2008	-	3,407	581 - 9,804	2,405	749 - 7,270	39,798	24,940 - 49,550
Conch Street	438	61.3	14	323	1.35	351	80.1	154	35.2	7,020	3,642	41	5	76	06/03/2007 - 06/04/2007	2.61	1,148	657 - 1,674	2,100	1,071 - 3,130	6,129	3,320 - 9,586
															9/5/2008 - 9/11/2008	4.01	2,985	350 - 6,131	7,652	959 - 14,670	69,788	5 - 254,585
															11/4/2008 - 11/7/2008	8.4	1,783	441 - 4,352	1,083	158 - 2,310	34,032	9,521 - 69,859
Soundside Road "Casino"	45	12	26.7	59	1.31	42	93.3	1.4	3.1	523	1,759	11	1	94.7	06/03/2007 - 06/04/2007	2.56	246	51 - 374	814	384 - 1,246	-	-
															12/15/2007 - 12/16/2007	2.03	152	5 - 668	57	5 - 170	23,234	7,914 - 79,454
															04/20/2008 - 04/23/2008	3.72	152	10 - 801	434	62 - 1,529	10,285	7,965 - 13,862
															9/5/2008 - 9/11/2008	2.74	14,176	3,654 - 36,540	9,719	1,234 - 24,196	147,557	5 - 492,867
															11/4/2008 - 11/7/2008	6.57	3,070	20 - 17,329	6,894	256 - 36,540	-	-
S Nags Head/Old Oregon Inlet Road	115	33	28.8	307	2.67	54	47	4.6	4	6,410	6,224			73.3	06/03/2007 - 06/04/2007	3.3	4,558	1,935 - 8,664	24,196	24,196	231	231
															12/15/2007 - 12/16/2007	3.67	334	5 - 1,500	9,074	223 - 24,196	56,103	541 - 134,133
															04/20/2008 - 04/23/2008	6.82	946	313 - 1,354	13,727	2,142 - 24,197	4,475	5 - 8,945
															9/5/2008 - 9/11/2008	8.18	2,294	548 - 5,172	26,594	15,531 - 51,720	-	-
															11/4/2008 - 11/7/2008	12.72	2,014	1,178 - 3,873	5,001	191 - 15,796	-	-
Whalebone Watershed	61	22.3	36.6	116	1.9	34	55.7			875	313				06/03/2007 - 06/04/2007	5.7	884	650 - 1,014	7,294	1,782 - 15,531	28,744	186 - 4,135
															12/15/2007 - 12/16/2007	7.53	289	5 - 905	927	5 - 5,172	208,792	72,803 - 476,541
															04/20/2008 - 04/23/2008	6.89	2,155	110 - 6,867	1,137	247 - 2,382	15,171	1,891 - 40,064
															9/5/2008 - 9/11/2008	10.49	30,187	3,664 - 92,080	8,485	1,076 - 17,620	-	-
															11/4/2008 - 11/7/2008	6.57	1,676	221 - 5,794	3,926	373 - 10,170	-	-

1.0 Project Background

1.1 Need

Stormwater outfalls in coastal NC are a cause for concern given the patterns and magnitude of precipitation, altered local landscapes (Line et al. 2000; Napton et al. 2010; Mallin et al. 2001), and the potential for delivery of significant loads of contaminants during hurricanes and Nor'easters (Parker et al. 2010, Converse et al. 2010, Stumpf et al. 2010). The North Carolina (NC) Shellfish Sanitation and Recreational Water Quality Sections (NCSSRWQ) routinely monitors over 200 coastal beach and estuarine sites for the fecal indicator bacteria (FIB) group, *Enterococcus* spp. North Carolina ranks 6th in the country in beach-related tourism and beaches contribute significantly to the State's economy. Beach water quality is generally good in North Carolina during dry weather periods, but storms, and the resulting stormwater lead to significant numbers of beach swimming advisories (Coulliette et al. 2009, Converse et al. 2010, Dorfman and Roselot 2011, Gonzalez et al. 2012). Storms produce overland runoff and increases in groundwater levels in shallow coastal systems, potentially delivering human fecal contamination from overburdened sewage and septic systems, feces from dogs (and other pets), wildlife, livestock, and birds to receiving waters.

1.2 Objectives

Given the challenges and potential economic impacts detailed above, the objectives of this study were to: 1) conduct extensive characterization of the watersheds and stormwater outfalls that contribute to nine NC Department of Transportation outfalls, including but not limited to land-use, groundwater, FIB and fecal source, and flow assessments, 2) use the collected information to prioritize the nine outfalls by discharge volumes, watershed characteristics, and fecal contamination patterns for BMP implementation, 3) install and assess the performance of a new pilot project BMP using innovative technologies and filtering technologies (as described in the original law) in a single outfall location, 4) conduct assessments of the distribution of FIB and fecal source markers according to storm size, and distance along receiving water beaches, and 5) develop preliminary BMP plans and designs for the remaining outfalls based on results from the pilot project as well as other known systems. An additional and vital component to this project was stakeholder and project team interaction through each step of the project.

1.3 Project History

The North Carolina Department of Transportation (NCDOT) was required through Session Law 2004-123, House Bill 1414 to implement a **Stormwater Pilot Project for NCDOT maintained ocean outfalls and associated outlets.** The bill required NCDOT to **implement new and innovative technologies and filtering mechanisms to improve stormwater discharge water quality from NCDOT maintained ocean outfalls and associated outlets.**

NCDOT completed an ocean outfall survey in the first quarter of 2000. Division engineers were contacted and data was collected on the location and type of ocean outfalls that serve the highway system. A summary report titled Ocean Outfalls Reported by Divisions was generated that identified twenty-six outfalls that discharge highway runoff to the ocean. These outfalls discharge directly to the ocean and do not include those discharging to Intracoastal or sound-side waters. Of the twenty-six outfalls, ten are maintained by NCDOT. Fifteen of the remaining outfalls, all located in New Hanover County, are maintained by the County and the Town of Kure Beach. One outfall in Dare County is maintained by the Town of Kill Devil Hills and discharges water from the Town's reverse osmosis water treatment plant. Of the ten ocean outfalls maintained by NCDOT, eight are in Dare County in the towns of Kill Devil Hills and Nags Head with the remaining two in New Hanover and Brunswick Counties.

Figure 1 shows the location of the eight Dare County outfalls maintained by NCDOT as well as the Oregon Avenue outfall maintained by the Town of Kill Devil Hills. In 2009, an additional outfall (not shown on **Figure 1**) with an outlet to the Albemarle Sound near Whalebone Junction was added to this study. The primary purpose of the NCDOT outfalls is to provide drainage of state maintained highways, however, local low land areas have been connected to the outfall systems. As the area continues to increase in development density, stormwater quantity and quality have become progressively more difficult to manage. During the 2004 hurricane season, three storms produced over ten inches of rainfall in the area, leading to standing water for more than 30 days in some communities.

Funding for this project was transferred to NCDENR under Session Law 2006-66, Senate Bill 1741, Section 21.14, and oversight authority was assigned to the Division of Water Resources. A majority of the funds were transferred in 2009 for capital improvement projects at North Carolina Aquarium Satellite Areas under Session Law 2009-14, House Bill 628, Section 2. Therefore, the original work plan was modified in order to come to a logical stopping point defined as the interim BMP pilot study and source investigation. This master plan was developed to summarize the work completed to date as well as provide the basis for implementation of additional BMPs which can be installed at a later date when funding allows.

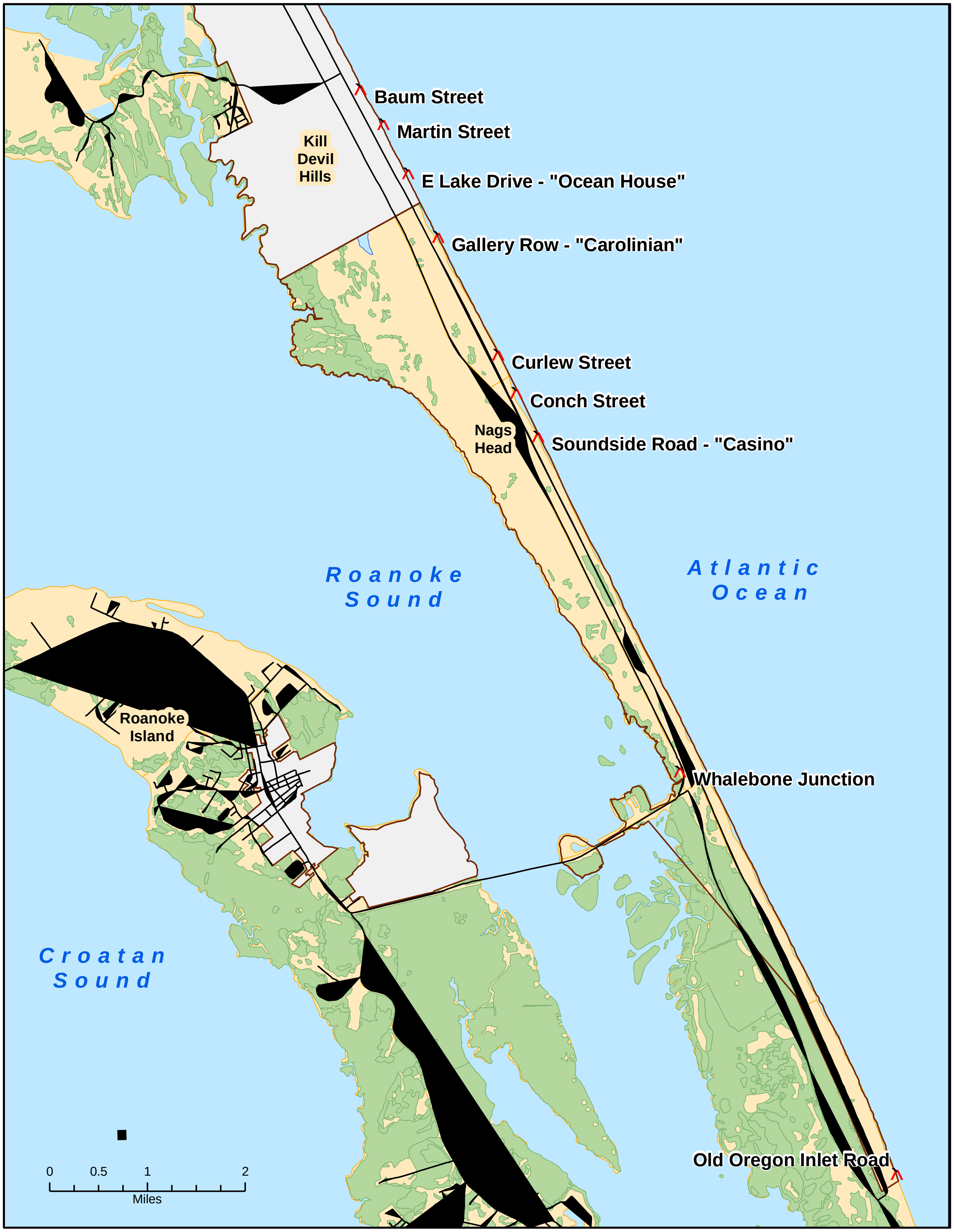


Figure 1. Location of Dare County Ocean Outfalls

2.0 Major Components of Study

2.1 Existing Data Review

Existing data were obtained from a number of different sources, including North Carolina State University (NCSU), NCDOT, the Towns of Nags Head and Kill Devil Hills, the US Geological Survey (USGS), the NC Flood Mapping Program, NC Recreational Water Quality (RWQ), the National Oceanic and Atmospheric Administration (NOAA) and the US Fish and Wildlife Service. The data assembled were:

1) Topographic surveys
2) Aerial photography
3) Hydrologic data
4) Soils data
5) Land use plans
6) Wetland mapping
7) Water quality measurements
8) Site basemap data, including roads and shorelines.

<u>Topographic Surveys</u>
Existing topographic data were compiled by NCSU researchers from NC Geological Survey data. A LIDAR digital elevation model and 1-ft, 2-ft and 5-ft contours for the study area were obtained from NCSU. Elevations across the barrier island ranged from sea level to +93 feet at the peak of the Wright Memorial.

<u>Aerial Photography</u>
Existing, black and white georectified aerial photographs dated 1998 were obtained from the NC Division of Coastal Management. Color orthophotos dated 2002 were provided by the Towns of Nags Head and Kill Devil Hills. The topography shown in **Figure 2** is presented overlaying the 2002 color orthophotography. The photography provided a base for all of the mapping completed during this study.

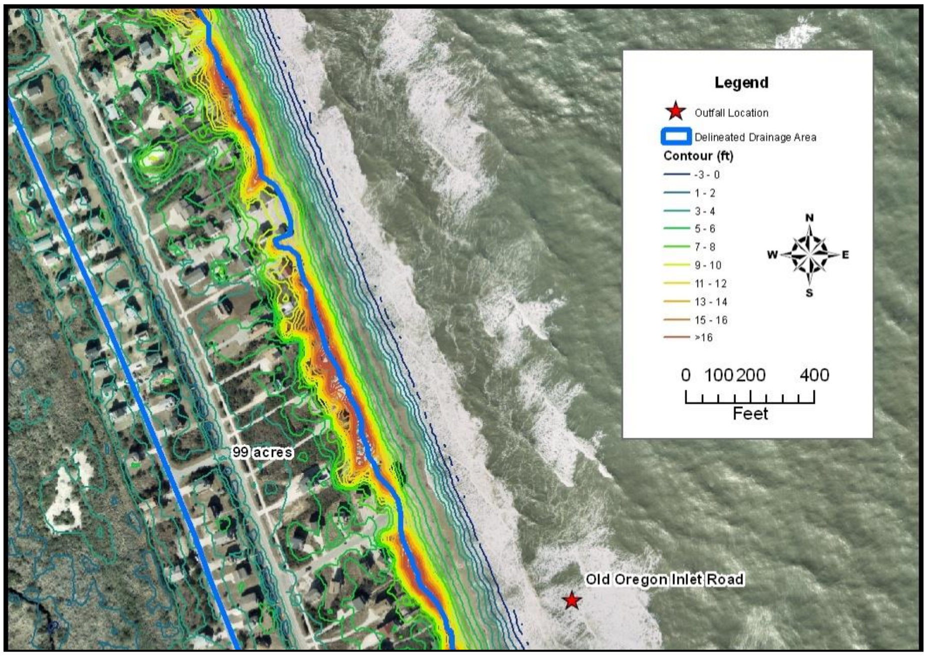


Figure 2. Example Topographic Contours with Orthophoto

<u>Hydrologic Data</u>

Updated precipitation frequency estimates for the study area were extracted from an online tool based on the "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 2, Version 2, 2004. **Table 2** presents the estimates for Station 31-4649 in Kill Devil Hills. These data would be used in later design stages to compute discharge estimates for each of the outfall watersheds.

Table 2. Precipitation Frequency Estimates (inches) for Kill Devil Hills, NC

Freq (yr)	5-min	10-min	15-min	30-min	60-min	120-min	3-hr	6-hr	12-hr	24-hr	2-day	4-day	7-day	10-day	20-day	30-day	45-day	60-day
2	0.53	0.85	1.07	1.48	1.86	2.13	2.35	2.87	3.43	4.04	4.71	5.27	6.00	6.73	8.89	10.87	13.30	15.82
5	0.63	1.00	1.27	1.80	2.31	2.71	3.00	3.69	4.41	5.21	6.04	6.71	7.54	8.34	10.81	13.07	15.89	18.69
10	0.70	1.12	1.42	2.06	2.68	3.19	3.56	4.37	5.25	6.21	7.19	7.90	8.81	9.67	12.40	14.84	18.03	21.01
25	0.79	1.26	1.60	2.37	3.15	3.86	4.36	5.37	6.50	7.68	8.92	9.62	10.63	11.56	14.63	17.28	21.06	24.17
50	0.86	1.37	1.74	2.61	3.54	4.41	5.04	6.23	7.59	8.93	10.42	11.08	12.16	13.14	16.47	19.21	23.51	26.66
100	0.93	1.48	1.87	2.86	3.94	5.00	5.78	7.16	8.78	10.32	12.09	12.66	13.78	14.82	18.39	21.20	26.06	29.18
200	1.00	1.59	2.00	3.12	4.37	5.63	6.59	8.19	10.11	11.84	13.96	14.36	15.53	16.61	20.42	23.24	28.73	31.74
500	1.09	1.73	2.17	3.46	4.96	6.54	7.76	9.71	12.09	14.10	16.77	17.17	18.05	19.18	23.27	26.04	32.45	35.21
1000	1.16	1.83	2.30	3.72	5.44	7.26	8.76	11.00	13.79	16.04	19.19	19.56	20.14	21.28	25.57	28.22	35.40	37.89

<u>Soils Data</u>

Soils data were developed by the US Department of Agriculture-Natural Resources Conservation Service and obtained by NCSU researchers. The soils information was provided in GIS format. **Figure 3** presents a sample of the soils data. The predominant soil types are Newhan, Fripp and Corolla sands, generally with 0 to 10 percent slopes.

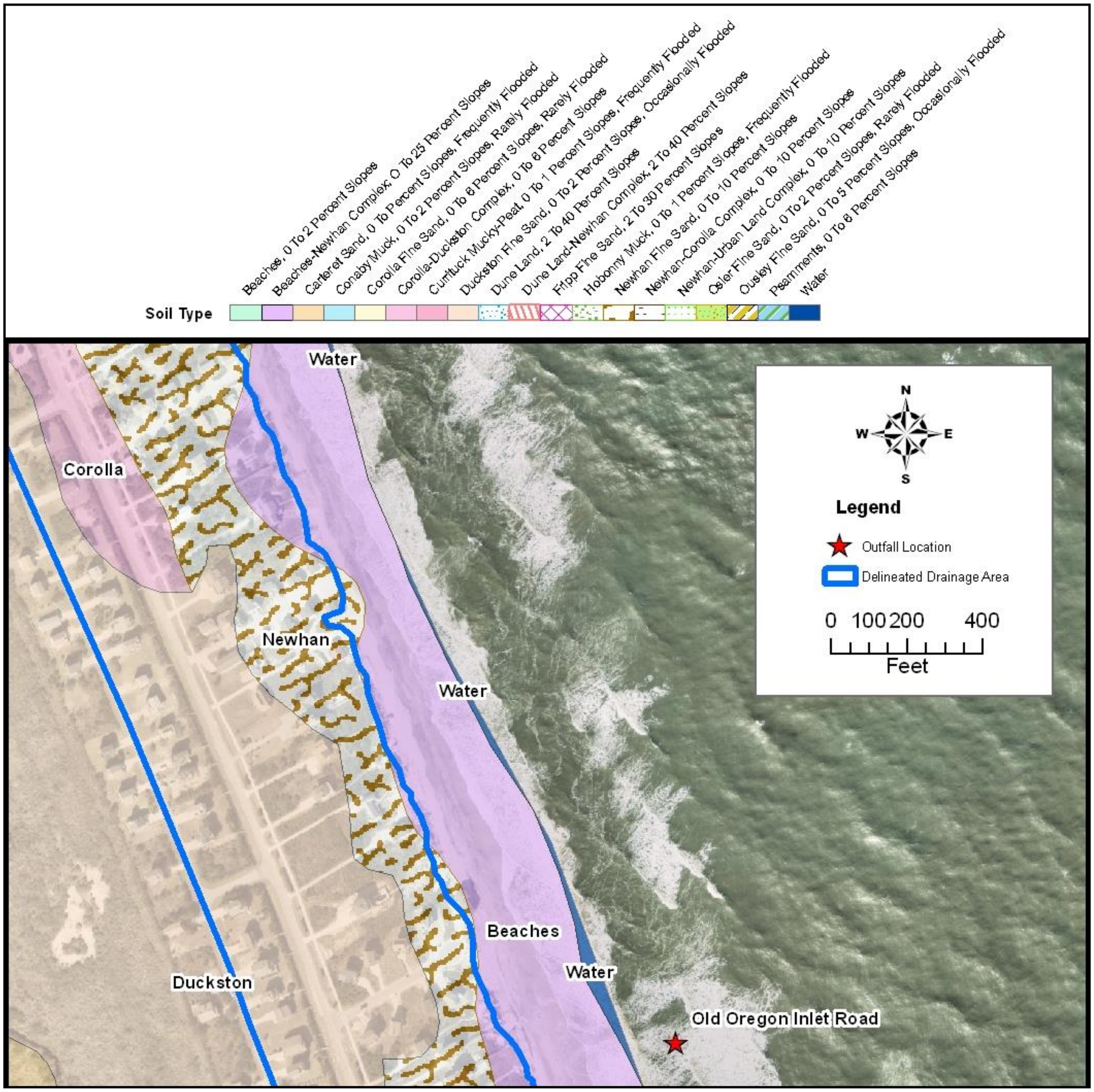


Figure 3. Example Soil Type Data

Land Use Plans

The 1997 Land Use Plan Update for the Town of Kill Devil Hills was obtained from the KDH planning department. The plan includes zoning and resource protection measures as well as economic and community development issues. The 2001 Stormwater Management Plan for the town of Kill Devil Hills was also provided by the planning department. The Town of Nags Head provided the Land and Water Use Plan completed in 2000.

Wetland Mapping

National Wetlands Inventory data were obtained from the US Fish and Wildlife Service's online mapping tool. Digital data for the study area were provided in GIS format, and a sample is presented in **Figure 4**. Although wetlands frequently occur along the barrier island, only five identified wetland areas were within the outfall drainage areas, for a total of approximately 2 acres of wetlands or 0.2 percent of the total drainage areas overall (almost all contained within the Martin Street outfall watershed). It should be noted that the National Wetlands Inventory database is useful for identifying larger scale wetland areas, but additional smaller localized wetland areas may exist as well.

Figure 4. Example National Wetlands Inventory Data

Water Quality Measurements

The North Carolina Department of Environment and Natural Resources Recreational Water Quality Program (RWQ) monitors water quality at numerous sites along the Dare County coastline, including all of the outfall pipes. **Table 3** lists the monitoring site corresponding to each of the ocean outfalls.

Table 3. RWQ Monitoring Sites near Ocean Outfalls

RWQ Station Number	RWQ Site	Outfall Location (South to North)
22	S.NAGS HEAD - S. BEACH ACCESS, DRAIN PIPE	Old Oregon Inlet Road
17A	NAGS HEAD, D/P* ACROSS FROM KH KITES	Soundside Road
17	NAGS HEAD, D/P ACROSS FROM BREW THRU	Conch Street
16A	NAGS HEAD D/P AT HOLLOWELL STREET	Curlew Street
16	KDH, D/P ACROSS FROM EMBERS REST.	Gallery Row
15	KDH, D/P @ LAKE DR. BEACH ACCESS	E Lake Dr
85A	ATLANTIC OC.- KDH, D/P AT MARTIN STREET	Martin Street
85	KDH, D/P ACROSS FROM FOUR FLAGS REST.	Baum Street
* D/P = Drain Pipe		

RWQ tests for *Enterococcus* bacteria, an indicator organism found in the intestines of warm-blooded animals. While it will not cause illness itself, its presence is correlated with that of organisms that can cause illness. RWQ staff collects each sample at the drain pipes approximately 10 feet from the side of the pipe, standing in ankle deep water, reaching out with a 16-foot telescopic pole to grab the sample in knee deep water. Sampling data for 2003 and 2004 were obtained from RWQ. The beach is posted any time a single sample exceeds 104/100mL or the geometric mean of 5 samples taken over a 30 day period exceeds 35/100mL. **Figure 5** and **Figure 6** show a summary of the sampling data for 2003 and 2004, respectively.

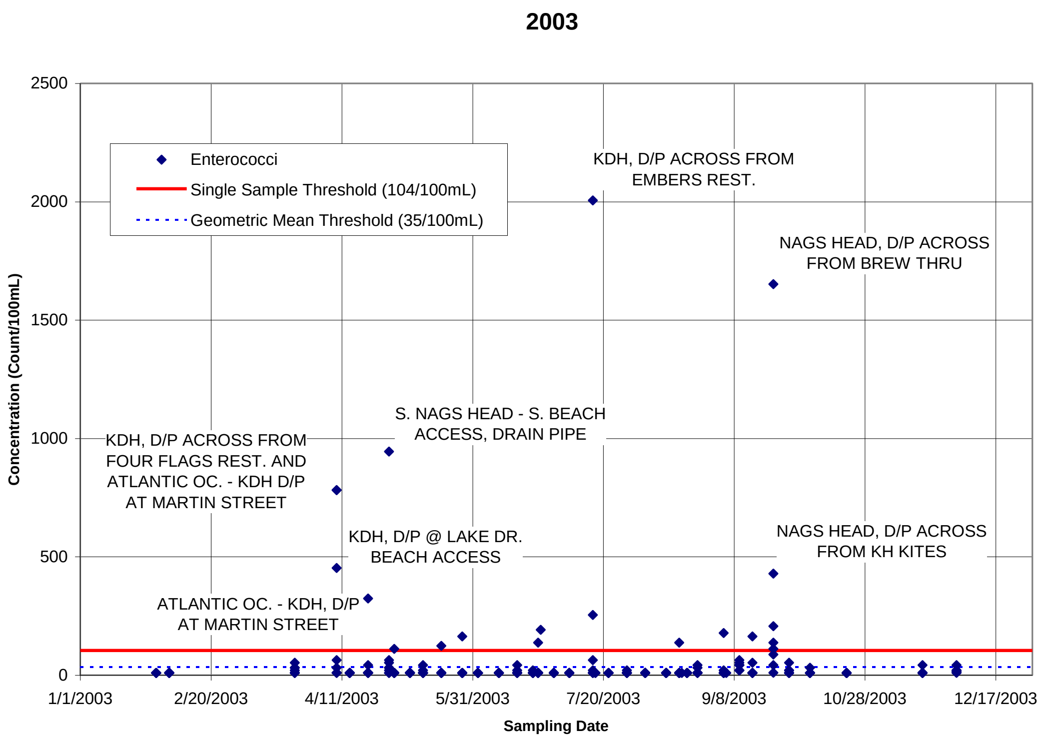


Figure 5. 2003 Water Quality Sampling Data at Outfall Locations

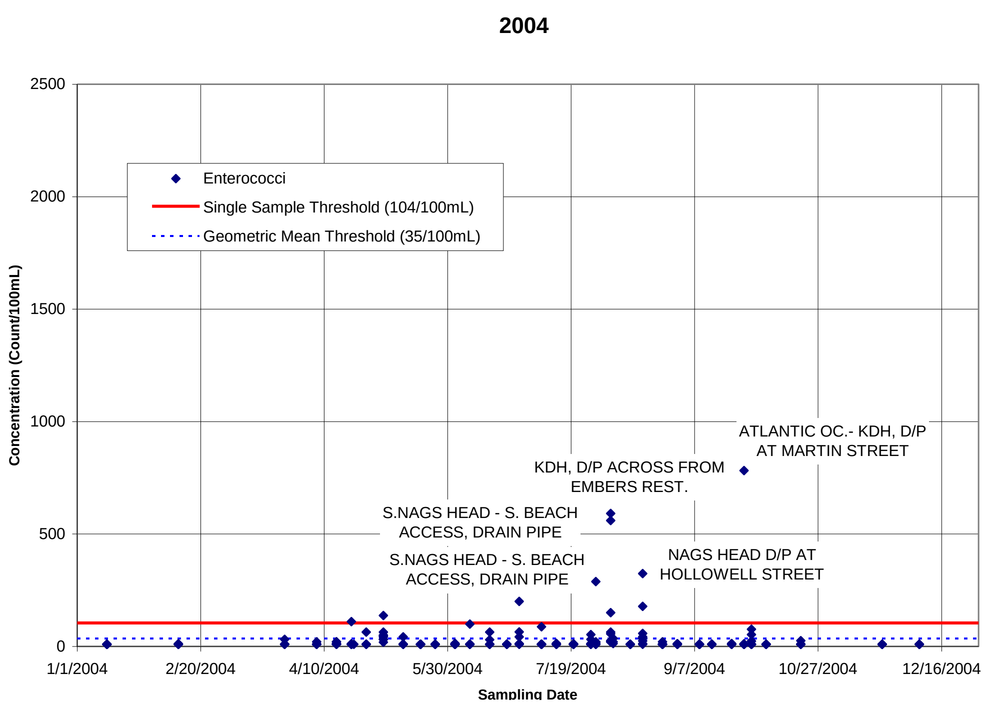


Figure 6. 2004 Water Quality Sampling Data at Outfall Locations

It should be noted that RWQ personnel have indicated that based on past catch basin sampling, all of the outfalls have been automatically posted any time an active discharge is present.

RWQ conducted a study sampling the outfall catch basins throughout the fall of 2002 to spring 2003. Each catch basin was sampled on 14 occasions and a summary of the data is presented in **Table 4**. As shown, a significant number of the samples exceeded the single sample standard for beach swimming advisories.

Table 4. RWQ Catch Basin Study Results

RWQ Name	NCDOT Name	Times Exceeding 104/100ml
Drain Pipe at MP 8 3/4	Baum Street	3
Drain Pipe at Martin Street	Martin Street	6
Drain Pipe at Lake Dr beach access	E Lake Drive	5
Drain Pipe at Hollowell St	Curlew Street	8
Drain Pipe at MP 10.5	Gallery Row	7
Drain Pipe at MP 12.5	Conch Street	4
Conch St beach access	Soundside Rd	3
Drain Pipe at S Nags Head/Federal Park Border	Old Oregon Inlet Rd	11

RWQ also developed new signage that will be permanently posted at the Dare County outfalls (**Figure 7**). This signage indicates that swimming is not recommended within 200 feet of the outfalls at any time. The wording was developed in this way because the Dare County outfalls frequently have a base flow discharge. Alternative signage is being placed on southern beaches that do not have a base flow discharge. Those signs state that if a discharge is present, swimming is not recommended within 200 ft of the outfall. The signage was developed in conjunction with local stakeholders and is in place to protect public health while minimizing unwanted publicity from press releases associated with new postings.

Figure 7. RWQ Sign Placed at Dare County Outfall Sites

In addition to the RWQ data, surface and groundwater monitoring has been conducted by the town of Nags Head since 2001 as part of the town's Septic Health Initiative. The Nags Head Initiative monitoring includes testing for fecal coliforms. These are gram-negative bacteria found in the guts of warm-blooded animals. *E. coli* is the most prominent subtype of fecal coliforms. Like other types of FIB, such as Enterococcus sp., high concentrations of fecal coliforms in receiving waters have been associated with heightened risk of illness for people using the water for recreation. **Figure 8** shows a summary of the monitoring data. Stations marked as "S" are surface water monitoring stations; "G" indicates groundwater monitoring.

The marine recreational swimming standard of 200 per 100mL is shown on **Figure 8** for reference. Although these samples were taken from various surface and groundwater locations throughout the town and not at the outfall pipes, it remains instructive to observe that the recreational swimming standard that was in existence at that time was regularly violated at both surface and groundwater locations. The ditch leading to the outfall at South Old Oregon Inlet Road (S.O.O.I.R) posted some of the higher readings, as did a number of surface and groundwater locations within the Nags Head Village development. The Ida Street beach access location, which shows additional high readings, is a groundwater station on the beach side of South Old Oregon Inlet Road in South Nags Head. As shown, the highest measured values across all the sampling sites were obtained during tropical storm Gustav, in September, 2002. It is noted that no sampling occurred during Hurricane Isabel in September, 2003, although it is speculated that high measured values may have been obtained at that time as well. These data indicate that while beach swimming advisories are a result of sampling conducted at the outfalls, there are water quality issues throughout the Town's watersheds. These must be considered when selecting the appropriate measures to improve beach water quality.

It should be noted that the marine recreational water fecal coliform single sample standard of 200 CFU or MPN per 100 mL was the existing standard in place when collection of these data began in 2002. In October 2002, to maintain compliance with the USEPA per the BEACH Act, the NC Recreational Water Quality Section within NCDENR began using enterococci as the FIB. The USEPA recommended recreational water quality standards, which are a geometric mean of 35 MPN or CFU per 100mL for 5 samples collected over a 30-day period, and 104 MPN or CFU per 100mL for a single sample. These are the standards that remain in place currently.

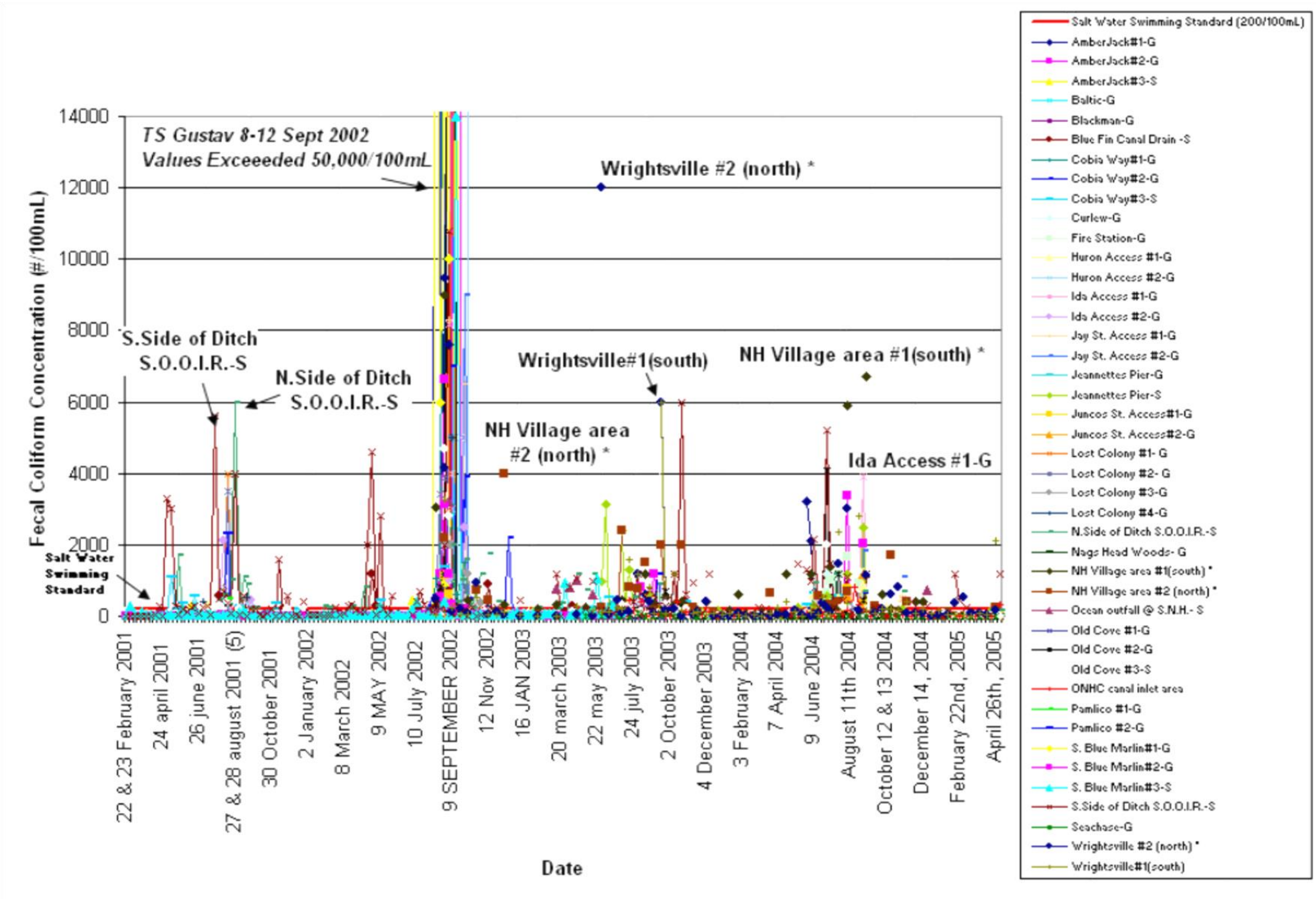


Figure 8. Nags Head Septic Health Initiative Sampling Data

Site Basemap Data

Roads for Dare County were downloaded from the NCDOT Web site and shoreline data were obtained from the National Oceanographic and Atmospheric Administration (NOAA). These were used along with the aerial photos as base mapping for the area. Property boundaries for the entire county were also obtained. **Figure 9** presents a sample of the data and Chapter 3 includes maps for each of the outfalls.

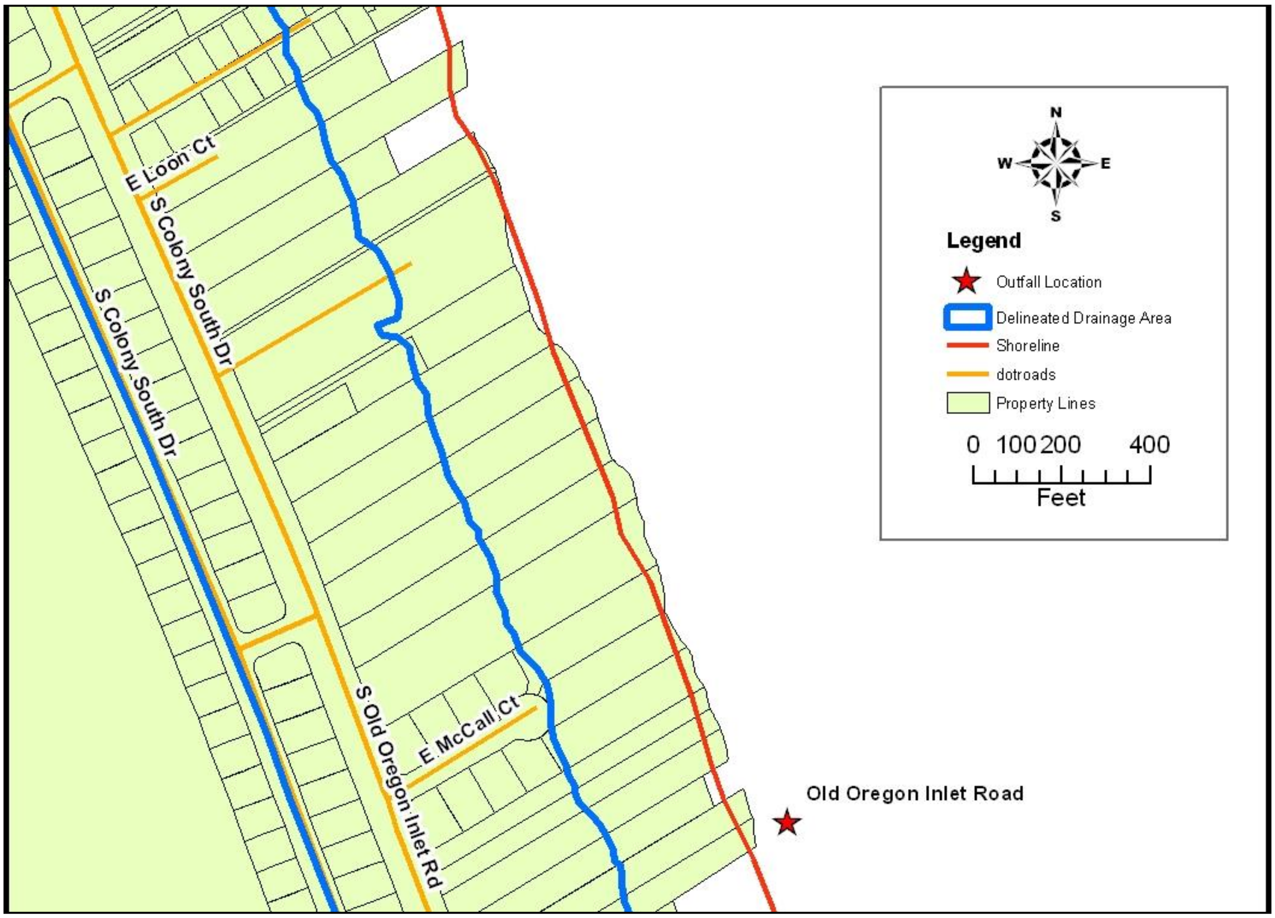


Figure 9. Example Basemap Data

Topographic Surveys

Given the limited data available for the existing stormwater infrastructure, NCDOT's Location and Surveys Unit provided resources to collect data on the ditches, catch basins and piping that drained to each outfall. Given resource constraints, not all infrastructure elevation and location data was collected by a significant portion of the individual systems were. In addition to this data, the NCDOT Photogrammetry Unit also provided detailed topographic data for the watersheds using photogrammetric techniques. Examples of the survey data collected are shown in **Figure 10** and **Figure 11**.

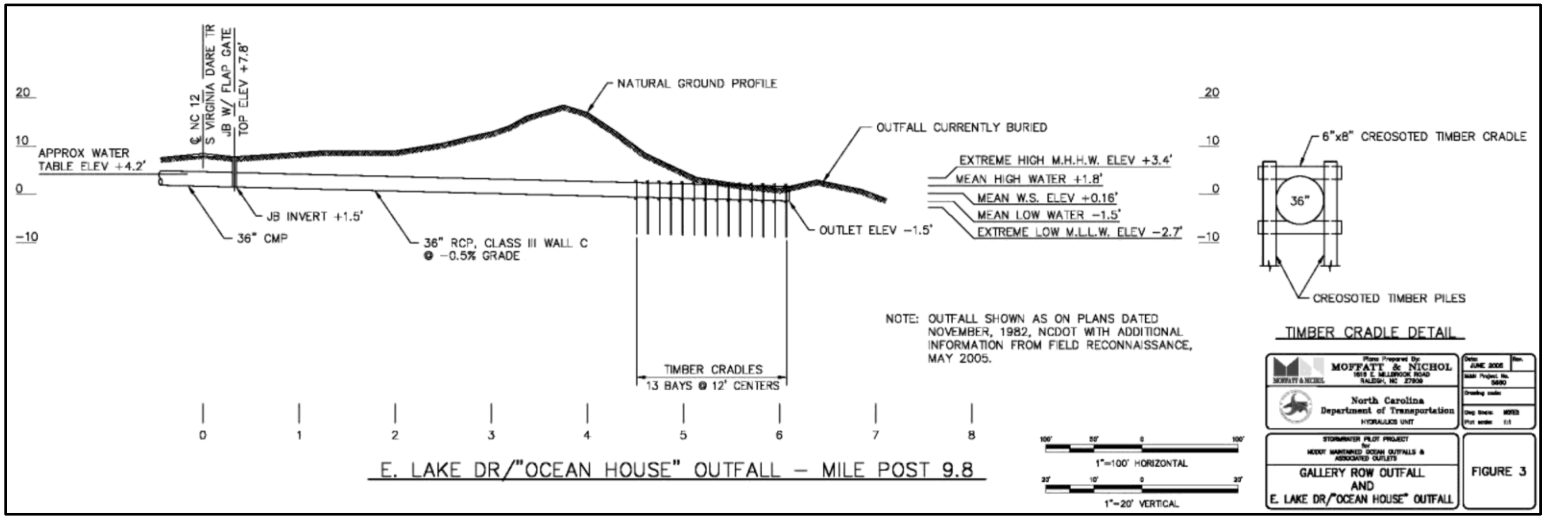


Figure 10. NCDOT Topographic and Infrastructure Survey Data- East Lake Drive Outfall

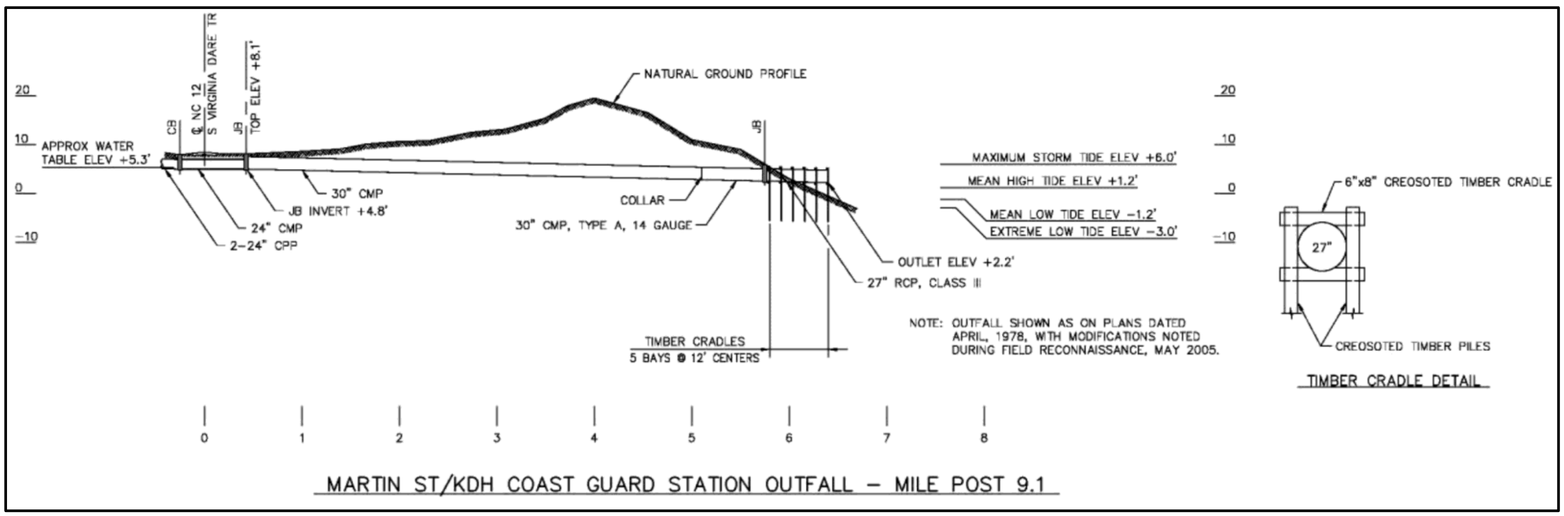


Figure 11. NCDOT Topographic and Infrastructure Survey Data- Martin Street Outfall

2.2 BMP Literature Review

Given that biological contaminants are the main issue of concern, a literature review of BMPs was conducted to determine what system had documented treatment performance for fecal coliform and *Enterococcus*. As part of this effort, a number of stormwater BMPs were evaluated. Both conventional and proprietary systems were evaluated and each BMP considered included a description of the BMP, design criteria, pollutant removal efficiencies, maintenance requirements, advantages, disadvantages, case studies, applicability to the project and sources of reference material.

Major findings from the BMP literature review included the following:

- Wet detention basins provide adequate bacteria removal and flood attenuation although they require large land areas for installation.
- Wetlands and shallow marsh systems offer great habit value and are low maintenance but are also very land intensive treatment techniques.
- Sand filters offer flexible design either above or below ground and can treat large drainage areas. However, maintenance and equipment requirements for these structures are high.
- Infiltration systems can provide excellent treatment in a limited space but are subject to soil properties and groundwater constraints. In addition, without frequent maintenance infiltration devices have a high failure rate.
- Bioretention areas provide high bacteria removal rates and aesthetic value although they are not suitable for areas with high water table elevations.
- Catch basin inserts such as the Ultra-Urban Filter with Smart Sponge™ technology have demonstrated reduction of bacteria concentrations in stormwater runoff for small drainage areas; however, maintenance costs are high.
- Biofilters such as the StormTreat™ system require small land area and low maintenance but are not appropriate treatment methods in areas with high groundwater elevations.
- Alum injection and UV disinfection systems provide exceptionally high bacteria removal rates although high maintenance and equipment requirements may outweigh benefits of the systems.
- Multi-chamber treatment trains generally require small land areas and are easily retrofit; however, they are only applicable to small drainage areas.

- Electrocoagulation treatment systems are fully automated and offer very high bacteria removal rates although high maintenance and equipment requirements may be limiting factors when considering this alternative.
- Proprietary filtration systems such as the StormFilter™ and VortFilter™ provide filtration for several pollutants and are easily retrofit into existing systems; however, bacteria removal efficiencies are not known for these types of treatment techniques.
- Hydrodynamic separators require little land area for implementation and can treat TSS, however, there is no documented information showing bacterial removal.
- Deepwater ocean outfalls could provide additional capacity for future stormwater improvements and improve water quality at the beaches, but require a substantial capital investment. In addition, construction of a deepwater outfall may require a lengthy permit process.

Given the costs and scarcity of land available in these coastal settings and the directive of the original law that innovative filtering technologies be used, it was determined that some proprietary BMP should be investigated. If a BMP could provide treatment while not taking up significant land, initial installation costs could be greatly reduced. If the BMP could be placed to work within the existing infrastructure, all the better.

Each of the conclusions above are based on extensive reviews of numerous scientific literature sources on the specific types of BMPs in question. Rather than list all of the individual references, the reader is referred to the original literature review document entitled: STORMWATER PILOT PROJECT FOR NCDOT MAINTAINED OCEAN OUTFALLS AND ASSOCIATED OUTLETS, Literature Review of Stormwater BMPs, (Moffatt & Nichol, 2010)

2.3 Characterization of Existing Stormwater Management Programs

Identification of fecal bacteria sources within the ocean outfall watersheds and management of those sources going forward is obviously a function of stormwater management activities within the study area. In that light, the following are brief summaries of the existing stormwater programs which impact the Ocean Outfall study area.

Town of Nags Head

For more than 30 years, the Town of Nags Head has been regulating stormwater management for commercial development and redevelopment. The current regulatory standards for commercial stormwater management are more stringent than the required state standards (retain and treat the first 4.3 inches of runoff, as opposed to 1.5 inches). This standard significantly reduces downstream surface water conveyance.

The Town regulatory standards for residential subdivision standards rely on a network of roadside vegetative swales to accommodate runoff from adjoining roadway surface. The objective of the drainage infrastructure language is to maximize infiltration in lieu of providing conveyance devices for downstream discharge.

Other measures the Town has undertaken include implementation of a pilot groundwater drawdown system at a neighborhood level scale in addition to a stormwater management ordinance overhaul which incorporates standards for management at the individual residential lot level, as well as permeable pavement incentives and vegetation preservation ordinance refinements.

Together, these approaches align themselves with the objective of promoting the implementation of LID techniques to provide treatment of runoff nearer to the source set forth in the Town's Stormwater Master Plan developed in 2006 and in the Outer Banks Hydrology Management Committee Report released in 2006. It should also be noted that the Town has also developed a subsequent Low Impact Design Development Manual, with assistance from the NC Coastal Federation.

Town of Kill Devil Hills

The Town of Kill Devil Hills has a stormwater ordinance in place that provides guidance for new and redevelopment to reduce the impacts of stormwater to adjoining properties and to include stormwater design as part of the engineered plan prior to approval by the Town. All properties are required to provide a comprehensive, engineered plan of stormwater management for their site with the exception of single or two-family dwellings. The Town's Public Services Department has the option to request an engineered plan if the single or two-family dwelling will be greater than 3,000 square feet. The engineered plan provides drainage information for on-site and off-site of the property to ensure that any stormwater generated on-site drains properly. The designed system is required to manage, at a minimum, runoff generated by a 10-year, 2-hour storm event (4.3 inches). Current stormwater designs acceptable by the Town include retention, detention, and infiltration devices.

In 2010, Kill Devil Hills performed a comprehensive review of stormwater managements systems and infrastructure and developed a comprehensive Stormwater Management Plan. Among other initiatives the plan included a detailed inventory of the extensive stormwater conveyance systems contained within Kill Devil Hills, and development of GIS-based decision support system (DSS) model that allowed for evaluation of hydrology & hydraulics, as well as the condition of individual elements within the Town's drainage systems. The inventory and assessment revealed that most elements of the conveyance system are currently at or above capacity for the amount of stormwater anticipated to be generated by a 10-year storm. Going forward, the DSS model allows the Town to visualize proposed alterations in land use that will impact the amount of stormwater entering a conveyance system. In addition, the DSS model provides input on what types of BMPs may be most appropriate. Potential opportunity areas for improving stormwater measures have already been identified based upon results from information from the Stormwater Management Plan including the rating of each conveyance system, water quality information, and results from the computer simulations.

NCDOT Stormwater Program

The Highway Stormwater Program (HSP), established in 1998, is an NCDOT-wide initiative to protect and improve water quality while fulfilling NCDOT's mission of providing and supporting a safe and integrated transportation system that enhances the state. The guiding principles of the program are as follows:

- Comply with NDPES Stormwater Permit requirements by managing and reducing stormwater pollutants from roadways and industrial areas.
- Design sustainable programs that can be effectively managed, implemented, and integrated into NCDOT
- Develop solutions that improve program delivery, are proactive, form partnerships, have technical merit, and are fiscally responsible.

NCDOT efforts under the HSP include a Stormwater System Inventory and Prioritization Program through which NCDOT maintains an inventory of its roadway system and sensitive waters of the state that is based on geographic information systems. This inventory allows NCDOT to prioritize locations for potential best management practices based on roadway and water quality attributes. NCDOT also tracks the location of outfalls from the Department's industrial facilities. As part of their compliance with the NDPES Stormwater Permit, NCDOT also conducts a BMP Retrofit Program, which applies or installs BMPs into the existing highway facility. NCDOT has constructed and will continue to construct BMPs across the state to improve water quality.

To support the Post-Construction Runoff Control Program, NCDOT has developed the BMP Toolbox and the BMP Inspection and Maintenance program to protect water quality and minimize post-construction impacts. This Post-Construction Runoff Control Program will incorporate watershed strategies and permit requirements from other sections of NCDOT's permit to create a comprehensive and sustainable program. The Stormwater BMP Toolbox provides guidance on the design of BMPs in the linear environment (i.e., along roadways). Each chapter describes a specific type of BMP. The entire toolbox is continually under evaluation for revision to include updated planning and design information synthesized from NCDOT's research and other related stormwater research work in North Carolina. Chapters are updated periodically, and new BMPs are added to the toolbox after their suitability has been evaluated. The BMP Toolbox is intended to serve as a resource for NCDOT employees, contractors and other entities concerned with stormwater management. The BMP Inspection and Maintenance Program is intended keep the BMPs in good operating condition to achieve maximum pollutant removal. The NCDOT BMP Inspection and Maintenance Manual includes written procedures outlining the inspection and maintenance requirements for stormwater BMPs.

2.4 Groundwater Monitoring Program

<u>Well Installation</u>

Twenty groundwater monitoring wells were installed between Kill Devil Hills and Nags Head, NC, between April 18-21, 2006. Three additional monitoring wells were installed approximately 8 miles south of Nags Head during the same period. These wells correspond to 8 stormwater outfalls. An "extra" well (B-24) was installed adjacent to monitor well B-1. See **Figure 12** for the well locations, which are shown in the context of the outfall subwatersheds delineated for the MIKESHE modeling analysis described in the Detailed Hydrologic/Hydraulic Modeling of Outfall Watersheds report (Moffatt & Nichol, 2010(2)).

Boring depths ranged from 10 – 25 feet below ground surface, and each boring was converted to a permanent well. Soil samples were collected during installation and results indicated that the project area generally consists of sands with varying degrees of coarseness.

The wells were installed using hollow-stem macro samplers. Well construction included a 5-foot section of 2-inch diameter slotted PVC pipe with solid PVC pipe to the surface. The wells were topped with a manhole cover, set into a concrete pad. Following the installation, each site was surveyed to determine the location of the well and the elevation of the adjacent ground surface. It should be noted that the top-of-casing elevations at each of the 24 wells were surveyed after the well docks, used to suspend a submersible pressure transducer inside each well, had been installed.

During testing of hydraulic conductivity by S&ME, it was determined that there was not enough water column at well location B-1 to sufficiently measure groundwater depth. Well B-24, adjacent to B-1, had a sufficient column. Well B-1 was abandoned in lieu of well B-24.

On April 20, 21 and 25, 2006, S&ME conducted in-situ hydraulic conductivity tests in 23 of the 24 groundwater monitoring wells to estimate the hydraulic conductivity in the aquifer material near each well. Hydraulic conductivity values from the slug tests ranged from 14.15 to 47.25 ft/day, and had an average of 29.80 ft/day. **Table 5** summarizes these values.

The groundwater monitoring wells collected and recorded data every 30 minutes. Data was then downloaded at approximately 3 month intervals for use. A more detailed description of the data and findings from the groundwater monitoring can be found in Section 2.4.

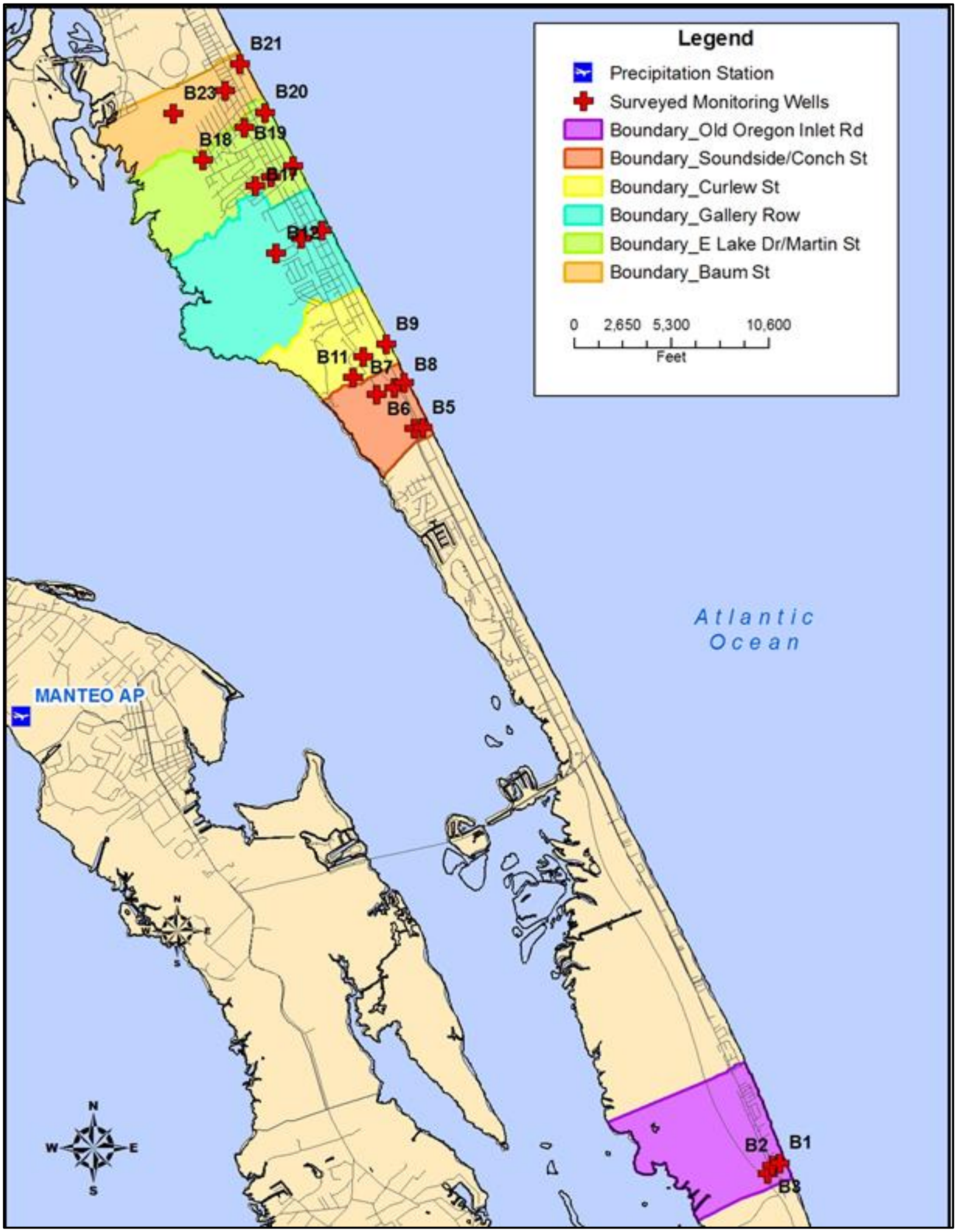


Figure 12. Ocean Outfall Sub-watersheds and Surveyed Monitoring Wells

Table 5. Summary of Slug Test Hydraulic Conductivity Data

Monitoring Well I.D.	Hydraulic Conductivity (K) (ft/day)
B2	44.61
B3	39.00
B4	25.54
B5	46.42
B6	18.47
B7	40.36
B8	43.42
B9	26.03
B10	47.25
B11	22.83
B12	15.85
B13	28.47
B14	21.85
B15	14.15
B16	19.26
B17	34.65
B18	20.48
B19	24.58
B20	38.40
B21	33.69
B22	15.72
B23	20.70
B24	43.61

Data Analysis

One- foot contour data was obtained from NCOneMap LIDAR data sets and interpolated into raster form for use. The original LIDAR data set is in NC State Plane Feet, NAVD88. The mean, maximum, and minimum groundwater levels (as recorded by the 23 monitoring wells) were then assigned to each monitoring well location within ArcGIS. The northern grouping (between Nags Head and Kill Devil Hills) was completed separately from the southern area, so as interpolation would not be extended across a wide gap, which would have the potential to produce significant errors. Additional data points were added to represent several large ponds and mean sea level. A regularized spline weighted interpolation was performed within ArcGIS to generate continuous surfaces of maximum, minimum, and mean groundwater levels across the two independent areas. The resulting surfaces are mapped in **Figure 13-Figure 16**.

Subtracting the interpolated mean, maximum, and minimum groundwater level surfaces from the LIDAR surface, a tin was created representing the elevation difference between the ground and the groundwater surface. The resulting data indicates the locations where the groundwater surface is within 0-3' below the ground surface, which is an important depth range because it is where most septic tanks and their drain fields are located. Groundwater interaction with septic systems proved to be a key factor in this study moving forward. The results of storm event sampling for FIB presented in the UNC-CSI Results Report (Noble, et al. 2010) strongly indicates, by virtue of the storm event distributions and dynamics of the of indicator bacteria found, that storm event bacteria loads are more heavily influenced by septic system sources than from surface runoff.

This groundwater data summarized in this report is limited by the small number of monitoring wells deployed, especially at the southern location. Having few data points located in close proximity does not yield a highly accurate interpolated surface. To accommodate for this in the southern region, a tension-weighted spline interpolation was performed in lieu of the more frequently utilized "regularized" option. This action tends to "flatten" out the resulting surfaces. This method was not used in the northern area because the monitoring wells are well spaced across the study area. As a result of interpolation error, only data displayed immediately south and east of monitoring wells #2, #3 and #24 is useful for interpretation. Data points used to create the surfaces extending into the north and west portions throughout most of the subwatershed in **Figure 14** and **Figure 15** were estimated and may not accurately reflect the groundwater surface in those larger portions of the map.

Additionally, groundwater levels along the sound-side of the island are not as vertically accurate due to the inconsistencies in LIDAR data and the lack of monitoring well data there. Surface accuracy is limited to approximately 0.5' vertically, and 10' horizontally in the vicinity of the monitoring wells.

Results & Discussion

At mean groundwater table levels (shown in **Figure 13** and **Figure 14**), the portions of the study area where groundwater is in the range of 0-3 feet below the surface are largely concentrated in more developed areas, which is problematic because that is where the highest concentrations of on-site septic systems are located. During times of high groundwater levels (**Figure 15** and **Figure 16**), groundwater passes up through the septic layer and can be seen at or above ground level as standing water throughout significant portions of the study area. Not only does this pose a health concern, but it also is an indication of a need for stormwater drainage. This upward movement though the "septic layer" and out to the surface may be an important dynamic in the high concentrations of FIB in stormwater runoff events.

The southern region, south of Nags Head, indicates a large area where the mean water level is between 0 and 3 feet. (See **Figure 14**.) Although the interpolation method is not likely applicable to the area north of the monitoring wells, a simple scan of the image shows a large quantity of ponds. This indicates that the groundwater level is coincident with the surface and should therefore be considered carefully.

The occurrence and spatial distribution of groundwater interaction with septic systems during isolated and extreme events may not be as important as the temporal frequency and duration of such interactions over time. For this reason the groundwater monitoring well data was processed to show the percent of data readings (recorded on 15 minute intervals) in which the groundwater level was 0-3 feet below the surface. As can be seen in **Table 6** below, about half of the wells do not see groundwater levels within 0-3 feet of the surface, but the wells that do experience groundwater within that range, do so on a frequent and sustained basis. Of particular note, 2 of the 3 wells in the Gallery Row subwatershed showed groundwater levels in the 0-3 feet range over 50% of the time. It should be noted that viewing this data in **Table 6** is not as instructive as viewing it on a spatial basis in **Figure 13-Figure 16** because several of the wells, in particular those with ground elevations of 13-20 feet, are located on dunes. Data showing little or no incidence of groundwater elevations near the surface a such wells may provide insight into the condition for the immediate surroundings at those locations, but the degree of interaction at the well located behind the primary dune line at the lower controlling elevation for the ocean outfall drainage systems are far more indicative of the potential for groundwater interaction with septic systems at the full watershed scale. As a result the interpolated groundwater surfaces displayed in **Figure 13-Figure 16** are far more instructive.

Table 6. Percentage data with Groundwater within 3' of surface

Well	Outfall Subwatershed	Percent data with water level between 0-3'	Ground Elevation (feet above Sea Level)
B-2	Old Oregon Inlet Rd	73.3%	4.4
B-3	Old Oregon Inlet Rd	0.0%	6.6
B-4	Soundside/Conch St	0.0%	13.5
B-5	Soundside/Conch St	94.7%	4.9
B-6	Soundside/Conch St	11.3%	9.3
B-7	Soundside/Conch St	0.0%	4.0
B-8	Soundside/Conch St	0.0%	16.2
B-9	Curlew St	0.0%	16.7
B-10	Curlew St	76.0%	7.0
B-11	Curlew St	0.0%	16.5
B-12	Gallery Row	10.1%	11.8
B-13	Gallery Row	89.6%	8.9
B-14	Gallery Row	57.5%	6.4
B-15	E Lake Dr/Martin St	0.0%	15.9
B-16	E Lake Dr/Martin St	39.5%	9.2
B-17	E Lake Dr/Martin St	29.5%	11.4
B-18	E Lake Dr/Martin St	15.4%	12.5
B-19	E Lake Dr/Martin St	39.8%	8.3
B-20	E Lake Dr/Martin St	0.0%	11.3
B-21	Baum St	0.0%	19.0
B-22	Baum St	11.1%	8.5
B-23	Baum St	76.8%	11.2
B-24	Old Oregon Inlet Rd	0.0%	20.2

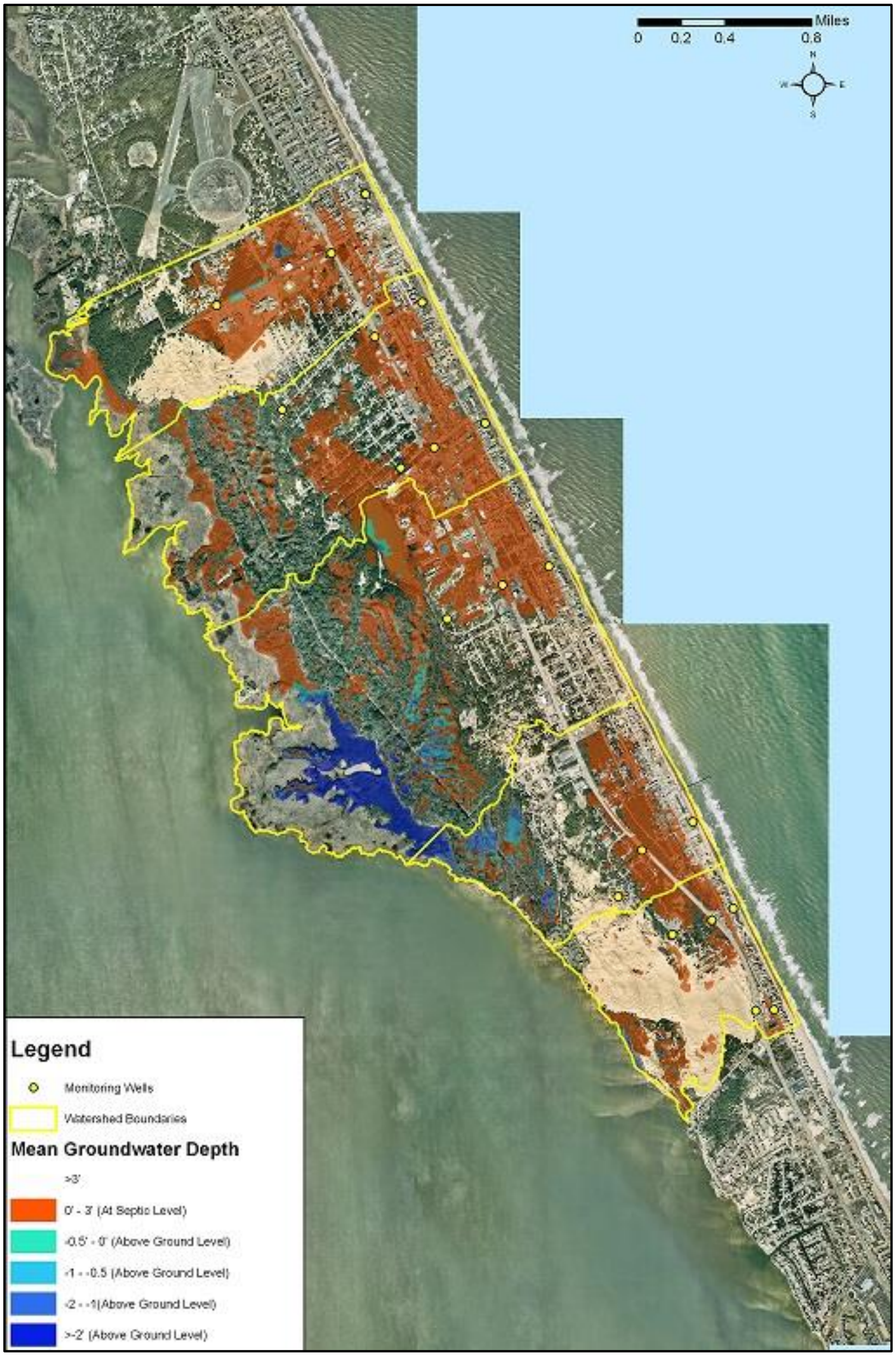


Figure 13. Mean Groundwater Levels from Monitoring Wells

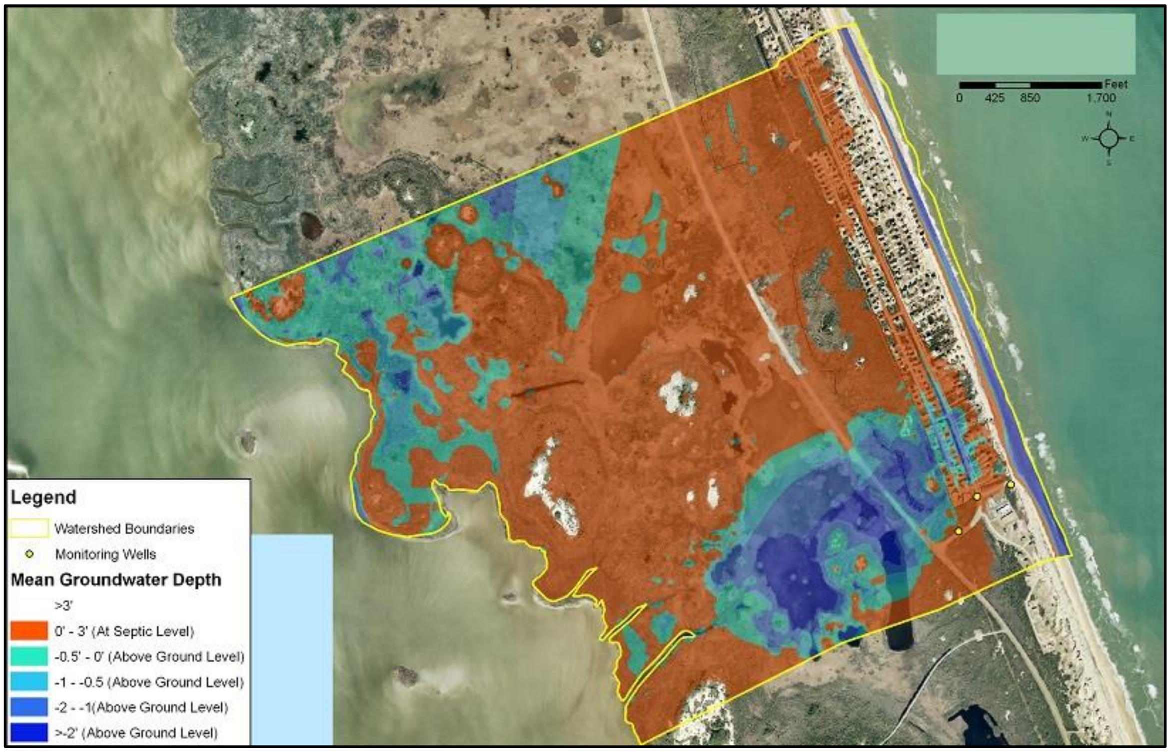


Figure 14. Mean Groundwater Levels from Southern Monitoring Wells

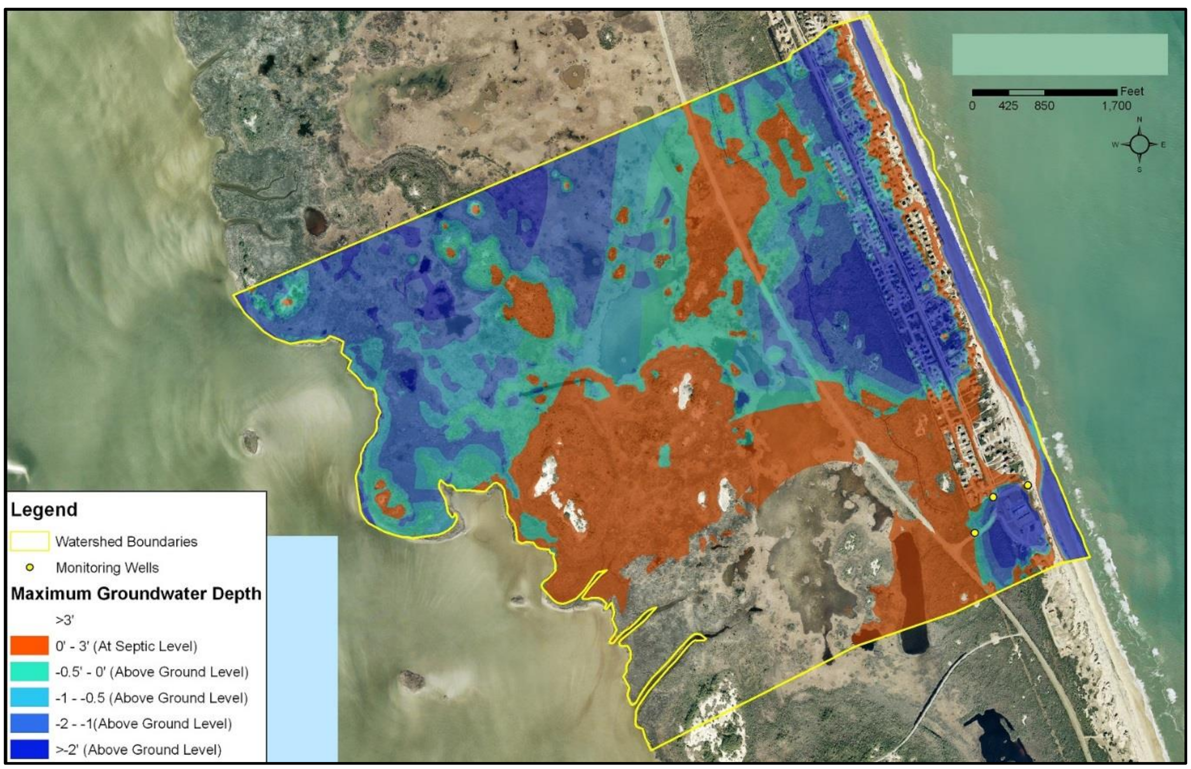


Figure 15. Maximum Groundwater Levels from Southern Monitoring Wells

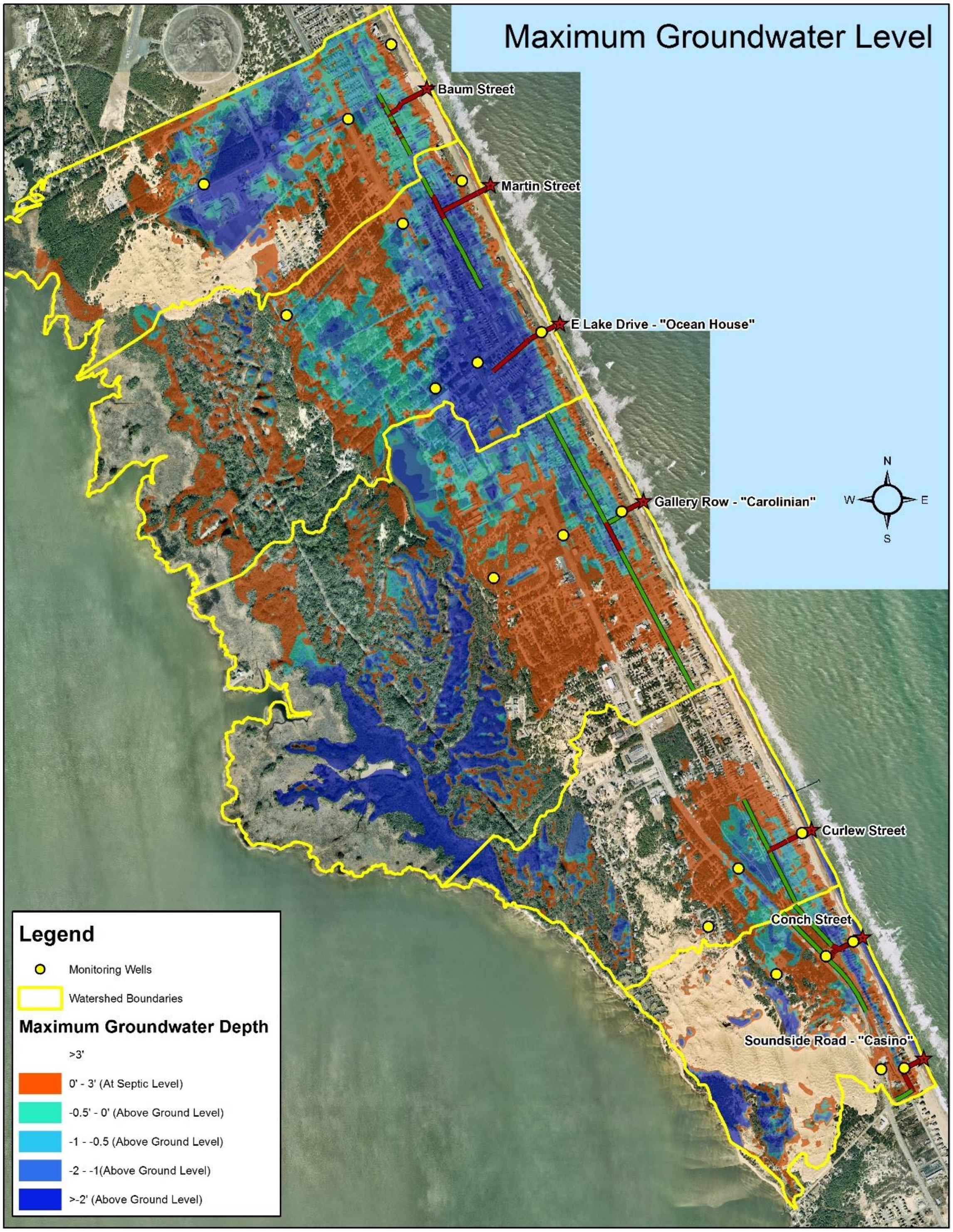


Figure 16. Maximum Groundwater Levels from Monitoring Wells

2.5 Conch Street BMP Implementation, Monitoring and Results

Conch Street BMP Background

A key component in this study was the development and implementation of interim best management practice (BMP) solutions for implementation and testing while long term solutions were being developed. Depending on results, these interim solutions could potentially be incorporated into the long terms solutions to address storm flows and pollutant loads from the ocean outfalls. In addition, there had always been significant interest in testing suitable proprietary technology for application in this ongoing project **based on the original statutory objectives for this pilot project.** The state of Rhode Island had experienced some success with application of AbTech Smart Sponge Technology to ocean outfalls there, and this technology showed promised for applicability here in coastal North Carolina. This section of the report describes the analysis and rationale utilized to identify the appropriate watershed and associated outfall for implementation of an interim BMP test project.

Criteria for Watershed Selection and Initial Assessment

The ocean outfalls on the North Carolina Outer Banks suffer many of the same constraints as those in Rhode Island; shallow groundwater, poor soils, limited land area available for treatment systems, and extremely high land costs. Based on Moffatt & Nichol's previous literature review of BMP feasibility and performance, it was determined that the AbTech Smart Sponge Plus® technology was well suited for addressing those constraints and that it was the only current innovative BMP with proven treatment effectiveness for *Enterococcus* and fecal coliform. For these reasons, it was selected for application to the interim test BMP site in this study.

Given the Rhode Island experience with regard to the limited hydraulic capacity of the Smart Sponge treatment system, it is obvious that this type of system is best suited for outfalls draining smaller watersheds with lower predicted storm flows, especially since our goal is to provide a greater level of treatment with the interim test BMP. **Table 7** shows the drainage areas and predicted flow rates (using simple Rational Method calculations) for the outfalls in this study. Based on the need to apply the Smart Sponge system to an outfall with lower predicted flow volumes, the set of candidate outfalls for an interim BMP application was narrowed to the Old Oregon Inlet Road, Soundside Road, and Conch Street outfalls.

Table 7. Drainage Areas Predicted Flows using the Rational Method

Outfall	Old Oregon Inlet Rd	Soundside Rd	Conch St	Curlew St	Gallery Row	E Lake Dr	Martin St	Baum St
Drainage Area (ac)	99	31	53	164	214	126	366	192
Storm Recurrence Interval (yrs)	Predicted Flow (cfs)	Predicted Flow (cfs)	Predicted Flow (cfs)	Predicted Flow (cfs)	Predicted Flow (cfs)	Predicted Flow (cfs)	Predicted Flow (cfs)	Predicted Flow (cfs)
2	122	53	64	187	264	260	301	181
5	151	64	77	229	325	316	376	224
10	174	72	88	263	374	360	436	258
25	205	83	101	306	436	416	515	303
50	230	91	112	340	486	460	580	339
100	255	99	123	375	537	504	646	376

Beyond the initial criteria of smaller watersheds and lower flow rates, the three candidate outfalls and their watersheds were then reviewed in more detail to examine further selection criteria including, but not limited to:

- Hydraulic capacities and characteristics of the existing drainage systems
- Space constraints
- Conflicts with existing infrastructure
- Land ownership issues and easements requirements
- Estimated Construction Costs
- Long Term Maintenance Issues and Access

The watershed for the Conch Street Outfall is in the middle of the three evaluated for the pilot project, and is of suitable size for the application while still being representative of all of the outfall watersheds. Perhaps most importantly, the Conch Street location offered the least difficulty in terms of the acquisition of necessary easements and future access for maintenance as it is located in and already public right of way, with the Town of Nags Head being completely amenable to granting the space and working with the project. In addition, the watershed for the Conch Street outfall included park land, commercial land, and residential land, providing the best mix of land uses out of the three watersheds, and the discharge estimates shown in **Table 7** indicate that flows from this outfall are in the middle of the three under consideration. Given that the predicted flows are toward the lower end of the range, it makes the hydraulic regime for this outfall fairly conducive to designing adequate storage capacity within the physical constraints of the site. As a result of these factors the Conch Street Outfall was selected for construction of the pilot BMP. It should be noted that the drainage areas in **Table 7** do not match those given for the same watershed later in the document due to the fact that the watershed boundaries were revised and improved based on newer topographic data received later in this study (refer to **Section 2.6**)

Design and Construction of the Pilot BMP

The Conch Street Outfall was selected for application of the pilot BMP in a large part because it offered the available space, already held in a public right-of-way, to accommodate the BMP structure itself and construction. This available space was due to the fact that prior to its terminus the Conch Street Outfall runs directly under the public beach access parking lot at the dead end of Conch Street (**Figure 17**). The BMP was constructed as an underground vault beneath the parking lot with sufficient structural integrity to allow for reconstruction of the highly valued parking spaces above the structure.

The concrete vault system consists of three separate chambers and connecting pipes. The first vault serves as a sedimentation chamber and flow splitter outfitted with a recessed floor and ceiling mounted weir to trap floatables which then leads to another weir set at an elevation to force lower flows into the treatment vault while allowing larger flows to bypass and be transmitted out to the ocean without treatment. The second low flow treatment vault consists of multiple rows of filters through which the stormwater will pass on its way to the ocean. The low flows and bypass flows (if present) both recombine at a third vault which then allows the water to pass through on to the ocean. All of the outlet pipes within the final vault are outfitted with rubber flap gates to minimize the occurrence of backflow through the system. Overall, the system was designed to provide treatment of up to 7200 gpm (16cfs) which was estimated to be approximately the runoff from a 0.5 inch storm. It was posited that persons would not likely be in the receiving waters for storms greater than this rainfall.

The combined vault system resulted in an underground structure approximately 62 feet long and 16 feet wide. A cutaway showing the distribution of filter arrays along the floor of the primary vault is shown in **Figure 18**, and a plan view of the design of the Conch Street BMP with illustration of flow routing is shown in **Figure 19**.

Figure 17. Conch Street Outfall Alignment Under Beach Access

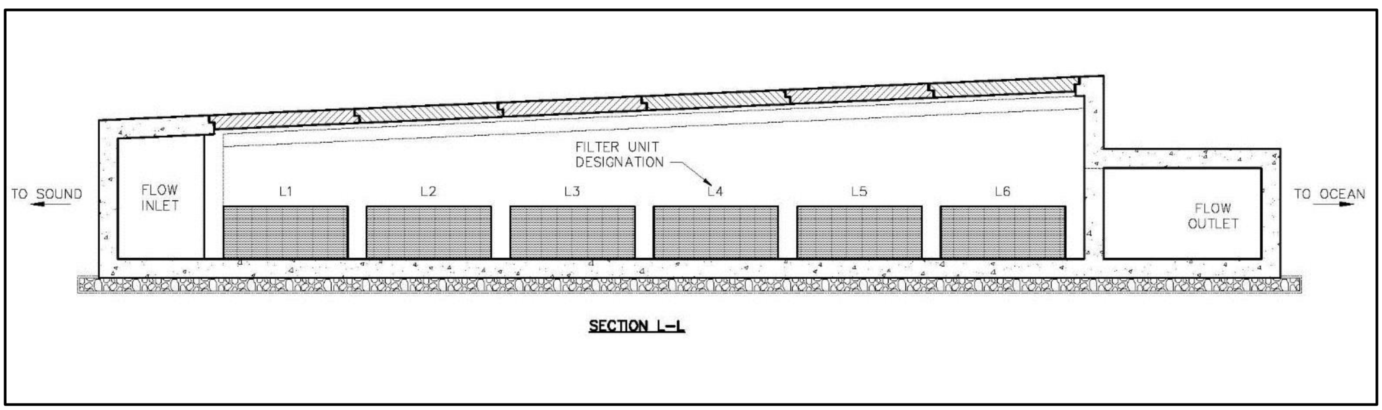


Figure 18. Cutaway View of Conch Street BMP Vault Showing Filter Arrays

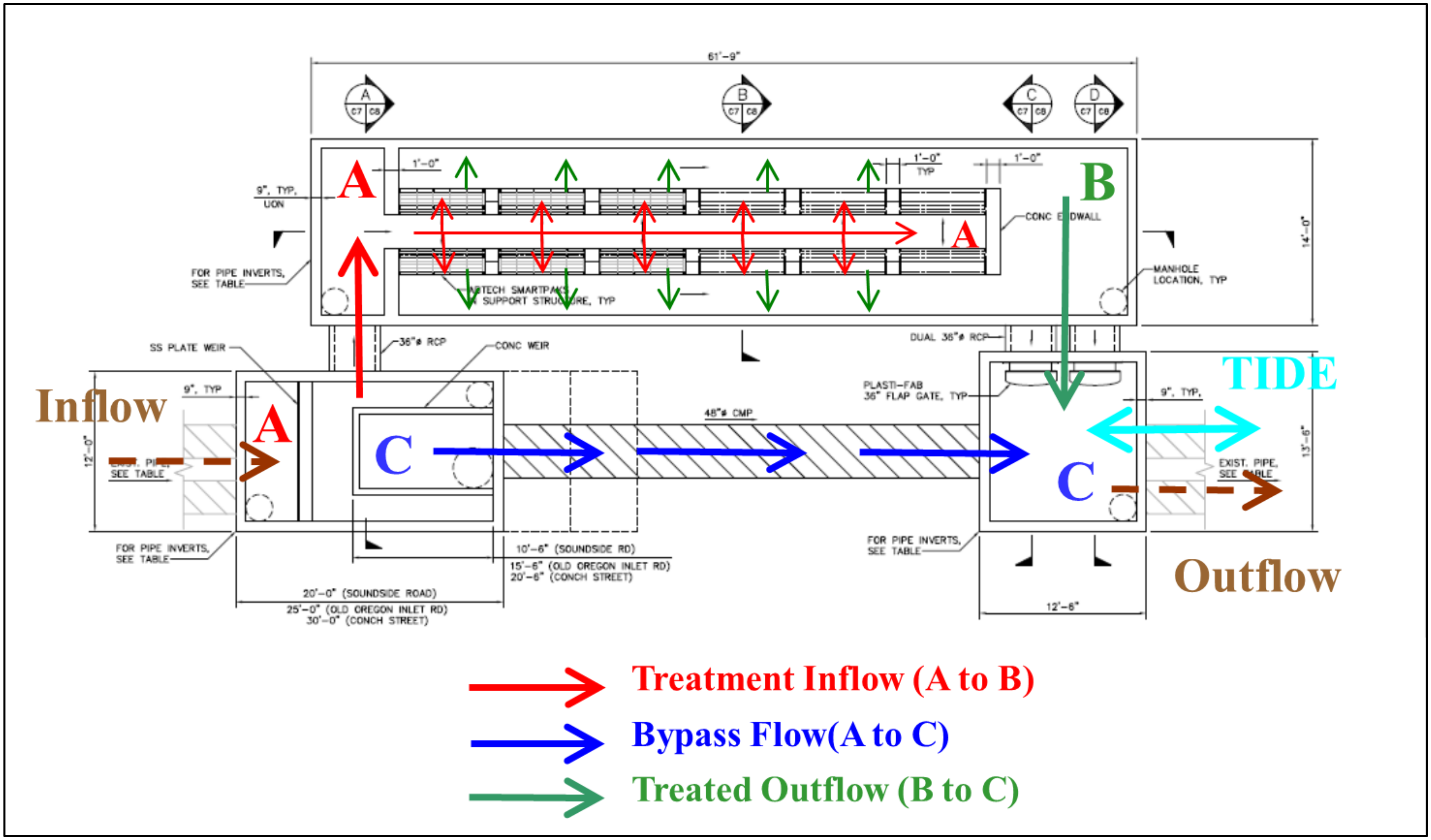


Figure 19. Plan View of Conch Street BMP Design with Routing Model Illustrated

Design work was completed on the vault and final permits for construction were obtained in August 2008. The initial effort to bid the project out was rejected because only two bidders submitted, and October 2008 the rebid process resulted in a winning construction bid from the firm of George Raper & Sons at $780,937. The Abtech Smart Pak filter media was purchased separately for $273,000, resulting in a total construction cost of $1,053,937. **Figure 20** and **Figure 21** illustrate the construction process. The BMP was completed and influent was released into the vault in December 2009. **Figure 22** shows the top of the completed Conch Street BMP with the top of the vault surrounded by the pervious grid pavers of the rebuilt parking lot.

Figure 20. Construction of the Conch Street BMP

Figure 21. Construction of the Conch Street BMP

Figure 22. Completed Conch Street BMP and Restored Parking Lot

Monitoring of the Pilot BMP

Once the Pilot BMP at Conch Street was up and running, it was subsequently monitored during twelve total storm events from 2010 to 2014. Importantly, these storms ranged in date of occurrence (seasonal coverage), duration (up to 72 hours), and precipitation amount (up to 2.8 inches of rain). **Table 8** shows summaries of information for each storm event, including the relative reduction or increase that is observed in *Enterococcus* concentrations from the entrance into the BMP vault system to the outflow of the outfall, which discharges directly into the ocean. The *Enterococcus* factors are the mean concentration of *Enterococcus* sp. in the discharge entering the ocean over the duration of a storm, divided by the mean concentration of the *Enterococcus* sp. in the inflow to the BMP vault system over the duration of a storm. A factor of > 1.0 indicates no removal of *Enterococcus* sp. by the BMP, a factor of <1.0 indicates reduction in the *Enterococcus* sp. concentration via the BMP system. The mean initial inflow *Enterococcus* sp. concentration is also shown. In addition, detailed descriptions of each storm event are provided, and graphical descriptions of each monitoring event are presented in Appendix A.

Table 8. Summary of Storm Event Monitoring at the Conch Street BMP

Dates	Number of Samples	Total Rainfall (in)	Duration (h)	Initial Enterococcus conc/100 ml	Enterococcus Factor (Average)
6/29-7/1/2010	4	2	40	13,000	0.79
8/5-8/6/2010	2	0.5	16	20,000	0.39
9/28-9/29/2010	4	1.93	20	2,800	0.87
11/4/2010	4	0.5	24	7,000	0.79
1/18/2011	4	2.04	6	600	1.45
3/30/2011	3	0.7	6	600	0.45
7/7/2011	3	0.78	24	8,000	0.80
7/11/2012	3	~1	24	14,000	1.49
8/2/2012	3	1.29	24	15,500	2.14
6/7/2013	3	1.71	24	20,000	1.09

June 29- July 1, 2010

During the storm of June 29, 2010 – July 1, 2010 there was 2.00 in of rainfall over a period of 72 hours. At the Conch Street Outfall, four sampling events were collected. The results from this sampling event are also illustrated graphically in **Figure 23** below. In the interest of space and formatting, the graphic illustrations of data for subsequent storms are shown in Appendix A. During the sampling events, *Enterococcus* concentrations ranged from 1,725 – 24,196 (mean 10,476) MPN 100 ml^{-1} and *E. coli* concentrations ranged from 2,359 – 11,199 (mean 4,298) MPN 100 ml^{-1}, with all *Enterococcus* values exceeding the state single sample maximum (SSM) of 104 MPN 100 ml^{-1}, before, during and at the outflow of the BMP filtered pipe. At the first sampling time point, flow was measured at 1,427 gpm (3.18 cfs) and by the last sampling point, flow had receded to 824 gpm (1.85 cfs). Regardless of tide or flow, *Enterococcus* and *E. coli* concentrations at the outfall were similar to or above concentrations (all within 0.5 log_{10} greater or less) entering the BMP filter. In all four rounds of sampling during the event *E. coli* concentrations in the outflow were greater than, or approximately equal to those present in the influent, but two of the sampling events showed reductions in *Enterococcus* with discharge concentrations equal to 79% of incoming stormwater levels (21% reduction), on average.

Figure 23. Conch Street BMP Monitoring Results for June 2010 Storm Event

August 5-6, 2010

During the storm of August 6, 2010 – August 7, 2010 there was 0.50 in of rainfall over 24 hours. At the Conch Street Outfall two sampling events were conducted during this time period. At the first sampling point flow was measured at 681 gpm (1.52 cfs), but by time point 2, 8 ½ hrs later, flow had returned to baseline levels (0 gpm). During the two sampling events the mean *Enterococcus* concentration was 16, 492 MPN 100 ml^{-1} (6,450– 24,890) and the mean *E. coli* concentration was 2,256 (706 – 4,106) MPN 100 ml^{-1}. There was approximately 0.5 log_{10} reduction for both *E. coli* and *Enterococcus* from the time the stormwater entered the BMP filter to the outfall, however all samples still exceed the SSM for *Enterococcus* of 104 MPN 100 ml^{-1}. Data from both sampling events from this storm indicate that reductions were being achieved for both *E. coli* and *Enterococcus* with discharge concentrations of the latter equal to 39% of those present in the influent (61% reduction), on average.

September 28-29, 2010

During the storm of September 28, 2010 – September 29, 2010 there was 1.93 in of rainfall over 24 hour time period. At the Conch Street Outfall four sampling events were collected over a period of 12.5 hrs. At the first sampling point, T1, flow measured 254 gpm (0.57 cfs) prior to entering the BMP filter. At T4, 12.5 hours later, flow was measured at 0 gpm. During the four sampling events, the mean *Enterococcus* concentration was 13,279 (2,560 – 72,700) MPN 100 $ml^{-1.}$ The mean *E. coli* concentration was 407 (71 – 2,489) MPN 100 ml^{-1}. All *Enterococcus* samples remained within less than 0.5 log_{10} for all points (prior to entering BMP, after BMP filter, and at the outfall) and all exceed the SSM of 104 MPN 100 ml^{-1}. *E coli*, however, did show a reduction from pre filter to the outfall of 0.1 log_{10} to 0.92 log_{10} reduction in concentrations. All four sampling events captured during this storm showed at least some reduction of *E. coli* concentrations, but only two samples showed reduction of *Enterococcus* with discharge concentrations of the latter equal to 87% of those present in the influent (13% reduction), on average.

November 4, 2010

During the storm of November 4, 2010 there was 0.51 in of rainfall over a 24 hour time period. At the Conch Street Outfall four sampling events were conducted over a period of 5 hrs. There is no flow data available for this event. During the first 3.5 hrs of sampling (T1-T3), there was a mean reduction of *Enterococcus* concentrations of 0.55 log_{10} and a mean reduction of *E. coli* of 0.83 log_{10}, however the SSM of 104 MPN 100 ml^{-1} for *Enterococcus* was still exceeded at the outfall. For sample T4, 2 hours later than T3, there was increase in concentrations of bacteria of 0.36 log_{10} for *Enterococcus* and 0.45 log_{10} for *E. coli*. During the four sampling events the mean *Enterococcus* concentration was 26, 549 (750 – 64,880) MPN 100 ml^{-1} and the mean *E. coli* concentration 2,994 (30 – 14,136) MPN 100 ml^{-1}. Two of the four sampling events captured during this storm showed substantial reductions in *E. coli* concentrations. One sample showed very little change, and one showed an increase in discharge concentrations at the end of pipe relative to the incoming stormwater runoff based concentrations. Three sampling events showed some reduction in *Enterococcus* concentrations, but the last event showed an increase, with average discharge concentration equal to 79% of the incoming stormwater runoff levels (21% reduction).

January 18, 2011

During the storm of January 18, 2011 there was 2.04 in of rainfall over a 24 hour time period. At the Conch Street Outfall four sampling events were conducted over a relatively short time period of 1 hr 20 min. The flow at the first sampling point, T1, was 1,458 gpm (3.25 cfs) and had reduced to 1,126 gpm (2.51 cfs) after roughly 1 ½ hrs. For all sampling time points, T1-T4, bacterial concentrations increased from the time that they entered the BMP to exiting the outfall pipe. For *Enterococcus* the average increase was 0.135 log_{10} and for *E. coli* there was on average an increase of 0.24 log_{10}. The *Enterococcus* concentrations exceeded the SSM of 104 MPN $100ml^{-1}$ by an average of 0.85 log_{10}. During the four sampling events, the mean *Enterococcus* concentration was 661 (307 – 1,102) MPN 100 ml^{-1} and the mean *E. coli* concentration was 146 (63 – 295) MPN 100 ml^{-1}. Three of the four samples captured during this storm event showed increased *E. coli* concentrations when considering discharge as compared to incoming stormwater. By the same token three of the four samples captured during this storm event showed increased *Enterococcus* concentrations, with the concentrations in the discharge 1.45 times those in the incoming stormwater runoff (45% increase).

March 30, 2011

During the storm of March 30, 2011 there was 0.70 in of rainfall over a 24 hour time period. At the Conch Street Outfall three sampling events were conducted over a period of 3.5 hrs on a rising tide. There was no flow data available for this event. For time points T1 and T2 there was an average reduction in bacterial concentrations from the time the storm water entered the BMP to exiting the outfall pipe. For *Enterococcus*, there was an average reduction of 0.825 log_{10} and for *E. coli* there was an average reduction of 0.45 log_{10}. It should be noted that T1 and T2 were collected on the rising limb of the tidal cycle. The third sampling point, T3, was collected at high tide and showed little variation between any of the pre-, post-, or outfall pipe samples for either *E. coli* or *Enterococcus*. Only the outfall pipe at time point, T1, had *Enterococcus* concentrations below the SSM of 104 MPN $100ml^{-1}$. The mean *Enterococcus* concentration was 519 (51-1,017) MPN 100 ml^{-1} and the mean *E. coli* concentration ranged from 5 - 41 MPN 100 ml^{-1}. For both *E. coli* and *Enterococcus* concentrations, two of the three samples collected during this storm showed reductions, and one showed almost no change. Concentrations of *Enterococcus* during this particular event demonstrated a 55% reduction from incoming stormwater runoff concentrations.

July 7, 2011

During the storm of July 7, 2011 there was 1.40 in of rainfall over 24 hours. At the Conch Street Outfall three sampling events total were conducted, although not all samples were collected at all sites for the entire storm event. For the first time in the course of the study, FIB concentrations were monitored in the surf in conjunction with the outfall monitoring. Results here are discussed in that context. The upcoast/downcoast monitoring is also discussed in greater detail in Section 2.4. Even at the beginning of the storm, the concentrations of *Enterococcus* remained above state water quality thresholds of 104 MPN 100 $ml^{-1,}$ respectively, at distances of 100 meters from the pipe. The human specific marker, HF183, was detected at six locations during this first sampling point, indicating the likely presence of human fecal contamination in the stormwater plume. For sampling period 2, the extent of contamination from the stormwater plume was 100 meters from the end of the pipe, with FIB concentrations exceeding the state water quality standard. The Fecal *Bacteroides* spp. Marker concentrations were 77,893 MPN 100 ml^{-1} at the end of the pipe, and were measured at 5 MPN 100 ml^{-1} at 100 m away from the pipe, indicating a 4 log reduction. During the 2nd sampling period, human marker was quantifiable at 100 meters from the outfall pipe, likely indicating the continued influence of human fecal contamination present in the stormwater plume.

Two of the three samples collected over the duration of this event showed moderate *Enterococcus* reduction, at 80% of the incoming stormwater runoff concentrations, the equivalent of a 20% reduction.

<u>Outfall Maintenance Event</u>

It should be noted that in June, 2012, after approximately two and a half years in operation, a full maintenance event was performed on the Conch Street BMP. The most critical portion of that event involved testing and replacing the worn out Smart Sponges in the device. Testing indicated that approximately two thirds of the media was no longer effective, and required replacement. The following storm events reflect the performance of the device after the maintenance event. The maintenance process is discussed in detail below after the remainder of the monitoring results.

<u>July 11, 2012</u>

During the storm of July 11, 2012 there was approximately 1 inch of rainfall over 24 hours. At the Conch Street Outfall three sampling events total were conducted. Even at the beginning of the storm, the concentrations of *Enterococcus* remained above state water quality thresholds of 104 MPN 100 ml^{-1}. The human specific marker, HF183, was detected at nine locations during this first sampling point, indicating the likely presence of human fecal contamination in the stormwater plume. The marker for Fecal *Bacteroides* spp. concentrations ranged from 5 – 93,912 CE 100 ml^{-1}. *E. coli* concentrations ranged from 1,201 - 19,863 MPN 100 ml^{-1}. *Enterococcus* concentrations also exceeded state recreational water quality standard in all samples ranging from 6,131 – 17,329 MPN 100 ml^{-1}. Gull marker concentrations were recorded in all samples ranging from 5 – 57,112 CE 100 ml^{-}, and were of the same magnitude as other fecal molecular markers, although no correlative relationships can be derived between the two markers. All three samples captured during this storm event showed increased *E. coli* concentrations in the discharge as compared to the incoming stormwater runoff. Two of the three samples showed very slight decreases in concentrations of *Enterococcus*, and one showed a substantial increase. The concentrations of *Enterococcus spp.* was 1.49 times that of the incoming stormwater runoff inputs, on average (49% increase).

August 2, 2012

During the storm of August 2, 2012 there was 1.29 in of rainfall over 24 hours. At the Conch Street Outfall three sampling events total were conducted. All concentrations of *Enterococcus* remained above state water quality single sample limits of 104 MPN 100 ml^{-1}. The human specific marker, HF183, was detected at nine locations during this first sampling point, indicating the likely presence of human fecal contamination in the stormwater plume. Fecal *Bacteroides* spp. concentrations ranged from 5 – 99,122 CE 100 ml^{-1}. *E. coli* concentrations ranged from 379 – 9,208 MPN 100 ml^{-1}. *Enterococcus* concentrations also exceeded state standard in all samples ranging from 1,600 – 13,330 MPN 100 ml^{-1}. Gull values were recorded in all samples ranging from 5 – 21,735 CE 100 ml^{-1}. For both *E. coli* and *Enterococcus* concentrations, two of the three samples collected during this storm showed significant increases, and one showed almost no change. Effluent concentrations of *Enterococcus* were reported at 2.14 times influent levels (114% increase), on average. These results also indicated that there are multiple sources of fecal contamination, with human and gull fecal contamination verified by molecular testing, being transported through the outfall pipe.

June 7, 2013

During the storm of June 7, 2013 there was 1.73 in of rainfall over 24 hours. At the Conch Street Outfall three sampling events total were conducted. All concentrations of *Enterococcus* remained above state water quality thresholds of 104 MPN 100 ml^{-1}. The human specific marker was detected at nine locations during this first sampling point, indicating the likely presence of human fecal contamination in the stormwater plume. All samples testing for Fecal *Bacteroides* spp. concentrations recorded 5 CE 100 ml^{-1}, and when compared to previous data, it is likely that these values are underestimating the load of Fecal Bacteriodes due to the presence of inhibitory substances within the sample matrix that interfere with processing. *E. coli* concentrations ranged from 6,770 – 29,870 MPN 100 ml^{-1}. *Enterococcus* concentrations also exceeded state water quality standards in all samples ranging from 6,070 – 51,720 MPN 100 ml^{-1}. Gull concentrations were recorded in all samples ranging from 5 – 37,834 CE 100 ml^{-1}. Two of the three samples captured during this storm event showed reductions *E. coli* concentrations, and one showed almost no change. Two of the three samples showed decreases in concentrations of *Enterococcus,* and one showed a substantial increase. Concentrations of *Enterococcus* in the discharge were reported at 1.09 times the incoming concentrations (9% increase), on average.

Discussion of BMP Monitoring Results

Following the construction of the stormwater treatment vault at the Conch Street outfall, 7 storms were sampled prior to the maintenance of the BMP, with sampling events occurring through summer, fall, winter and spring. Multiple samples were taken throughout the storms. Four storms had 4 samples, two storms had 3 samples and one storm had 2 samples. After the maintenance of the BMP, three summer storms were sampled, with three samples collected during each event. Stormwater FIB concentrations varied widely among the storms sampled; mean E coli concentrations ranged from 146 to 4,298 cells/100ml and *Enterococcus* concentrations ranged from 519-26,499 cells/100ml. **Figure 23**, and the figures in Appendix A showing concentrations of FIB prior to the treatment media, after the treatment media and leaving the vault reveal the range of observed conditions. There were several storms that showed a general trend of reduction in

FIB, however the patterns of concentration were neither consistent nor predictable. Degree of efficacy was not predicted by season, beginning concentration of FIB or storm size.

Samples taken entering and exiting the stormwater treatment vault for concentrations of FIB were used to calculate treatment factors. Values less than 1 indicate reduction (ie factor of 0.75 indicates a 25% reduction). For *E. coli*, treatment factors suggested removal 10 out of 21 times measured and for *Enterococcus* they indicated removal 13 out of 21 measurements. There were also numerous occasions when treatment factors indicated the vault was a source of FIB. *E. coli* in particular had treatment factors approaching 4, indicating four-times higher concentrations leaving the vault than entering it. These data, taken as a whole support the finding that the vault was not a consistently effective treatment structure. During our assessment several factors appeared to contribute to the lower than predicted efficacy. Among those factors were: 1) elevated water level from diurnal tides preventing consistent unidirectional flow through the vault, 2) close proximity of the treatment vault to the groundwater table, 3) the inability of tide gates to completely seal the vault leading to consistent standing water which may have created conditions favorable for FIB growth and 4) fouling of the front faces of the treatment media by stormwater borne debris and sediment rendering the antimicrobial compounds ineffective.

Maintenance of the Pilot BMP

In the second year of operation of the BMP, regular visual observations by monitoring staff from the Coastal Studies Institute and a preliminary inspection by M&N staff indicated that the performance of the filter array in vault was likely becoming impeded by sediment deposition. **Figure 24** is a photo taken during the preliminary inspection showing sediment caked on the leading face of the treatment media racks. In early 2012 NCDENR contracted M&N to plan, coordinate and oversee a maintenance event for the Conch Street BMP, and in June, 2012, after approximately two and a half years in operation, the vault at Conch Street was opened and disassembled for inspection and maintenance. The firm that originally constructed the BMP, George Raper & Sons, was hired to assist in the maintenance event and assistance was provided by AbTech and NCDOT as well.

The main purposes of the maintenance event were to clean the sediment from the vault sand change out the treatment media. Given the high cost of the AbTech Smart Pak sponges, the existing sponges deployed in the original loading of the vault were tested for viability and reused when possible. Approximately one third of the individual Smart Paks were reused from the original set, leaving two thirds of the treatment media array that had to be replaced with new Smart Paks. Fees and expenses for the maintenance event totaled $212,048, including $155,859 in expenses for the new treatment media. The maintenance event took four full days.

Figure 24. Conch Street BMP Treatment Media with Sediment Deposition

It was observed during the maintenance event, and during other inspections of the vault, that water appear to be passing back through the flap gates during high tides and remaining in the vault for extended periods of time. In order to monitor depths and volumes of water occupying the vault a water level recorder was deployed from August, 2012 to October 2013. Based on the dimensions of the device, the water depth recordings were utilized to calculate the ongoing volumes of water standing in the vault. It was determined that the bottom row of sponges remains mostly, if not fully, inundated half the time or more, diminishing the effectiveness of half the sponges in the device. This condition is partly due to the performance of the flap gate at the downstream end of the vault and partly due to the aggravating factor of a significant amount of sediment accumulated in the bottom of the vault.

Given the varied performance of the BMP and the observations made during the maintenance event, the following recommendations to improve the performance of the device were developed.

Recommendation: Retrofit the BMP with a Solar Pump

It is recommended that the Conch Street BMP be retrofitted with a pump to remove the standing water from there floor of the contact vault daily. Volume calculations relative to pump capacities determined that the water could be effectively pumped out each day with a solar powered pump which would render the bottom half of the sponge faces dry and better prepared for inflows resulting from storm event when they occurred.

Recommendation: Change the type of Contact Media

If the costs savings from the Smart Sponge units that were left over from the initial installation and held by the Town of Nags Head were not a factor, the cost of a typical change-out is likely to exceed $200,000, and the manufacturer recommends that media testing, rotation and replacement be conducted annually.

A new company has been identified, FabCo Industries, which can supply and alternative contact media for the vault that fit the exiting physical structures at a significantly lower cost. The FabCo contact media for treatment of bacteria uses the same active agents as the AbTech Smart Sponge system while utilizing a different foam rubber material for manufacturing. As a result, the FabCo media is much less expensive than the comparable media from AbTech. FabCo supplied a quote for full replacement of the contact media in the Conch Street for slightly less than $50,000.

Recommendation: Increase Frequency of Inspection and Partial Maintenance

Regardless of which brand of media discussed above is utilized in the Conch Street Stormwater BMP in the future, and media that work on the basis of flow through and contact are subject to being compromised by sediment deposition on the outer surface. Field engineers and product development scientists at both companies discussed have all attested to the sensitivity of the contact media to sediment.

The degree of fouling of the contact media due to sediment deposition could be greatly alleviated with regular clean outs of the device's sediment trap. It is recommended that NCDOT or the Town of Nags Head visually inspect the vault, and especially the sediment trap, every 3 months. The most desired result from regular inspections would be to deploy a vacuum truck to clean the sediment trap when accumulated sediment volumes reach significant amounts.

Alternate Recommendation: Remove Treatment Media and Clean Sediment Trap

If no funding source is identified, and no further improvements are made, and it is no longer desired to utilize the Conch Street BMP as a treatment device, it is recommend that the sediment trap be cleared and the vault opened and the treatment media removed. The June 2012 maintenance event revealed that a great deal of sediment had accumulated in the sediment trap and in the treatment chamber of the Conch Street BMP. Given that the event occurred over three years ago at the time of this drafting, the sediment has built up again, and at some point will likely become an obstruction to effective drainage to outfall. Removal of the expired Smart Pak sponges will also reduce sediment accumulation, promote better drainage, and reduce the potential for bacterial regrowth in the device.

2.6 Upcoast/Downcoast Ocean Monitoring

Early in this stormwater project, results demonstrated high FIB concentrations in stormwater discharge from outfall pipes along Dare County beaches. In addition, the total FIB loading estimated from these outfall locations, even for small storms, was extensive, sometimes approaching 10^{11} *Enterococcus* cells per hour. Two actions stemmed from those findings, first, a pilot BMP system was put in place at Conch Street Outfall to implement FIB concentration reductions in discharge (as discussed in the previous section). In addition, it was determined in interactions among project team members, and stakeholder groups, that an assessment of the impact of the stormwater plume up and down the beach was vital. The reasoning was that there was only a poor understanding of the true impact of storm events along the extent of beach impacted by active stormwater discharge. Therefore, an effort was initiated to sample the discharge from the outfall pipe of the Pilot BMP at the Conch Street Outfall, as well as sampling conducted termed upcoast/downcoast" sampling. This sampling was conducted at consistent distances (0, 25, 50, 100 and 200 meters) over a range of storms. Early in this portion of the project, only the Conch Street Outfall was targeted for sampling, but as the project continued, Soundside and Curlew Outfalls were included in each sampling event.

Curlew Street Outfall

July 16, 2014

During the storm of July 16, 2014 there was 1.02 in of rainfall over two hours. At the Curlew Street Outfall, two sampling events over the course of the storm. The sampling was conducted at the end of the outfall pipe and 25m, 50m, 100m, and 200m in the north and south direction from the outfall pipe. The results from this sampling event are also illustrated graphically in **Figure 25** below. In the interest of space and formatting, the graphic illustrations of data for subsequent storms are shown in Appendix B. The flow for time point 1 (T1) was 1,162 gpm (2.59 cfs) and subsided to 362 gpm (0.81 cfs) at time point 2 (T2), two hours later. Even though the duration of this storm was short, the second sampling point indicated a strong influence of stormwater contamination up and down coast with concentrations of *Enterococcus* remaining above the state water quality threshold of 104 MPN 100 ml^{-1}, respectively, at distances of 100 meters upstream and 200 meters downstream from the end of the outfall pipe. The second sampling point showed a log increase in *E. coli* concentrations at the northern most sampling points (100m and 200m up coast). The *Enterococcus* and *E. coli* concentrations were highest at the end of the pipe (4.85 log_{10} and 3.59 log_{10} for T1; 4.61 log_{10} and 4.02 log_{10}, respectively). Even though a clear impact of the storm water inputs at the Curlew Street site exists from this up coast and down coast storm assessment, it is possible that additional stormwater influences are being observed from nearby (Conch Street) locations and is evident for all the storm samples collected during additional storms. The mean *E. coli* concentration was 1592 100 ml^{-1}, ranging from 200 – 12,590 100 ml^{-1}. The mean *Enterococcus* concentration was 7,009 100 ml^{-1}, ranging from 50 – 86,640 100 ml^{-1}. The highest concentrations occurred at the outfall at the end of the pipe.

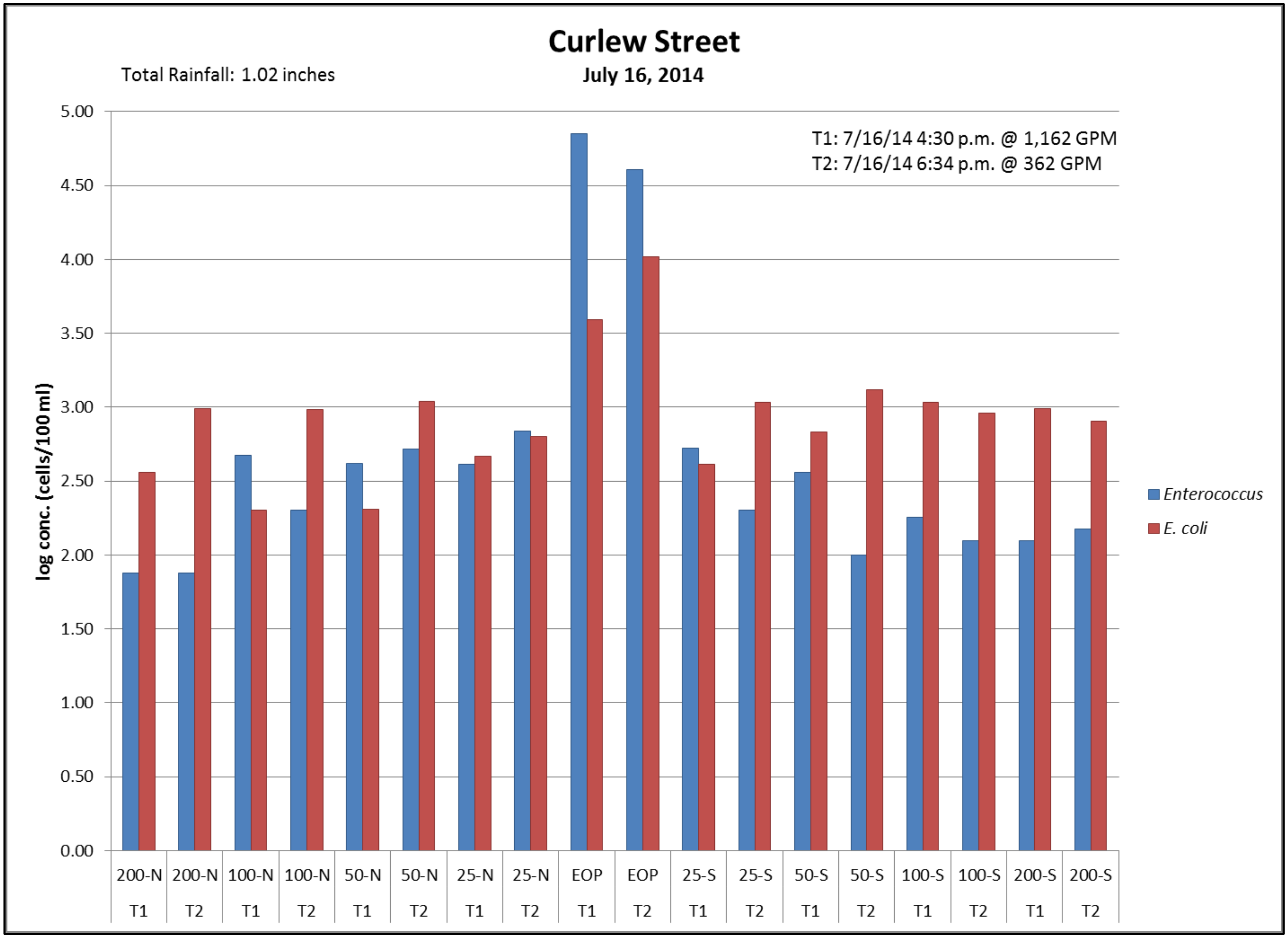


Figure 25. Upcoast/Downcoast Monitoring Results for Curlew Street Outfall, July 2014

August 3-4, 2014

Three samples were taken over a period of 21.5 hours during a relatively small rainfall event in which 0.71 in of rain fell on August 3-4, 2014. Samples consisted of sampling at the end of the outfall pipe and 25m, 50m, 100m, and 200m North and South of the outfall and is hereafter referred to as Up and Down coast sampling as well as from an automated sampler in the outfall pipe (ISCO). Initial sampling after the first pulse of rain (T1) indicated the state recreational water quality level (104 MPN 100 ml^{-1}) for *Enterococcus* was being exceeded at the end of the pipe at the ocean outfall, but that the upstream/downstream levels were below state water quality levels. The second (T2) and third (T3) samples also showed state water quality exceedances at the outfall, with higher levels of *E. coli* being observed at the 2nd time period and exceedances in *E. coli* observed at the 3rd time period, up to 100 meters away from outfall. This pattern indicates that a "first flush" phenomenon, or landscape scouring is not occurring, and as the storm proceeds concentrations of FIB continue to increase. The pattern of increasing *E. coli* with storm duration is similar to that of the prior storm (July 16, 2014). In addition, to measurements for *E. coli* and *Enterococcus*, a molecular microbial source tracking marker, Fecal *Bacteroides*, which indicates the presence fecal contamination and has been associated with human fecal contamination was measured with a mean concentration of 19,539 (9,127 – 47,626) Cell Equivalents (CE) 100 ml^{-1}. The highest concentration of Fecal *Bacteroides* was measured at 25m down coast. The mean concentration of *E. coli* was 328 MPN 100 ml^{-1}, ranging from 100 – 1,790 100 ml^{-1}. The mean concentration of *Enterococcus* was 793 100 ml^{-1}, ranging from 50 – 11,895 100 ml^{-1}. The highest concentrations of *E. coli* and *Enterococcus* were measured at the outfall at end of the pipe.

September 8, 2014

From September 7-8, 2014 a large two pulse event storm resulted in a total of 2.60 in of rain in the Curlew Watershed. Three sampling time points (T1. T2, and T3) were conducted over a time period of 2 hrs 40 min. and were taken after both rainfall events had passed and water flow was 509 gpm (1.13 cfs) in the outfall pipe. At T1, the flow measured 1240 gpm (2.76 cfs) and had decreased to 716 gpm (1.60 cfs) 55 min. later at T2. The highest *E. coli* and *Enterococcus* concentrations were measured at the outfall at the end of the pipe for all time points T1 through T3, with concentrations approaching 100, 000 MPN 100 $ml^{-1,}$ which is 4 log greater than the state single sample maximum (SSM) recreational water quality standard for *Enterococcus* (104 MPN 100 ml^{-1}). Even at 200m down coast, state water quality standards were still exceeded and were at or just above the SSM at 200m up coast of the outfall. The mean *Enterococcus* concentration was 9,248 (50 – 94,500 MPN 100 ml^{-1}) and for *E. coli* the mean concentration was 5,048 (465 – 48,840 MPN 100 ml^{-1}). In addition, the human associated molecular marker, Fecal *Bacteroides* was measured and returned a mean concentration of 1,766 CE 100 ml^{-1} (308 – 2,924 CE 100 ml^{-1}), which is considered a baseline measurement for this marker. Gull fecal marker was also examined and showed widespread Gull fecal contamination across the beach with a mean concentration of 72, 227 CE 100 ml^{-1} and ranging from 2,986 – 466,788 CE 100 ml^{-1}. The highest concentrations of the Gull marker were recorded 200 m up and down coast of the outfall.

Conch Street Outfall

July 7, 2011

During the storm of July 7, 2011 there was 1.40 in of rainfall over 24 hours. At the Conch Street Outfall three sampling events were conducted, although not all markers were measured at all sites for the entire study. A sampling event consisted of Pre Filter (prior to entering the filter at the BMP), Post Filter (after leaving the BMP filter), 25m, 50m and 100m down coast, with the exception of T3 which was only pre and post filter. Even at the beginning of the storm, the concentrations of *Enterococcus* remained above SSM of 104 MPN 100 ml^{-1}, at distances of 100 meters from the pipe. The human specific marker, HF183, was detected at six locations during this first sampling point, indicating the likely presence of human fecal contamination in the stormwater plume. *Enterococcus* never reached levels below the state SSM with mean concentrations of *Enterococcus* concentration measuring 7,277 (235 – 23,820) MPN 100 $ml^{-}1$, even at 100m down coast from the outfall. The Fecal *Bacteroides* spp. concentrations were 77,893 CE 100 ml^{-1} at the end of pipe, and were not quantifiable 100 m away from the pipe either due to being below the limit of detection (BLD) or from interfering substances within the sample matrix that prevented an accurate assessment. The mean *Fecal Bacteroides* concentration was 18,505 (5 – 79,823) CE 100 ml^{-1}. During the 2nd sampling period, human specific marker, HF183, was quantifiable at 100 meters from the outfall pipe, likely indicating the continued influence of human fecal contamination present in the stormwater plume. The human specific molecular marker, HF183, had a mean concentration of 28 (5 – 298) CE 100 ml^{-1}, with the highest concentration 2.47 log_{10} measured post filter at T3, indicating the presence of human contamination well into the precipitation event. In addition, Gull fecal marker was also measured and was widespread across the beach and even in the pre and post filter samples with a mean concentration of 10,904 (5-47,899) CE 100 ml^{-1}.

July 16, 2014

During the storm of July 16, 2014 there was 1.02 in of rainfall over 24 hours. At the Conch Street Outfall two sampling events (T1 and T2) were conducted. At T1, the flow measured 521 gpm (1.16 cfs) and 2 hrs. 17 min later, the flow was measure at 712 gpm (1.59 cfs). *Enterococcus* concentrations exceeded state water quality thresholds of 104 MPN 100 ml^{-1} in 16 out of 20 samples. *E. coli* concentrations ranged from 200 - 5,015 MPN 100 ml^{-1} with a mean concentration of 1,031 MPN 100 ml^{-1} and Enterococci concentrations ranged from 50 – 15,340 MPN 100 ml^{-1} with a mean concentration of 1,449 MPN 100 ml^{-1}. The highest concentration of both were found at the outfall at the end of the pipe. General trends of decreasing concentrations further from outfall were observed though *Enterococcus* concentrations which exceeded state single sample maximum (SSM) were observed 200 and 350 meters from outfall. The *Enterococcus* and *E. coli* loads for this storm were 2.19 x 10^{10} and 9.07 x 10^{9} MPN per h. Again, since levels of FIB remained relatively high and constant throughout the monitoring period, this is likely indicative of a continued source of human fecal contamination. No other markers were measured for this storm event.

<u>August 3-4, 2014</u>

Three sampling time points (T1, T2, and T3) were taken during a relatively small rainfall event in which 0.71 in of rain fell on August 3-4th, 2014. At T1, the flow measured 14,323 gpm (31.91 cfs). At T2, 18 hours after first flow measurement, the flow measured 6,884 gpm (15.34 cfs) and by T3, 1 hr 25 min later, the flow still measured 5,080 gpm (11.32 cfs). The highest concentrations of *E. coli* and *Enterococcus* were measured at the outfall pipe for all three sampling time points. The concentrations were reduced by one log or greater for *Enterococcus*, falling below the SSM of 104 MPN 100 ml^{-1} by 25m up or down coast with the exception of one sample for *Enterococcus* at 25m for T1. The mean *E. coli* concentration was 570 (30 – 9,880) MPN 100 ml^{-1} and averaged 285 MPN 100 ml^{-1} for *Enterococcus*. The *Enterococcus* and *E. coli* loads for this storm were 7.98 x 10^{10} and 1.46 x 10^{10} cells per h. Molecular source tracking markers were also measured during this storm event. Human associated Fecal *Bacteroides* was found consistently throughout the samples and gave a mean concentration of 26,697 (13,607 – 67,173) CE 100 ml^{-1}. The human specific marker, HF183, had the highest concentrations at the end of the outfall pipe (mean of T1-T3 5.6 $\log_{10}$) and remained high throughout the event with a mean concentration of 369,925 (129,442 – 782,691) CE 100 ml^{-1} . Gull marker was not measured for this storm.

<u>September 8, 2014</u>

From September 7-8th, 2014 a large two pulse event dropped 2.80 in of rain in the Conch Watershed. All three sampling events (T1, T2, and T3) occurred after both rainfall events had passed and water flow was high. At T1, the flow measured 1060 gpm (2.36 cfs). 1.5 hrs after T1, at T2, flow was reduced to 874 gpm (1.95 cfs), and by T3, 1 hr later, the flow was down to 592 gpm (1.32 cfs). *Enterococcus* concentrations were greatest at the outfall pipe with a mean of 4.51 $\log_{10}$ and while *E. coli* concentrations at the end of the outfall pipe were the highest at T1 (4.35 $\log_{10}$) and decreased with each sampling event (T3 mean concentration 3.35 $\log_{10}$). State water quality levels for *Enterococcus* concentrations were exceeded in 52 of the 54 samples that were collected, with exceedances occurring up to 200 meters from outfall. Only two samples (T2, 100m up coast and T3, 25m up coast) were below the SSM for *Enterococcus*. The mean concentration of *E. coli* was 2,270 (360 - 22,390) MPN 100 ml^{-1}. The mean concentration for *Enterococcus* was 4,645 (50 – 59,625) MPN 100 ml^{-1}. The *Enterococcus* and *E. coli* loads for this storm were 7.14 x 10^{10} and 2.34 x 10^{10} MPN per h. Additional molecular markers were measured for this storm event. The mean Fecal *Bacteroides* concentration was 164,639 CE 100 ml^{-1}. The mean human specific marker, HF183, concentration was 6,117 (4,104 – 8,130) CE 100 ml^{-1}. Gull fecal marker mean concentrations were 494,202 100 ml^{-1}.

Soundside Road Outfall

<u>September 8, 2014</u>

From September 7-8th a large two pulse event dropped 2.80 in of rain. Three samples (T1, T2, and T3) were taken after both rainfall pulses had passed and water flow was high. At T1, the flow measured 13,439 gpm (29.94 cfs). At T2, 2.5 hr after T1, the flow was 5,422 gpm (12.08 cfs). The third flow measurement, T3, 1 hr after T2, measured flow at 3,173 gpm (7.07 cfs). *Enterococcus* and *E. coli* concentrations were highest at the outfall. For *Enterococcus,* most of the measurements receded to levels below that of the SSM of 104 MPN 100 ml^{-1} . During the 3 sampling events *Enterococcus* concentrations ranged from 75 – 4,530 (mean 549) MPN 100 ml^{-1} and *E. coli* concentrations ranged from 685 – 10,200 (mean 2,199) MPN 100 ml^{-1}. Other molecular source tracking markers were measured for this storm. The human associated, Fecal *Bacteroides*, and the human specific marker, HF183, were detected throughout the storm event. The Fecal *Bacteroides* had a mean concentration of 2,053 CE 100 ml^{-1} (1,324 – 2,782 CE 100 ml^{-1}) while the HF183 marker gave a mean concentration of 6,232 (3,842 – 8,778) CE 100 ml^{-1}. Gull fecal contamination was seen throughout the up and down coast sampling with a mean concentration of 79,777 (12,932 – 326,711) CE 100 ml^{-1} with the highest concentration (5.51 log_{10} CE 100 ml^{-1}) occurring during T2, 200m up coast of the outfall pipe.

Discussion of Upcoast/Downcoast Ocean Monitoring Results

The objective of the upcoast/downcoast stormwater outfall storm assessments were to determine the dispersion of FIB and MST molecular markers of fecal contamination during storms to understand potential risk to public health across an extent of beach. We have studied three stormwater outfalls, Curlew Street, Conch Street, and Soundside, all high use beaches in NC to determine the extent and magnitude of impact during storms of varying sizes and durations.

Our findings indicate that during even small storms (< 1” total rainfall), a significant elevation in FIB signal occurs over the entire duration of the storm. It appears from this analysis that the elevated FIB signal persists for a period of hours after the storms, but it is likely that the persistence of the signal is likely dictated by the size, duration, and intensity of any given storm event. It is also likely that saturated ground conditions and therefore antecedent rainfall patterns play strong roles. In addition, for the study we considered the impact of wind, tide, and longshore currents although those factors were not quantitatively incorporated into any formal data analysis.

Importantly, this project initially included an assessment of Conch Street stormwater dispersion along the coast, as it was of interest to BMP performance. Fortunately, later work included the Curlew and Soundside Outfalls. The assessment of all three outfalls permitted the project team to observe that stormwater contamination and dispersion over the course of storm events was not outfall specific, and furthermore, that outfalls within close proximity to one another had additive impacts on beach water quality.

Currently, stormwater outfalls at the beach in NC are permanently posted only at the stormwater outfall pipe and the data collected support this as all samples exceed the state recreational water quality single sample maximum for both *E. coli* and *Enterococcus*. There have been concerns, however, that existing signage does not adequately protect those using nearby beaches and our data supports this as some locations exhibit FIB concentrations greater than one log greater than the allowable limits. Accomplishment of this objective directly informs the placement of appropriate signage at the beach to protect public health. Other coastal states have implemented two approaches for improved public notification, 1) improved signage along the beach, and 2) rainfall based advisories for beaches proximal to stormwater runoff inputs. It is of future interest to utilize the information gathered to create an add-on feature to the existing internet-based NCSSRWQ public notification system regarding recreational swimming near stormwater outfalls.

Decisions to close or reopen beaches for recreational activities rely on accurate assessment of fecal contamination. Both culture based (FIB enumeration of *E. coli* and *Enterococcus*) and molecular methods (quantification of Fecal *Bacteroides* spp., HF183 human specific marker, and gull marker) were measured during storm events at these three locations. Plume dispersion sampling was conducted in a subset of events at point zero, as well as transects in each direction at increments of 25m up to 200 m in the north and south from the end of the outfall pipe. At Conch Street, eight storms were studied, ranging in total rainfall amounts of 0.71 to 2.80 in. At Curlew, three storm events were studied, ranging in total rainfall amounts of 0.71 to 2.60 in. At Soundside outfall, four storm events were studied ranging in rainfall amounts of 0.71 to 2.80 in. The three storm events studied that were common to Conch, Curlew, and Soundside were conducted in summer 2014, and represented storms from July, August, and September, all at the height of the swimming season. These three outfalls are in close proximity to one another, so the ability to study the extent of contamination across this entire outfall impacted beach area was unprecedented (see **Figure 26**).

During all storms, for every single sample collected at the end of the pipe of the three outfalls, *Enterococcus* concentrations exceeded the EPA recommended SSM (104 MPN $100ml^{-1}$), sometimes by more than 2 orders of magnitude (n=44). For example, during the September 8, 2014 storm, *Enterococcus* concentrations at the end of pipe at Curlew and Conch Outfalls were 94,500 and 59,625 MPN $100ml^{-1}$, respectively. Of additional concern is that during almost all storms, *Enterococcus c*oncentrations at distances 100 m from the outfall pipe remained in exceedance of the State standard of 104 MPN $100ml^{-1}$over the duration of storms, sometimes further. *E. coli* concentrations were generally higher and persisted above recommended recreational water quality limits up to 200 m from the outfall pipe. Fecal *Bacteroides* concentrations during storm events, were observed to be very high (10^4-10^6 CE $100ml^{-1}$) at the end of the pipe during several storms. Furthermore, HF183, the human specific marker of fecal contamination was detected at both the outfall and in samples along the beach, but not consistently observed in all samples, indicating the presence of human fecal contamination that poses a serious public health risk at specific times. Finally, while the molecular MST marker for gull fecal contamination was not measured for all storms, when it was quantified, the contribution of sea gull fecal contamination was noted at both the outfalls and at significant distances up and down the beach from the outfall (200 m in each direction). Interestingly, while FIB and *Bacteroides* based markers appear to have a bimodal distribution from the outfall pipe, the sea gull fecal contamination sometimes appeared to be in high concentrations across the entire beach extent, possibly indicating input of sea gull fecal contamination from beach-based bird populations and nearby ditch and dune locations.

The salient points to be summarized from the upcoast/downcoast stormwater dispersion work conducted as part of this project are the following: 1) To date, storms of all sizes appear to have a significant localized impact on beach water quality. This impact is observed not only at the discharge location of the outfall pipe, but it is also observed at distances from the outfall pipe that exceed 100 m, 2) That gull fecal contamination has been noted extensively in recent samples collect at the outfalls and along the beach sampled. However, it is difficult to interpret the relative contribution of gull-specific fecal contamination to the total. Plans to further control feeding and open access to garbage cans for shore birds along Outer Banks beaches could be useful, and 3)

Human fecal contamination, as determined via the quantification of HF183 molecular marker, has been quantified in stormwater discharge at distances away from the pipe exceeding 100 m. This human specific marker has been related to risk in swimmers.

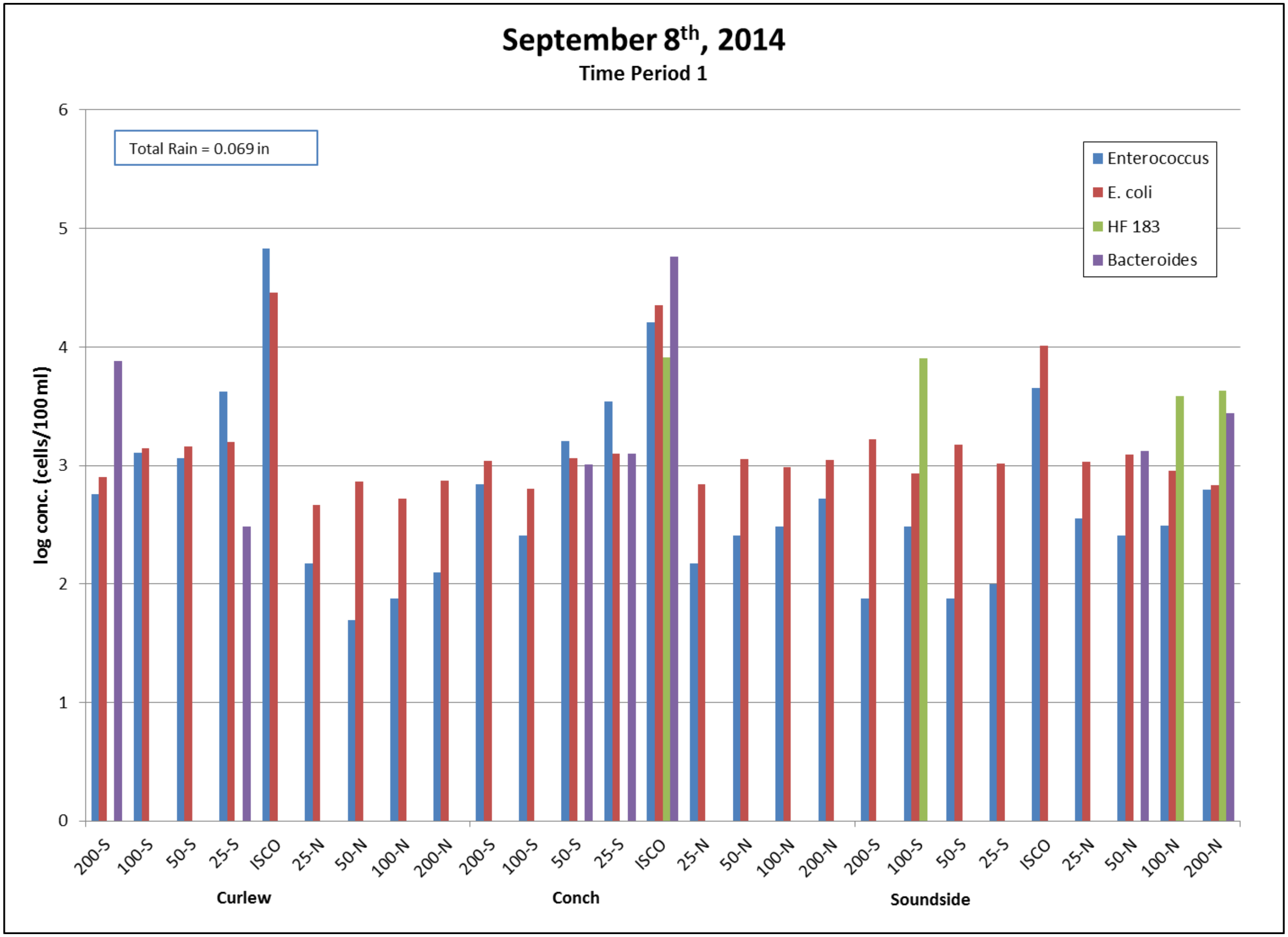


Figure 26. Upcoast/Downcoast Monitoring Results for September 2014 Storm Event – Time 1

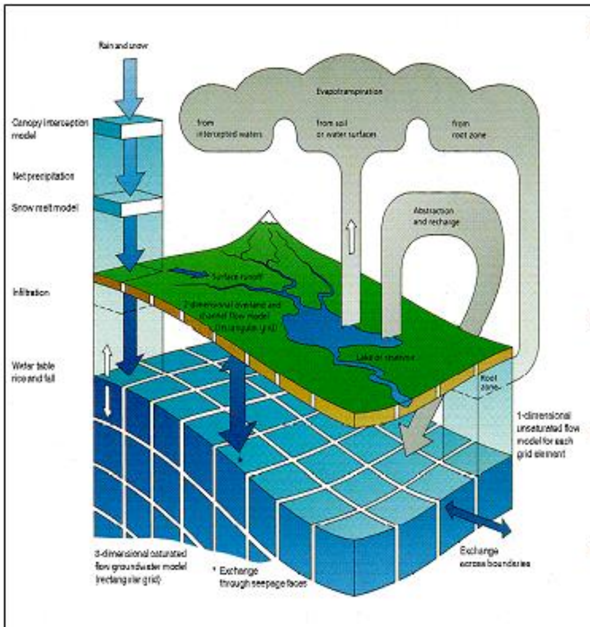
2.7 Hydrologic/Hydraulic Modeling

Based upon past experience, a coupled surface water/groundwater model was developed for each outfall watershed to more accurately quantify the range of water quality and quantity loadings expected at each outfall. The modeling analysis utilized is the Danish Hydraulic Institute's (DHI) MIKESHE model. MIKESHE model is, to the best of our knowledge, the only model in the world which currently links surface water and groundwater behaviors in the same model.

The model is very unique in the fact that it is actually a series of linked submodels which provide detailed solutions for each phase of the hydrologic cycle. The phases include:

- Groundwater Flows – (Saturated Zone (SZ) and Unsaturated Zone (UZ) Submodels),
- Surface Water Flows – (Overland/Channel Flow (OC) Submodel),
- Evapotranspiration (ET) Losses – (Evapotranspiration Submodel),
- Irrigation (IR) Losses – (Irrigation Submodel), and
- Snowmelt (SM) Inputs – (Snowmelt Submodel).

A graphic of all these phases can be seen in **Figure 27**. **Figure 28** shows how the different submodels relate to one another. The model also can fully dynamic coupled with MIKE11, a fully dynamic river/canal hydraulic model, to simulate the dynamic exchange between aquifers and rivers/canals.



- **ET Interception/Evapotranspiration**
  - **Interception of Rainfall by the Canopy**
  - **Drainage From the Canopy**
  - **Evaporation From the Canopy Surface**
  - **Evaporation From the Soil Surface**
  - **Uptake of Water by Plant Roots and Its Transpiration**
- **OC Overland and Channel Flow**
  - **Surface Runoff**
  - **Routing in Rivers**
- **UZ Unsaturated Zone Flow**
  - **Infiltration**
  - **Moisture Distribution**
- **SZ Saturated Zone Flow**
  - **3D Groundwater Flow**
  - **Exchange With Boundaries**

Figure 27. MIKESHE Graphic Showing the Phases of the Hydrologic Cycle It Solves

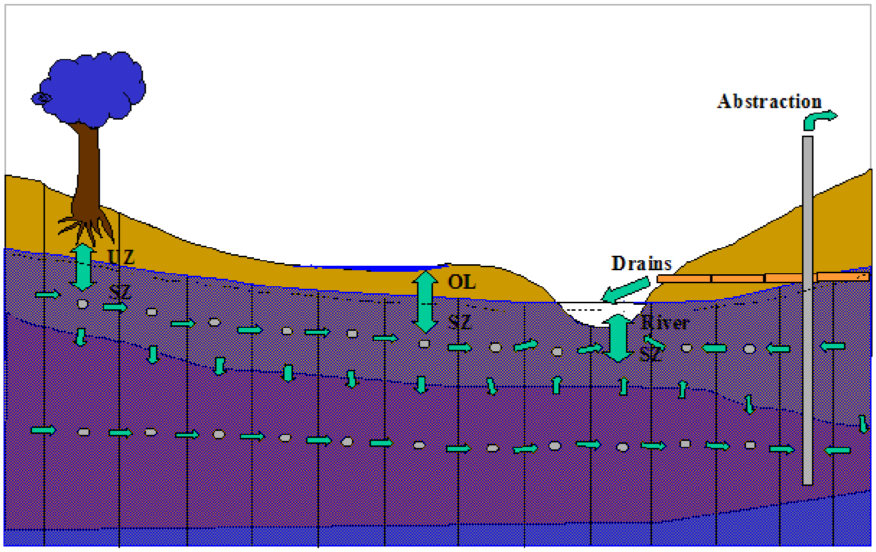


Figure 28. Interrelation of MIKESHE Submodels

MIKESHE is a finite difference model which means that the model grids consist of data located equidistant apart in the X and Y plane. The mathematical equations used for the individual submodels are well-known and accepted solutions that can be found in many of the public domain models available in the U.S. For example, MIKESHE solves the 3-D Boussinesq equation for saturated flow in the groundwater model (like MODFLOW). The 1-D Richards' equation is used for unsaturated flow in the groundwater model. The 2-D St. Venant's equation is used for overland flow, and the 1-D St. Venant's equation is used for river flows in the surface model (like SWMM).

Data collected from the detailed geotechnical and survey investigations were used to help build the proposed MIKESHE/MIKE11 models. The outfall watersheds were split up to six sub-watersheds to speed model run times: Old Oregon Inlet Road, Soundside/Conch Street, Curlew Street, Gallery Row, East Lake Drive/Martin Street, and Baum Street. However, it should be noted that these delineations are based on topography and field reconnaissance only and that potential groundwater influences are not included. **Figure 29** shows the delineated six sub-watersheds along with the surveyed monitoring wells to be used in the MIKESHE model calibration.

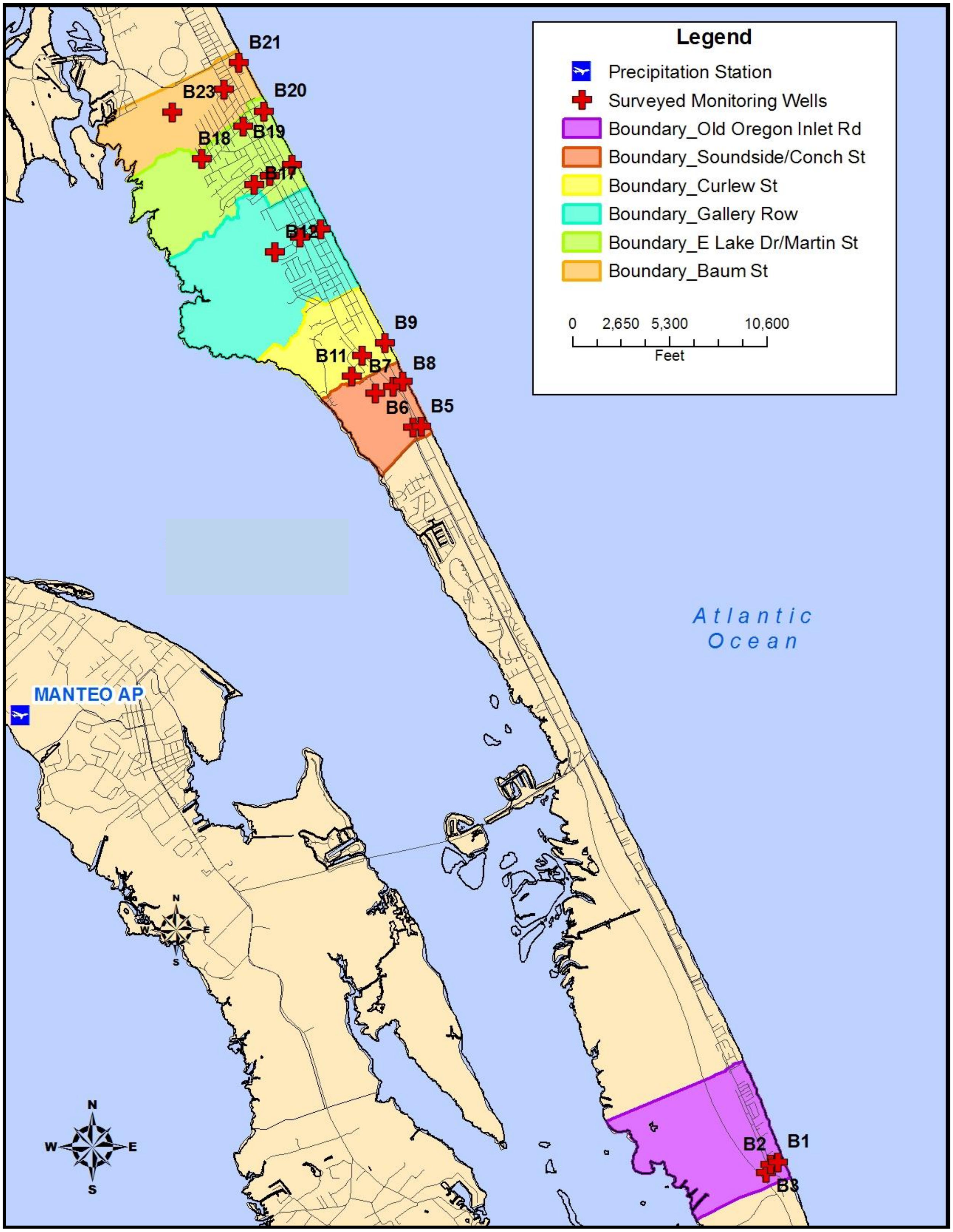


Figure 29. MIKESHE Sub-watershed and Surveyed Monitoring Wells

Model Setup

A complex model like MIKESHE requires a complex model setup. The first step was to generate a topographic grid file to accurately determine overland flow directions for the Overland/Channel flow submodel. In order to accurately capture small-scale topographic effects and to allow for accurate modeling of impervious areas, a 7m x 7m (~ 23ft x 23ft) grid spacing was chosen. The topographic data compiled and listed in the data collection and reconnaissance report were used to create the grid file. **Figure 30** presents a sample of the topographic grid for Soundside/Conch Street sub-watershed.

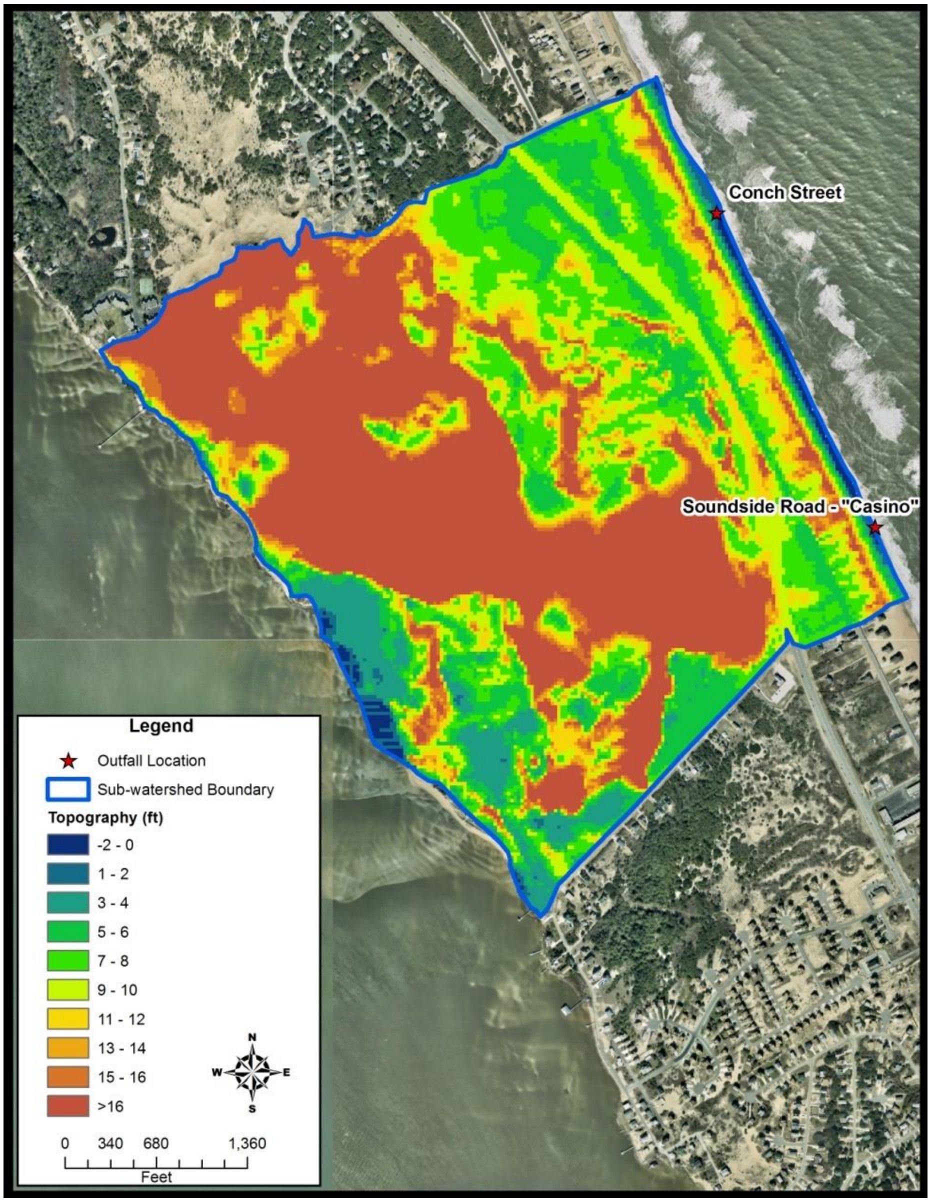


Figure 30. Example Topographic Grid for Soundside/Conch Street

For evapotranspiration (ET) effects to be included within the model, vegetation types were first identified. MIKESHE requires the creation of a vegetation database which requires (for each type of vegetation specified) root depth, leaf area index (LAI), and other empirical parameters. The LAI was calculated from existing aerial topography and the other parameters were estimated from extensive literature searches at NCSU for the known vegetation types. Another requirement of the ET model was the estimation of potential evapotranspiration (PET). Most PET models use pan evaporation as a base to the equation and then include wind effects, solar radiation measurements, etc. to arrive at PET. Due to our data limitation of only pan evaporation measurements, a simplified PET model was used which used monthly coefficients multiplied by the pan evaporation to estimate PET. The last piece of the ET submodel needed were actual grid maps of the vegetation coverage. They were created from the aerial photographs collected. **Figure 31** presents the vegetation grid for Soundside/Conch Street.

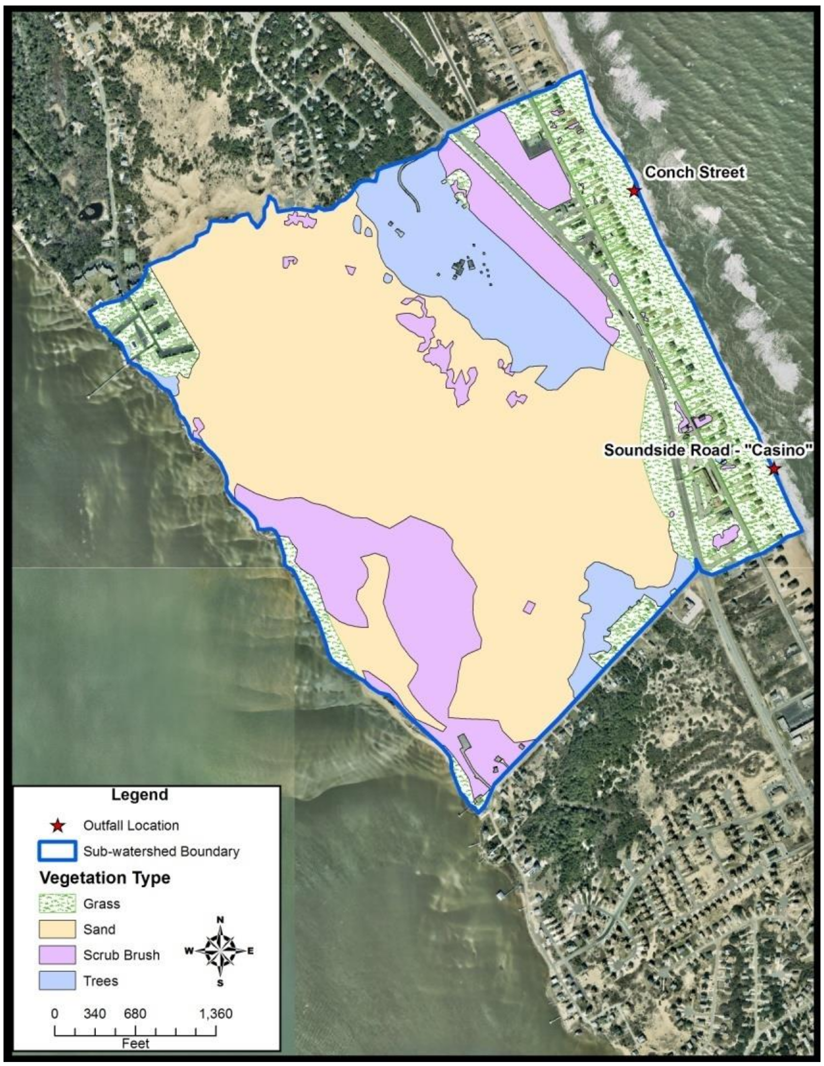


Figure 31. Example Vegetation Grid for Soundside/Conch Street

The surface soils (unsaturated zone) model was the next submodel to be included in the overall MIKESHE setup. The datasets outlined in data collection phase were the main input used to create maps and soil parameters required by the submodel. After lumping like soil groups together and including a separate soil type for impervious areas, the map outlined in **Figure 32** was created for Soundside/Conch Street subdomain.

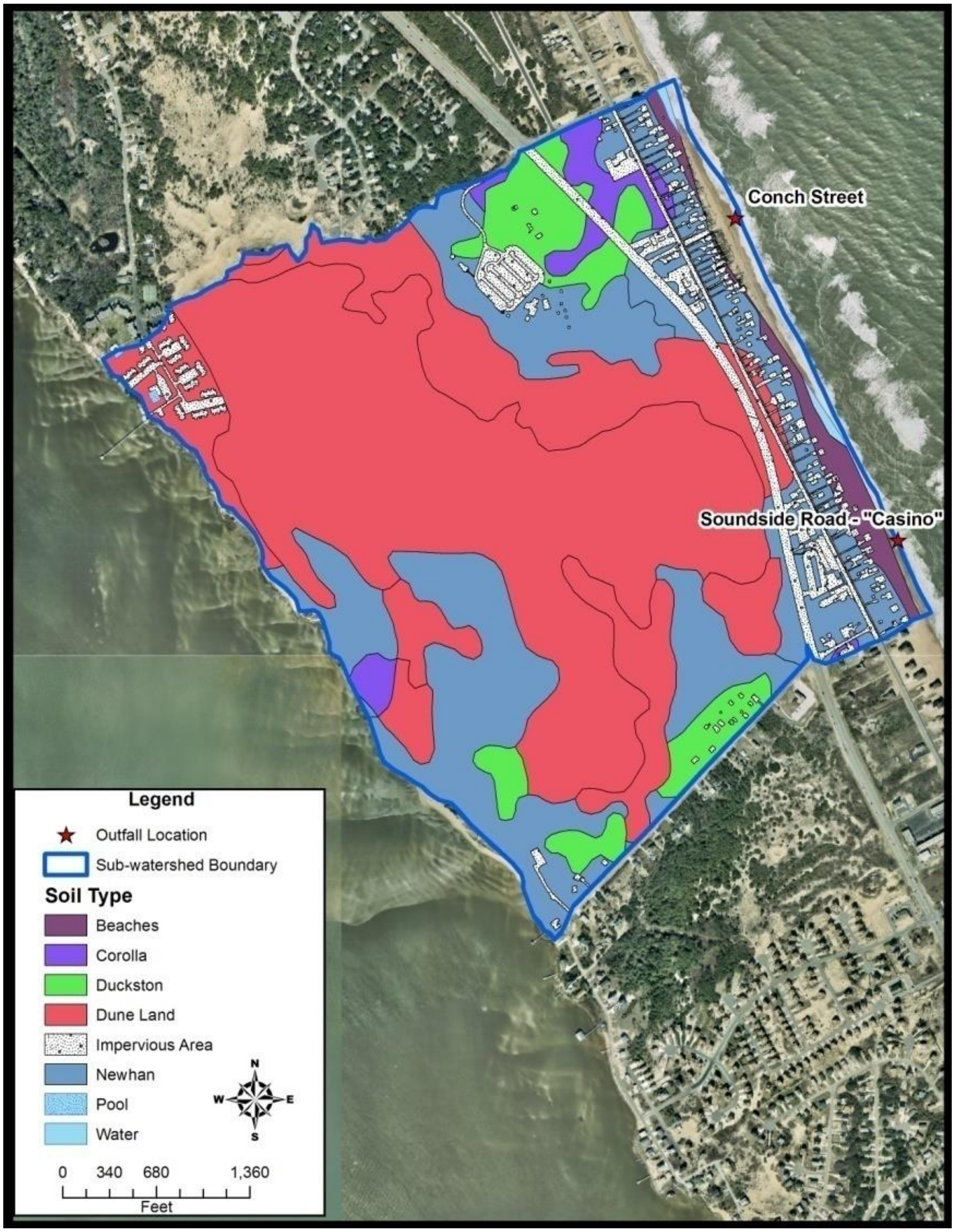


Figure 32. Example Soil Type Data for Soundside/Conch Street

For the unsaturated zone model, MIKESHE also required the creation of a soils database much like the vegetation database used in the ET model. For each soil type listed, estimates of two curves had to be provided. The first was an estimate of how hydraulic conductivity of the soil changes with water content. Hydraulic conductivity is a measure of how fast water will travel through the soil with units of in/hr, ft/day, etc. Water content is a measure of how much of the void spaces within the soil are filled with water vs. air. The other curve required was how capillary head (suction) changes with water content. Capillary head is defined by how high water will travel above the normal water table due to surface tension/pressure effects. To estimate parameters for both of these curves, values for different soil types from Emerald Isle Coast Guard Road Stormwater Study were adopted.

The last submodel to be included was the subsurface soils (saturated zone) submodel. Input required by this model included subsurface soil parameters for each layer modeled, initial groundwater levels, and boundary conditions directly affecting the groundwater table. The first decision to be made was how many geological layers of the subsurface would be modeled to accurately account for the flows within the saturated zone. Experiences showed the inclusion of only the surficial sand aquifer in our saturated zone submodel was sufficient. The soil parameters required for input were horizontal and vertical hydraulic conductivities (K), specific yield, and a storage coefficient. Estimates of specific yield and storage were taken from experimental data found during literature searches. On April 20, 21 and 25, 2006, S&ME, under subcontract with M&N, conducted in-situ hydraulic conductivity tests in 23 of the 24 groundwater monitoring wells to estimate the hydraulic conductivity in the aquifer material near each well. Hydraulic conductivity values from the slug tests ranged from 14.15 to 47.25 ft/day, and had an average of 29.80 ft/day. **Table 9** summarized these values. The hydraulic conductivity grids were generated by interpolation from these data as one example shown in **Figure 33**. The vertical hydraulic conductivities were assumed to be ¼ of the corresponding horizontal values based on a literature review.

Table 9. Summary of Slug Test Hydraulic Conductivity Data

Monitoring Well I.D.	Hydraulic Conductivity (K) (ft/day)
B2	44.61
B3	39.00
B4	25.54
B5	46.42
B6	18.47
B7	40.36
B8	43.42
B9	26.03
B10	47.25
B11	22.83
B12	15.85
B13	28.47
B14	21.85
B15	14.15
B16	19.26
B17	34.65
B18	20.48
B19	24.58
B20	38.40
B21	33.69
B22	15.72
B23	20.70
B24	43.61

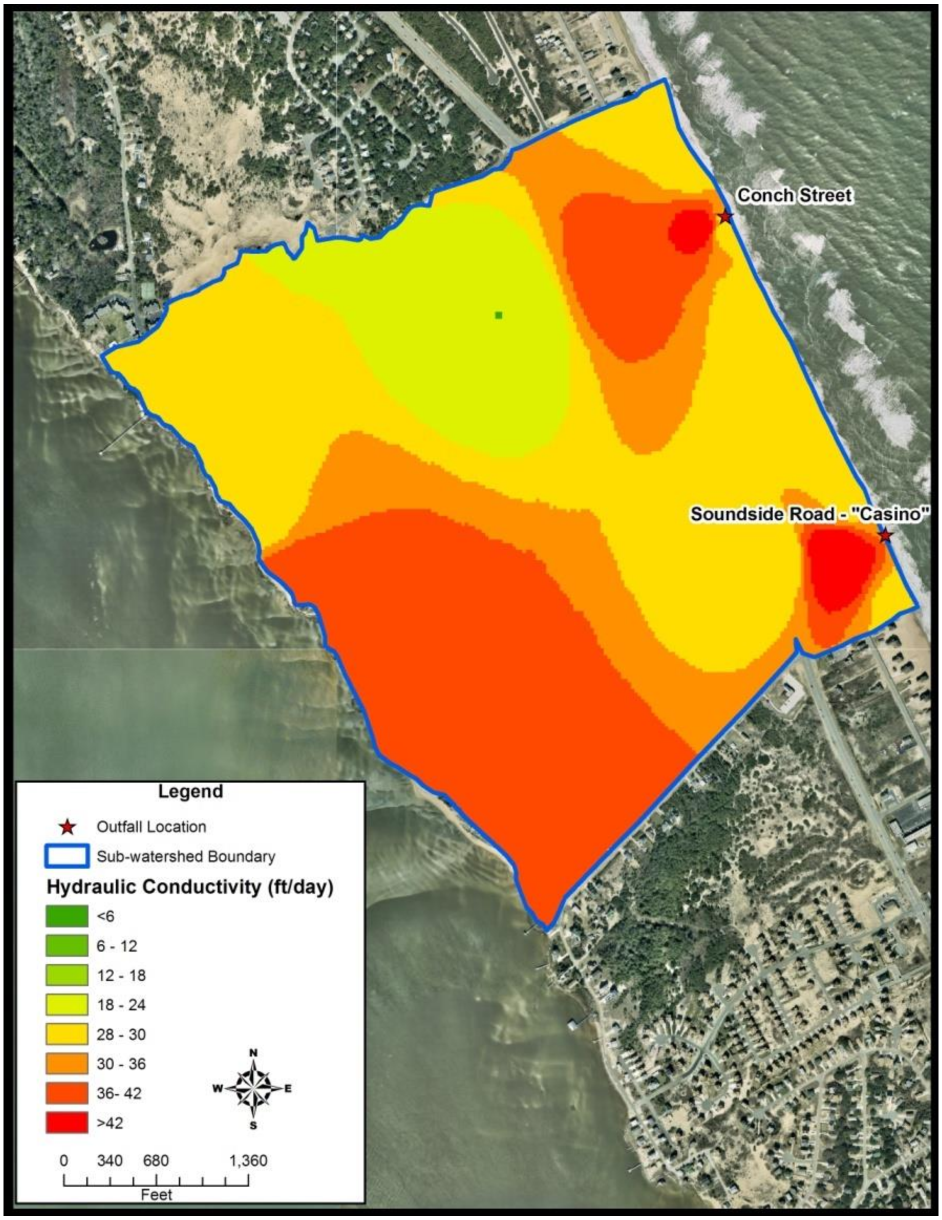


Figure 33. Example Horizontal Hydraulic Conductivity Data for Soundside/Conch Street

Two other saturated zone submodel inputs are initial groundwater levels and boundary conditions that would drive the submodel. In this case, the boundary conditions for the saturated zone model were tides. The tides work along the perimeter of the project site and force groundwater levels to rise and fall as the tide rises and falls. Two tidal boundaries exist for each sub-watershed model: one is tide from the Atlantic Ocean, and the other is from the Albemarle Sound. The land side boundaries were determined to be zero-flux boundaries. This land boundary condition type may block the water exchange between adjacent sub-watersheds. It is better to simulate the whole watershed in a single model. However, due to limitation of computer resources, it is restricted to current setup.

Initial groundwater levels and boundary conditions are to be determined based on the simulation period, and discussed in detail in the calibration/verification section. Another input for the simulation period is precipitation. Precipitation is the primary water load into the model and hourly data was needed to accurately model storm events. Observed precipitation data from Manteo Airport, Manteo, NC was used.

The one-dimensional MIKE11 for each outfall was determined based on a limited field survey completed on May 16-18, 2005, by NCDOT. **Figure 34** shows the sketch for Soundside/Conch St Outfall ad the channel/pipe network simulated using MIKE11 within MIKESHE.

Figure 34. Example MIKE11 One-Dimensional Model for Soundside/Conch Street

Model Calibration and Verification

Two historical storm events were selected to calibrate and verify the model, Tropical Storm Ernesto (8/29/06 – 9/05/06), and Tropical Storm Barry (6/03/07 – 6/05/07). These two storm events occurred after the monitoring wells were installed, so measurements of groundwater levels were recorded.

Tropical Storm Ernesto

Initial groundwater level grids were generated using the measured groundwater level from the monitoring wells. **Figure 35** shows an example of initial groundwater level for Soundside/Conch Street sub-watershed. **Figure 36** presents the comparison between the measurements and modeled groundwater levels for wells B4 to B8 which located in Soundside/Conch Street sub-watershed. Overall, there is very good agreement between the model and observed results.

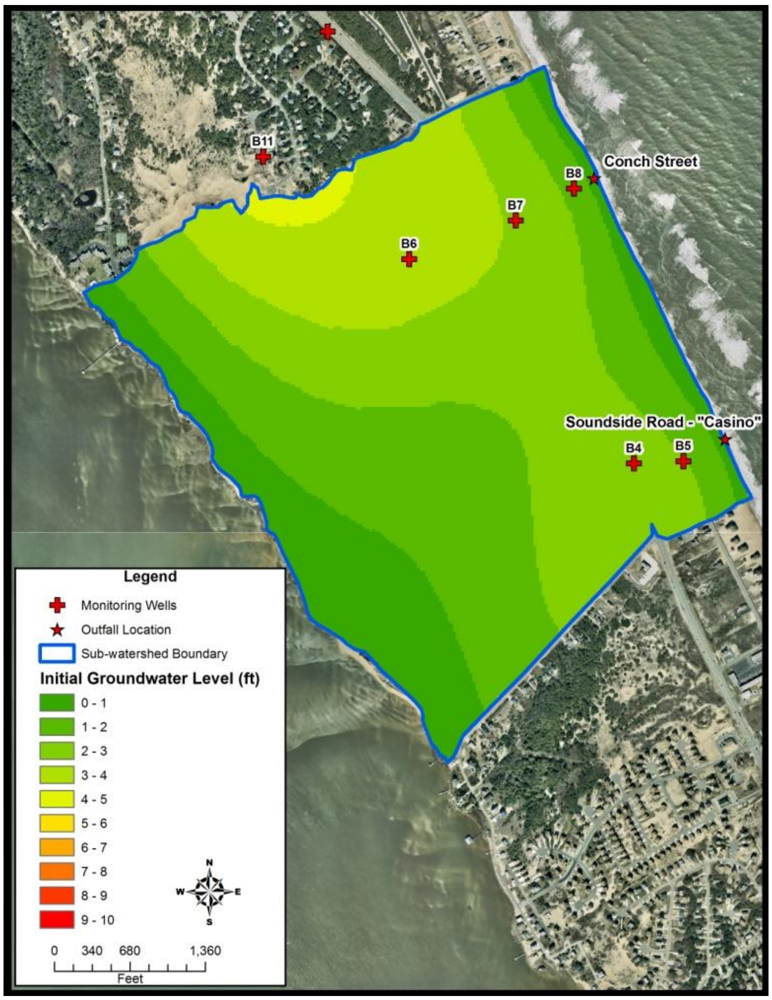


Figure 35. Initial Groundwater Level Data for Soundside/Conch Street, Tropical Storm Ernesto

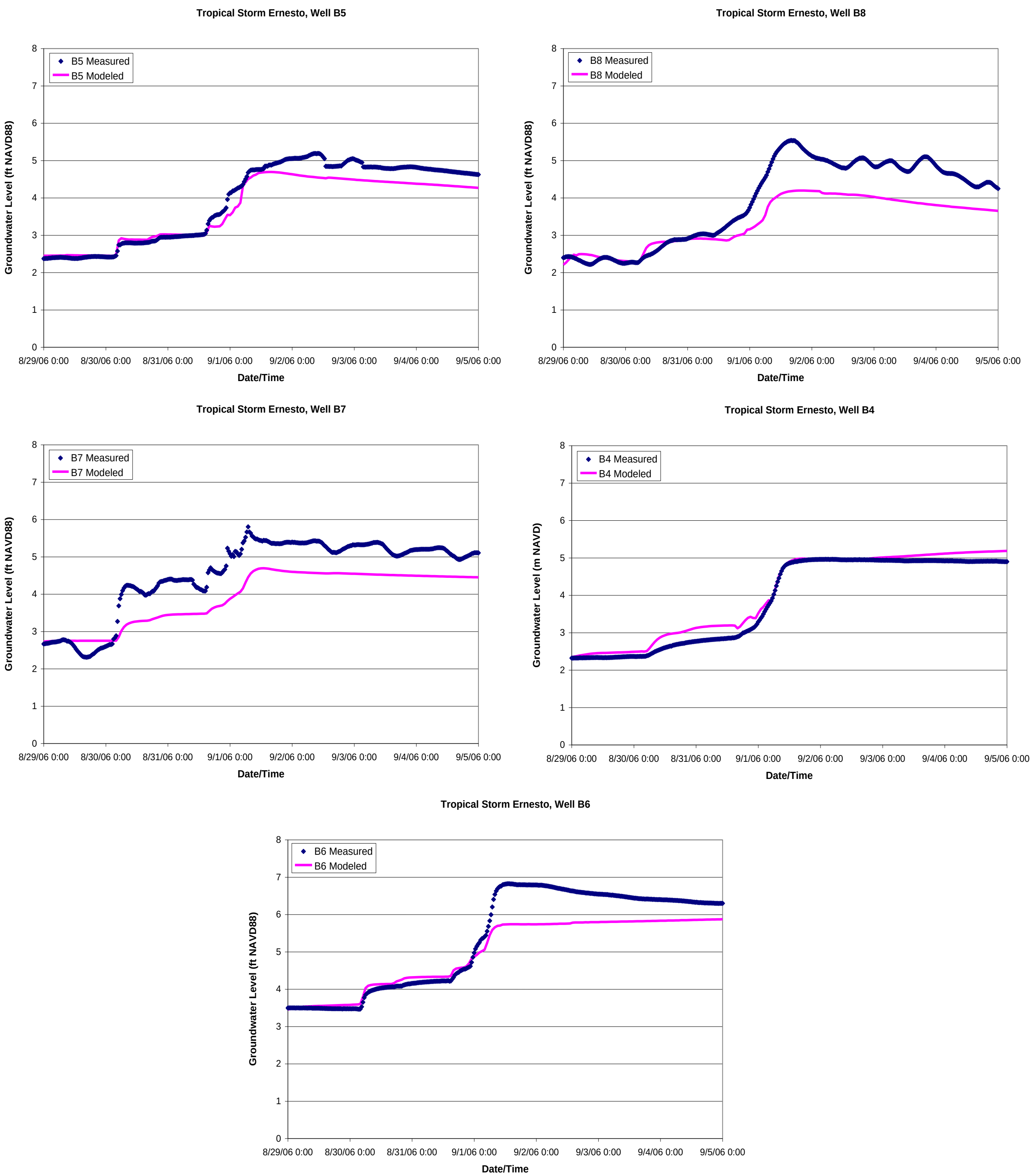


Figure 36. Groundwater Comparison Results from Calibration Run, Tropical Storm Ernesto

<u>Tropical Storm Barry</u>

Initial groundwater level grids were generated using the measured groundwater level from the monitoring wells. **Figure 37** shows an example of initial groundwater level for Soundside/Conch Street sub-watershed. **Figure 38** presents the comparison between the measurements and modeled groundwater levels for wells B4 to B8 which located in Soundside/Conch Street sub-watershed. Overall, very good agreement between the model and observed results is also achieved. **Figure 39** shows the outfall flow rates comparison between measured and modeled results along with precipitation. Model predictions at Conch St Outfall match the two big rainfall events; while at the Soundside Rd Outfall, the flow rate on first big rainfall is much smaller than the second. Given the high local variability of rainfall patterns on the Outer Banks, it is very likely that the rainfall inputs from the monitoring station used in the model were different from what was actually experienced at the outfall, which is especially possible with such low measured flows.

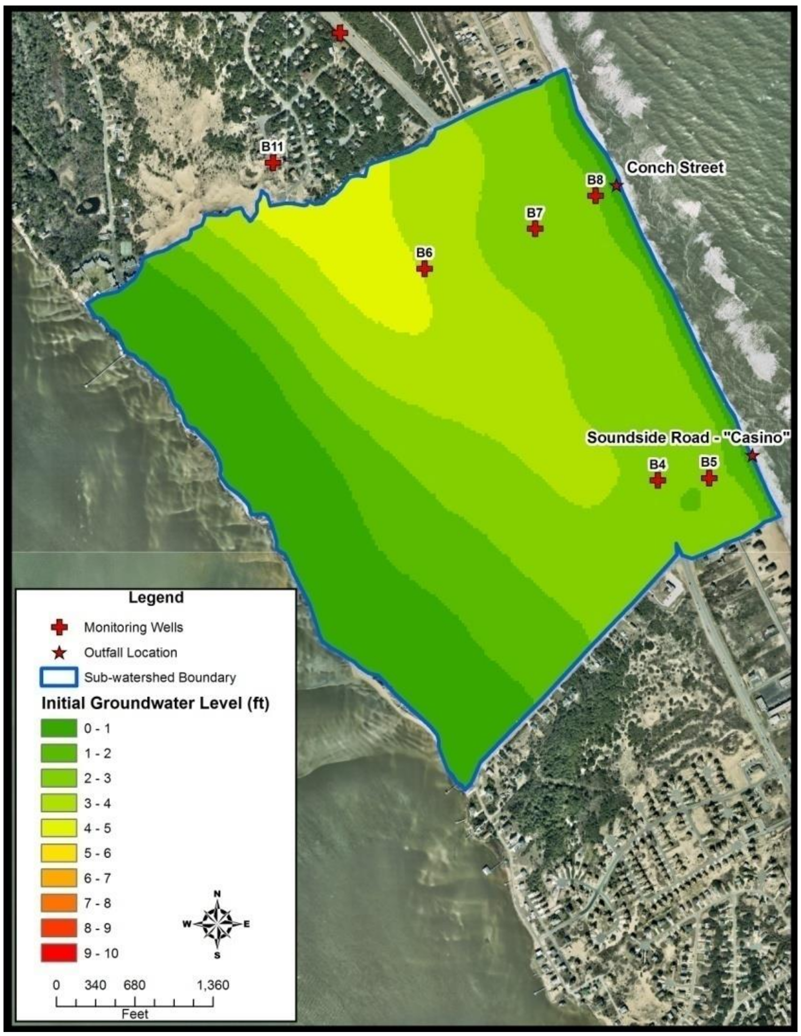


Figure 37. Initial Groundwater Level Data for Soundside/Conch Street, Tropical Storm Barry

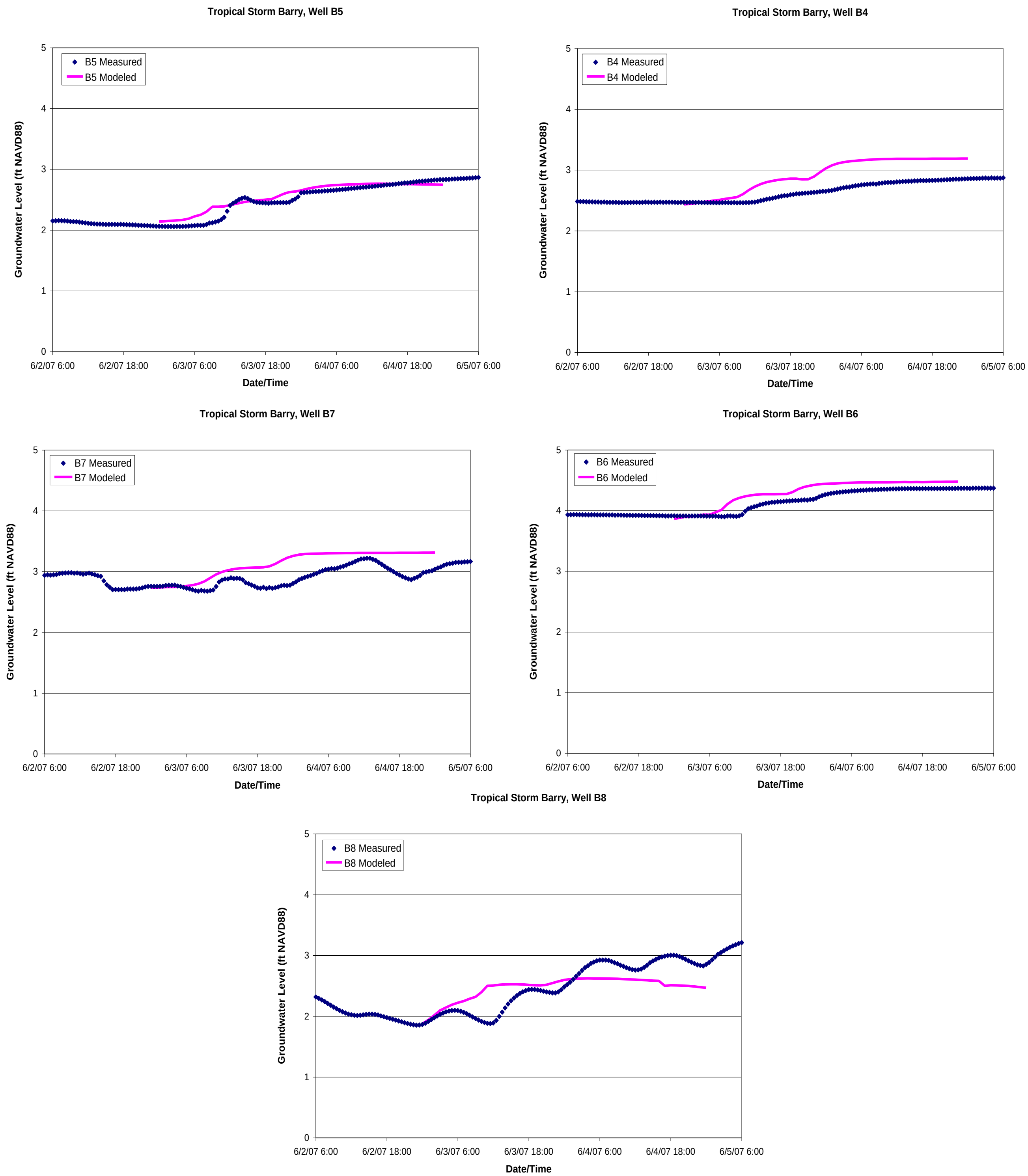
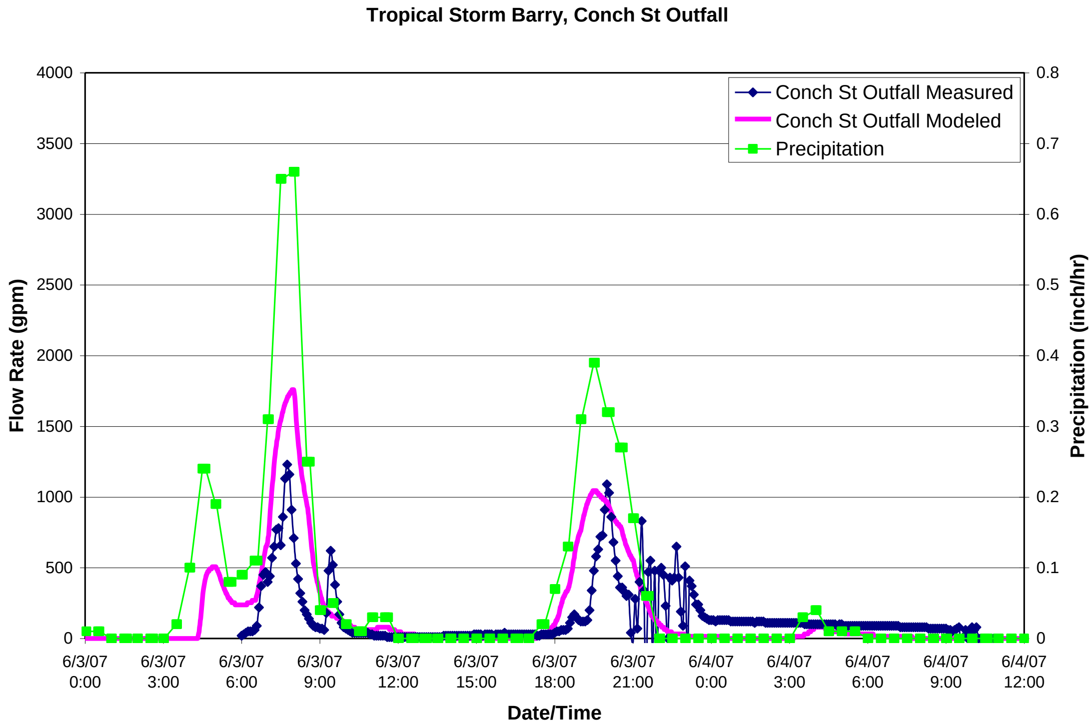


Figure 38. Groundwater Comparison Results from Calibration Run, Tropical Storm Barry



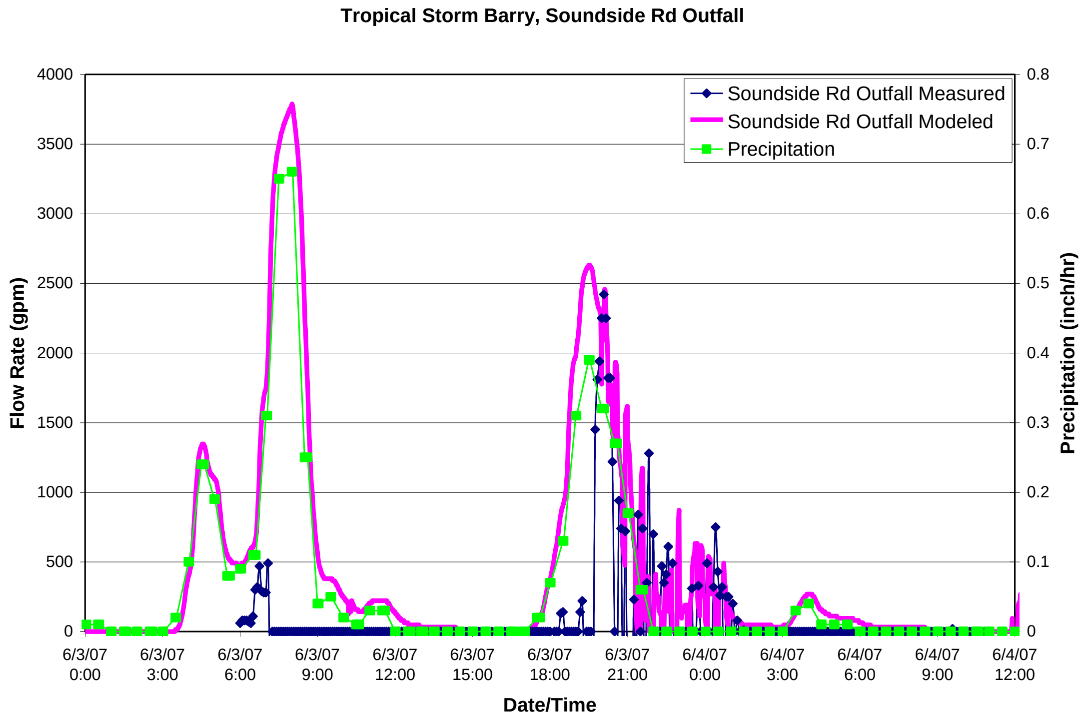


Figure 39. Outfall Flow Rate Comparison Results from Calibration Run, Tropical Storm Barry

2.8 Watershed Re-Delineation and Model Update

In 2012, improved topographic data and new GIS data for previously unmapped portions of the storm drain network obtained from the towns of Nags Head and Kill Devil Hills allowed for an improved delineation of the watersheds for the ocean outfalls. The delineation process began with the generation of a triangulated irregular network (TIN) from the most recent LIDAR data to represent the topographic surface. Watersheds were initially delineated based strictly on land contours and predicted surface flow patterns. Those initial delineations were then overlaid with all available information on the artificial drainage network of pipes and ditches. The artificial network was utilized to correct the watershed boundaries where it altered surface flow patterns. The updated watersheds for the seven northern outfalls are shown in **Figure 40**. The updated watershed were used for the reminder of the study, including the watershed characterizations and strategies presented below in Chapter 3.

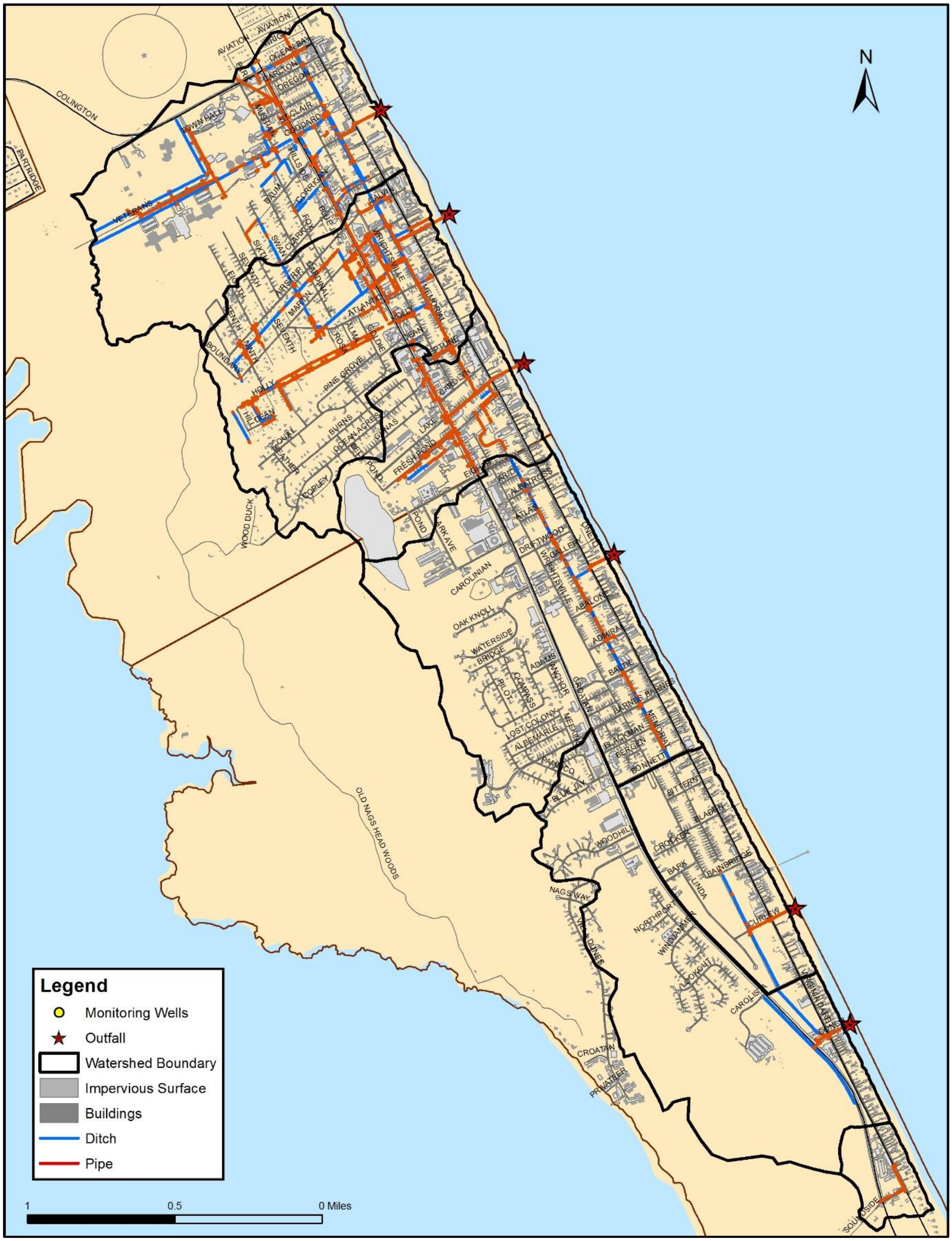


Figure 40. Seven Northern Ocean Outfall Watershed as Revised in 2012

The updated watersheds were also utilized to do a minor update and recalibration and verification of the MIKESHE/MIKE11 modeling frame work used to simulate the hydrology and hydraulic behavior of the outfalls and their watersheds. On this occasion, actual data from Tropical Storms Barry and Hurricane Irene (August 27, 2011) were again used to recalibrate/re-verify the revised models. Calibration results for groundwater elevations as compared to actual levels recorded at four groundwater wells for Tropical Storm Ernesto are shown below in **Figure 41** and for Hurricane Irene in **Figure 42**. Calibration verification results for both MIKESHE and MIKE11 are presented in Appendix C.

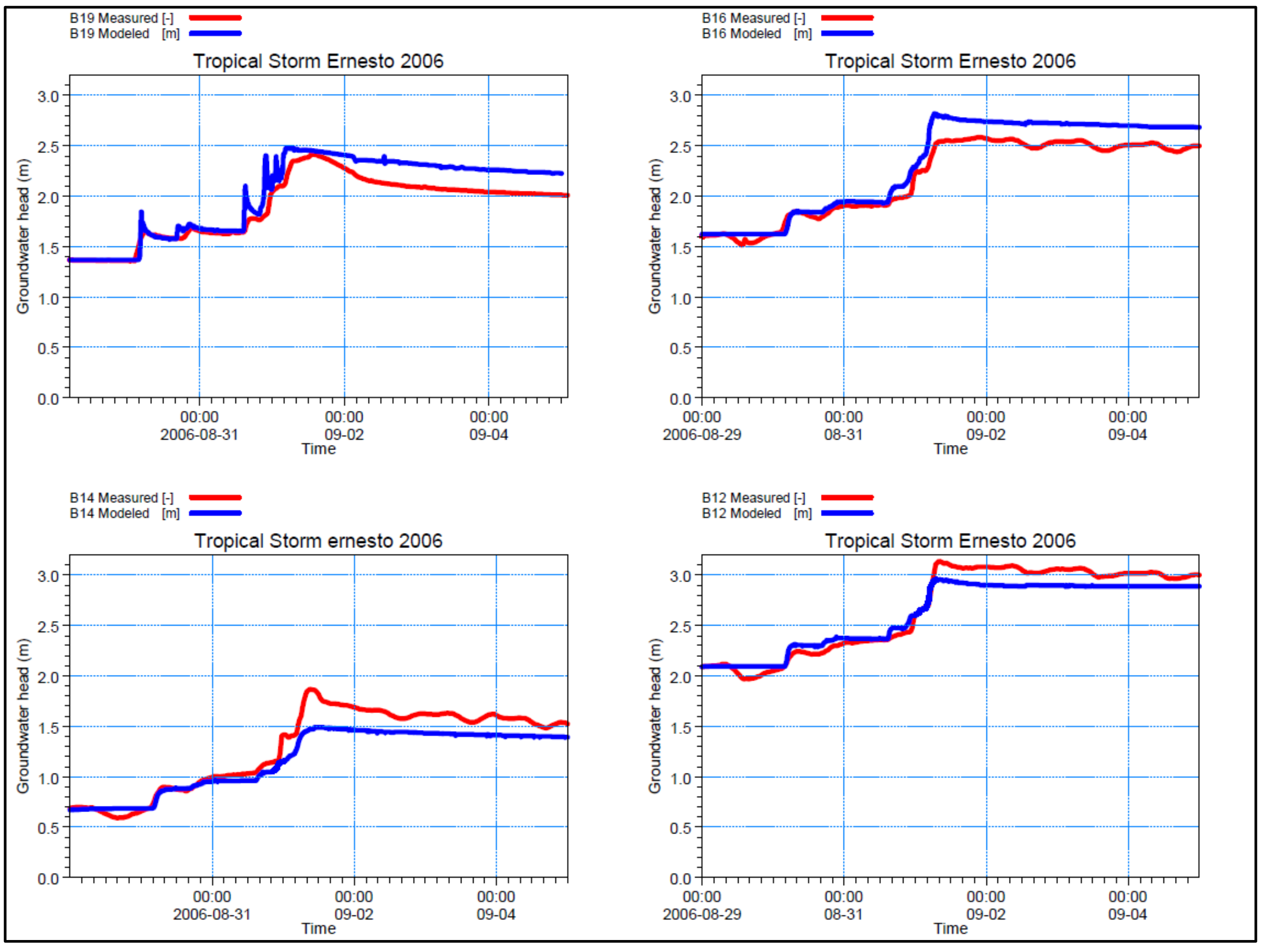


Figure 41. Predicted vs. Actual Groundwater Level Results from Calibration Run, Tropical Storm Ernesto

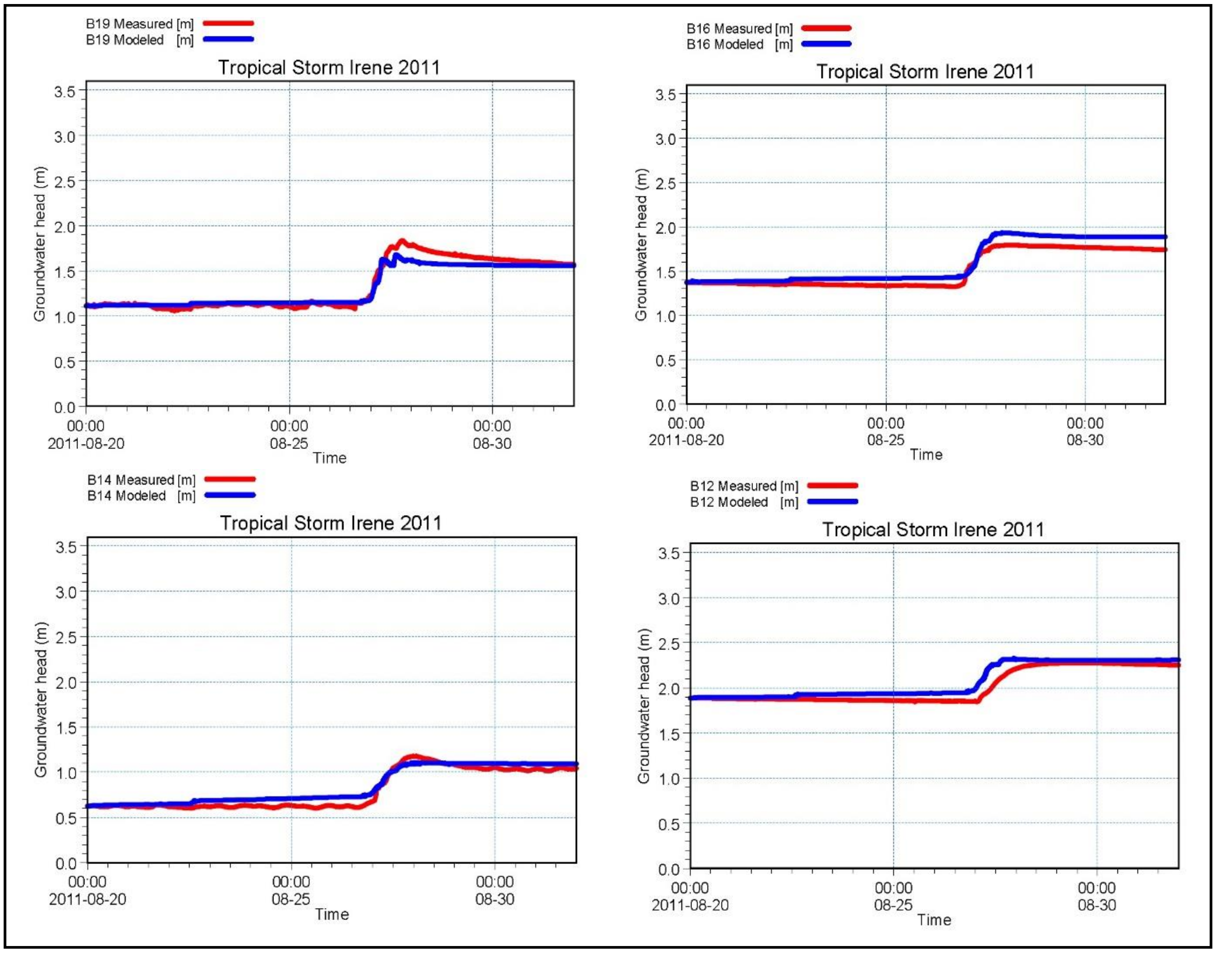


Figure 42. Predicted vs. Actual Groundwater Level Results from Calibration Run, Hurricane Irene

<u>Synthetic Storm Events To Determine Watershed Hydraulic Loading</u>

With the model now updated, re-calibrated and verified, it was run for various storm events to determine the hydraulic loadings for the watersheds and the peak discharges that potential BMPs would experience within the watersheds near the outfall locations. Rainfall depths from the Kill Devil Hills Station for various storm events were used and mated to a SCS Type 3 rainfall distribution. The predicted hydrographs from the series of synthetic storm events for the Baum Street outfall are shown in **Figure 43**. **Table 10** below shows the peak flow predictions for all outfalls modeled. Detailed model input data and hydrograph predictions for all outfall are presented in Appendix C.

Table 10. MIKESHE/MIKE11 Peak Flow Predictions for an Array of Storm Conditions

Watershed	Peak Flow Rate (cfs)																			
	1 in		1.5 in		2 in		1-year		2-year		5-year		10-year		25-year		50-year		100-year	
	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW	Median Initial GW	90% Initial GW
Baum Street	0.3	0.9	0.6	1.3	1.1	2.0	2.8	3.9	3.9	5.2	6.0	7.3	8.0	9.5	10.7	13.3	13.6	17.2	18.0	23.7
Conch Street	8.7	9.5	15.0	15.9	21.1	22.1	34.0	34.4	38.7	39.0	43.3	43.4	46.3	46.4	50.2	51.3	55.9	56.3	63.7	63.6
Curlew Street	7.8	8.0	12.6	12.8	17.0	17.2	28.2	28.3	33.1	33.2	39.3	39.5	44.3	44.5	50.9	51.8	55.4	57.1	60.1	63.3
E. Lake Drive	3.0	3.0	5.4	5.4	8.1	8.2	19.0	19.3	25.3	25.5	32.0	32.6	35.5	36.9	39.9	43.2	43.5	48.5	47.4	52.2
Gallery Row	4.4	4.9	7.2	7.8	10.3	10.9	19.6	20.3	24.8	25.5	33.6	35.2	41.5	44.1	54.2	60.6	66.0	73.2	75.9	80.7
Martin Street	2.7	3.3	4.4	4.9	6.2	6.7	11.4	11.9	13.9	14.4	17.4	17.9	19.7	20.2	22.5	23.1	23.9	24.3	25.0	26.3
Old Oregon Inlet Road	7.1	8.2	8.4	9.5	10.9	11.4	17.0	17.4	19.7	19.9	22.4	22.6	23.6	23.7	24.9	25.1	26.1	26.3	27.3	27.6
Soundside Road	4.9	4.9	7.7	7.7	10.5	10.5	16.9	16.9	20.0	20.0	24.2	24.1	29.5	29.5	36.9	38.9	42.8	44.5	48.1	52.3

It is interesting to note that the estimates for peak discharges from the model are significantly less than peak discharges that would be estimated using normal techniques such as the Rational Method and TR-55. The lack of stormwater infrastructure delivering flows to the outfalls quickly in many portions of the outfall watersheds as well as the level of infiltration and groundwater transmission in these systems are likely the main reasons for this behavior. One of the biggest challenges in the modeling analysis was estimating the amount of impervious surface in each watershed that was directly connected to the man-made storm drainage, and the lack of mapping information on that infrastructure is a source of uncertainty and potential error in the model predictions. Despite these challenges, the peak flow results from the modeling analysis compare quite favorably to actual flow data for storms of similar intensity for most outfalls. Detailed stormwater infrastructure asset inventory and mapping data, if it were available would be very helpful in improving the accuracy of these model predictions.

As shown in **Table 10** the model was run for each synthetic storm with an initial condition reflecting median groundwater level and again with an initial condition reflecting a 90^{th} percentile groundwater level in order to examine the impact of high antecedent soil moisture conditions on the predicted hydrographs for each event. The predicted peak flow results from the Baum Street outfall prediction are shown in **Figure 44**. The variation in antecedent soil moisture conditions had the greatest effect on predicted flow for Baum Street. For all the other outfalls the difference was less than would be expected.

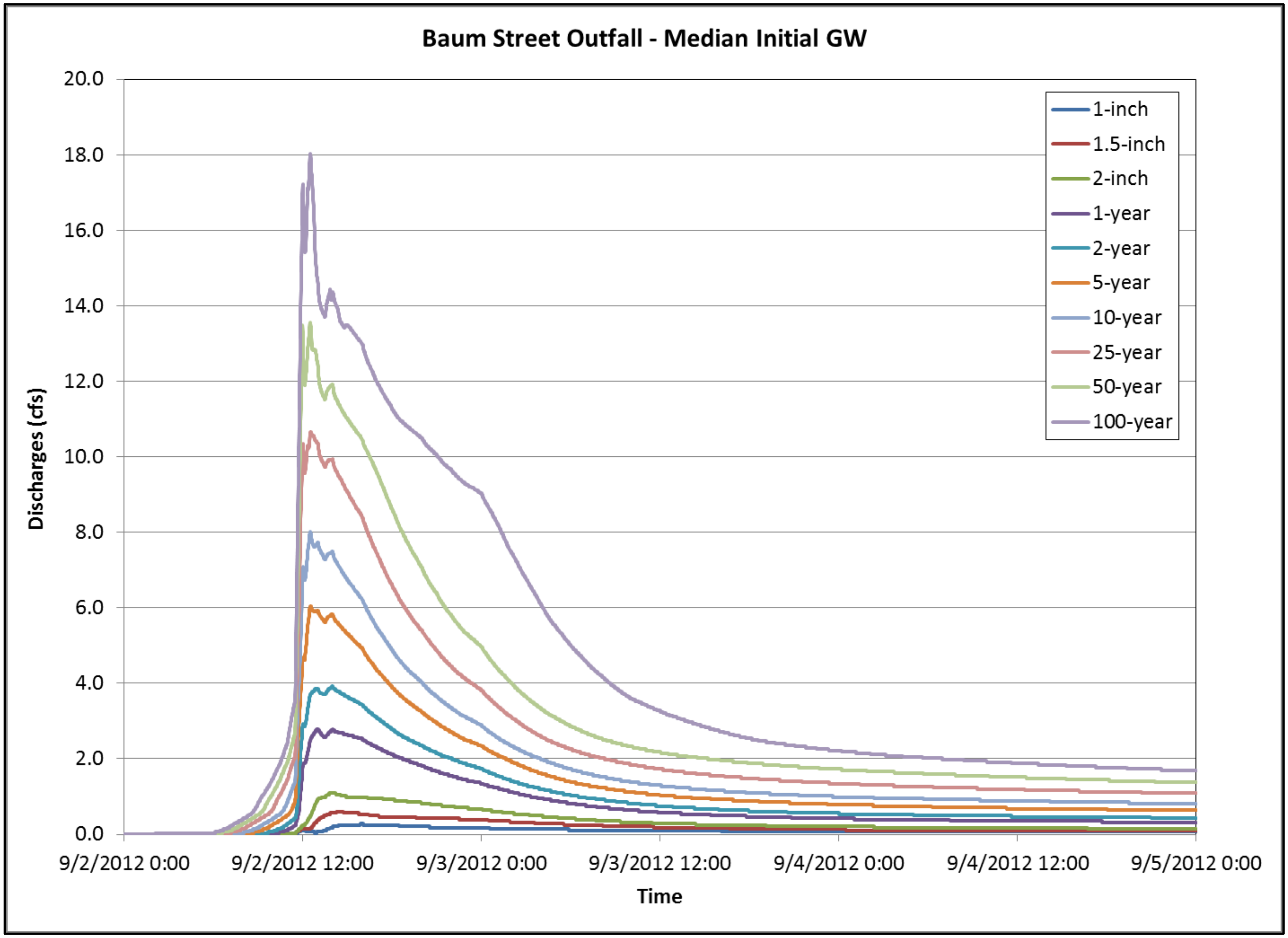


Figure 43. Predicted Storm Hydrographs for Baum Street Outfall with Median Groundwater Levels

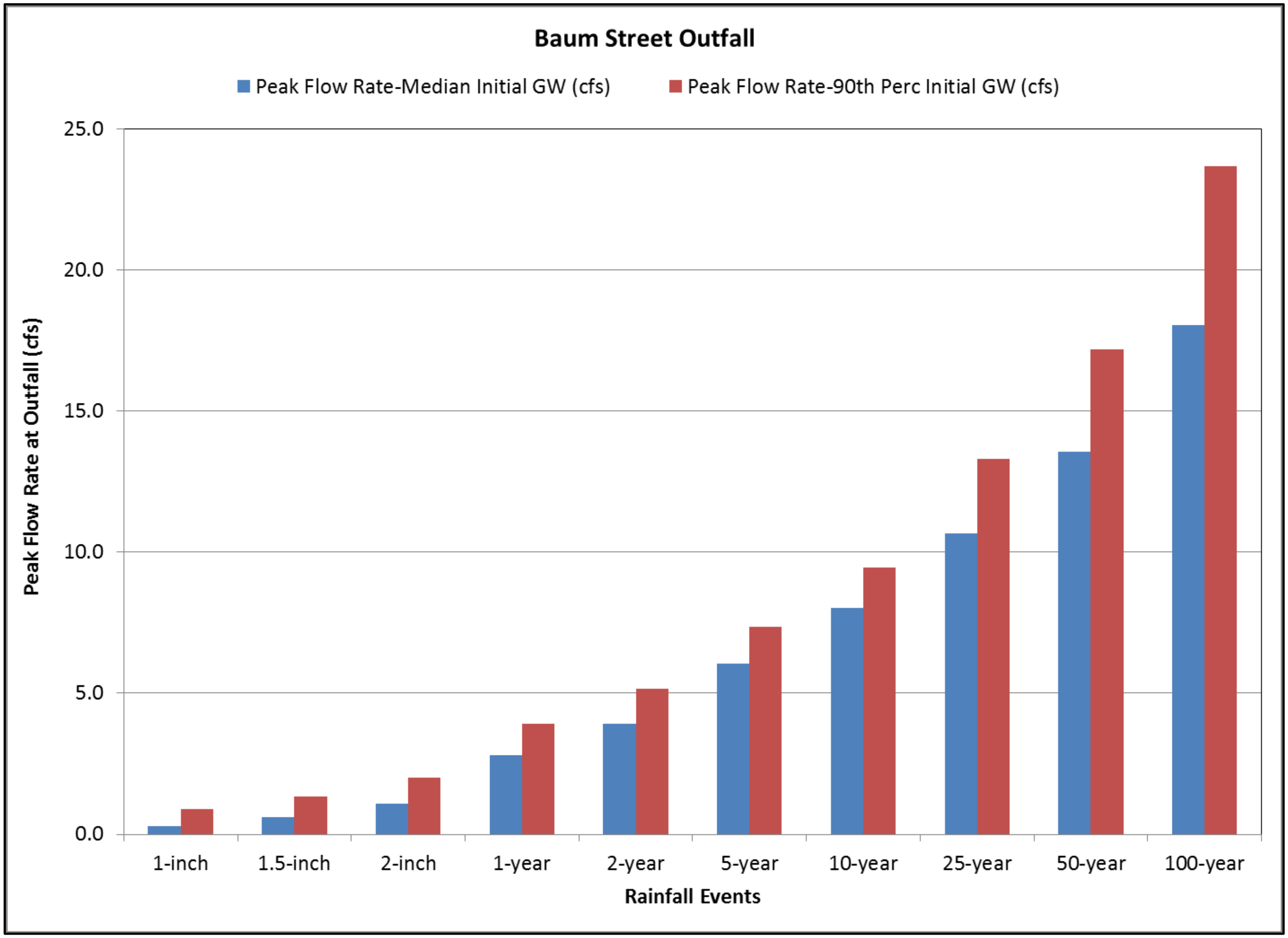


Figure 44. Predicted Peak Flows for Baum Street Outfall with Median and 90th Percentile Groundwater Levels

3.0 Watershed Strategies

3.1 Baum Street Watershed

The Baum Street watershed is comprised of an area approximately 435 acres extending from the end of Veterans Drive to the west, to the front dunes along the shoreline to the east. Land use in the area is mostly developed, with a mixture of residential, recreational, and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 45**.

3.1.1 Watershed Characterization

Impervious

The Baum Street watershed contains approximately 131.4 acres of impervious surfaces, which is 30.2% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, sidewalks and recreational surfaces such as basketball and tennis courts. There are 546 buildings with approximately 29 acres or 7% of the total watershed area of building footprint. Buildings within the watershed area are primarily residential or commercial, with some institutional facilities (schools).

Septic Density

For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Baum Street watershed is 546, which equates to an estimated density of 1.26 systems per acre. A review of Dare County permits for septic system repairs and new installs within the Baum watershed from 2006-2012 is summarized in **Table 11** below.

Table 11. Baum Street Septic Repair and Install Permits

Year	Total New System Permits	Total System Repair Permits
2006	2	6
2007	7	5
2008	4	3
2009	3	8
2010	2	2
2011	2	11
2012	0	0
Total:	**20**	**35**

Soils

A summary of soils within the Baum Street watershed is provided in **Table 12**. The entire watershed contains hydric soils. Therefore, interactions between groundwater and septic systems would likely be high in this watershed. See **Figure 46** for Baum Street watershed soils mapping.

Table 12. Baum Street Watershed Soils Summary

Soil Type	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Osier Fine Sand, 0-2 percent slopes	Yes	11.1	3	Poorly drained; rapid permeability
Fripp Fine Sand, 2-30 percent slopes	Yes	2.4	1	Excessively drained; very slow runoff; rapid permeability
Dune Land, 2-40 percent slopes	Yes	74.1	17	None provided
Newhan-Corolla Complex, 0-10 percent slopes	Yes	57.7	13	Excessively drained; very slow runoff; rapid permeability
Dune Land-Newhan Complex, 2-40 percent slopes	Yes	10.6	2	Excessively drained; very slow runoff; rapid permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	38.4	9	Excessively drained; very slow runoff; rapid permeability
Beaches-Newhan Complex, 0-25 percent slopes	Yes	13.4	3	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand	Yes	0.1	<1	Excessively drained; very slow runoff; rapid permeability
Ousley Fine Sand, 0-5 percent slopes	Yes	27.9	6	Somewhat poorly drained; rapid permeability
Duckston Fine Sand, 0-2 percent slopes	Yes	52.8	12	Poorly drained; very slow runoff; very rapid permeability above the water table.
Corolla Fine Sand, 0-6 percent slopes	Yes	127	29	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Corolla-Duckston Complex, 0-6 percent slopes	Yes	20.2	5	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.

Vegetation

The Baum Street watershed contains approximately 40 acres of trees, with most forested habitat occurring in residential areas just to the south of the center of the watershed. Some areas of significant scrub brush vegetation have been converted to parking lots for commercial buildings. The remaining vegetated areas within the watershed consist of actively maintained and natural grassy areas. Given that the majority of forested vegetation is located outside of highly developed areas, there will not be a significant effect on groundwater levels in areas of dense development. Patterns of vegetation are mapped in **Figure 47**.

Groundwater

Three groundwater monitoring wells installed by Moffatt & Nichol in 2006 are located within the Baum Street watershed. B-21 is located at the shoreline end of East Oregon Avenue. Moffatt & Nichol scientists found that this well had no recorded groundwater levels within 0 to 3 feet of the surface for the period of collection. B-22, located alongside NC 158 (Croatan Highway) had groundwater levels within 0 to 3 feet for approximately 11% of the total data samples collected. Groundwater well B-23 had recorded groundwater levels within 0 to 3 feet for approximately 77% of the data samples collected. All of the wells are located in developed areas. It should be noted that B-21 is located on the western slope of the primary dune, at an elevation of 19 feet above sea level, so that fact that it has no incidence of groundwater within 0-3 feet of the surface does not reflect the potential for such occurrence throughout the watershed. As a point of reference, the controlling elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road, occurs at an elevations of 6-7 feet above sea level in the Baum Street watershed. Wells B-22 and B-23, located at elevations of 8 and 11 feet, respectively are far better indicators of the potential interaction between shallow groundwater and septic systems throughout the watershed. Indeed the 77% incidence at B-23 indicates a high potential for such interaction in the western portion of the watershed.

Drainage Systems and Infrastructure

The Baum Street watershed contains approximately 16,020 feet of open channel ditch and approximately 40,997 feet of piping. Drainage network spatial data and detailed contours of the Baum Street watershed indicate that there is approximately 227 acres of the watershed drained by piping and open channel ditches. This area represents approximately 52% of the total watershed area and occurs primarily in heavily developed areas within the watershed. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and commercial facilities where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. However, approximately a third of the watershed is residential development, with much of it occurring in hydric soil areas. In these areas, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

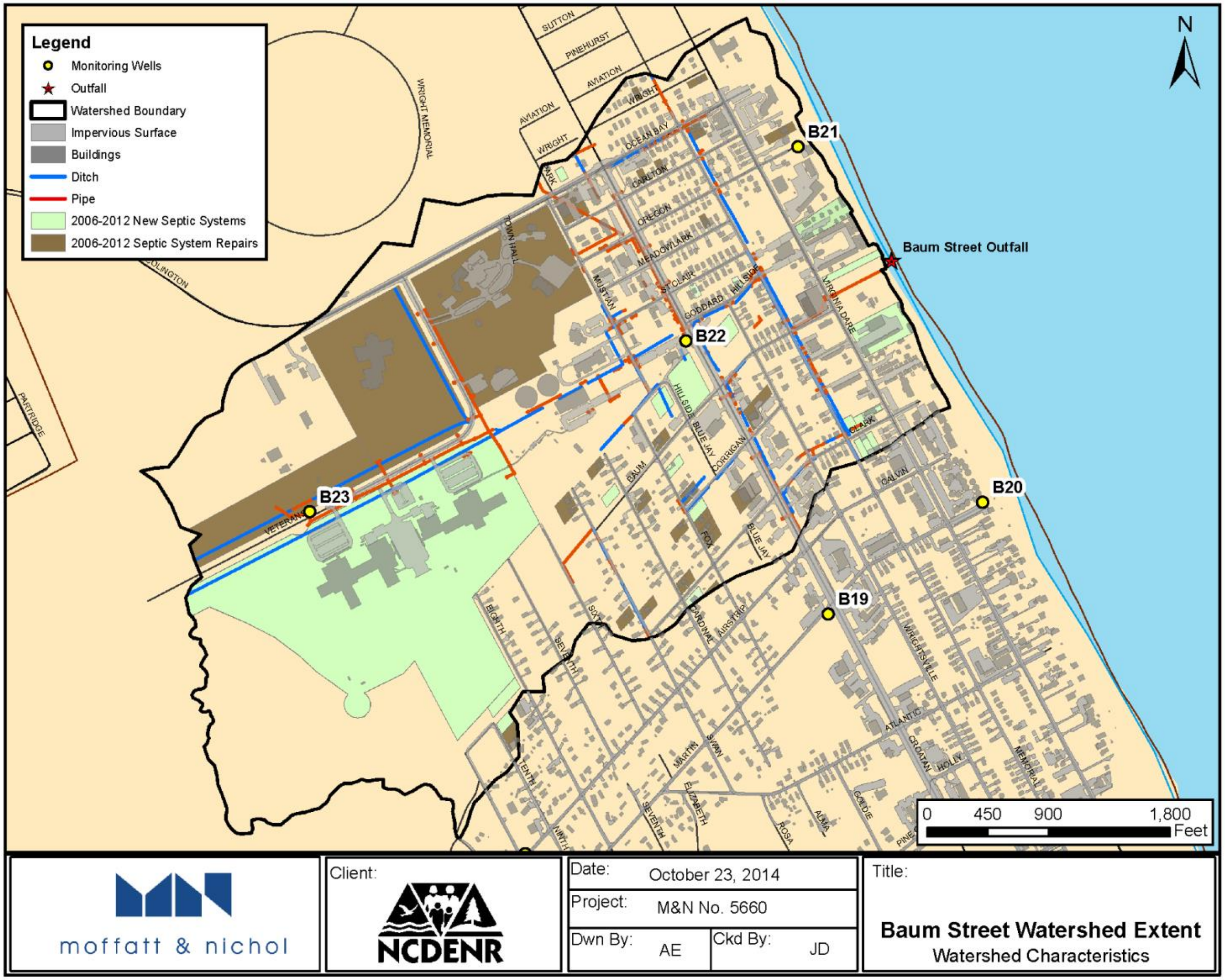


Figure 45. Baum Street Watershed Extent Map

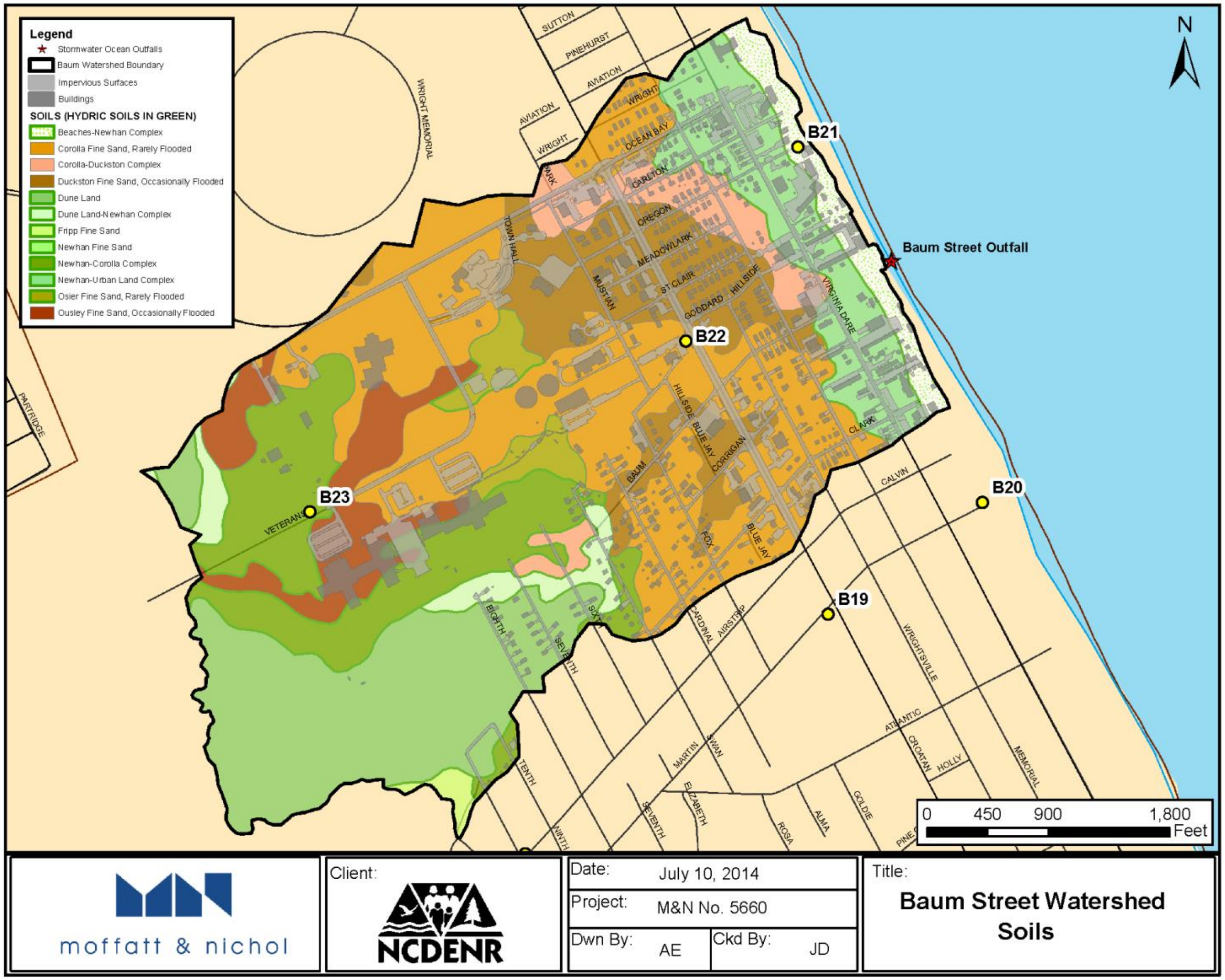


Figure 46. Baum Street Watershed Soils Map

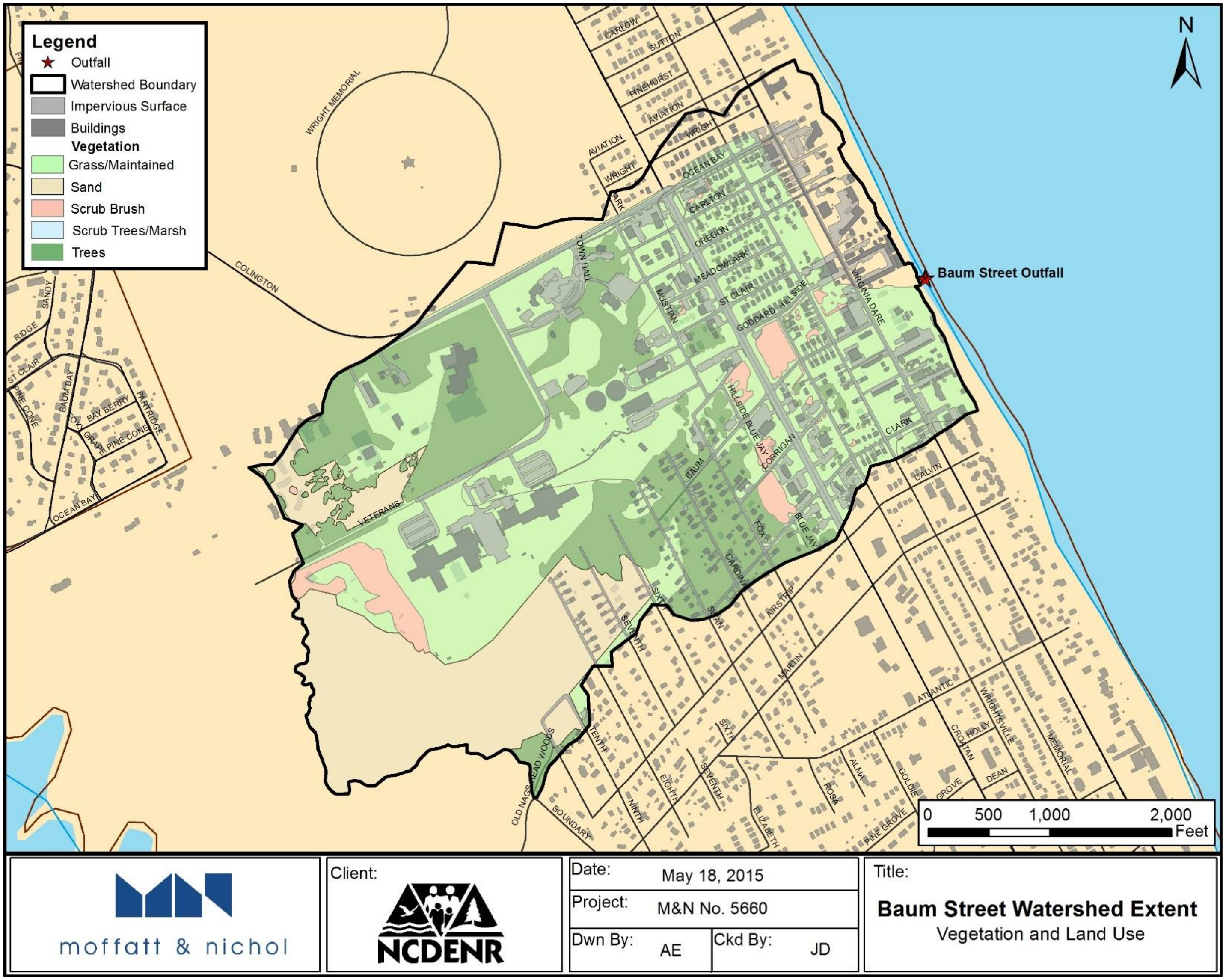


Figure 47. Baum Street Watershed Vegetation Map

3.1.2 Watershed Results

Baum Street is the northernmost watershed included in our project effort. It is characterized by 435 acres, of which 30.2% is impervious. Septic density is 1.26 per acre. There is a total open channel length of 1,007 feet and 35,706 feet of drainage piping. Over the course of this project, Baum Street was monitored during four large storm events that occurred from the fall 2007 through the fall 2008. A high number of grab sampling events occurred over the duration of storm sampling at the Baum Street Outfall. FIB sampling results for each of the storms monitored are discussed below, and the results from each storm are presented graphically in Appendix D. The storm summaries are also presented in **Table 13**.

<u>December 15-16, 2007</u>
For the storm that occurred December 15-16, 2007, there was a total of 2.35 in. of rainfall. Six grab samples were collected for microbial contaminant measurements over the course of the storm. The FIB, *Enterococcus* and *E. coli* concentrations ranged from 52 – 2,110 MPN 100 ml^{-1}, and from 200 - 68,670 MPN 100 ml^{-1}, respectively. Fecal *Bacteroides* spp. concentrations ranged from 30,182 - 303,340 cell equivalents (CE) 100 ml^{-1} over the course of the storm. The highest concentration of *Enterococcus*, *E. coli,* and Fecal *Bacteroides* spp. concentrations occurred during the first grab sample at the beginning of the storm when flow measurements were near zero. Fecal *Bacteroides* spp. concentrations were on the order of 3 logs greater than *Enterococcus* concentrations and one log higher than *E. coli*. concentrations. *Enterococcus* and *E. coli* concentrations decreased after the initiation of the storm and followed the pattern of the hydrograph, with peak concentrations occurring with storm peaks and subsiding to lower levels after the storm. The Fecal *Bacteroides* spp. concentrations remained consistent throughout the course of the storm.

The discharge hydrograph was characterized by multiple large and broad peaks. The baseline flow measurement for this storm was 23 gpm (0.05 cfs), peaking at 417 gpm (0.93 cfs), with the tail of the storm discharge observed for hours after the peak of the storm. The majority of the rainfall occurred during the rising limb of the hydrograph. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loadings for this storm were 7.65×10^{8}, 3.86×10^{10} and 3.40×10^{11} MPN or CE, respectively, equating to loads of 7.47×10^{7}, 3.76×10^{9} and 3.32×10^{10} per h based upon examined storm length of 10.25 hours. As with many storm recorded during the 2006-2008 monitoring period, this event was characterized by high discharge concentrations, but very low hydraulic flow rates, so the FIB load rates were driven far more by concentration than flow. Even though this is true, the high amount of artificial drainage infrastructure in the Baum Street watershed causes periodic high volumes of flow to be conveyed over the course of certain storms.

<u>April 20-23, 2008</u>
For the storm that occurred April 20-23, 2008, there was a total of 2.58 in. of rainfall. Six grab samples were collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 318 – 14,136 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 771 – 9,208 MPN 100 ml^{-1}, and Fecal *Bacteroides* spp. concentrations ranged from 43,908 – 91,274 CE 100 ml^{-1}. *Enterococcus* and *E. coli* concentrations were similar with the highest concentrations occurring after the first peak of the hydrograph and then subsiding to lower

levels after the peak of the storm. Fecal *Bacteroides* spp. concentrations were higher than *Enterococcus* or *E. coli*, and fell slightly during the course of the storm but decreased to lower levels during the tail end of the storm discharge hydrograph.

The discharge hydrograph is characterized by an initial pulse followed by a broad peak containing multiple intense peaks with a slow return to base flow. The baseline flow measurement was 30 gpm (0.07 cfs), peaking at 1,070 gpm (2.38 cfs). Forty eight hours after the peak of the storm, the tail of the discharge hydrograph had still not reached baseline flow levels. This pattern is a classic spring pattern due to the heightened groundwater levels observed from high levels of antecedent rainfall. Rainfall fell in three distinct hydrographic increments over this time period. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loadings for this storm were 1.95×10^{11}, 1.62×10^{11}, and 5.02×10^{14} MPN or CE, respectively, which equates to loads of 3.06×10^{9}, 2.54×10^{9} and 7.87×10^{12} MPN or CE per h based upon examined storm length of 63.75 hours. Similar to the December 2007 event, this event was characterized by high discharge concentrations, but hydraulic flow rates were much higher for this storm because of the higher peaks during active rainfall and the slower receding of the tail of the hydrograph. Very high loads of Enterococcus were observed over the course of this storm, at 10^{9} cells per hour for *Enterococcus* spp.

<u>September 5-11, 2008</u>

For the storm that occurred September 5-11, 2008, a total of 3.27 in. of rain fell. Five grab samples were collected for microbial contaminant measurements over the course of the storm. The FIB, *Enterococcus* and *E. coli* concentrations ranged from 1,201 – 17,329 MPN 100 ml^{-1} and from 121 - 481 MPN 100 ml^{-1} , respectively and Fecal *Bacteroides* spp. concentrations ranged from 53,323 – 199,282 CE 100 ml^{-1} over the course of the storm. This storm discharge hydrograph is characterized by four sharp intense or "flashy" peaks with the maximum values for *Enterococcus* and *E. coli* occurring during the second peak and subsiding to lower levels during the tail of the storm. Fecal *Bacteroides* spp. levels remained high throughout the storm and values were on the order of a magnitude higher than the FIB. *Enterococcus* concentrations were around a log higher than *E. coli* concentrations throughout the duration of the storm.

The baseline flow for this storm started at 0 gpm and peaked at 1,050 gpm (2.34 cfs). Four separate rain events and peaks in the hydrograph were observed during this week, over which a range of samples were collected. It is interesting to note that after the first three events, the flow quickly returned to baseline levels, however after the fourth peak in the hydrograph, the tail of the hydrograph required 24 hours to return to levels elevated that were slightly above base flow. This is an example of the responsive nature of groundwater levels to antecedent rainfall patterns. The total loading of *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. for this entire storm event was 1.68×10^{11}, 1.11×10^{10} and 4.11×10^{12} MPN or CE, respectively, which equates to loads of 1.19×10^{9}, 7.89×10^{7} and 2.93×10^{10} MPN or CE per h based upon examined storm length of 140.5 hours. With over 3 inches of rain, both hydraulic flow rates and FIB concentrations were high..

<u>November 4-7, 2008</u>

For the storm that occurred November 4-7, 2008, there was a total of 3.89 in. of rainfall. Seven grab samples were collected for microbial contaminant measurements over the course of the storm.

Enterococcus concentrations ranged from 155 – 3,873 MPN 100 ml-1 and *E. coli* concentrations ranged from 52 – 12,997 MPN 100 ml-1 over the course of the storm. The storm exhibited two distinct peaks in the hydrograph with maximum values for *Enterococcus* occurring on November 5, 2008 09:00, during the falling limb of first hydrograph. Maximum values for *E. coli* occurred at base flow before storm event. Fecal *Bacteroides* spp. concentrations had a range of 36,690 – 64,030 CE 100 ml-1 over the course of the storm with the peak value occurring midway between the two peaks in the hydrograph (November 5, 2008 17:00). The *Enterococcus* and *E. coli* concentrations were similar in magnitude and levels were highest during the initiation of the storm and falling to below baseline levels during the receding limb of the hydrograph. Fecal *Bacteroides* spp. concentrations remained constant throughout the storm event.

Flow at baseline measured 0 gpm, peaking at 2,310 gpm (5.15 cfs). Two peaks in the hydrograph were observed during this time period. The tail of the hydrograph had yet to reach base flow after 48 hours from the second peak in the hydrograph which was observed on November 5, 2008. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loadings for this storm were 1.88 x 10^{11}, 1.16 x 10^{11}, and 4.76 x 10^{12} MPN or CE respectively, which equates to loads of 2.69 x 10^{9}, 1.66 x 10^{9} and 6.80 x 10^{10} MPN or CE per h based upon examined storm length of 70 hours.

Table 13. Baum Summary Statistics

Storm Date	# of Grab Samples	E. Coli Mean (cells/100ml)	E. Coli Range (cells/100ml)	Enterococcus Mean (cells/100ml)	Enterococcus Range (cells/100ml)	Bacteroides Mean (cells/100ml)	Bacteroides Range (cells/100ml)	Total Enterococcus Load cells	Total E. Coli Load cells	Total Bacteroides Load cells	Enterococcus Load per hour	E. Coli Load per hour	Bacteroides Load per hour
12/15-16/2007	6	13,290	200-68,670	475	52-2,110	110,597	301,82-303,340	7.65×10^{8}	3.86×10^{10}	3.40×10^{11}	7.47×10^{7}	3.76×10^{9}	3.32×10^{10}
4/20-23/2008	6	3,625	771-9,208	3,240	318-14,136	73,704	43,908-91,724	1.95×10^{11}	1.62×10^{11}	5.02×10^{14}	3.06×10^{9}	2.54×10^{9}	7.87×10^{12}
9/5-11/2008	5	325	121-481	7,475	1,201-17,329	132,813	53,353-199,292	1.68×10^{11}	1.11×10^{10}	4.11×10^{12}	1.19×10^{9}	7.89×10^{7}	2.93×10^{10}
11/4-7/2008	7	2,730	52-12,997	1,648	155-3,873	48,164	36,690-64,030	1.88×10^{11}	1.16×10^{11}	4.76×10^{12}	2.69×10^{9}	1.66×10^{9}	6.80×10^{10}

3.1.3 Watershed Strategies

The Baum Street watershed is one of the largest (at 435 acres) and most developed watersheds (over 30% imperviousness) for any of the ocean outfalls studied. Perhaps most important, as a result if the level of commercial and residential development within it, the Baum Street watershed has one of the most extensive networks of artificial drainage infrastructure of any of the watersheds. Groundwater data analysis presented in Section 2.2 shows that groundwater surface elevations spend a considerable amount of time within the upper portions of the soil column where interaction with septic system drain fields would occur, increasing the potential for delivery of human-derived FIB to the ocean outfall. This potential interaction is likely to explain the pattern where the high Fecal *Bacteroides* spp. levels, which can be indicative of human fecal pollution, tend to remain very high, or even increase, late in the hydrographic response for each storm. Data collection at the Baum and Martin Street outfalls was complete over the course of this study, i.e. the system remained available for study and for flow characterization with few minor problems. The number of grab samples collected at this location over the course of the storms characterized was also relatively high. For example, in November 2008, a storm was characterized with seven grab sampling events over the duration of the 72 hour event. This extensive data collection across and within storms permits it to be placed within the prioritization exercises according to *Enterococcus* spp. mean concentration and loading of *Enterococcus* sp. at this outfall site. Because Baum Street is one of the largest watersheds, combined with the high amount of artificial drainage infrastructure, it often emerged as being either number one or two in loading of *Enterococcus* sp. bacteria to the coastal zone.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- Due to a lesser level of single-family residential development in the watershed, the density of on-site septic systems is relatively low. However, there are several large-scale on-site systems that serve the schools, hotels and multi-family resort properties in the watershed. In particular, the septic systems that serve the public school complex are surrounded by piped drainage infrastructure that may facilitate delivery of fecal contamination during high groundwater periods. Improvements to the performance of these systems could yield direct benefits in terms of load reductions transmitted through the outfall. Similar opportunities may exist with the on-site systems for the hotels and resort properties in the watershed.
- Given the intensive drainage infrastructure that short circuits the natural flow paths of barrier island hydrography, retrofitting of BMPs that interrupt those artificial flow paths or direct stormwater away from them would be advantageous. With the level of development in the watershed, opportunities for large regional BMPs will be limited, so the focus is more likely to be on diffuse landscape-integrated BMPs such as the high –rate infiltration sand filters discussed in section 4.1 or other such BMPs typically associated with low impact development.
- Given that *Enterococcus* sp. loading is very high, but that the system also conveys high water volumes over a range of different storm types and seasons, the Baum Street

watershed should be considered for upstream improvements to provide incremental reductions in load.

- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 be effective in reducing FIB loads to beach receiving waters, the possibility of implementing such a system in the Baum Street watershed is aided by the presence of town-owned land immediately west of the watershed where the drawdown effluent could be discharged. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIB are extremely high whereas flow rates are relatively low, making it readily possible to deploy pump systems capable of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.

3.2 Martin Street Watershed

The Martin Street watershed is comprised of an area approximately 394 acres extending from parts of Boundary Street and Ocean Acres Drive to the southwest, to the front dunes at the shoreline to the east. Land use in the area is mostly developed, with a mixture of residential, recreational, and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 48**.

3.2.1 Watershed Characterization

Impervious

The Martin Street watershed contains approximately 103.6 acres of impervious surfaces, which is approximately 26.3% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, sidewalks and recreational surfaces such as pools and tennis courts. There are 861 buildings with 31 acres of building footprint, which is approximately 8% of the total watershed area of building footprint. Buildings within the watershed area are primarily residential or commercial.

Septic Density

For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Martin Street watershed is 861, which equates to an estimated density of 2.19 systems per acre. A review of Dare County permits for septic system repairs and new installs within the Martin Street watershed from 2006-2012 is summarized in **Table 14** below.

Table 14. Martin Street Septic Repair and Install Permits

Year	Total New System Permits	Total System Repair Permits
2006	8	14
2007	11	2
2008	2	11
2009	2	10
2010	2	12
2011	6	13
2012	0	1
Total:	**31**	**63**

Soils

A summary of soils within the Martin Street watershed is provided in **Table 15**. The watershed contains 392 acres of hydric soils and approximately 2 acres of non-hydric soils. Therefore, interactions between groundwater and septic systems would likely be high in this watershed. See **Figure 49** for Martin Street watershed soils mapping.

Table 15. Martin Street Watershed Soils Summary

Soil Type	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Osier Fine Sand, 0-2 percent slopes	Yes	3.2	<1	Poorly drained; rapid permeability
Fripp Fine Sand, 2-30 percent slopes	Yes	7.0	2	Excessively drained; very slow runoff; rapid permeability
Dune Land, 2-40 percent slopes	Yes	3.1	<1	None provided
Newhan-Corolla Complex, 0-10 percent slopes	Yes	19.3	5	Excessively drained; very slow runoff; rapid permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	23.7	6	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand	Yes	46	12	Excessively drained; very slow runoff; rapid permeability
Beaches-Newhan Complex, 0-25 percent slopes	Yes	10.3	2	Excessively drained; very slow runoff; rapid permeability
Psamments, 0-6 percent slopes	No	1.9	<1	
Duckston Fine Sand, 0-2 percent slopes	Yes	45.1	11	Poorly drained; very slow runoff; very rapid permeability above the water table.
Corolla Fine Sand, 0-6 percent slopes	Yes	191.3	49	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Ousley Fine Sand, 0-5 percent slopes	Yes	43.1	11	Somewhat poorly drained; rapid permeability

Vegetation

The Martin Street watershed contains approximately 149 acres of trees, with most of it occurring in the western portion of the watershed. The remaining fragmented vegetated areas within the watershed are primarily grassed. Areas of forested vegetation are dispersed throughout the western portion of the watershed and likely do not have a significant effect on groundwater levels due to evapotranspiration. Patterns of vegetation are mapped in **Figure 50**.

Groundwater

Three groundwater monitoring wells installed by Moffatt & Nichol in 2006 are located within the Martin Street watershed. B-20 is located at the shoreline end of Martin Street. Moffatt & Nichol scientists found that this well had no recorded groundwater levels within 0 to 3 feet of the surface for the period of collection. B-19, located alongside NC 158 (Croatan Highway) had groundwater levels within 0 to 3 feet for approximately 39% of the total data samples collected. Groundwater well B-18 had recorded groundwater levels within 0 to 3 feet for approximately 15% of the data samples collected. All of the wells are located in developed areas. It should be noted that Well B-20 was destroyed in 2008 by adjacent construction activities, resulting in it recording four years' less data than the other two wells in this watershed. In addition B-20 was located along the lower western slope of the primary dune line, at an elevation over 11 feet above sea level. Well B-19 with a ground surface elevation of 8.3 feet is far more reflective of the controlling elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road. The lowest point of that trough occurs at an elevations of 5-6 feet above sea level in the Martin Street watershed. The results show that the groundwater data has great potential to illuminate problem areas for flooding during wet periods. The data collected at these wells also illustrates the important potential for groundwater – septic system interactions, which could be a key factor in pollutant loading of FIB to the ocean outfalls in this watershed.

<u>Drainage Systems and Infrastructure</u>

The Martin Street watershed contains approximately 9,821 feet of open channel ditch and approximately 60,598 feet of piping. Drainage network spatial data and detailed contours of the Martin Street watershed indicate that there is approximately 195 acres of the watershed drained by piping and open channel ditches. This area represents approximately 50% of the total watershed area and occurs primarily in heavily developed areas within the watershed. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and commercial facilities where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. However, a significant portion of the watershed is residential development, with some areas of development located over hydric soils. In these areas, especially adjacent to the shoreline in the eastern portion of the watershed, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

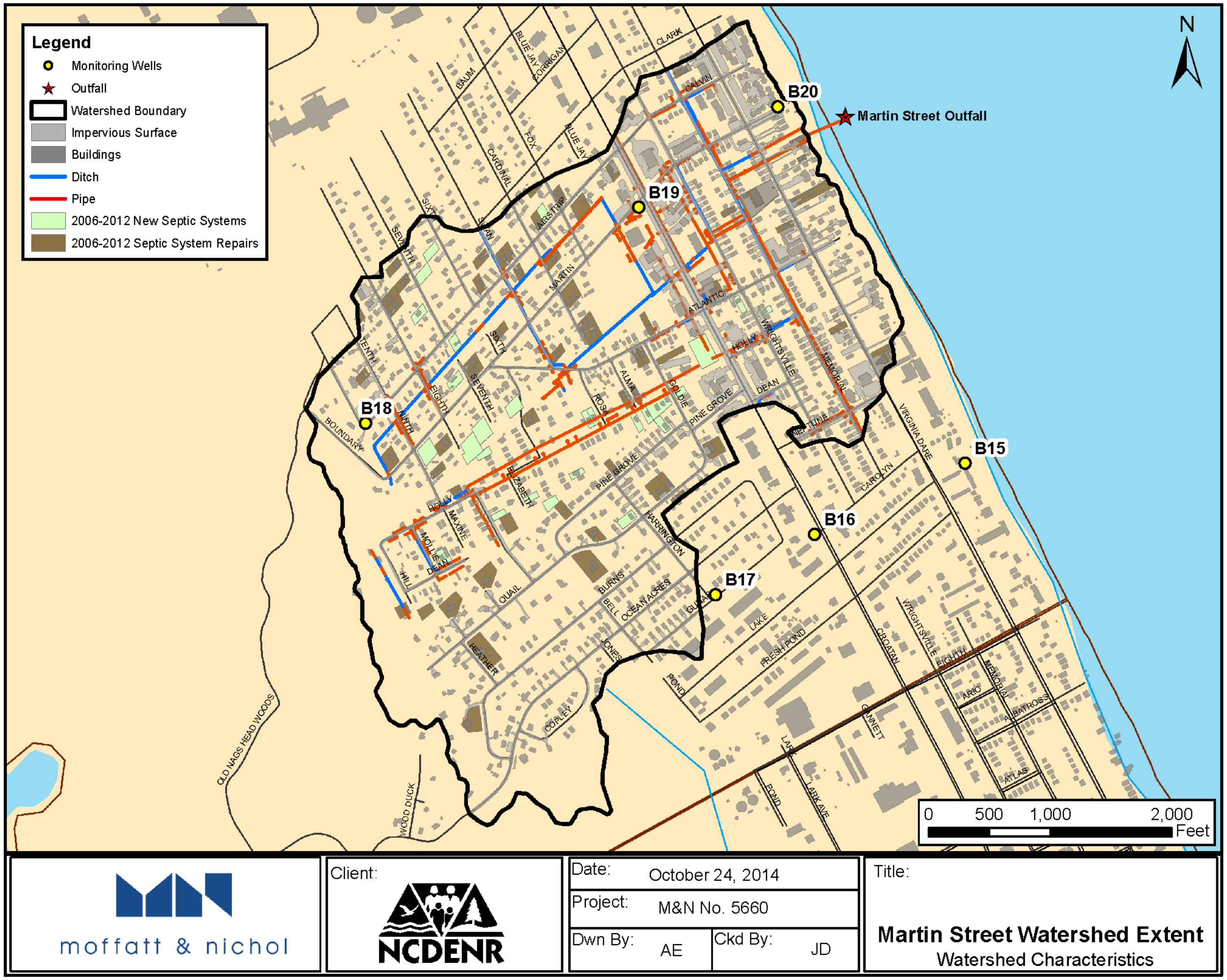


Figure 48. Martin Street Watershed Extent Map

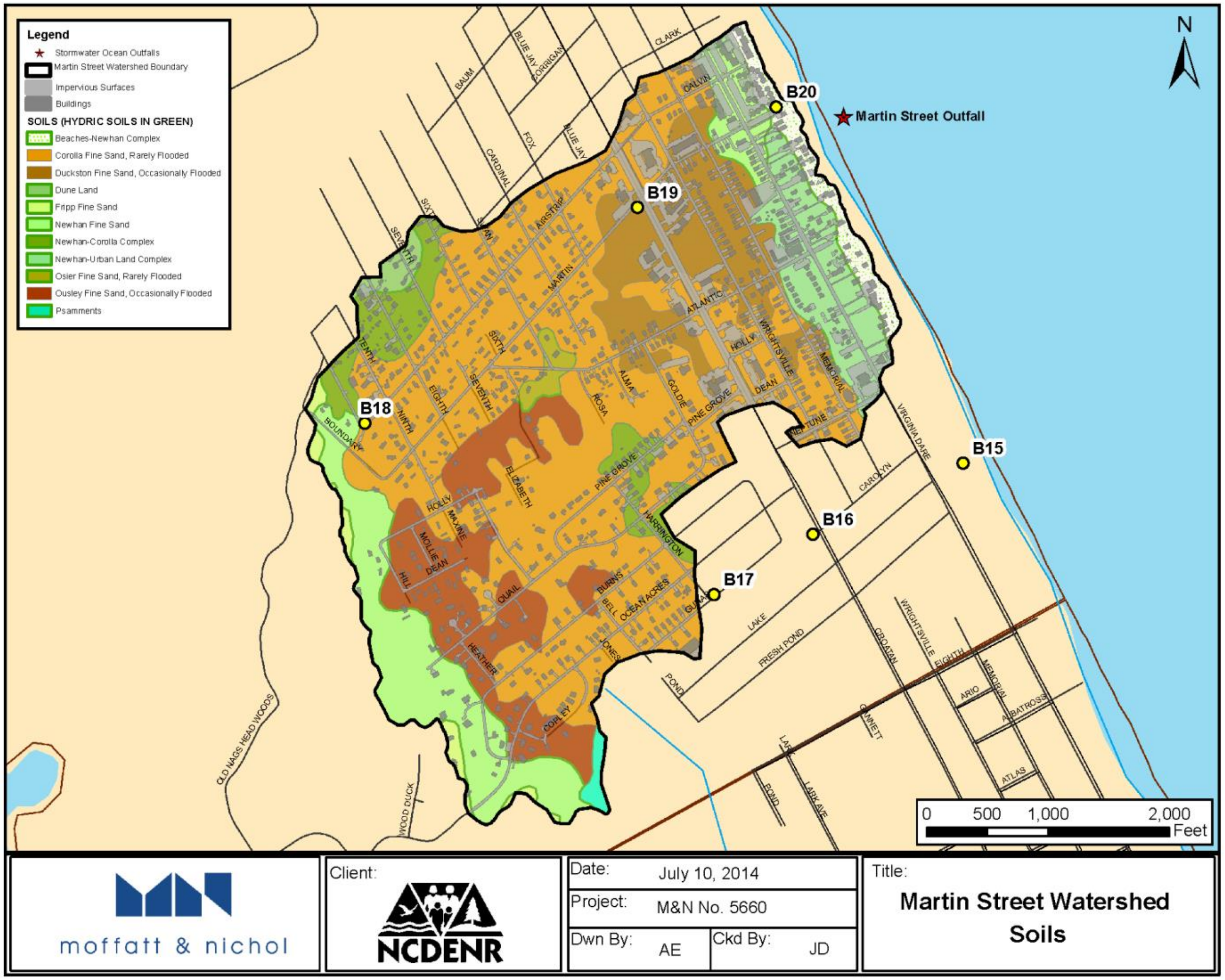


Figure 49. Martin Street Watershed Soils Map

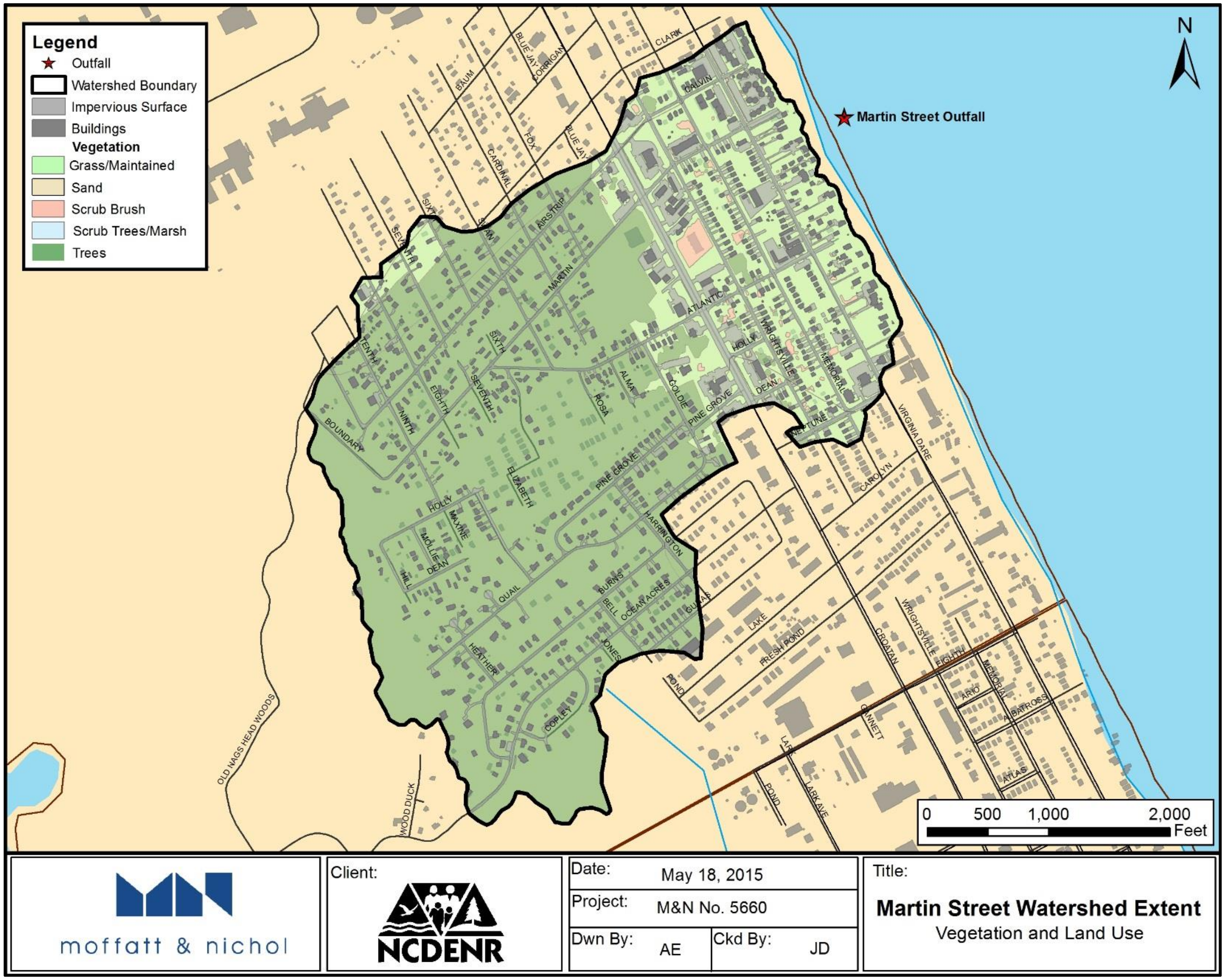


Figure 50. Martin Street Watershed Vegetation Map

3.2.2 Watershed Results

Martin Street watershed is 394 acres in size of which 26.3% is impervious. The density of septic systems is 2.19 per acre. There is a total open channel length of 1,907 feet, with a total length of drainage piping of 2,248 feet. Over the course of the initial monitoring and prioritization period of this project Martin Street was monitored during five large storm events that occurred from summer 2007 through fall 2008. This means that it was one of the best studied, and most accessible outfalls for collecting both grab samples and flow related data. FIB sampling results for each of the storms monitored are discussed below, and the results from each storm are presented graphically in Appendix D. Relevant summary data from each storm are also presented in **Table 16**.

<u>June 3-4, 2007</u>

For the storm that occurred June 3-4, 2007, there was a total of 1.19 in of rainfall. Three grab samples were collected for microbial contaminant measurements over the course of the storm, on June 3, 2007 at 07:45 and 11:45 and on June 4, 2007 10:30 *Enterococcus* concentrations ranged from 5,475 - 24,196 MPN 100 ml-1, *E. coli* concentrations ranged from 2,382 - 5,172 MPN 100 ml-1 and Fecal *Bacteroides* spp. concentrations ranged from 801 – 8,081 CE 100 ml-1 over the entire duration of the storm. The flow was measured throughout this entire storm and started at a baseline measurement of 17 gpm (0.04 cfs) and peaked at 2,863 gpm (6.38 cfs). The storm discharge hydrograph exhibited two distinct peaks with a rapid return to base flow levels. *Enterococcus* and *E. coli* concentrations were similar in magnitude and the maximum values recorded for *Enterococcus* and *E. coli* occurred during the falling limb of the first peak in discharge in the storm.

The peak Fecal *Bacteroides* spp. concentrations were observed with the first peak in discharge. Interestingly, *Enterococcus* concentrations exceeded that of the Fecal *Bacteroides* spp. during the rising and falling limb of the first peak in discharge. This is an interesting occurrence, because it is typically expected that Fecal *Bacteroides* sp. concentrations will exceed *Enterococcus* sp. concentrations by at least an order of magnitude, and sometimes two orders of magnitude. Both discharge peaks increased and decreased rapidly over a short time period. Additionally, base flow remained relatively high 270 gpm (0.60 cfs) for several hours after storm. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loadings over the entire storm were 9.28×10^{11}, 2.50×10^{11} and 1.64×10^{11} MPN or CE respectively, which equates to loads of 2.92×10^{10}, 7.88×10^{9}, and 5.16×10^{9} MPN or CE per h based upon the examined storm length of 31.75 hours..

<u>December 15-16, 2007</u>

For the storm that occurred December 15-16, 2007, there was a total of 2.35 in. of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm on December 16, 2007. *Enterococcus* concentrations ranged from 10 - 168 MPN 100 ml-1, *E. coli* ranged from 1,529 – 11,120 MPN 100 ml-1 and Fecal *Bacteroides* spp. concentrations ranged from 31,176 – 286,294 CE 100 ml-1 over the course of the storm. All maximum values recorded for *Enterococcus, E. coli* and Fecal *Bacteroides* spp. occurred during the rising limb of the discharge hydrograph (Grab sample point December 16, 2007 00:00). *E. coli* values exceed that of *Enterococcus* by 1-2 log over the entire course of the storm. Fecal *Bacteroides* spp. concentrations dropped through the course of the storm.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and the peak measurement was 3,150 gpm (7.02 cfs). The tail of the hydrograph quickly decreased and a steady baseline was observed of 60 gpm (0.13 cfs) occurred seven hours after final peak in the discharge. The total *Enterococcus, E. coli* and Fecal *Bacteroides* spp. loads for this storm were 3.25 x 10^9, 1.29 x 10^{11} and 3.39 x 10^{12} cells respectively, which equates to loads of 3.61 x10^8, 1.43 x 10^{10} and 3.77 x 10^{11} cells per h based upon examined storm length of 9 hours. This is very short storm event, but a very important event to characterize, given that the system responded with high flows for a short rainfall duration but rainfall of very high intensity. The fact that the FIB and Fecal Bacteroides spp. also responded with the highest concentrations during the rising limb of the hydrograph is very interesting to note.

<u>April 20-23, 2008</u>

For the storm that occurred April 20-23, 2008, there was a total of 2.58 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 460 – 5,475 MPN 100 m $^{-1}$ *E. coli* ranged from 121 – 2,098 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 55,317 – 63,571 CE 100 ml^{-1} over the course of the storm. The hydrograph was characterized by a brief initial pulse of flow followed by a steeply rising limb with three additional pulses (**Figure 51**). There was a slow return to base flow. Fecal *Bacteroides* spp. values remained constant throughout the storm and were consistently a log higher than either *Enterococcus* or *E. coli* values. Interestingly, *E. coli* and *Enterococcus* values were very similar, tracking each other closely, and peaked with the steeply rising limb of the hydrograph and concentrations receded with storm flow. Fecal *Bacteroides* spp. concentrations were greater than a magnitude greater than either *Enterococcus* or *E. coli*, and its concentration remained high and steady throughout the storm.

Baseline flow measurement started at 0 gpm and peak measurements were recorded at 1,810 gpm (4.03 cfs). The storm hydrograph had several peaks and tail of hydrograph still exhibited elevated flow over 400 gpm (0.90 cfs) 36 h. after final hydrograph peak. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 2.06 x10^{11}, 1.15 x 10^{11} and 5.81 x 10^{12} MPN or CE respectively, which equates to loads of 3.50 x 10^9, 1.95 x 10^9 and 9.84 x 10^{10} MPN or CE per h based upon examined storm length of 59 hours. Similar to the Baum Street outfall data from this storm event, at Martin Street, this event was characterized by high discharge concentrations, but very low hydraulic flow rates, so the FIB load rates were driven far more by concentration than flow.

The potential interaction between rainfall and groundwater in this barrier island system becomes apparent when examining **Figure 51**. For example, during this event in April 2008, over multiple rainfall periods, a strong increase in groundwater surface elevation is noted. During this period in time, it can be observed that FIB concentrations (*E. coli* and *Enterococcus*) generally follow the pattern of the hydrograph, i.e. peak at peak rainfall and decrease during the tail of the storm. However, the pattern of Fecal *Bacteroides* spp. concentrations over the duration of the storm is different. These are organisms that would be more closely associated with human fecal contamination, and during the strong increase in groundwater surface elevation, the fecal *Bacteroides* sp. concentrations remain high through the tail of the storm. This indicates the possibility that while Enterococcus and E. coli can be stemming from a range of sources over the duration of a storm, that during the late periods of a storm, the sources may be more likely to be septic or package treatment systems that are suffering from the high groundwater level interactions. This series of observations is only a trend, but it indicates the need for a more specific examination of groundwater/septic system interaction.

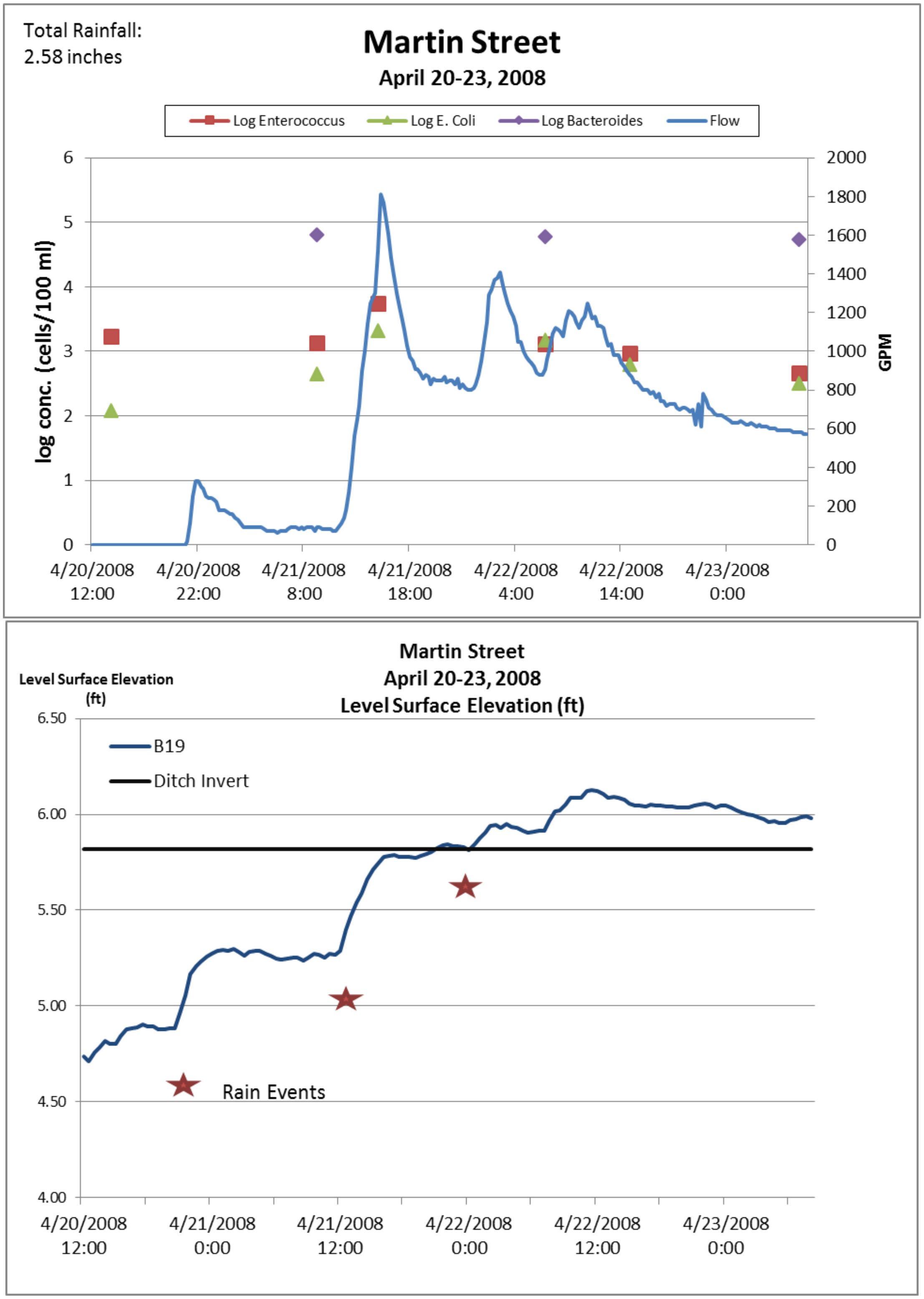


Figure 51. Martin Street FIB Concentrations and Groundwater Surface Elevations for April 2008 Storm Event

<u>September 5-11, 2008</u>

For the storm that occurred September 5-11, 2008, there was a total of 3.20 in of rainfall. There were five grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 691 – 12,033 MPN 100 ml^{-1}, *E. coli* ranged from 1,145 – 7,270 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 5 – 380,699 CE 100 ml^{-1} over the course of the storm. The hydrograph could be termed as flashy exhibiting five distinct and steep peaks which rapidly returned to base flow levels. *Enterococcus* and *E. coli* concentrations were relatively similar and appeared to track the hydrograph peaks. Maximum values recorded for *Enterococcus* and *E. coli* occurred during the 2^{nd} peak in the hydrograph (September 6, 2008 09:15). The peak Fecal *Bacteroides* spp. Concentrations occurred at the beginning of the storm, September 5, 2008 13:30. The low Fecal *Bacteroides* spp. values recorded during September 6, 2008 are uncharacteristic for this marker and most likely represent an underestimation of the real concentrations due to inhibitory substances which can interfere with the assay's performance. Every effort is made to avoid and account for interference by the inclusion of multiple controls.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 3,030 gpm (6.75 cfs), the tail of the hydrograph was still falling twelve hours after last peak in the hydrograph. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loadings for this storm were 1.58 x 10^{12}, 7.51 x 10^{11} and 2.22 x 10^{13} MPN or CE respectively, which equates to loads of 1.12 x 10^{10}, 5.34 x 10^{9} and 1.58 x 10^{11} MPN or CE per h based upon examined storm length of 140.75 hours.

<u>November 4-7, 2008</u>

For the storm that occurred on November 4-7, 2008, there was a total of 2.98 in. of rainfall. There were seven grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 959 – 19,863 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 987 – 4,106 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 4,867 – 168,605 CE 100 ml^{-1} over the course of the storm. This was a dampened hydrograph exhibiting an initial steep rising limb, another pulse, and then a very slow return to baseline. *Enterococcus* and *E. coli* concentrations were very similar in magnitude, however only the *Enterococcus* peaked with the rising limb and subsided to baseline levels. Fecal *Bacteroides* spp. concentrations, while initially a magnitude greater than the FIB, peaked with the rising limb, fell to levels below that of *Enterococcus*, and then slowly rose back to baseline levels. The maximum *E. coli* values occurred at the beginning of storm was and did not significantly differ from other values measured throughout the storm.

Flow was measured for this storm and started at a baseline measurement of 0 gpm, peaking at 4,390 gpm (9.78 cfs). The storm discharge continued at a high flow rate >2,000 gpm (>4.5 cfs) greater than 24 hours after end of storm event. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 2.34 x 10^{12}, 9.31 x 10^{11}, and 1.68 x 10^{13} MPN or CE respectively, which equates to loads of 3.33 x 10^{10}, 1.33 x 10^{10}, and 2.39 x 10^{11} MPN or CE per h based upon examined storm length of 70.25 hours.

Table 16. Martin Summary Statistics

Storm Date	# of Grab Samples	E. Coli Mean (cells/100ml)	E. Coli Range (cells/100ml)	Enterococcus Mean (cells/100ml)	Enterococcus Range (cells/100ml)	Bacteroides Mean (cells/100ml)	Bacteroides Range (cells/100ml)	Total Enterococcus Load cells	Total E. Coli Load cells	Total Bacteroides Load cells	Enterococcus Load per hour	E. Coli Load per hour	Bacteroides Load per hour
6/3-4/2007	3	3,386	2,382-5,172	13,901	5,475-24,196	3,321	801-8,081	9.28×10^{11}	2.50×10^{11}	1.64×10^{11}	2.92×10^{10}	7.88×10^{9}	5.16×10^{9}
12/15-16/2007	6	3,833	1,529-11,120	96	10-168	101,221	31,176-286,294	3.25×10^{9}	1.29×10^{11}	3.39×10^{12}	3.61×10^{8}	1.43×10^{10}	3.77×10^{11}
4/20-23/2008	6	854	121-2,098	1,868	460-5,475	59,598	55,317-63,571	2.06×10^{11}	1.15×10^{11}	5.81×10^{12}	3.5×10^{9}	1.95×10^{9}	9.84×10^{10}
9/5-11/2008	5	4,169	1,145-7,270	7,253	691-12,033	114,292	5-380,699	1.58×10^{12}	7.51×10^{11}	2.22×10^{13}	1.12×10^{10}	5.34×10^{9}	1.58×10^{11}
11/4-7/2008	7	2,753	987-4,106	5,942	959-19,863	51,604	4,867-168,605	2.34×10^{12}	9.31×10^{11}	1.68×10^{13}	3.33×10^{10}	1.33×10^{10}	2.39×10^{11}

3.2.3 Watershed Strategies

The Martin Street watershed is one of the four largest (at 394 acres) and, while not as heavily developed as that of the Baum Street watershed, it remains one of the more heavily developed watersheds (over 26% imperviousness). It also has the largest network of piped storm drainage of any of the watersheds, but this metric should be considered carefully as the data are not available to accurately reflect the full extents of engineered storm drain networks in all watersheds. Indeed, the mapped and inventoried storm drain systems in all the outfall watershed are partial at best, and often outdated as new pipes and connections have been installed in recent years. Perhaps most important, the Martin street watershed has the highest number of buildings (861), and associated septic systems of all of the watersheds. Groundwater data analysis presented in Section 2.2 shows that groundwater surface elevations spend a considerable amount of time within the upper portions of the soil column where interaction with septic system drain fields would occur, increasing the potential for delivery of human-derived FIB to the ocean outfall. This potential interaction is likely to explain the pattern illustrated in Figure 40 (above) where the high Fecal *Bacteroides* spp. levels, which are indicative of human sources, tend to remain very high, or even increase, late in the hydrographic response for each storm, despite the fact that the other FIB species tend to decline in concentration with the falling limb of the hydrograph. Collectively, the Martin Street ocean outfall has one of the largest watersheds that consistently exhibits some of the highest flow volumes, which combine with the extensive storm drain network that facilitate consistent delivery of some of the highest total FIB loads of all the ocean outfalls.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- Unlike the adjacent Baum Street watershed, Martin Street has a very large number of single family residential structures, translating into high numbers of small on-site septic systems. The distributed nature of these systems as sources and their high level of connectivity for delivery via the extensive drainage network point to the need for more intensive management of the performance and maintenance of on-site systems in this watershed. Improvements in these areas could involve requirements or incentives for upgrades, active and publicly supported maintenance programs, and more frequent and rigorous inspections.
- There are several large on-site septic systems that serve hotels and multi-family resort properties in the watershed, and given that these systems tend to be located in the eastern portion of the watershed in near vicinity to the outfall, improvements in their operation and performance may generate tangible benefits.
- Given the intensive drainage infrastructure that short circuits the natural flow paths of barrier island hydrography, retrofitting of BMPs that interrupt those artificial flow paths or direct stormwater away from them would be advantageous. The Martin Street watershed is one of the few ocean outfall watersheds where a sufficient amount of undeveloped land, which is also in a hydrologically advantageous location, could be identified in which to site a large, regional-scale BMP. Just west of the Bypass, several undeveloped parcels exist where a BMP could be sited to capture and treat the flows from up to 112 acres of the Martin Street watershed. It should be noted that the majority of the land in question is

privately owned, which would necessitate acquisition. The potential opportunity is discussed in detail in Section 4.1.

- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 be effective in reducing bacterial pollution loads, the possibility of implementing such a system in the Martin Street watershed is aided by the fact that it could be implemented in conjunction with a system for the Baum Street outfall, taking advantage of economies of scale by constructing a single force main to the discharge location. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIBs are extremely high whereas flow rates are relatively low, making it readily possible to deploy pump systems capable of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.
- It is possible that the Martin and Baum Street watersheds, although large in nature, and relatively highly developed, will benefit from examination of potential dual outfall strategies for both flow reduction and reduction of high groundwater levels during late periods of storms.

3.3 East Lake Drive "Ocean House" Watershed

The East Lake Drive watershed is comprised of an area approximately 196 acres. Land use in the area is mostly developed, with a mixture of residential, recreational, and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 52**.

3.3.1 Watershed Characterization

Impervious

The East Lake Drive watershed contains approximately 95.1 acres of impervious surfaces, which is approximately 48.5% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, sidewalks and recreational surfaces such as pools and tennis courts. There are 355 buildings with 17.6 acres of building footprint, which is approximately 9% of the total watershed area. Buildings within the watershed area are primarily residential or commercial.

Septic Density

For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the East Lake Drive watershed is 355, which equates to an estimated density of 2.82 systems per acre. A review of Dare County permits for septic system repairs and new installs within the East Lake Drive watershed from 2006-2012 is summarized in **Table 17** below.

Table 17. East Lake Drive Septic Repair and Install Permits

Year	Total New System Permits	Total System Repair Permits
2006	3	3
2007	0	4
2008	1	3
2009	1	2
2010	2	3
2011	1	3
2012	0	0
Total:	**8**	**18**

Soils

A summary of soils within the East Lake Drive watershed is provided in **Table 18**. There are 193 acres of hydric soils within the watershed boundary and approximately 3 acres of non-hydric soils within the watershed. Therefore, interactions between groundwater and septic systems are likely high. See **Figure 53** for East Lake Drive watershed soils mapping.

Table 18. East Lake Drive Watershed Soils Summary

Soil Type*	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Psamments, 0-6 percent slopes	No	3.4	2	Poorly drained; rapid permeability
Newhan-Corolla Complex, 0-10 percent slopes	Yes	4.2	2	Excessively drained; very slow runoff; rapid permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	15.7	8	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand	Yes	9.8	5	Excessively drained; very slow runoff; rapid permeability
Beaches-Newhan Complex, 0-25 percent slopes	Yes	10.8	6	Excessively drained; very slow runoff; rapid permeability
Duckston Fine Sands	Yes	11.9	6	Poorly drained; very slow runoff; very rapid permeability above the water table.
Corolla Fine Sands	Yes	116.3	59	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston-Corolla Complex	Yes	2.4	1	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.

*There was approximately 20 acres of water included in the soils data.

Vegetation

The East Lake Drive watershed contains approximately 15 acres of trees, with most of it occurring in the western portion of the watershed. Some areas previously identified as scrub brush vegetation have been converted to impervious surfaces or are now vegetated with trees. The remaining fragmented vegetated areas within the watershed are primarily grassed. Areas of forested vegetation are dispersed throughout the western portion of the watershed and likely do not have a significant effect on groundwater levels due to evapotranspiration. Patterns of vegetation are mapped in **Figure 54**.

Groundwater

Three groundwater monitoring wells installed by Moffatt & Nichol in 2006 are located within the East Lake Drive watershed. B-15 is located at the shoreline end of East Lake Drive. Moffatt & Nichol scientists found that this well had no recorded groundwater levels within 0 to 3 feet of the surface for the period of collection. It should be noted that B-15 is located on the western slope of the primary dune, at an elevation of 16 feet above sea level, so that fact that it has no incidence of groundwater within 0-3 feet of the surface does not reflect the potential for such occurrence throughout the watershed. As a point of reference, the controlling elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road, occurs at an elevations of 7 feet above sea level in the East Lake Drive watershed. B-16, located alongside NC 158 (Croatan Highway) at an elevation of 9 feet, had groundwater levels within 0 to 3 feet for approximately 40% of the total data samples collected. Groundwater well B-17, located at an elevation of slightly more than 11 feet, had recorded groundwater levels within 0 to 3 feet for approximately 30% of the data samples collected. All of the wells are located in developed areas. The data collected at these wells also illustrates significant potential for groundwater – septic system interactions, which could be an important factor in pollutant loading of FIB to the ocean outfalls in this watershed.

Drainage Systems and Infrastructure

The East Lake Drive watershed contains approximately 24,247 feet of piping and 633 feet of open channel ditching. Drainage network spatial data and detailed contours of the East Lake Drive watershed indicate that there is approximately 84 acres of the watershed drained by piping and open channel ditches. This area represents approximately 43% of the total watershed area and occurs primarily in heavily developed areas within the watershed. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and commercial facilities where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. In areas without drainage infrastructure and where hydric soils are located below dense areas of residential development, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

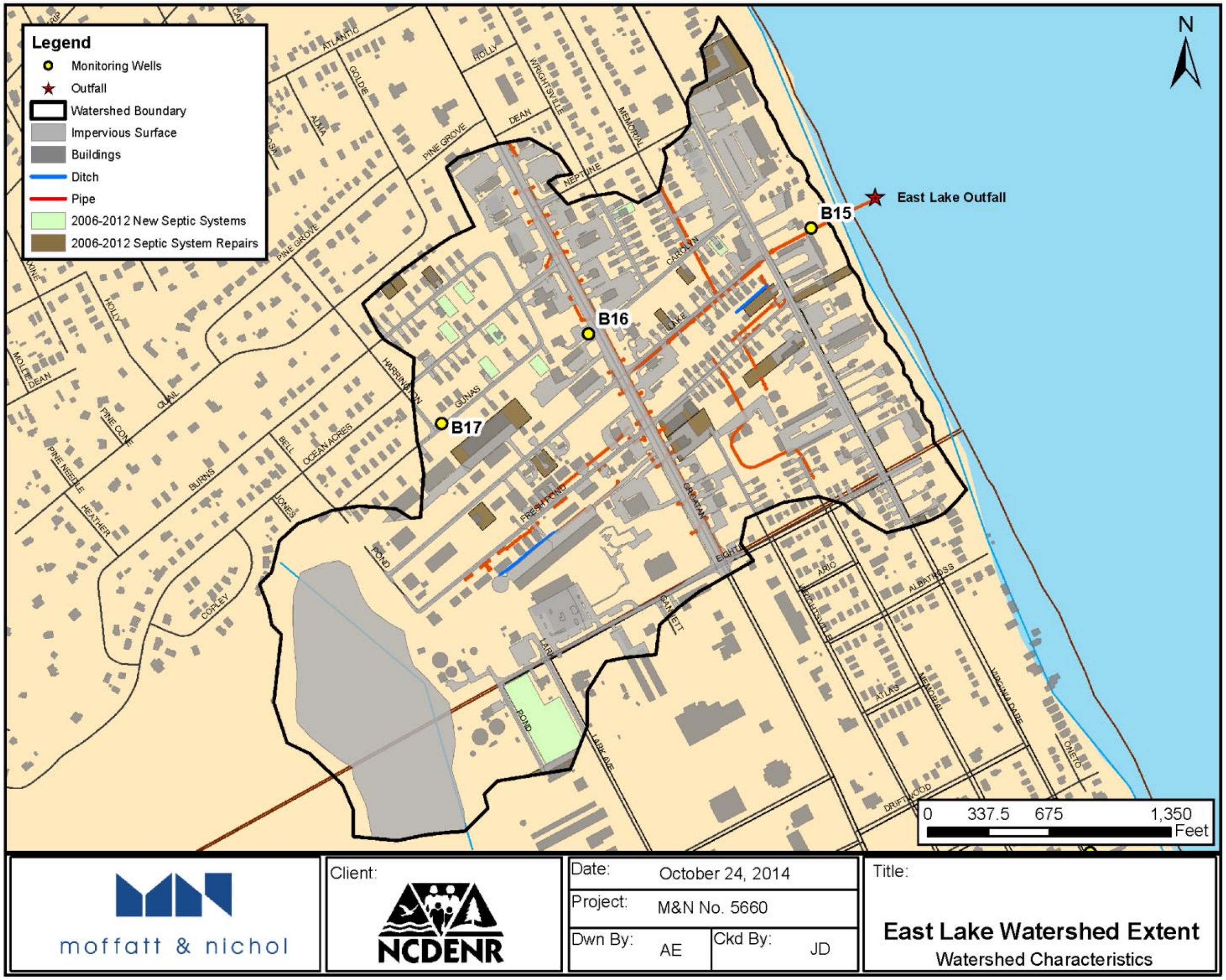


Figure 52. East Lake Drive Watershed Extent Map

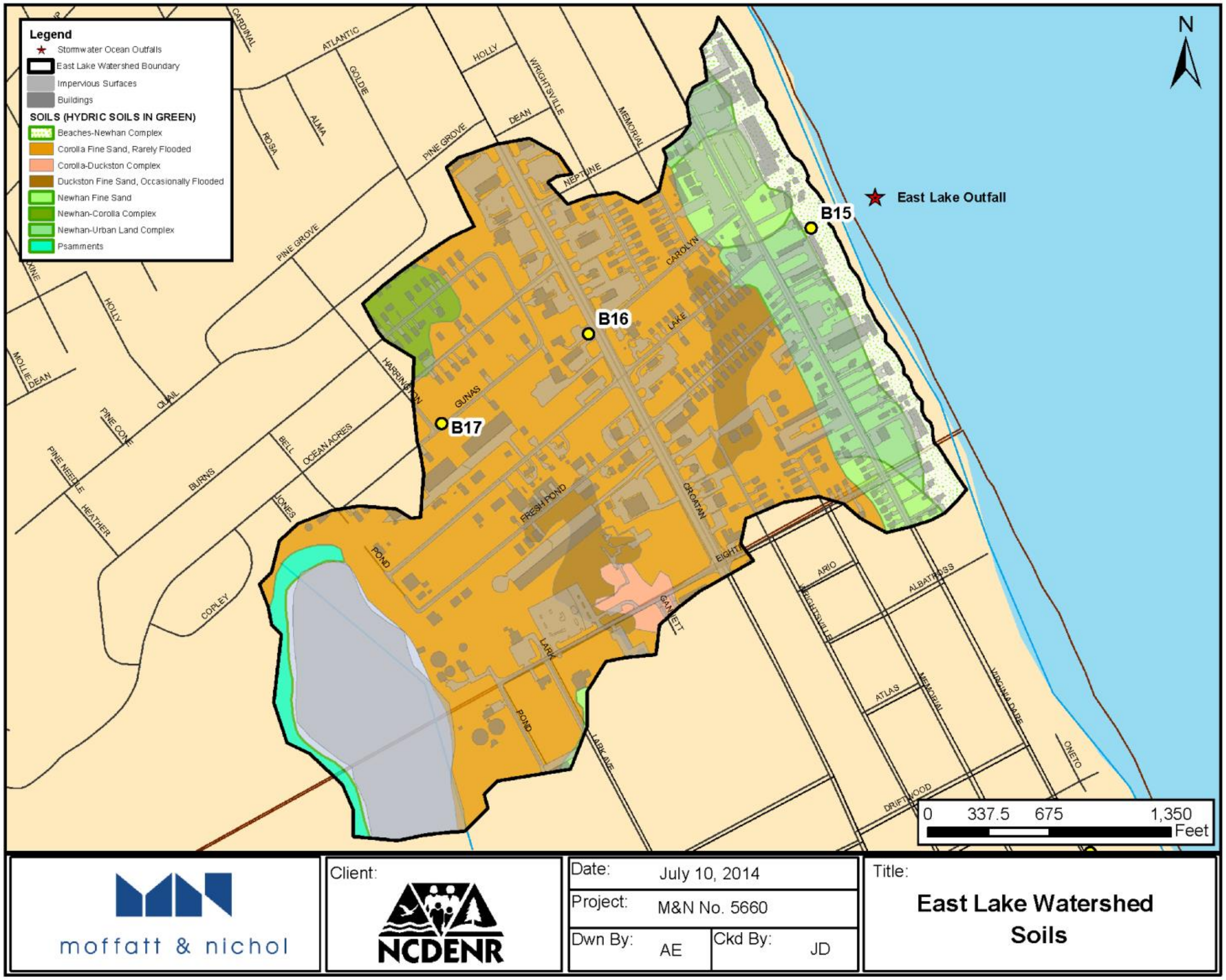


Figure 53. East Lake Drive Watershed Soils Map

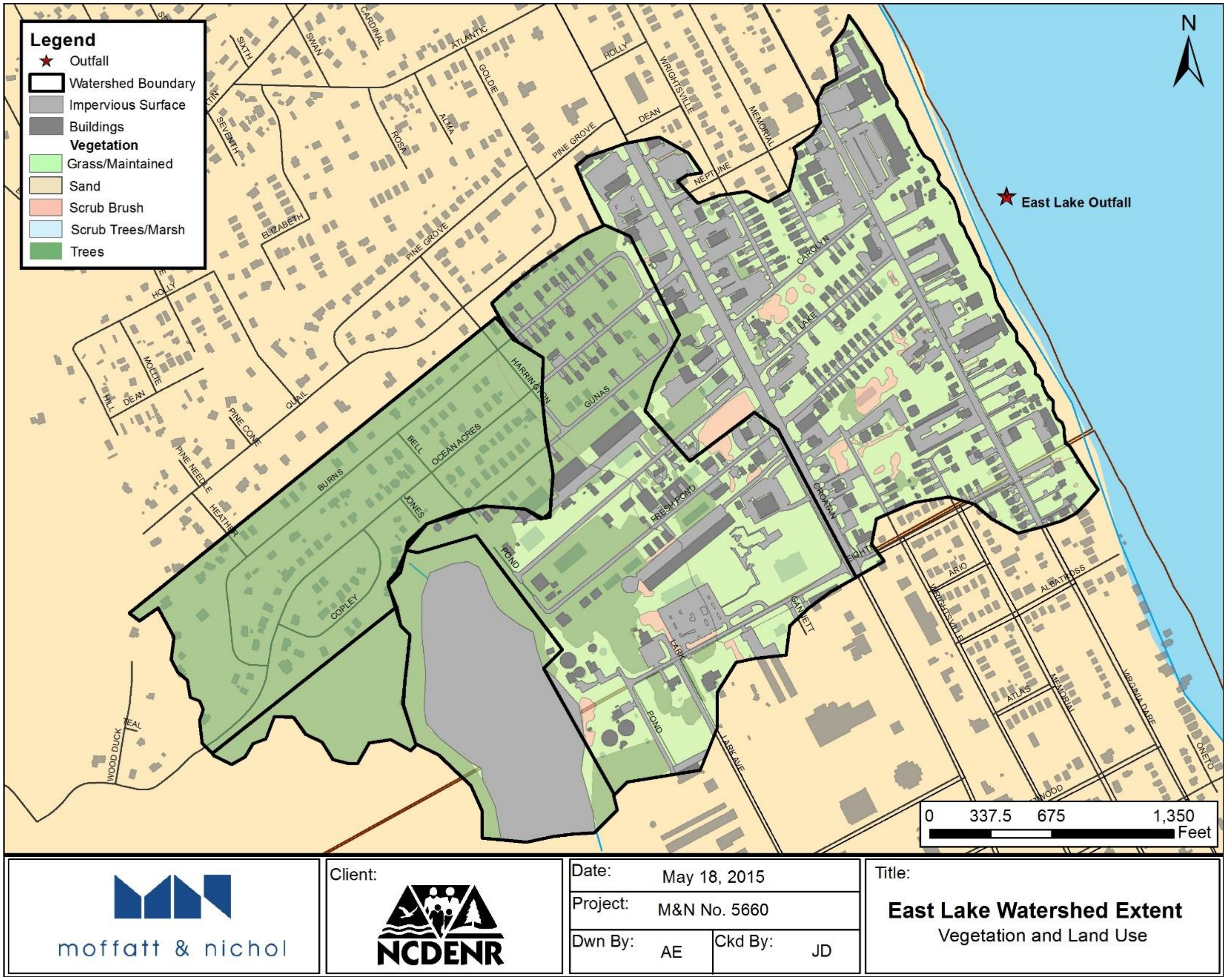


Figure 54. East Lake Drive Watershed Vegetation Map

3.3.2 Watershed Results

Flow and FIB levels were not monitored at the East Lake Drive outfall during the course of this study, because the outfall was also more frequently than not buried by sand and not flowing. It was never equipped with conduits for instrument cables and pump hoses for an automatic sampler like those used for the other outfalls. It should be noted that during storm events when the outlet was blocked at East Lake Drive, flow is diverted out through the Martin Street outfall, due to the storm drain connection between the two outfalls. This may be contributed to the high flows observed at the Martin Street outfall at certain times.

3.3.3 Watershed Strategies

The East Lake Drive watershed is right in the middle of the ocean outfall watersheds in terms of size (at 196 acres) and, by measure of imperious cover (over 48% imperviousness) is the most intensively developed of all of them. The high percentage of impervious surface is partly owing to the intensive commercial development along the Bypass in this watershed, and the area of commercial and industrial buildings to the west of the Bypass. The numbers of buildings and associated on-site septic systems yield a high septic system density in this medium sized watershed, but they may not be as important sources of FIB contamination as those associated with the intensive levels of single family home development in the neighboring watersheds.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- While no data are available to support this contention, with the high levels of imperviousness in the East Lake watershed, management that focuses on build-up, wash-off mechanisms for FIB pollution may be best suited in this watershed. For this reason, the East Lake watershed was chosen as the hypothetical test case for intensive retrofitting of small scale stormwater BMPs. The retrofit scenario, which was intended to capture and treat runoff from as much of the watershed as possible, is presented in detail in Section 4.1.1.
- Just as with the Baum and Martin Street watersheds, there are several large on-site septic systems that serve hotels in the East Lake watershed, and given that these systems tend to be located in the eastern portion of the watershed in near vicinity to the outfall, improvements in their operation and performance may generate tangible benefits.
- It should also be noted that the Baum Street, Martin Street, and East Lake Drive watersheds are all connected via storm drains and ditches. In conjunction with improved storm drainage asset inventories, a study deploying a sufficient number of flow gages for a period of time to understand how flow exchange between the three outfalls might yield useful results in terms of improving management of stormwater runoff quantities as well as FIB loads in the three watersheds. Of course such gages would have to be capable of measuring bi-directional flow.

3.4 Gallery Row "Carolinian" Watershed

The Gallery Row "Carolinian" watershed is comprised of an area approximately 488 acres. Land use in the area is mostly developed, with a mixture of residential, recreational, and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 55**.

3.4.1 Watershed Characterization

<u>Impervious</u>
The Gallery Row "Carolinian" watershed contain s approximately 155.7 acres of impervious surfaces, which is approximately 31.9% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, sidewalks and recreational surfaces such as pools and tennis courts. There are 857 buildings with 36 acres of building footprint, which is approximately 7% of the total watershed area. Buildings within the watershed area are primarily residential or commercial.

<u>Septic Density</u>
For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Gallery Row "Carolinian" watershed is 857, which equates to an estimated density of 1.76 systems per acre. A review of Dare County permits for septic system repairs and new installs within the Gallery Row "Carolinian" watershed from 2006-2012 is summarized in **Table 19** below. It is important to note that in several cases within this watershed, there are examples of repair permits issued in 2006 or 2007, and then a new permit issued later at the same parcel in 2010 or 2011.

Table 19. Gallery Row Septic Repair and Install Permits

Year	Total New System Permits	Total System Repair Permits
2006	13	14
2007	2	13
2008	3	14
2009	1	25
2010	0	24
2011	4	14
2012	0	0
Total:	**23**	**104**

<u>Soils</u>
A summary of soils within the Gallery Row "Carolinian" watershed is provided in **Table 20**. There are 481 acres of hydric soils within the watershed boundary and 7 acres of non-hydric soils within

the watershed. Generally, hydric soils are located along the shoreline, or closer to the sound and maritime forest area to the west. Developed areas are located over both non-hydric and hydric soils. In areas where hydric soils underlay dense development, interactions between groundwater and septic systems are likely high. See **Figure 56** for Gallery Row "Carolinian" watershed soils mapping.

Table 20. Gallery Row Watershed Soils Summary

Soil Type*	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Psamments, 0-6 percent slopes	No	7	1	Poorly drained; rapid permeability
Newhan-Corolla Complex, 0-10 percent slopes	Yes	28.7	6	Excessively drained; very slow runoff; rapid permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	28.6	6	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand	Yes	70.6	15	Excessively drained; very slow runoff; rapid permeability
Dune Land-Newhan Complex, 2-40 percent slopes	Yes	3.6	<1	Excessively drained; very slow runoff; rapid permeability
Dune Land	Yes	16	3	None provided
Fripp Fine Sand, 2-30 percent slopes	Yes	17	4	Excessively drained; very slow runoff; rapid permeability
Beaches-Newhan Complex, 0-25 percent slopes	Yes	11.5	2	Excessively drained; very slow runoff; rapid permeability
Osier Fine Sand, 0-2 percent slopes	Yes	1.7	<1	Poorly drained; rapid permeability
Corolla Fine Sands	Yes	209	43	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston-Corolla Complex	Yes	15.5	3	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston Fine Sands	Yes	27.7	6	Poorly drained; very slow runoff; very rapid permeability above the water table.
Ousley Fine Sand, 0-5 percent slopes	Yes	39.6	8	Somewhat poorly drained; rapid permeability

*There was approximately 5 acres of water included in the soils data.

<u>Vegetation</u>

The Gallery Row “Carolinian” watershed contains approximately 105 acres of trees, with most of it occurring in the western portion of the watershed. The remaining fragmented vegetated areas within the watershed are primarily grassed. Patterns of vegetation are mapped in **Figure 57**.

<u>Groundwater</u>

Three groundwater monitoring wells installed by Moffatt & Nichol in 2006 are located within the Gallery Row “Carolinian” watershed. B-14 is located at the shoreline end of Gallery Row at an elevation of 6 feet. Moffatt & Nichol scientists found that this well had groundwater levels within 0 to 3 feet of the surface for approximately 58% of the period of collection. B-13, located alongside NC 158 (Croatan Highway), at an elevation of 9 feet, had groundwater levels within 0 to 3 feet for approximately 90% of the total data samples collected. Groundwater well B-12 (elevation 12 feet) had recorded groundwater levels within 0 to 3 feet for approximately 10% of the data samples collected. As a point of reference, the controlling elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road, occurs at an elevations of 6-7 feet above sea level in the Gallery Row watershed. Collectively, the groundwater monitoring data from these wells shows that the Gallery Row watershed exhibits some off the highest potential for groundwater-septic system interaction of any watershed in this study. This is particularly troubling in light of the fact that the watershed has the second highest number of septic systems located within it.

<u>Drainage Systems and Infrastructure</u>

The Gallery Row “Carolinian” watershed contains approximately 12,618 feet of major open channel ditching and approximately 11,799 linear feet of piping. Drainage network spatial data and detailed contours of the Gallery Row “Carolinian” watershed indicate that there is approximately 183 acres of the watershed drained by piping and open channel ditches. This area represents approximately 38% of the total watershed area and occurs primarily in heavily developed areas within the watershed. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and commercial facilities where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. In areas without drainage infrastructure and where hydric soils are located below dense areas of residential development, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

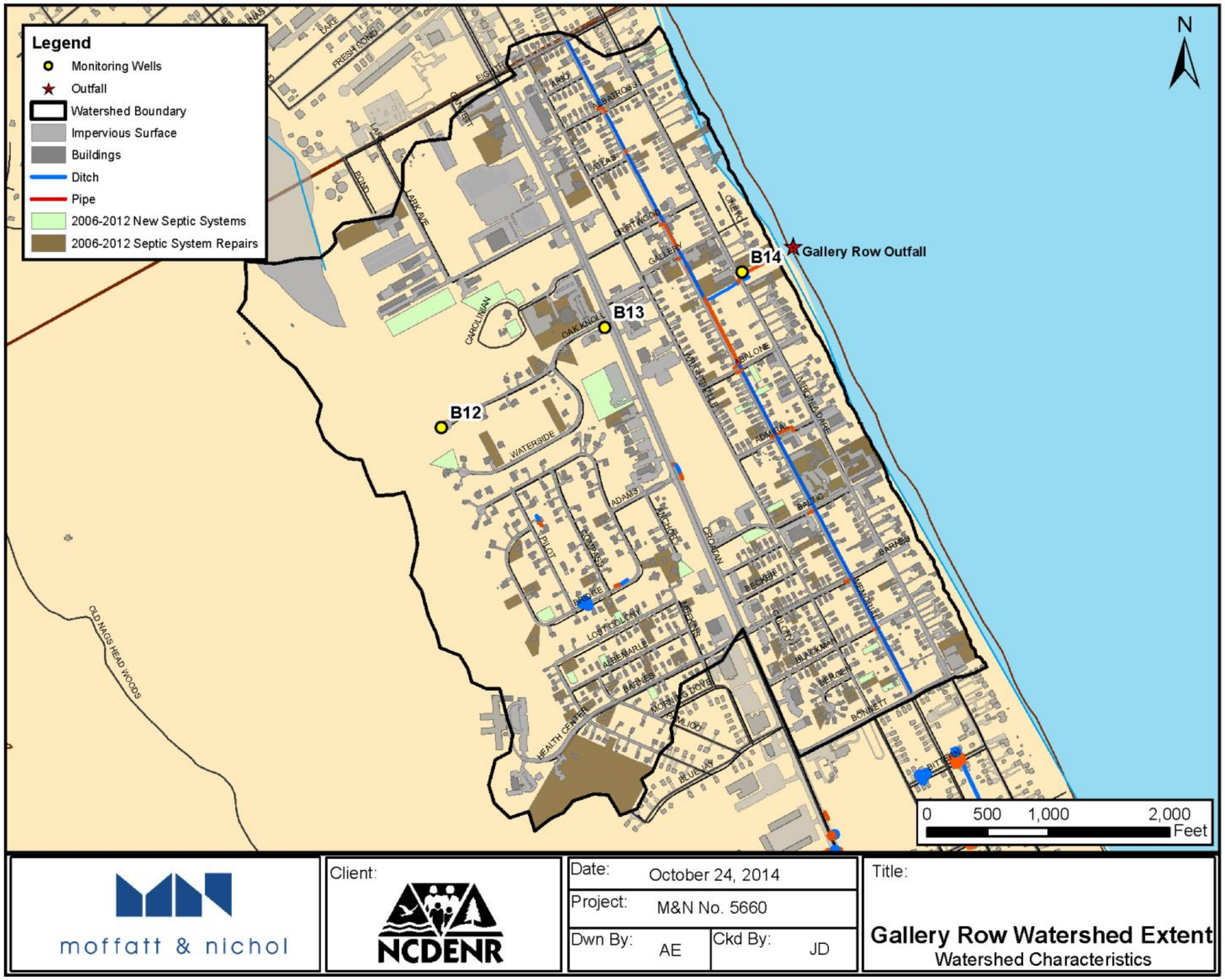


Figure 55. Gallery Row Watershed Extent Map

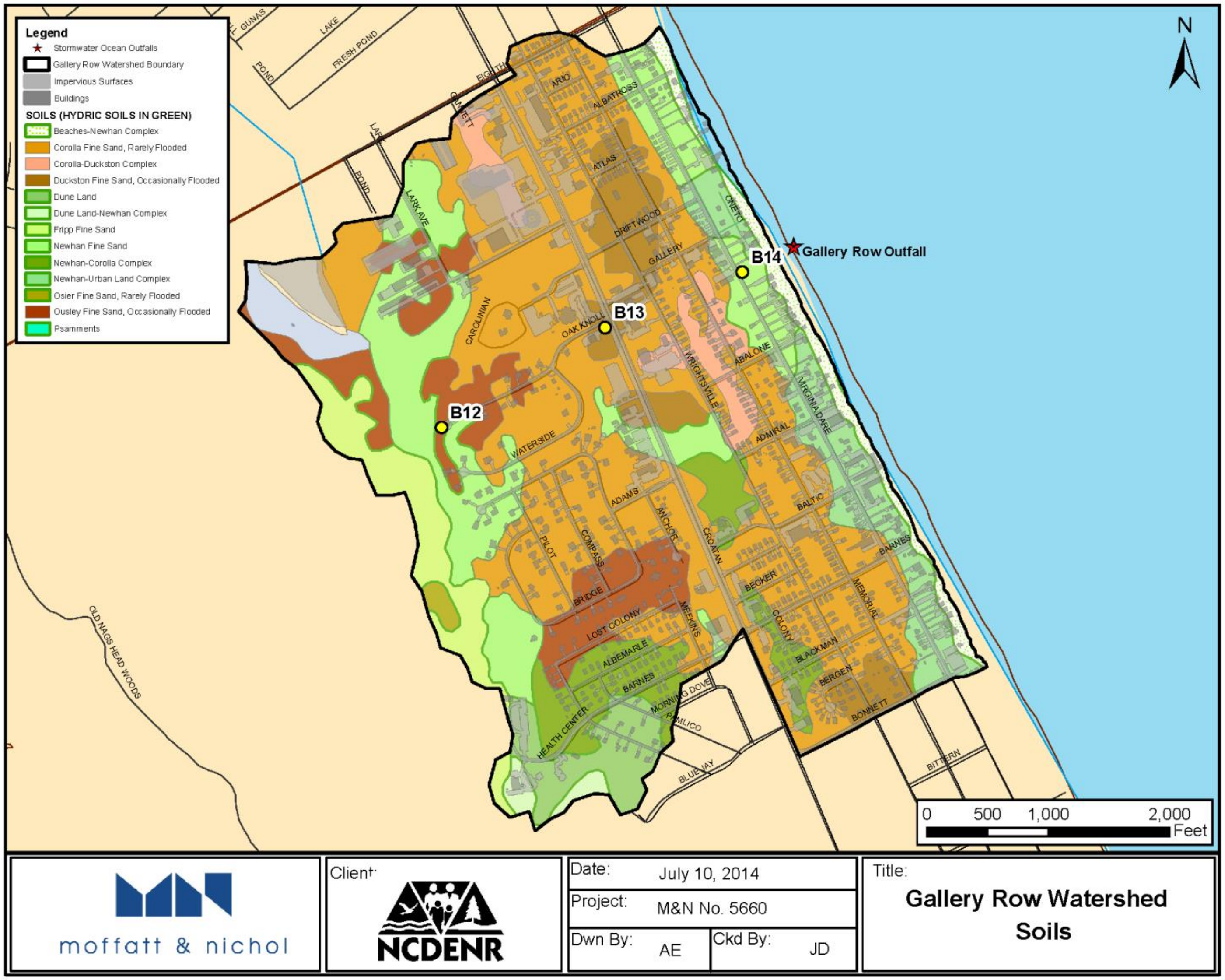


Figure 56. Gallery Row Watershed Soils Map

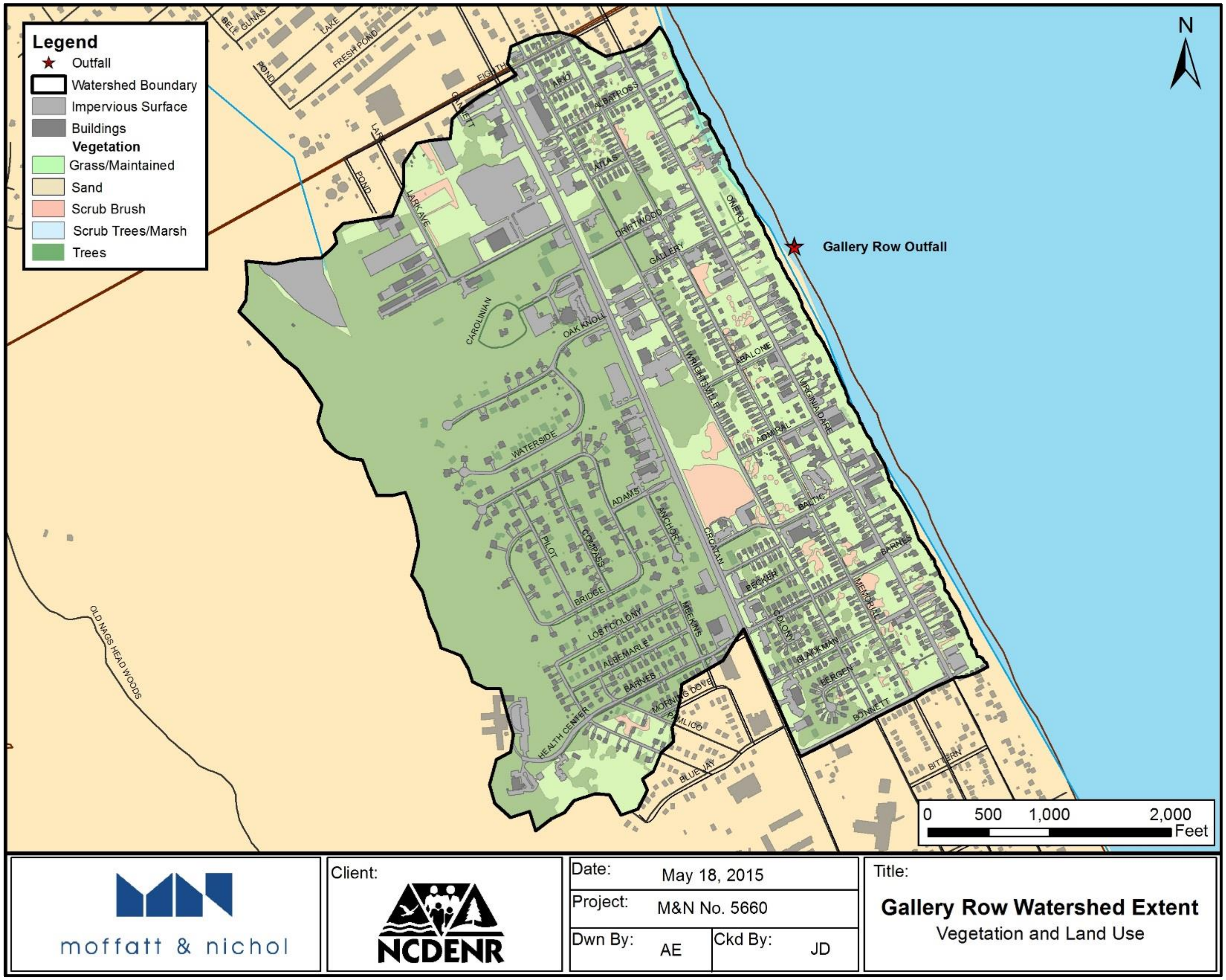


Figure 57. Gallery Row Watershed Vegetation Map

3.4.2 Watershed Results

Gallery Row "Carolinian" watershed is characterized by 488 acres of which 31.9% is impervious. Septic density is 1.76 per acre. There is a total open channel length of 5,716 feet with a total length of drainage piping at 1,889 feet. Over the course of this project Gallery Row was monitored during four large storm events that occurred from the summer 2007 through the fall 2008. It is interesting to note that a main factor driving the patterns of FIB and Fecal Bacteroides spp. in the Gallery Row system appears to be high groundwater levels, especially late in the period of major, long storm events. This finding was confirmed by a continuing trend of high fecal Bacteroides spp. concentrations observed in this system late in storms. FIB sampling results for each of the storms monitored are discussed below, and the results from each storm are presented graphically in Appendix D. The storm summaries are presented in **Table 21**.

<u>June 3-4, 2007</u>

For the storm that occurred June 3-4, 2007, there was a total of 1.19 in. of rainfall. There were four grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 888 – 24,196 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 323 – 5,475 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 10,896 – 12,065 CE 100 ml^{-1} over the course of the storm. This hydrograph could be classified as flashy as there were several distinct peaks, however base flow fluctuated greatly which could be an indication of tidal fluctuation into the outfall pipe. Maximum values recorded for *Enterococcus* and Fecal *Bacteroides* spp. were recorded prior to first rainfall event with the 2^{nd} grab sample. The maximum *E. coli* concentrations occurred between the two discharge peaks in the hydrograph (June 4, 2007 10:15). The *Enterococcus* values were uncharacteristically higher than the Fecal *Bacteroides* spp. values, which varied little throughout duration of storm. *Enterococcus* and *E. coli* values tracked each other for this event.

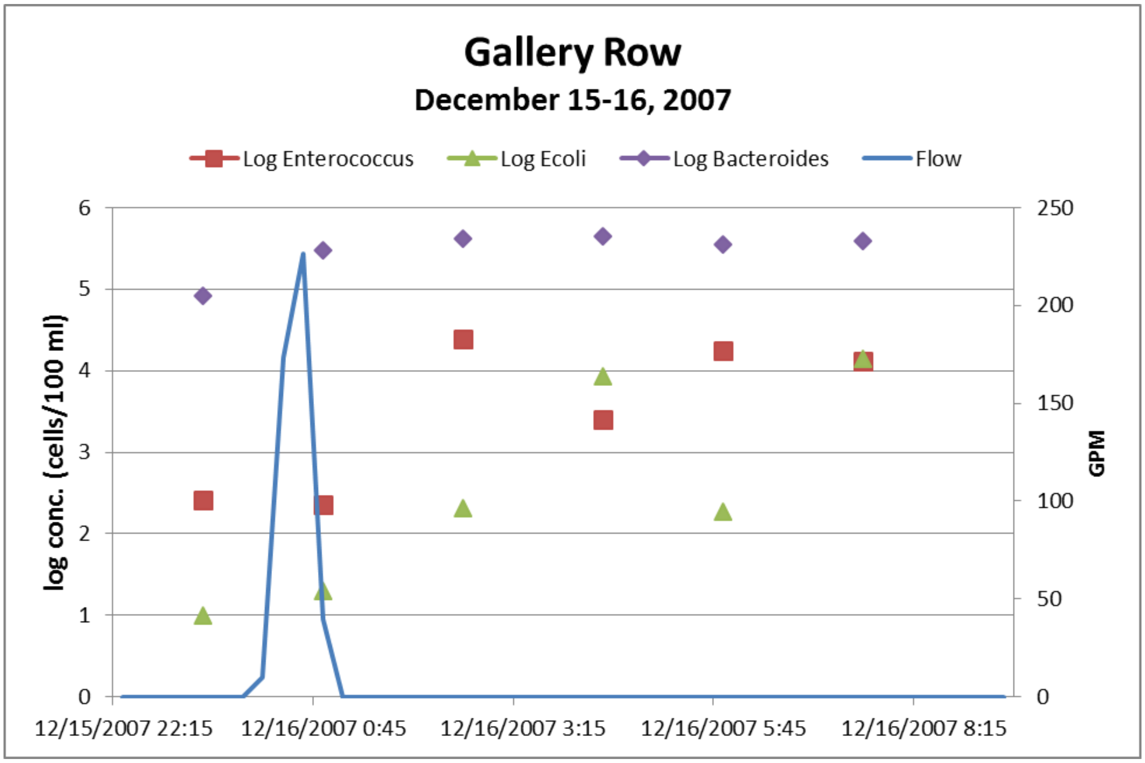
Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 1,243 gpm (2.77 cfs). Two distinct pulses were recorded on the storm discharge hydrograph. Base flow quickly returned several hours after 2^{nd} peak of discharge. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 5.06×10^{10}, 1.48×10^{10}, and 6.67×10^{8} MPN or CE respectively, which equates to loads of 1.91×10^{9}, 5.57×10^{8}, and 2.52×10^{7} MPN or CE per h based upon examined storm length of 26.5 hours. Base flow measurements were highly variable during this storm suggesting a possible intrusion of salt water or other water source other than that due to storm flow. However, with many storm recorded during the 2006-2008 monitoring period, this event was characterized by high discharge concentrations, but very low hydraulic flow rates, so the FIB load rates were driven far more by concentration than flow.

<u>December 15-16, 2007</u>

For the storm that occurred December 15-16, 2007, there was a total of 2.48 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 226 -24,196 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 10 – 14,136 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. values ranged from 82,106 – 441,060 CE 100 ml^{-1} over the course of the storm (**Figure 58**). This high level of fecal Bacteroides (>400,000 CE per 100 ml), All maximum concentrations recorded for *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. occurred after the hydrograph had returned to base flow. This was a classic flashy hydrograph characterized by a steep rising and falling and a quick return to base flow.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 227 gpm (0.51 cfs). The tail of the hydrograph quickly decreased and a baseline of 0 gpm occurred within 30 minutes after the peak discharge The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 5.98 x 10^7, 4.54 x 10^6, and 6.49 x 10^{10} MPN or CE respectively, which equates to loads of 3.99 x 10^7, 3.03 x 10^6 and 4.33 x 10^{10} MPN or CE per h based upon examined storm length of 1.5 hours. The magnitude of the storm was not great enough to cause a significant flux in the microbial measurements.

As indicated in the groundwater information for this watershed, there is an important dynamic between groundwater and fecal contamination in this system during storms. During the December 2007 storm, it can be observed from Figure 43 that during periods of groundwater increase after heavy rainfall (i.e. pulse of > 2 inches in December 2007), the *E. coli* and *Enterococcus* sp. concentrations increase to greater than 10,000 MPN per 100 ml. This also coincides with very high concentrations of Fecal *Bacteroides* sp. After the peak rainfall period, the Fecal *Bacteroides* sp. concentrations in the remaining four time points were all greater than 100,000 CE per 100 ml. These extremely high concentrations of both FIB and human associated molecular marker indicate the potential in this system for groundwater-septic system connections to be driving the delivery of fecal contamination to beaches.



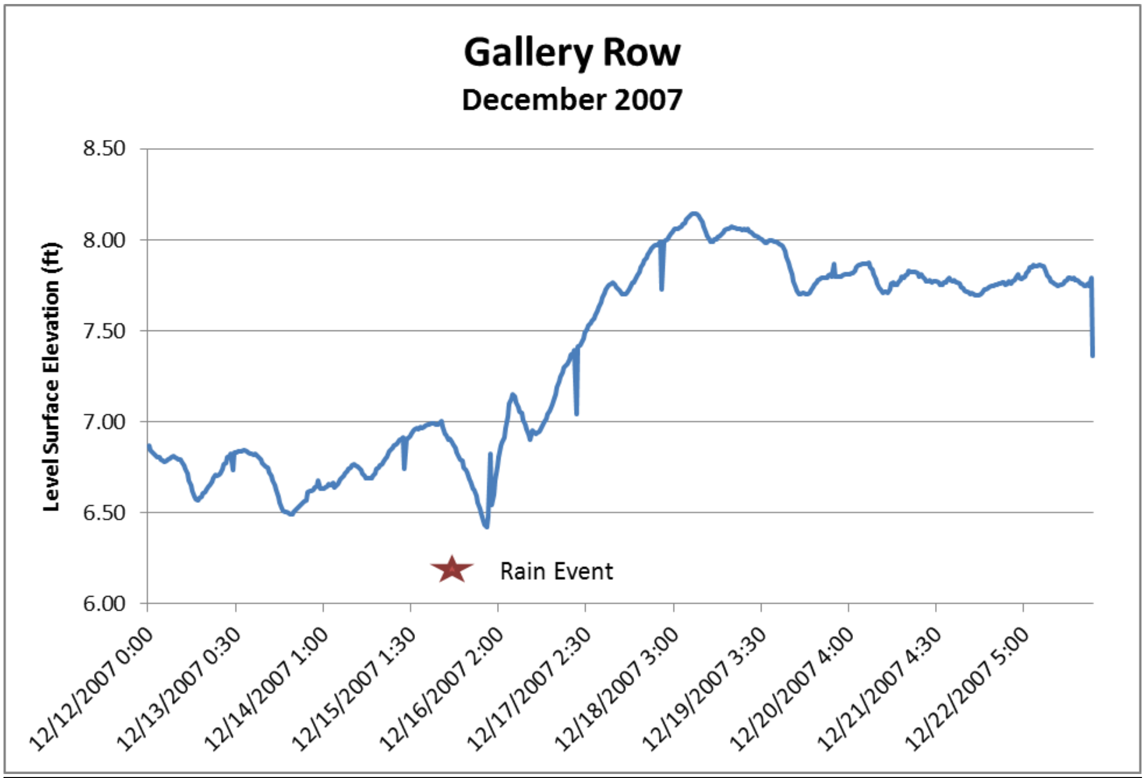


Figure 58. Gallery Row FIB Concentrations and Groundwater Surface Elevations for December 2007

<u>April 20-23, 2008</u>

For the storm that occurred April 20-23, 2008, there was a total of 2.72 in. of rainfall. There were five grab samples collected for microbial contaminant measurements the course of the storm. *Enterococcus* concentrations ranged from 160 – 1,968 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 318 – 1,076 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. values ranged from 77,072 – 255,098 CE 100 ml^{-1} over the course of the storm. The hydrograph is characterized by four distinct and sharp peaks with rapidly rising and receding limbs followed by quick return to near base flow. The Fecal *Bacteroides* spp. values increased slightly over course of the storm while *Enterococcus* and *E. coli* generally followed a trend of decreasing concentrations with *E. coli* peaking during the last grab sample. The maximum values recorded for *Enterococcus* occurred prior to rainfall. The maximum *E. coli* and Fecal *Bacteroides* spp. values occurred as the discharge was returning to base flow.

Baseline flow measured of 0 gpm and peak measurements were 1,810 gpm (4.03 cfs). The storm hydrograph had several peaks and the tail of hydrograph still exhibited elevated flow over 400 gpm (0.90 cfs) a day and a half after final discharge peak. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 2.69 x 10^{10}, 2.20 x 10^{10}, and 4.50 x 10^{12} MPN or CE respectively, which equates to loads of 5.79 x 10^{8}, 4.72 x 10^{8} and 9.68 x 10^{10} MPN or CE per h based upon examined storm length of 46.5 hours. Just as with the December 2007 storm event, this event was characterized by high discharge concentrations, but relatively low hydraulic flow rates.

<u>November 4-7, 2008</u>

For the storm that occurred November 4-7, 2008, there was a total of 2.98 in of rainfall. There were seven grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 364 – 7,270 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 228 – 6,867 MPN 100 $ml^{-1}$and Fecal *Bacteroides* spp. values ranged from 82,028 – 208,946 CE 100 ml^{-1} over the course of the storm. Maximum values recorded for *E. coli* and Fecal *Bacteroides* spp. occurred on the rising limb of the hydrograph. Maximum *Enterococcus* concentration occurred on falling limb of first peak in hydrograph. Fecal *Bacteroides* spp. concentrations were a magnitude higher than either *Enterococcus* or *E. coli* and remained high and constant throughout the storm, while the *Enterococcus* and *E. coli* peaked during the second peak of the hydrograph and then fell as the storm subsided in strength.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 8,150 gpm (18.16 cfs), the tail of the hydrograph continued at high rate of flow >3,800 gpm (>8.5 cfs) after the end of storm. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 9.79 x 10^{11}, 2.21 x 10^{11}, and 4.43 x 10^{13} MPN or CE respectively, which equates to loads of 1.74 x 10^{10}, 3.92 x 10^{9}, and 7.87 x 10^{11} MPN or CE per h based upon examined storm length of 56.25 hours.

Table 21. Gallery Row Summary Statistics

Storm Date	# of Grab Samples	E. Coli Mean (cells/100ml)	E. Coli Range (cells/100ml)	Enterococcus Mean (cells/100ml)	Enterococcus Range (cells/100ml)	Bacteroides Mean (cells/100ml)	Bacteroides Range (cells/100ml)	Total Enterococcus Load cells	Total E. Coli Load cells	Total Bacteroides Load cells	Enterococcus Load per hour	E. Coli Load per hour	Bacteroides Load per hour
6/3-4/2007	4	3,506	323-5,475	15,825	888-24,196	11,376	10,896-12,065	$5.06 X 10^{10}$	$1.48 X 10^{10}$	$6.67 X 10^{8}$	$1.91 X 10^{9}$	$5.57 X 10^{8}$	$2.52 X 10^{7}$
12/15-16/2007	6	3,870	10-14,136	9,586	226-24,196	330,515	82,106-441,060	$5.98 X 10^{7}$	$4.54 X 10^{6}$	$6.49 X 10^{10}$	$3.99 X 10^{7}$	$3.03 X 10^{6}$	$4.33 X 10^{10}$
4/20-23/2008	5	665	318-1,076	986	160-1,968	137,631	77,072-255,098	$2.69 X 10^{10}$	$2.20 X 10^{10}$	$4.50 X 10^{12}$	$5.79 X 10^{8}$	$4.72 X 10^{8}$	$9.68 X 10^{10}$
11/4-7/2008	7	1,464	228-6,867	2,582	364-7,270	121,384	82,028-208,946	$9.79 X 10^{11}$	$2.21 X 10^{11}$	$4.43 X 10^{13}$	$1.74 X 10^{10}$	$3.92 X 10^{9}$	$7.87 X 10^{11}$

3.4.3 Watershed Strategies

The Gallery Row watershed is the largest (at 488 acres) of the ocean outfall watersheds and is also one of the most heavily developed (32% imperviousness). In terms of the metric examined for these watershed characterizations Gallery Row has one of the three highest total lengths of open engineered drainage network (channel and piped combined). This metric becomes more impressive when you take into account that most of the drainage network within the watershed remains unmapped and/or poorly characterized. The Gallery Row watershed has the second highest number of buildings (857), and associated septic systems (second only to Martin Street). It should be noted that the dominant type of development in the Gallery Row watershed is single family dwellings, and due to the topology of the watershed, where by the watershed does not reach as far west on the barrier island as some of the others, that dense residential development tends to be squeezed to areas much closer to the actual outfall location. Groundwater data analysis presented in Section 2.2 shows that groundwater surface elevations spend a considerable amount of time within the upper portions of the soil column where interaction with septic system drain fields would occur, increasing the potential for delivery of human-derived FIB to the ocean outfall. One of the groundwater monitoring wells in the eastern portion of the Gallery Row watershed (B-13) yielded the second highest incidence of groundwater levels, dwelling 89.6% of the time in the top 1-3 feet of the soil profile, where interaction with on-site septic systems and their drain fields is most likely (refer to **Table 6**). This potential interaction results in the same pattern exhibited by data from Baum and Martin Streets where the high Fecal *Bacteroides* spp. levels, which are potentially indicative of human sources, tend to remain very high, or even increase, late in the hydrographic response for each storm, despite the fact that the other FIB species tend to decline in concentration with the falling limb of the hydrograph.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- Gallery Row has the highest building/septic tank count and is dominated by single family residential structures, translating into high numbers of small on-site septic systems. The distributed nature of these systems as sources and their geographic distribution in the eastern portion of the watershed where groundwater interaction and drainage connectivity facilitate FIB loading point to the need for more intensive management of the performance and maintenance of on-site systems in this watershed. Indeed the Town of Nags Head already has the Septic Health Initiative and a Decentralized Wastewater Master Plan, and this program represents an excellent foundation on which to continue aggressively pursuing improved tracking and performance of on-site systems. It should be noted that Gallery Row had, by far, the highest number of reported septic system repairs (104) of any ocean outfall watershed. This could be driven by Nags Head's diligent efforts to inspect and monitor on-site systems and/or the fact that most of the development in the watershed is located at lower elevations where soils are more often saturated and challenging to on-site systems. Both factors likely play a role.
- There are several large on-site septic systems that serve hotels and commercial facilities in the watershed, and given that these systems tend to be located in the eastern portion of the

watershed in near vicinity to the outfall, improvements in their operation and performance may generate tangible benefits.

- The Gallery Row watershed is one of the few ocean outfall watersheds where a sufficient amount of undeveloped land, could be identified in which to site a large, regional-scale BMPs in a few locations. However, so little is known about the collective drainage network in the watershed that it is difficult to evaluate the hydrologic position of the available spaces. A thorough and accurate inventory of the Gallery Row drainage network would be essential to establishing viable stormwater BMP retrofit locations.
- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 are effective in reducing bacterial pollution loads, the possibility of implementing such a system in the Gallery Row watershed is aided by the presence of town-owned land immediately west of the watershed where the drawdown hydraulic volumes could be discharged. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIB are extremely high whereas flow rates are relatively low, making it amenable to deployment of pump systems that are capable of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.

3.5 Curlew Street Watershed

The Curlew Street watershed is comprised of an area approximately 161 acres. Land use in the area is mostly developed, with a mixture of residential, recreational, and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 59**.

3.5.1 Watershed Characterization

Impervious

The Curlew Street watershed contains approximately 34.3 acres of impervious surfaces, which is approximately 21.3% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, sidewalks and recreational surfaces such as pools and tennis courts. There are 345 buildings with 11 acres of building footprint, which is approximately 7% of the total watershed area. Buildings within the watershed area are primarily residential or commercial.

Septic Density

For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Curlew Street watershed is 345, which equates to an estimated density of 2.14 systems per acre. A review of Dare County permits for septic system repairs and new installs within the Curlew Street watershed from 2006-2012 is summarized in **Table 22** below.

Table 22. Curlew Street Septic Repair and Install Permits

Year	Total New System Permits	Total System Repair Permits
2006	12	3
2007	2	6
2008	5	2
2009	5	8
2010	0	9
2011	3	7
2012	0	0
Total:	**27**	**35**

Soils

A summary of soils within the Curlew Street watershed is provided in **Table 23**. There are 52 acres of hydric soils within the watershed boundary and 109 acres of non-hydric soils within the watershed. Generally, hydric soils are located along the shoreline. Developed areas are located over both non-hydric and hydric soils. In areas where hydric soils underlay dense development, interactions between groundwater and septic systems are likely high. See **Figure 60** for Curlew Street watershed soils.

Table 23. Curlew Street Watershed Soils Summary

Soil Type	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	45.3	28	Excessively drained; very slow runoff; rapid permeability
Beaches-Newhan Complex, 0-25 percent slopes	Yes	6.7	4	Excessively drained; very slow runoff; rapid permeability
Corolla Fine Sands	Yes	88.7	55	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston Fine Sands	Yes	20.4	13	Poorly drained; very slow runoff; very rapid permeability above the water table.

Vegetation

The Curlew Street watershed contains approximately 32 fragmented acres of trees, with most of it occurring in the western portion of the watershed. Some areas previously identified as scrub brush vegetation have been converted to impervious surfaces or are now vegetated with trees. The remaining fragmented vegetated areas within the watershed are primarily grassed. Patterns of vegetation are mapped in **Figure 61**.

Groundwater

Groundwater monitoring well B-9 installed by Moffatt & Nichol in 2006 is located within the Curlew Street watershed at the shoreline end of Curlew Street. Moffatt & Nichol scientists found that this well had no groundwater levels within 0 to 3 feet of the surface for the period of collection. It should be noted that B-9 is located on the western slope of the primary dune, at an elevation of 17 feet above sea level, so that fact that it has no incidence of groundwater within 0-3 feet of the surface does not reflect the potential for such occurrence throughout the watershed. As a point of reference, the controlling elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road, occurs at an elevations of 6-7 feet above sea level in the Curlew watershed. Further analysis of the data showed that groundwater levels at B-9 remained at elevations above 3 feet in elevation approximately 25% of the time, indicating some potential for groundwater interaction with septic systems in this watershed. It should be noted that Well B-10 showed a 76% incidence of groundwater levels in the top 0-3 feet of the soil profile, and while it is located just over the line into the Conch Street watershed, it is indicative of the potential for groundwater-septic system interaction in this watershed.

Drainage Systems and Infrastructure

The Curlew Street watershed contains approximately 6,413 feet of major open channel ditching and approximately 3,063 linear feet of piping. Drainage network spatial data and detailed contours of the Curlew Street watershed indicate that there is approximately 96 acres of the watershed drained by piping and open channel ditches. This area represents approximately 60% of the total watershed area. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and commercial facilities where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. In areas without drainage infrastructure and where hydric soils are located below dense areas of residential development, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

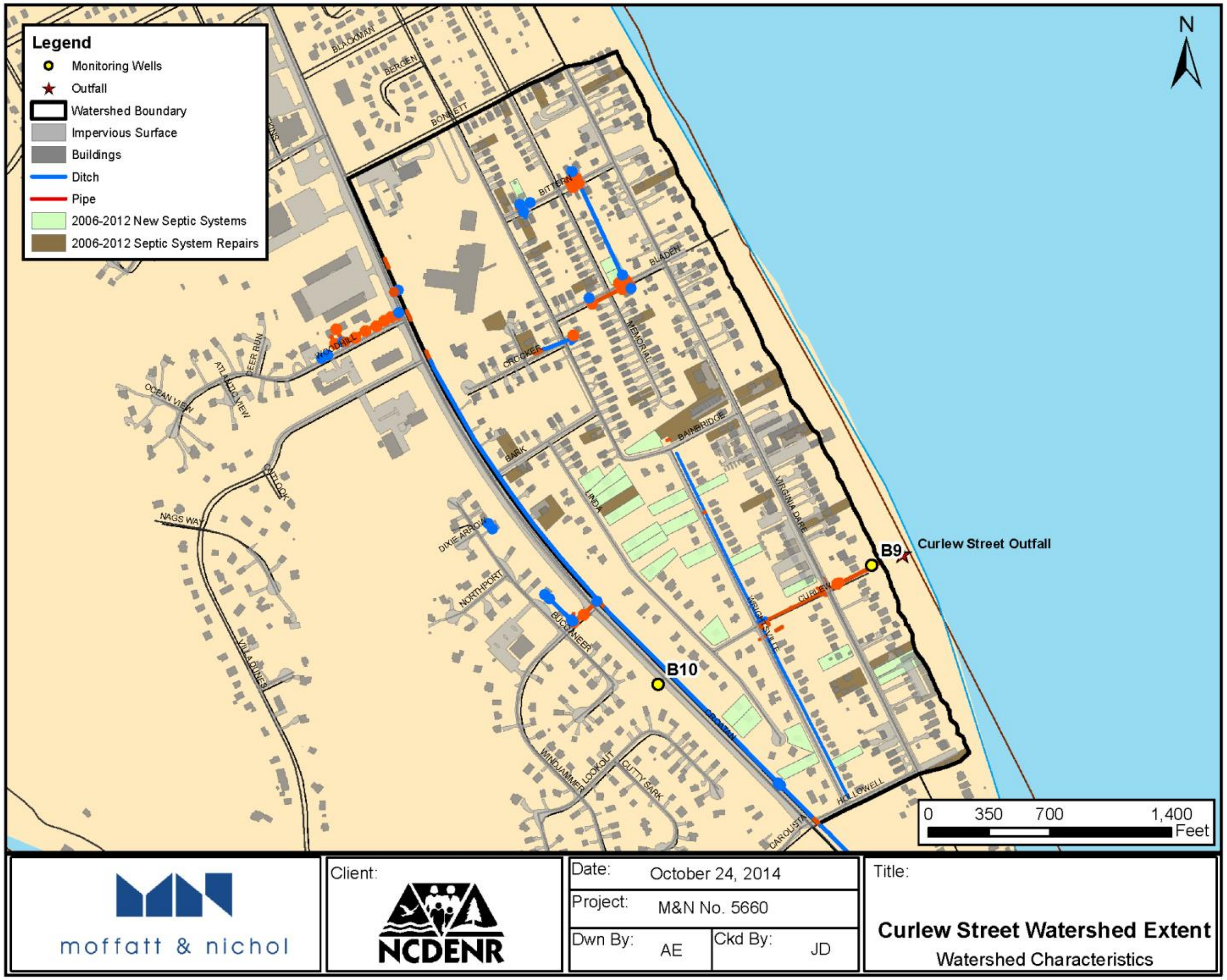


Figure 59. Curlew Street Watershed Extent Map

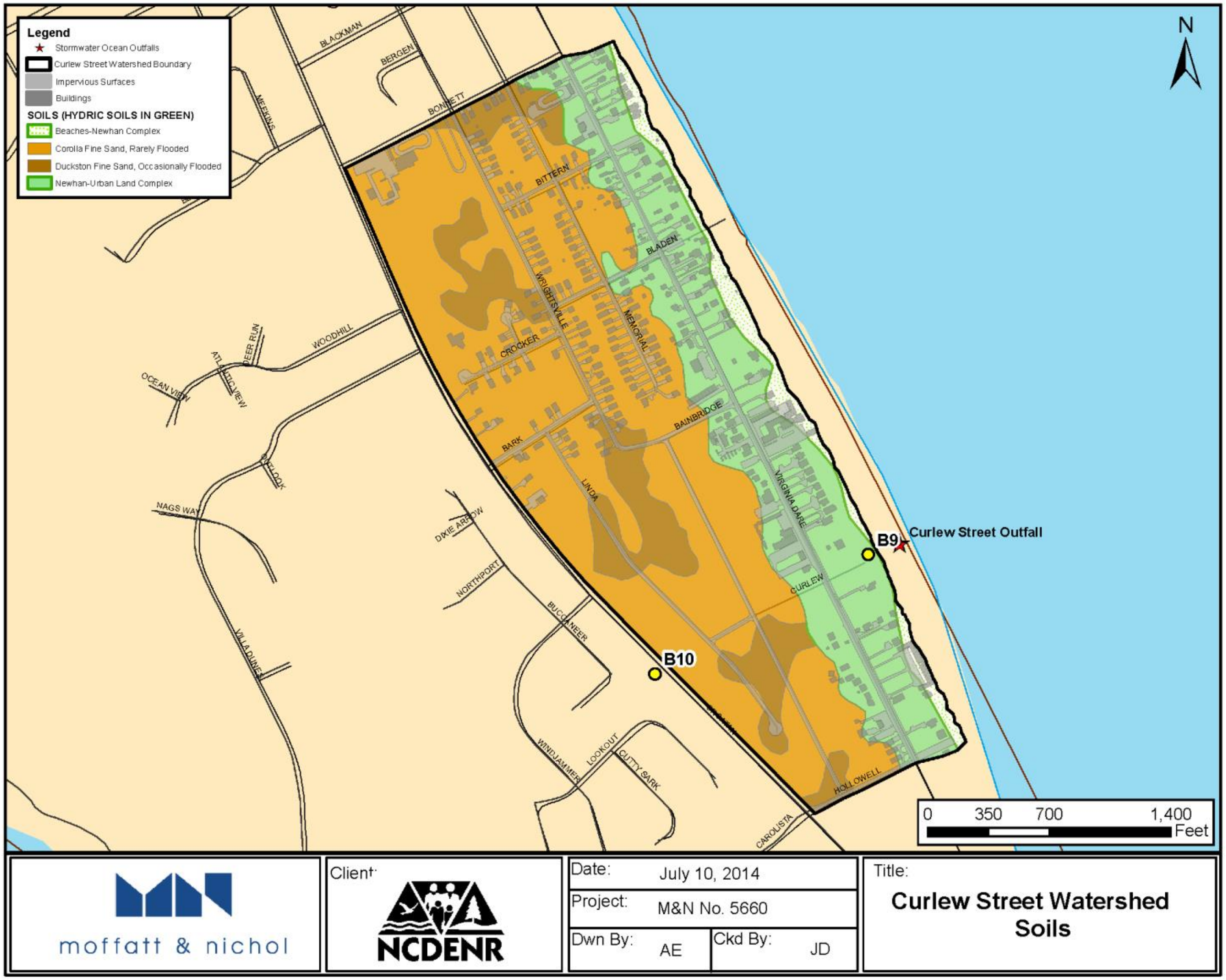


Figure 60. Curlew Street Watershed Soils Map

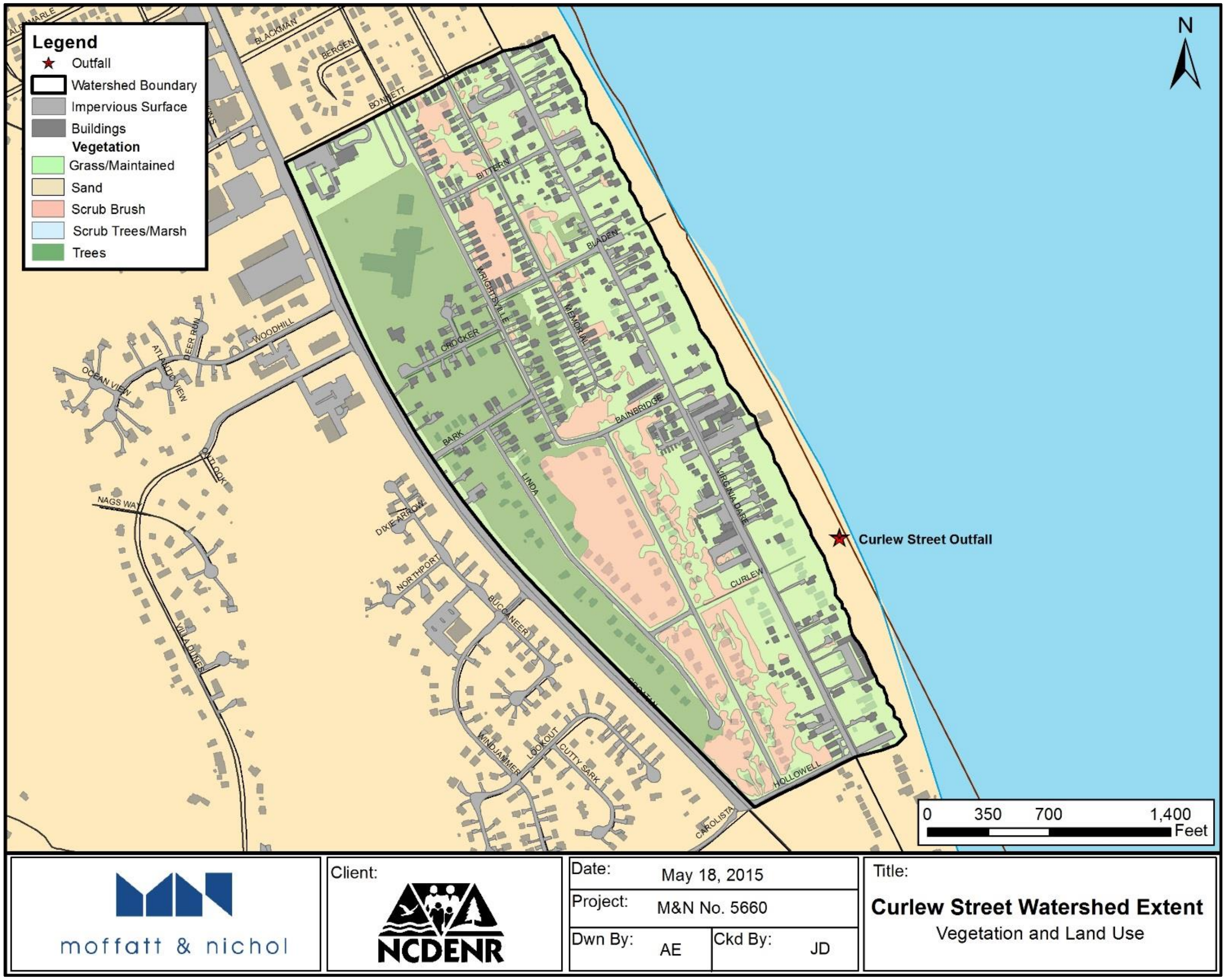


Figure 61. Curlew Street Watershed Vegetation Map

3.5.2 Watershed Results

Curlew Street watershed is characterized by 161 acres of which 21.3% is impervious. The density of septic systems is 1.34 per acre. There is a total open channel length of 2,163 feet with a total length of drainage piping at 1,594 feet. Over the course of this project Curlew Street was monitored during three large storm events that occurred from the summer 2007 through the spring 2008 and upstream/downstream during three storm events that occurred July – September 2014. FIB sampling results for each of the storms monitored are discussed below, and the results from each storm are presented graphically in Appendix D. The storm summaries are presented in **Table 24**.

<u>June 3-4, 2007</u>
For the storm that occurred June 3-4, 2007, there was a total of 1.19 in of rainfall. There were three grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 9,804 – 24,196 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 2,382 – 24,196 MPN 100 ml^{-1}. Fecal *Bacteroides* spp. concentrations were not evaluated for this storm for this site. The hydrograph for this storm is characterized by an initial steep peak followed by elevated flow with a few dips below baseline flow levels indicating possible fluxes with seawater intrusion. Maximum values recorded for *Enterococcus* and *E. coli* occurred during the falling limb of the hydrograph's first storm pulse and decreased in concentration throughout the duration of the storm.

Baseline flow was measured of 0 gpm and peaked at 2,323 gpm (5.18 cfs). The hydrograph peaked quickly, and then appeared to be affected by tidal flow (negative flow rates recorded). The total *Enterococcus* and *E. coli* loads for this storm were 1.11 x 10^{12} and 1.93 x 10^{10} MPN or CE, which equates to loads of 2.60 x 10^{10} and 4.52 x 10^{8} MPN or CE per h based upon examined storm length of 42.75 hours.

<u>December 15-16, 2007</u>
For the storm that occurred December 15-16, 2007, there was a total of 2.48 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 206 – 24,196 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 250 – 6,867 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. values ranged from 12,921 – 113,443 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus* and Fecal *Bacteroides* spp. occurred before storm event. The maximum value for *E. coli* occurred on the rising limb of the hydrograph.

Baseline flow measured of 0 gpm and peaked at 913 gpm (2.03 cfs). The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 2.99 x 10^{9}, 2.52 x 10^{10}, and 2.65 x 10^{11} MPN or CE respectively, which equates to loads of 4.43 x 10^{8}, 3.73 x 10^{9}, and 3.92 x 10^{10} MPN or CE per h based upon examined storm length of 6.75 hours. Similar to the data recorded at other outfalls for this event, the Curlew Street outfall data was characterized by high discharge concentrations, but very low hydraulic flow rates, so the FIB load rates were driven far more by concentration than flow.

<u>April 20-23, 2008</u>

For the storm that occurred April 20-23, 2008, there was a total of 2.72 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm event. *Enterococcus* concentrations ranged from 749 – 7,270 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 581 – 9,804 MPN 100 $ml^{-1}$and Fecal *Bacteroides* spp. values ranged from 24,940 – 49,550 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. occurred during rising limb of hydrograph. The hydrograph was missing data due to malfunction of equipment and therefore loading totals and rates were not calculated for this storm event.

Table 24. Curlew Summary Statistics

Storm Date	# of Grab Samples	E. Coli Mean (cells/100ml)	E. Coli Range (cells/100ml)	Enterococcus Mean (cells/100ml)	Enterococcus Range (cells/100ml)	Bacteroides Mean (cells/100ml)	Bacteroides Range (cells/100ml)	Total Enterococcus Load cells	Total E. Coli Load cells	Total Bacteroides Load cells	Enterococcus Load per hour	E. Coli Load per hour	Bacteroides Load per hour
6/3-4/2007	3	13,571	2,382-24,196	19,399	9,804-24,196	-	-	1.11×10^{12}	1.93×10^{10}	-	2.60×10^{10}	4.52×10^{8}	-
12/15-16/2007	6	2,996	250-6,867	4,329	206-24,196	47,475	12,921-113,443	2.99×10^{9}	2.52×10^{10}	2.65×10^{11}	4.43×10^{8}	3.73×10^{9}	3.92×10^{10}
4/20-23/2008	6	3,407	581-9,804	2,405	749-7,270	39,798	24,940-49,550	-	-	-	-	-	-
7/16/2014	2	1,592	200-12,590	7,009	50-86,640	-	-	-	-	-	-	-	-
8/3-4/2014	3	328	100-1,790	793	50-11,895	-	-	-	-	-	-	-	-
9/8/2014	3	5,048	465-48,840	9,248	50-94,500	-	-	-	-	-	-	-	-

3.5.3 Watershed Strategies

The Curlew Street watershed is one of the smallest four (at 161 acres) of the ocean outfall watersheds. Given this fact, the high concentrations of *E. coli* and *Enterococcus* in the outfall discharge, measured over multiple storms, were unexpected. In the six storms studied at this outfall, five of the storms indicated maximum *Enterococcus* spp. concentrations over 12,000 MPN per 100 ml, with four of the storms having maximum concentrations in exceedance of 24,000 MPN per 100 ml, with a maximum (worst-case) measured concentration of 90,000 MPN per 100 ml. For reference, using similar methods, the concentration of *Enterococcus* spp. in a recent study of untreated sewage influent in the Hampton Roads region ranged from 100,000-1,000,000 MPN per 100 ml. The western edge of the watershed runs along the Bypass, which forms a drainage boundary between the Curlew and Conch Street watersheds. All of the land area south of gallery Row and west of the Bypass drains down the ditch along the west side of the Bypass to the Conch Street Outfall. As a result, the entirety of the Curlew Street watershed is confined to the space between the Bypass and the ocean. Just as with Gallery Row, most of the drainage network within the watershed remains unmapped. The landuse in the watershed is almost entirely medium density single-family dwellings. For its small size, the Curlew Street watershed has a relatively high number of buildings (345), and associated septic systems, resulting in a septic tank density of more than two per acre, putting it on the higher side of the ocean outfalls in terms of this metric. Groundwater data analysis presented in Section 2.2 shows that groundwater surface elevations spend a lesser amount of time within the upper portions of the soil column relative to most ocean outfalls. One of the groundwater monitoring wells on the border of the Curlew Street and Conch Street watersheds (B-10) exhibited a high incidence of groundwater levels, dwelling 76% of the time in the top 0-3 feet of the soil profile (refer to Table 5), and that well is located near the topographic trough that is controlling elevation for storm drainage in the Curlew watershed. As a result, it is expected that groundwater interaction with septic systems is still important in this watershed, especially when it is taken into account that septic system density is greater than 2 systems/acre. While only limited storm event data for FIB were collected in this watershed (2 full storms and 1 partial), the limited data still shows an elevated signal from Fecal *Bacteroides* spp. later in storm events whereas the levels of other indicator bacteria track more closely with the hydrograph, indicating that septic systems likely play a role in the FIB loads form this watershed.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- The Curlew Street watershed has the relatively high count of septic systems for a smaller watershed because the land-use is dominated by single family residential structures. FIB monitoring results have indicated the presence of human fecal contamination markers in the discharge from this outfall, so continued diligent efforts to improve septic system maintenance and performance on the part of the Town of Nags Head’s Septic Health Initiative would benefit this watershed. Given its high density of swimmers during summer months, further characterization and assessment of the potential human fecal contamination sources will be an important step for the future in this system.

- There are a few large on-site septic systems that serve a public school campus and a hotel in the watershed, and given that these systems are located in near vicinity to the outfall, improvements in their operation and performance may generate tangible benefits.
- Opportunities to address the build-up/wash-off mechanisms of delivery of bacterial pollutants should also be an area of focus. Much of the development in the Curlew Street watershed has occurred recently (in the last 10 years) and several lots throughout the watershed remain undeveloped. If land acquisition could be achieved, some of these lots would be suitable for retrofitting of diffuse landscape-integrated BMPs such as the high – rate infiltration sand filters discussed in section 4.1 or other such BMPs typically associated with low impact development, such as bio-retention cells. However, as with Gallery Row, little is known about the collective drainage network in the Curlew Street watershed, so it would be difficult to evaluate the hydrologic position and suitability of these available spaces. A thorough and accurate inventory of the Curlew Street drainage network would be essential to establishing viable stormwater BMP retrofit locations. The inventory would also allow for identification of potential locations for larger BMPs, which would be a real potential given that significant portions of the watershed remain undeveloped.
- It should also be noted that field observations have indicated the Curlew Street and Gallery Row watersheds are all connected via storm drains and ditches. In conjunction with improved storm drainage asset inventories, a study deploying a sufficient number of flow gages for a period of time to understand how flow exchange between these two outfalls might yield useful results in terms of improving management of stormwater runoff quantities as well as FIB loads in the three watersheds. Of course such gages would have to be capable of measuring bi-directional flow.
- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 be effective in reducing bacterial pollution loads, the possibility of implementing such a system in the Curlew Street watershed is aided by the presence of town-owned land immediately west of the watershed near the Jockey's Ridge State Park where the drawdown effluent could be discharged. By virtue of scale and propinquity, the Curlew Street, Conch Street, and Soundside Road watersheds lend themselves to a combined groundwater lowering system that could benefit from economies of scale by utilizing a single force main to deliver discharge. That hypothetical system is illustrated in detail in Section 4.2. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIB are extremely high whereas flow rates are relatively low, making it readily possible to deploy pump systems capable of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.

3.6 Conch Street Watershed

The Conch Street watershed is comprised of an area approximately 438 acres. Land use in the area is developed but also includes acreage from Jockey's Ridge State Park. Jockey's Ridge is a large dune and includes areas of typical dune vegetation, maritime forest and scrub-shrub habitat. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 62**. This watershed was the selected location of the BMP implementation that occurred as part of this project in late 2009. For more specific treatment of the results observed during the installation and testing of BMP function for this watershed, as well as results related to upcoast/downcoast monitoring of this system, refer to sections 2.3 and 2.4.

3.6.1 Watershed Characterization

Impervious

The Conch Street watershed contains approximately 61.3 acres of impervious surfaces, which is approximately 14% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, sidewalks and recreational surfaces such as pools and tennis courts. There are 323 buildings with 14 acres of building footprint, which is approximately 3% of the total watershed area. Buildings within the watershed area are primarily residential or commercial.

Septic Density

For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Conch Street watershed is 323, which equates to an estimated density of 1.35 systems/acre. A review of Dare County permits for septic system repairs and new installs within the Conch Street watershed from 2006-2012 is summarized in **Table 25** below.

Table 25. Conch Street Septic Repair and Install Permits

Year	Total New System Permits	Total System Repair Permits
2006	3	6
2007	0	8
2008	1	10
2009	1	6
2010	0	6
2011	0	5
2012	0	0
Total:	**5**	**41**

Soils

A summary of soils within the Conch Street watershed is provided in **Table 26**. There are 351 acres of hydric soils within the watershed boundary and 87 acres of non-hydric soils within the watershed. Hydric soils are located throughout the majority of the Conch Street watershed. In areas where hydric soils underlay dense development, interactions between groundwater and septic systems are likely high. See **Figure 63** for Conch Street watershed soils mapping.

Table 26. Conch Street Watershed Soils Summary

Soil Type	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Newhan-Corolla Complex, 0-10 percent slopes	Yes	73.8	17	Excessively drained; very slow runoff; rapid permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	24.3	6	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand	Yes	39.4	9	Excessively drained; very slow runoff; rapid permeability
Dune Land-Newhan Complex, 2-40 percent slopes	Yes	92.5	21	Excessively drained; very slow runoff; rapid permeability
Dune Land	Yes	118	27	None provided
Beaches-Newhan Complex, 0-25 percent slopes	Yes	2.8	<1	Excessively drained; very slow runoff; rapid permeability
Corolla Fine Sands	Yes	67.8	16	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston Fine Sands	Yes	18.8	4	Poorly drained; very slow runoff; very rapid permeability above the water table.

Vegetation

The Conch Street watershed contains approximately 154 acres of trees, with most of it occurring in the central and eastern portions of the watershed. The remaining fragmented vegetated areas within the watershed are primarily grassed. Patterns of vegetation are mapped in **Figure 64**.

Groundwater

Five groundwater monitoring wells installed by Moffatt & Nichol in 2006 are located within the Conch Street watershed. B-8 is located at the shoreline end of Conch Street. Moffatt & Nichol scientists found that this well had no groundwater levels within 0 to 3 feet of the surface for the period of collection. B-7, located alongside NC 158 (Croatan Highway) had no groundwater levels within 0 to 3 feet of the surface for the period of collection. Groundwater well B-6 had groundwater levels within 0 to 3 feet for approximately 11% of the period of collection. Groundwater well B10, located at an elevation of 7 feet, had groundwater levels within 0 to 3 feet for approximately 76% of the period of collection. Groundwater well B11 had no groundwater levels within 0 to 3 feet of the surface for the period of collection. It should be noted that B-8 is located on the western slope of the primary dune, at an elevation of 16 feet above sea level, so that fact that it has no incidence of groundwater within 0-3 feet of the surface does not reflect the potential for such occurrence throughout the watershed. As a point of reference, the controlling elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road, occurs at an elevations as low as 5-6 feet above sea level in the southern portion of Conch Street watershed. A prominent drainage feature of the Conch Street watershed is that a large area of land west of the Bypass drains to the Conch Street outfall by way of a long drainage ditch flowing south along the west side of the Bypass. The ditch often provides the controlling elevation for groundwater levels in the watershed. By virtue of that controlling factor, the greatest potential for groundwater-septic system interaction in the Conch Street watershed is in the vicinity of well B-10, which is located near the significant are of suburban residential development west of Bypass in the northern portion of the watershed.

Drainage Systems and Infrastructure

The Conch Street watershed contains approximately 7,020 feet of major open channel ditching and approximately 3,642 linear feet of piping. Drainage network spatial data and detailed contours of the Conch Street watershed indicate that there is approximately 144 acres of the watershed drained by piping and open channel ditches. This area represents approximately 33% of the total watershed area and occurs primarily in heavily developed areas within the watershed. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and commercial facilities where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. In areas without drainage infrastructure and where hydric soils are located below areas of residential development, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

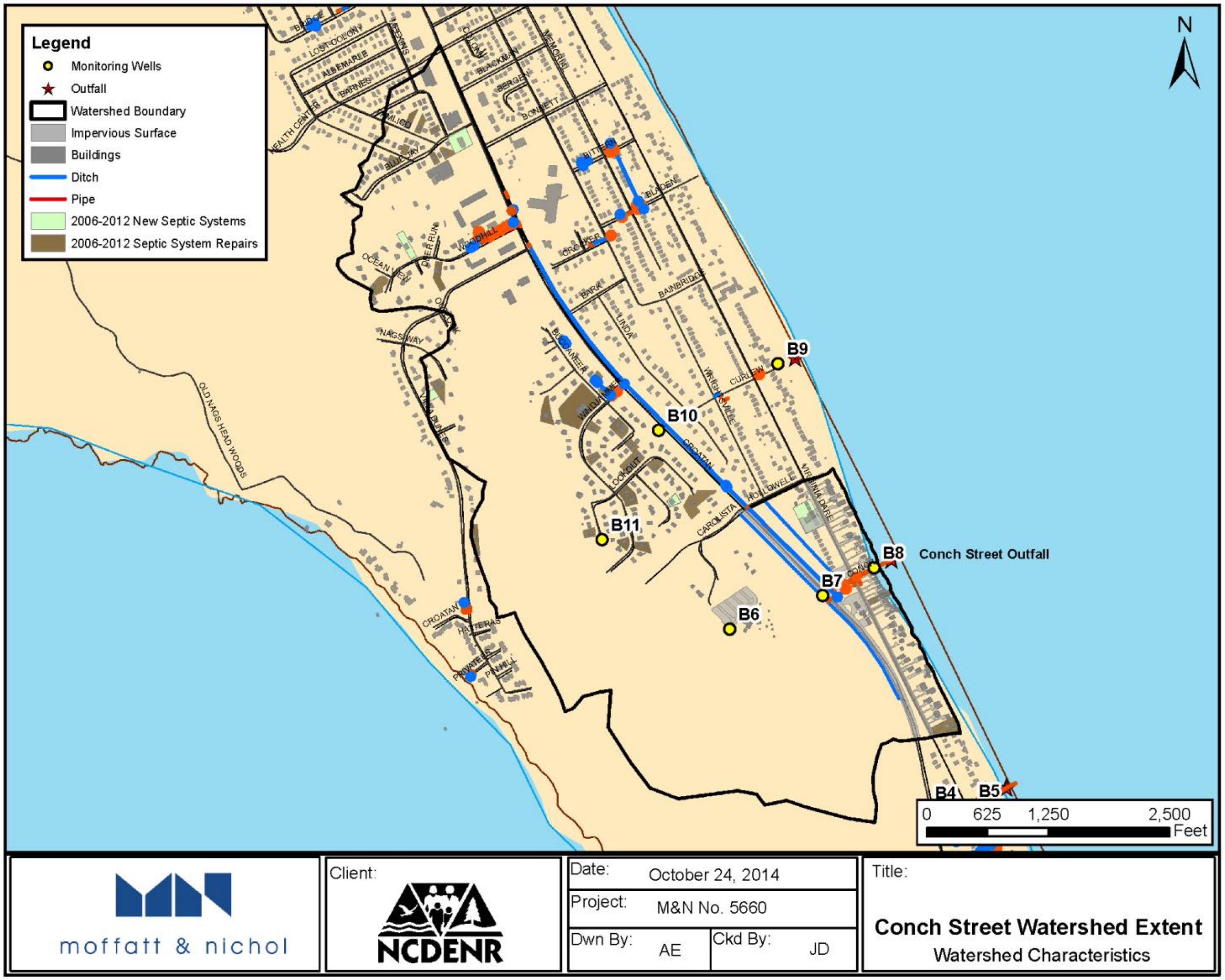


Figure 62. Conch Street Watershed Extent Map

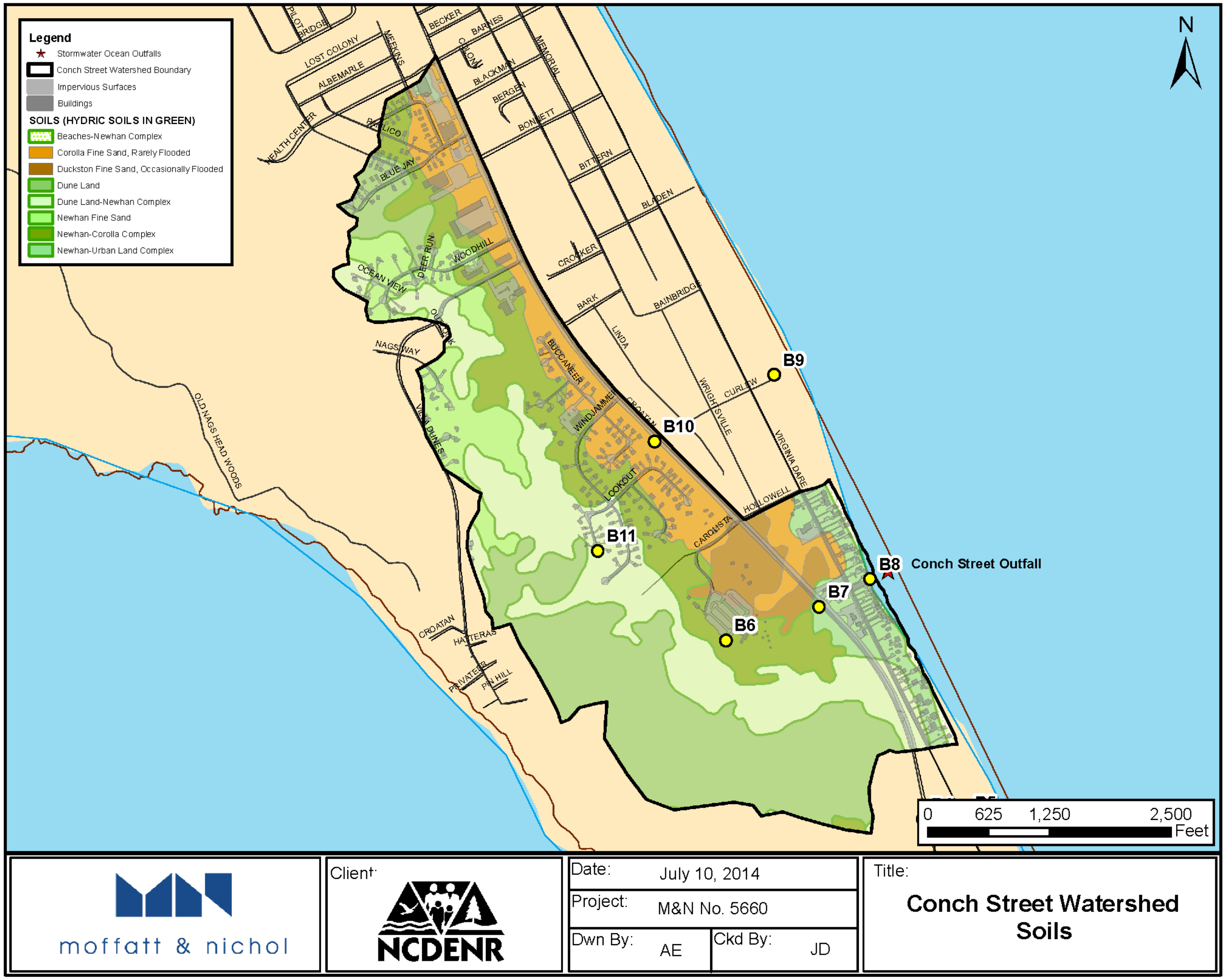


Figure 63. Conch Street Watershed Soils Map

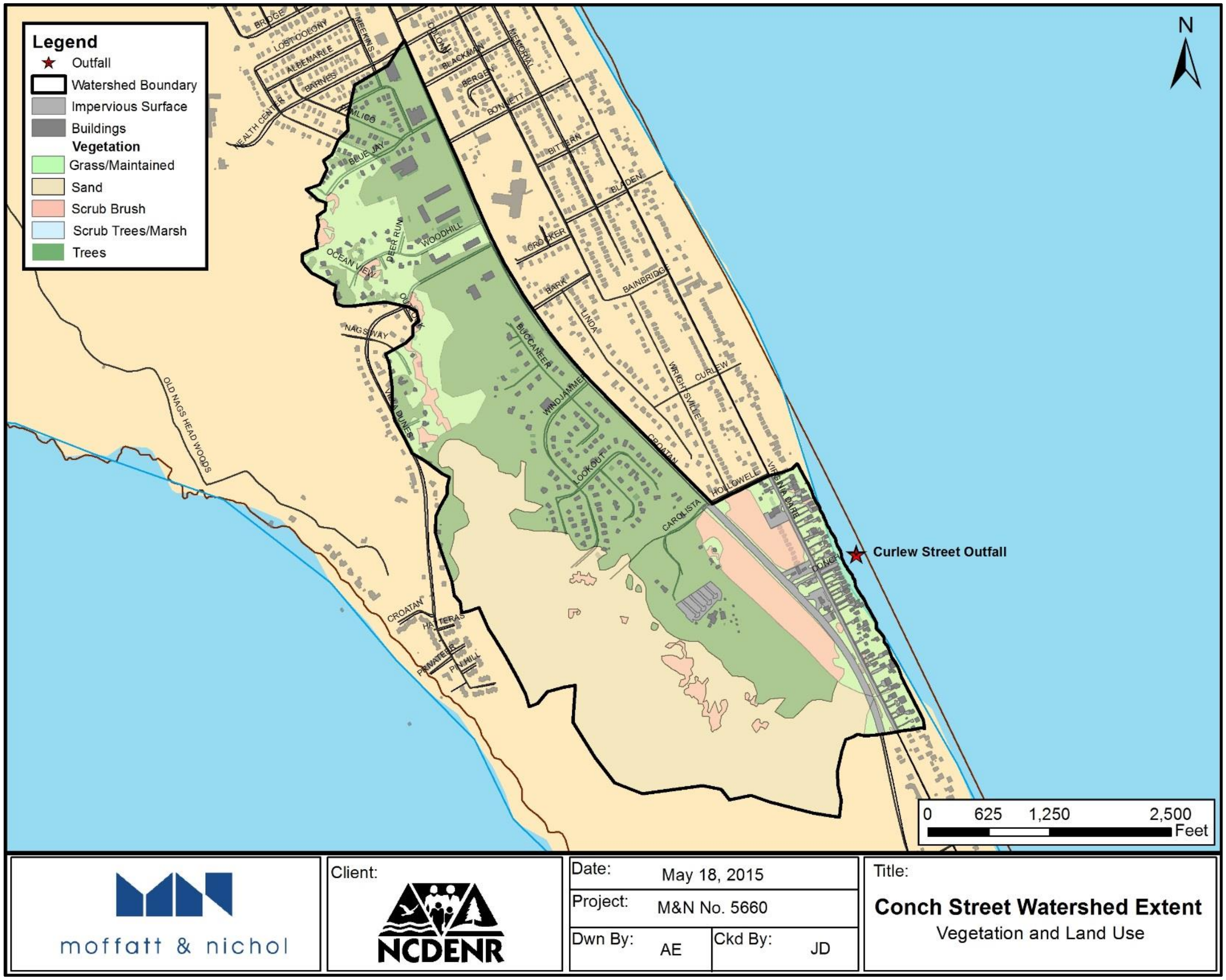


Figure 64. Conch Street Watershed Vegetation Map

3.6.2 Watershed Results

Conch Street watershed is characterized by 438 acres of which 14% is impervious. Septic density is 1.35 per acre. There is a total open channel length of 3,563 feet with a total length of drainage piping at 1,759 feet. In the initial prioritization phase of this project (2007-2009) Conch Street was monitored during three large storm events that occurred from the summer 2007 through the fall 2008. Following this period, based upon total loading observed at the specific watersheds, along with the potential for implementation of BMP strategies, Conch Street watershed was selected as the location for the AbTech SmartSponge BMP technology. Subsequent to the construction of the vault in the parking area at the Conch Street outfall location, and the design and construction of a modified version of the AbTech SmartSponge system, a performance assessment period for the BMP ensued. This involved an assessment of the inflow water to the vault BMP system, and in vault assessment of sponge performance, and samples collected at the Outflow. The outfall was monitored during thirteen storms that span from the summer 2010 to the summer 2014, so the system has been extensively characterized. In fact, this monitoring program implemented for the Conch Street system may make it one of the best studied stormwater outfalls along the entire NC coast. FIB sampling results for each of the storms monitored are discussed below, and the results from each storm are presented graphically in Appendix D. The storm summaries are presented in **Table 27**.

June 3-4, 2007

For the storm that occurred June 3-4, 2007, there was a total of 1.19 in of rainfall. There were three grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 1,071 – 3,130 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 657 – 1,674 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 37 – 6,008 CE 100 ml^{-1} over the course of the storm. The hydrograph is characterized as flashy having several rapid rising and receding limbs followed by a quick return to base flow. The maximum Fecal *Bacteroides* spp. value occurred during the first grab sample at the beginning of the storm and then decreased slightly over the course the storm. Maximum values for *Enterococcus* and *E. coli* lagged slightly after the first peak and then receded in strength as the flow returned to near base flow levels.

Baseline flow measurements were 0 gpm and peaked at 1,170 gpm (2.61 cfs), with two distinct pulses were recorded on the hydrograph. Base flow returned a day after the last pulse of rainwater. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 2.31×10^{10}, 1.27×10^{10} and 2.71×10^{10} MPN or CE respectively, which equates to loads of 8.12×10^{8}, 4.45×10^{8} and 9.51×10^{8} MPN or CE per h based upon examined storm length of 28.5 hours. As with many storm recorded during the 2006-2008 monitoring period, this event was characterized by high discharge concentrations, but very low hydraulic flow rates, so the FIB load rates were driven far more by concentration than flow.

April 20-23, 2008

For the storm that occurred April 20-23, 2008, there was a total of 2.72 in of rainfall. Six grab samples collected for microbial contaminant measurements over the course of the storm. Two large pulses of rain occurred April 20, 2008 and April 21, 2008 along with small amounts of rain throughout the day on April 22nd, 2008 This was reflected in the hydrograph by two large spikes and then smaller spikes, flow was still around 1,000 gpm (2.2 cfs) at end of sampling. Fecal *Bacteroides* spp. concentrations increased during the duration of the sampling, whereas *Enterococcus* levels remained fairly constant and *E. coli* concentrations, after peaking at 2nd sample, followed a slight downward trend throughout the duration of the sampling.

Baseline flow measurements were 370 gpm (0.82 cfs) and peaked at 3,310 gpm (7.38 cfs) after the 2nd pulse of rainfall. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 9.44×10^{10}, 4.46×10^{10} and 2.40×10^{13} MPN or CE respectively, which equates to loads of 1.43×10^{9}, 6.76×10^{8} and 5.14×10^{11} MPN or CE per h based upon examined storm length of 66 hours.

<u>September 5-11, 2008</u>

For the storm that occurred September 5-11, 2008, there was a total of 3.27 in of rainfall. There were five grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 959 – 14,670 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 350 – 6,131 MPN 100 ml^{-1}, and Fecal *Bacteroides* spp. concentrations ranged from 5 – 254,585 CE 100 ml^{-1} over the course of the storm. The hydrograph is characterized by four rapidly rising and falling peaks with a quick return to base flow levels. Maximum values recorded for *Enterococcus* and *E. coli* occurred at the second peak and then again on the receding limb of the fourth peak. Fecal *Bacteroides* spp. concentrations for the first two grab samples are inaccurate due to interfering substances found within the storm water. Peak Fecal *Bacteroides* spp. values occurred during the fourth peak of the recorded hydrograph.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 1,800 gpm (4.01 cfs). The hydrograph had four quick pulses of water throughout the recorded storms, and quickly returned to base flow after each pulse. The total *Enterococcus*, *E. coli* and conservative Fecal *Bacteroides* spp. (due to interference) loads for this storm were 1.85×10^{11}, 5.77×10^{10}, and 2.94×10^{12} MPN or CE respectively, which equates to loads of 1.30×10^{9}, 4.04×10^{8}, and 2.06×10^{10} MPN or CE per h based upon examined storm length of 142.75 hours. Just as with the June 2007 storm event, this event was characterized by high discharge concentrations, but very low hydraulic flow rates.

<u>November 4-7, 2008</u>

For the storm that occurred November 4-7, 2008, there was a total of 2.98 in of rainfall. There were seven grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 158 – 2,310 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 441 – 4,352 MPN 100 ml^{-1} and Fecal *Bacteroides* concentrations ranged from 9,521 – 69,859 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus* and *E. coli* occurred during the rising limb of the hydrograph. The maximum Fecal *Bacteroides* spp. occurred as the hydrograph returned to base flow levels.

Flow was measured for this storm and started at a baseline measurement of 30 gpm (0.07 cfs) and peak measurements were 3,770 gpm (8.40 cfs). Multiple rain events occurred during this time period, which prevented the hydrograph from returning to base flow during the period of observation. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 1.44×10^{11}, 2.41×10^{11}, and 5.50×10^{12} MPN or CE respectively, which equates to loads of 2.64×10^{9}, 4.41×10^{9}, and 1.00×10^{11} MPN or CE per h based upon examined storm length of 54.75 hours.

Table 27. Conch Summary Statistics

Storm Date	# of Grab Samples	E. Coli Mean (cells/100ml)	E. Coli Range (cells/100ml)	Enterococcus Mean (cells/100ml)	Enterococcus Range (cells/100ml)	Bacteroides Mean (cells/100ml)	Bacteroides Range (cells/100ml)	Total Enterococcus Load cells	Total E. Coli Load cells	Total Bacteroides Load cells	Enterococcus Load per hour	E. Coli Load per hour	Bacteroides Load per hour
6/3-4/2007	3	1,148	657-1,674	2,100	1,071-3,130	2,410	37-6,008	2.31×10^{10}	1.27×10^{10}	2.71×10^{10}	8.12×10^{8}	4.45×10^{8}	9.51×10^{8}
4/20-23/2008	6	183	20-410	399	156-512	133,191	19,971-237,616	9.44×10^{10}	4.46×10^{10}	2.40×10^{13}	1.43×10^{9}	6.76×10^{8}	5.14×10^{11}
9/5-11/2008	5	2,985	350-6,131	7,652	959-14,670	69,788	5-254,585	1.85×10^{11}	5.77×10^{10}	2.94×10^{12}	1.30×10^{9}	4.04×10^{8}	2.06×10^{10}
11/4-7/2008	6	1,783	441-4,352	1,083	158-2,310	34,032	9,521-69,859	1.44×10^{11}	2.41×10^{11}	5.50×10^{12}	2.64×10^{9}	4.41×10^{9}	1.00×10^{11}
6/29/10-7/1/10	4	4,298	2,359-11,199	10,476	1,725-24,196	-	-	-	-	-	-	-	-
8/5-6/2010	2	2,256	706-4,106	16,492	6,450-24,890	-	-	-	-	-	-	-	-
9/28-29/2010	4	407	74-2,489	13,279	2,560-72,700	-	-	-	-	-	-	-	-
11/4/2010	4	2,994	30-14,136	26,549	750-64,880	-	-	-	-	-	-	-	-
1/18/2011	4	146	63-295	661	307-1,102	-	-	-	-	-	-	-	-
3/30/2011	3	693	100-1,460	519	51-1,017	-	-	-	-	-	-	-	-
7/7/2011	3	1,159	450-4,083	7,277	235-23,820	-	-	-	-	-	-	-	-
7/11/2012	3	4,473	1,201-19,863	13,605	6,131-17,329	-	-	-	-	-	-	-	-
8/2/2012	3	3,265	379-9,208	6,779	1,600-15,650	-	-	-	-	-	-	-	-
6/7/2013	3	15,742	6,770-29,870	25,478	6,070-51,720	-	-	-	-	-	-	-	-
7/16/2016	2	1,031	200-5,015	1,449	50-15,340	-	-	-	-	-	2.19×10^{10}	9.07×10^{9}	-
8/3-4/2014	3	285	40-1,925	570	30-9,880	-	-	-	-	-	7.98×10^{10}	1.46×10^{10}	-
9/8/2014	3	2,270	360-22,390	4,645	50-59,625	-	-	-	-	-	7.14×10^{10}	2.34×10^{10}	-

3.6.3 Watershed Strategies

The Conch Street watershed is the second largest (at 438 acres) of the ocean outfall watersheds. However, a substantial portion of that acreage is occupied by Jockey's Ridge State Park which holds it in a state of perpetual conservation. As a result, the watershed is only 14% impervious. Most of the development in the watershed is medium to low density detached homes and it is distributed into two discrete sections, one in the upper watershed, above the Jockeys Ridge complex and one along the beach near the outfall. The eastern edge of the watershed runs along the Bypass, which forms a drainage boundary between the Curlew and Conch Street watersheds. All of the land area south of Gallery Row and west of the Bypass drains down the ditch along the west side of the Bypass to the Conch Street Outfall. It should be noted that the invert of downstream portion, in the vicinity of where it intercepts the pipe that takes flow across the Bypass to the outfall, is low enough in elevation that the hydraulic connection to groundwater in nearly continuous. Just as with Gallery Row and Curlew Street watersheds, most of the drainage network within the watershed remains unmapped. Groundwater data analysis presented in Section 2.2 shows that groundwater surface elevations spend a lesser amount of time within the upper portions of the soil column relative to most ocean outfalls. One of the groundwater monitoring wells on the border of the Curlew Street and Conch Street watersheds (B-10) exhibited a high incidence of groundwater levels, dwelling 76% of the time in the top 0-3 feet of the soil profile (refer to Table 5), and that well is located near the large drainage ditch that provides controlling elevation for storm drainage in the upper Conch Street watershed. As a result, there is significant potential for groundwater-septic system interaction in the vicinity of the significant are of suburban residential development west of Bypass in the northern portion of the watershed.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- It is interesting to note that the Conch Street outfall has been repeatedly demonstrated to discharge stormwater runoff that contains quantifiable human fecal contamination specific markers. In addition, bird (gull) fecal contamination has been quantified in the outfall discharge and along the beach. The human fecal contamination signal, combined with the relatively high concentrations of *Enterococcus* sp. that are discharged from this outfall, make it a potential site for stormwater mitigation.
- The Conch Street watershed has the relatively low count of septic systems for a large watershed because the land-use is dominated by conserved lands, but analysis of groundwater elevations indicates that groundwater interaction with septic systems is important in portions in this watershed as in some others. FIB monitoring results have indicated the presence of human fecal contamination markers in the discharge from this outfall, so continued efforts to improve septic system maintenance and performance on the part of the Town of Nags Head's Septic Health Initiative would benefit this watershed.
- Unlike all the other watersheds in this study, the Conch Street watershed is already equipped with a BMP structure design to remove FIB from stormwater runoff prior to discharging it to the ocean. While the proprietary FIB treatment technology applied in the BMP has not demonstrated consistent significant reductions, newer contact/filtration media

have been developed that exhibit promising performance and lower purchase costs. The performance of the Conch Street BMP is discussed in detail in Section 2.3, but it should be noted that factors that cannot not be attributed to the treatment media alone contributed to the inconsistent performance of the Conch Street BMP, including interference from sediment loads and tides and extremely high influent loading. A clean out and upfit of the BMP with new media performed in conjunction with the other improvement recommended in Section 2.3 could very well generate substantial water quality benefits for this outfall.

- Given that the groundwater-septic system interaction in the Conch Street watershed is less severe than in others, the build-up/wash-off mechanisms of delivery of bacterial pollutants should be the area of focus. Several lots in the upper portion of the watershed remain undeveloped. If land acquisition could be achieved, some of these lots would be suitable for retrofitting of diffuse landscape-integrated BMPs such as the high –rate infiltration sand filters discussed in Section 4.1 or other such BMPs typically associated with low impact development, such as bio-retention cells. In addition, the generous amounts of open space around the buildings and parking facilities for Jockey's Ridge State Park would allow for relatively unfettered retrofitting of BMPs to treat runoff from those impervious surfaces. Should the Conch Street BMP, be rehabilitated and placed back into service, these hypothetical upstream BMPs could potentially enhance its performance by reducing influent sediment loads and FIB concentrations.
- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 be effective in reducing bacterial pollution loads, the possibility of implementing such a system in the Conch Street watershed is aided by the presence of town-owned land immediately west of the watershed near the Jockey's Ridge State Park where the drawdown volume could be discharge. By virtue of scale and propinquity, the Curlew Street, Conch Street, and Soundside Road watersheds lend themselves to a combined groundwater lowering system that could benefit from economies of scale by utilizing a single force main to deliver the discharge. That hypothetical system is illustrated in detail in Section 4.2. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIBs are extremely high whereas hydraulic flow rates are relatively low, making it readily possible to deploy pump systems capable of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.

3.7 Soundside Road "Casino" Watershed

The Soundside Road "Casino" watershed is comprised of an area approximately 45 acres. Land use in the area is mostly developed, with a mixture of residential and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 65**.

3.7.1 Watershed Characterization

Impervious
The Soundside Road "Casino" watershed contains approximately 12 acres of impervious surfaces, which is approximately 26.7% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, sidewalks and recreational surfaces such as pools and tennis courts. There are 59 buildings with 2.7 acres of building footprint, which is approximately 6% of the total watershed area. Buildings within the watershed area are primarily residential or commercial.

Septic Density
For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Soundside Road "Casino" watershed is 59, which equates to an estimated density of 1.31 systems per acre. A review of Dare County permits for septic system repairs and new installs within the Soundside Road "Casino" watershed from 2006-2012 is summarized in **Table 28** below.

Table 28. Soundside Road Septic Repair and Install Permits

Year	Total New System Permits	Total System Repair Permits
2006	0	2
2007	0	2
2008	1	1
2009	0	4
2010	0	1
2011	0	1
2012	0	0
Total:	**1**	**11**

Soils
A summary of soils within the Soundside Road "Casino" watershed is provided in **Table 29**. There are 42 acres of hydric soils within the watershed boundary and approximately 3 acres of non-hydric soils within the watershed. Hydric soils are located throughout the majority of the Soundside Road "Casino" watershed, with only a small area of non-hydric soils located in the southern section of the watershed. In areas where hydric soils underlay dense development, interactions between

groundwater and septic systems are likely high. See **Figure 66** for Soundside Road "Casino" watershed soils mapping.

Table 29. Soundside Road Watershed Soils Summary

Soil Type	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Newhan-Corolla Complex, 0-10 percent slopes	Yes	3.2	7	Excessively drained; very slow runoff; rapid permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	23.4	52	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand	Yes	2.4	5	Excessively drained; very slow runoff; rapid permeability
Dune Land-Newhan Complex, 2-40 percent slopes	Yes	4.6	10	Excessively drained; very slow runoff; rapid permeability
Dune Land	Yes	6.6	15	None provided
Beaches-Newhan Complex, 0-25 percent slopes	Yes	2.2	5	Excessively drained; very slow runoff; rapid permeability
Corolla-Duckston Complex, 0-6 percent slopes	Yes	1.9	4	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston Fine Sands	Yes	0.8	2	Poorly drained; very slow runoff; very rapid permeability above the water table.

<u>Vegetation</u>
The Soundside Road "Casino" watershed contains approximately 1.4 acres of trees, with most of it occurring in the southern portion of the watershed. The remaining fragmented vegetated areas within the watershed are primarily grassed. Patterns of vegetation are mapped in **Figure 67**.

<u>Groundwater</u>
Two groundwater monitoring wells installed by Moffatt & Nichol in 2006 are located within the Soundside Road "Casino" watershed. B-5 is located along Virginia Dare Trail and had groundwater levels within 0 to 3 feet of the surface for approximately 95% of the period of collection. B-4, located alongside NC 158 (Croatan Highway) had no groundwater levels within 0 to 3 feet of the surface for the period of collection. It should be noted that B-4 is located on the near the base of the eastern slope of Jockeys Ridge, at an elevation of 13.5 feet above sea level, so that fact that it has no incidence of groundwater within 0-3 feet of the surface does not reflect the potential for such occurrence throughout the watershed. As a point of reference, the controlling

elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road, occurs at an elevations of 4-5 feet above sea level in the Soundside Road watershed. As a result, well B-5, located at an elevation of 4.8 feet is far more indicative of the potential for groundwater-septic system interaction in this watershed, and it shows a high potential. Fortunately, the Soundside Road watershed has the lowest count and one of the lowest densities of septic systems of all watersheds in this study.

Drainage Systems and Infrastructure

The Soundside Road "Casino" watershed contains approximately 523 feet of major open channel ditching and approximately 1,759 linear feet of piping. Drainage network spatial data and detailed contours of the Soundside Road "Casino" watershed indicate that there is approximately 14 acres of the watershed drained by piping and open channel ditches. This area represents approximately 31% of the total watershed area and occurs primarily in heavily developed areas within the watershed. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and commercial facilities where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. In areas without drainage infrastructure and where hydric soils are located below areas of residential development, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

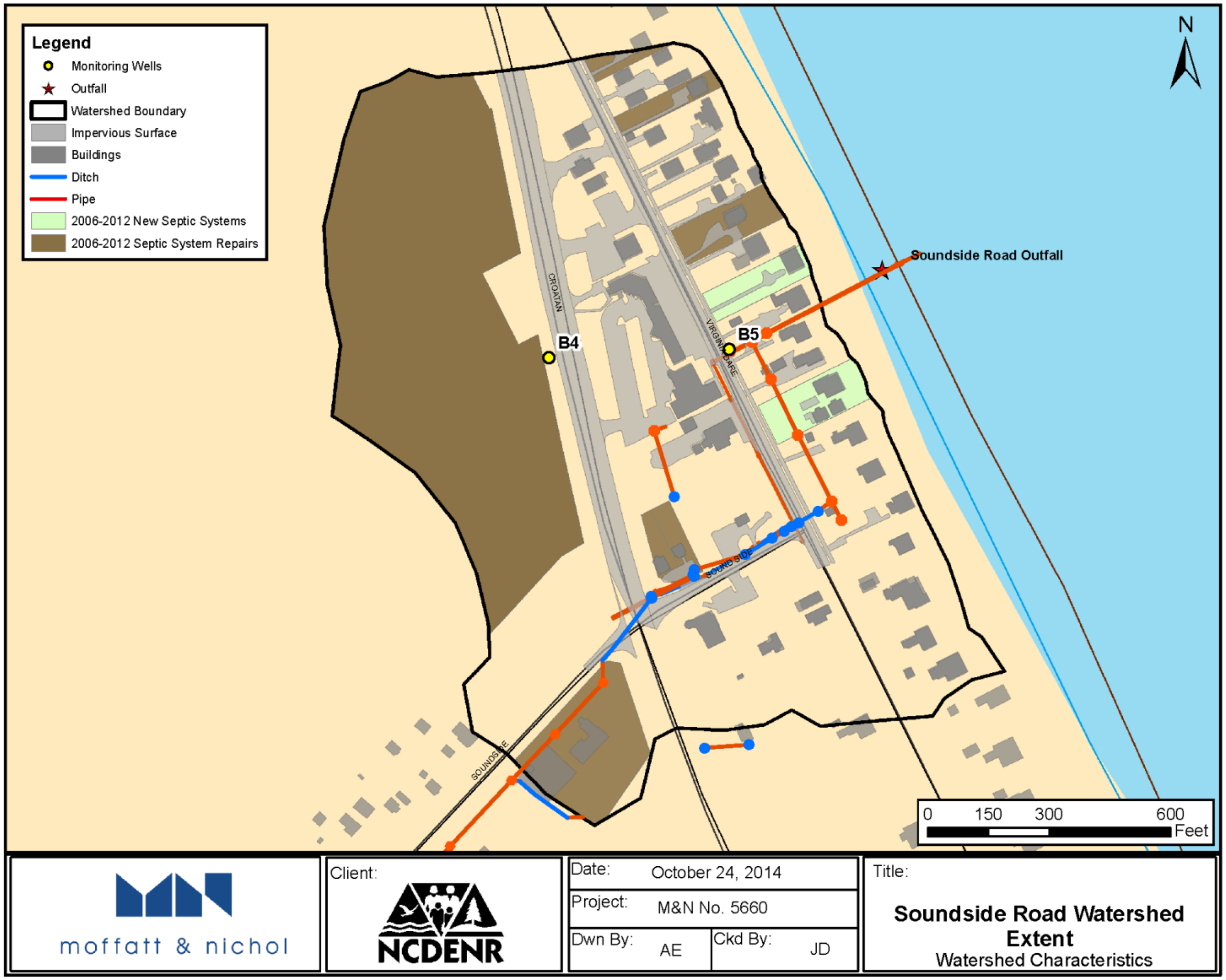


Figure 65. Soundside Road Watershed Extent Map

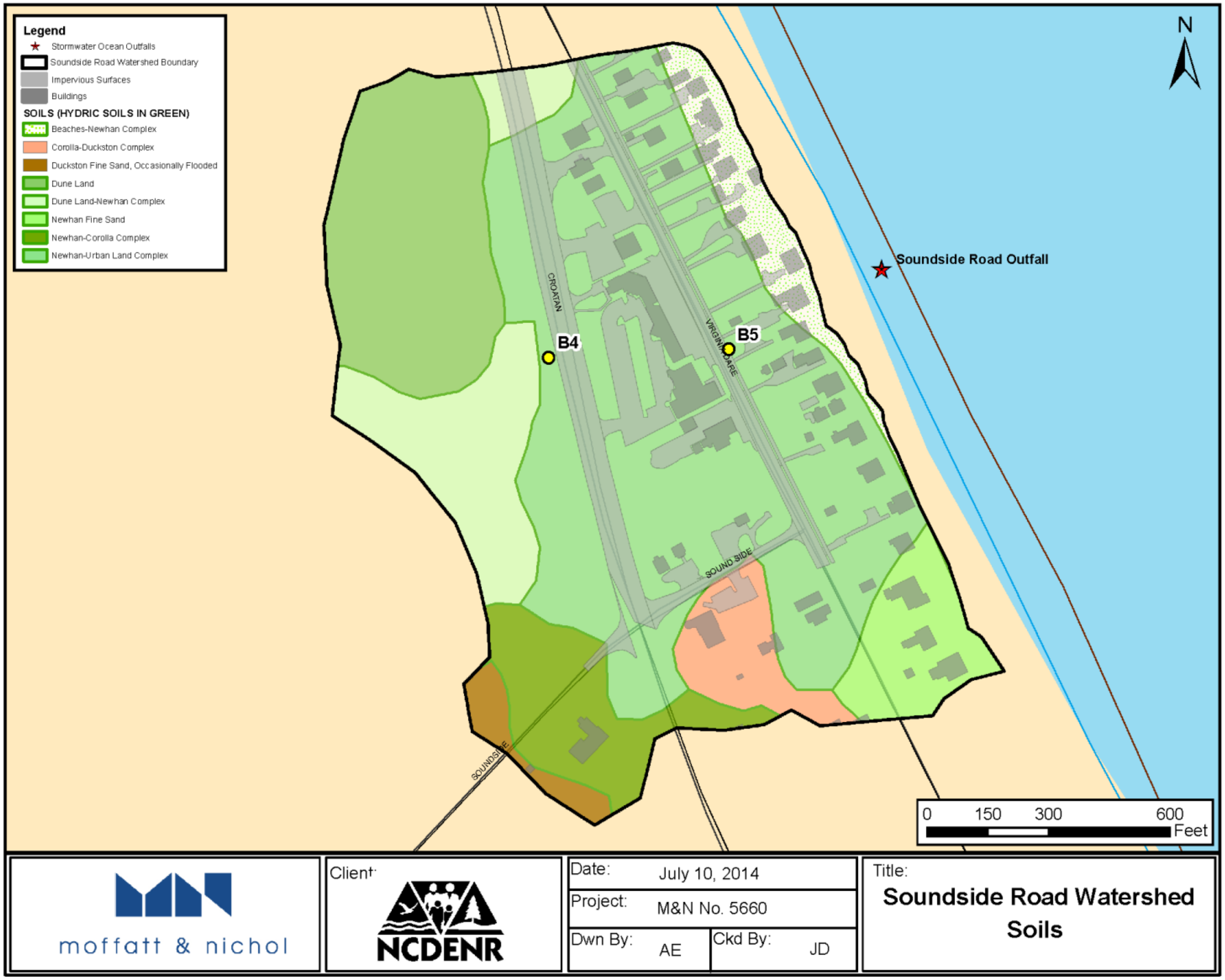


Figure 66. Soundside Road Watershed Soils Map

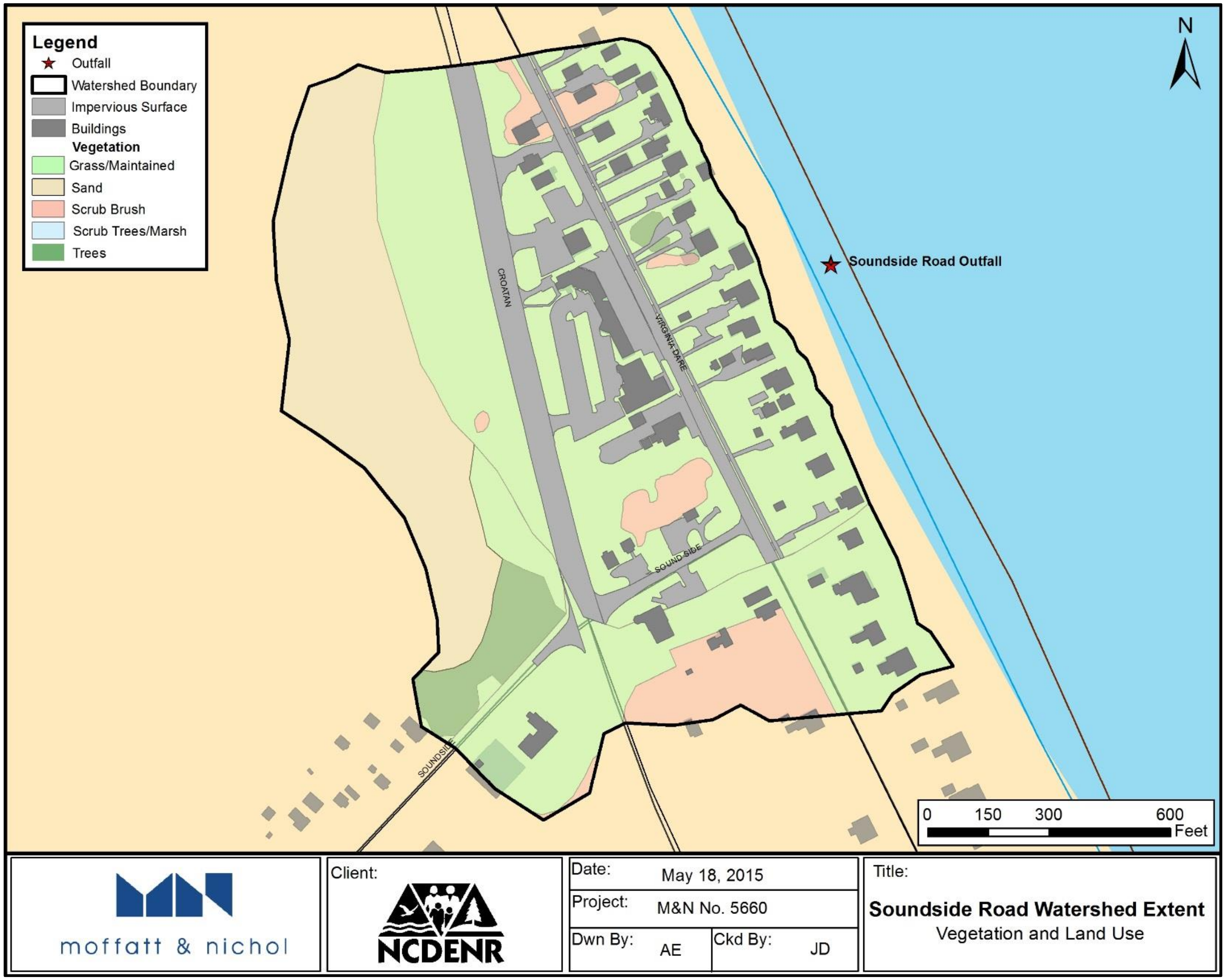


Figure 67. Soundside Road Watershed Vegetation Map

3.7.2 Watershed Results

Soundside Road watershed is characterized by 45 acres of which 26.7% is impervious. Septic density is 1.31 per acre. There is a total open channel length of 373 feet with a total length of drainage piping at 1,526 feet. Over the course of this project Soundside Road was monitored during five large storm events that occurred from the summer 2007 through the fall 2008 and upstream/downstream during four storm events that occurred 2011-2014. FIB sampling results for each of the storms monitored are discussed below, and the results from each storm are presented graphically in Appendix D. The storm summaries are presented in **Table 30**.

<u>June 3-4, 2007</u>

For the storm that occurred June 3-4, 2007, there was a total of 1.19 in of rainfall. There were three grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 384 – 1,246 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 51 - 374 MPN 100 ml^{-1} and all three samples of Fecal *Bacteroides* spp. concentrations returned 5 CE 100 ml^{-1}. This hydrograph is characterized as flashy having a steep rising and falling limb, followed by a rapid return to base flow. The maximum values recorded for *Enterococcus* and *E. coli* occurred prior to the hydrograph's storm pulse. The next grab sample was taken after the peak and the values of both *Enterococcus* and *E. coli* has decreased below that of baseline measurements.

Baseline flow measured at 0 gpm and peaked at 1,150 gpm (2.56 cfs). The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 1.78 x 10^9, 7.40 x 10^8, 1.39 x 10^7 MPN or CE, which equates to loads of 5.97 x 10^8, 2.49 x 10^7, 4.67 x 10^5 MPN or CE per h based upon examined storm length of 29.75 hours. Similar to the behavior of this event at other outfalls, at Soundside Road, this event was characterized by high discharge concentrations, but very low hydraulic flow rates, so the FIB load rates were driven far more by concentration than flow. Partly due to the small size of the watershed, this pattern holds true for almost all events for which flow data exist at Soundside Road.

<u>December 15-16, 2007</u>

For the storm that occurred December 15-16, 2007, there was a total of 2.48 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 5 - 170 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 5 - 668 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations values ranged from 7,914 – 79,454 CE 100 ml^{-1} over the course of the storm. This hydrograph is characterized by two distinct peaks with rapidly rising limbs and a slower receding limb. *Enterococcus* and *E. coli* baseline levels were extremely low in comparison to other storms (62 MPN 100 ml^{-1} and 5 MPN 100 ml^{-1}, respectively). Maximum values recorded for *Enterococcus* (170 MPN 100 ml^{-1}) occurred at hydrograph peak whereas *E. coli* continued to rise to a maximum value of 668 MPN 100 ml^{-1} after the hydrograph peak. The maximum concentrations for Fecal *Bacteroides* spp. (79,454 CE 100 ml^{-1}) occurred before storm event and fell throughout the duration of the storm.

Baseline flow measurements were 0 gpm and peaked at 913 gpm (2.03 cfs). The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 6.41 x 10^8, 1.60 x 10^9, and 6.89 x 10^{10} MPN or CE respectively, which equates to loads of 6.93 x 10^{7}, 1.73 x 10^{8}, and 7.45 x 10^{9} MPN or CE per h based upon examined storm length of 9.25 hours.

April 20-23, 2008

For the storm that occurred April 20-23, 2008, there was a total of 2.72 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm event. *Enterococcus* concentrations ranged from 62 – 1,529 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 10 - 801 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 7,965 -13,862 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. occurred midway through the storm events.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 1,670 gpm (3.72 cfs). The hydrograph had several pulses throughout this period and quickly returned to base flow after each pulse. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 1.55 x 10^{10}, 6.47 x 10^{9}, and 2.26 x 10^{11} MPN or CE respectively, which equates to loads of 2.34 x 10^{8}, 9.77 x 10^{7}, and 3.41 x 10^{9} MPN or CE per h based upon examined storm length of 66.25 hours.

September 5-11, 2008

For the storm that occurred September 5-11, 2008, there was a total of 3.27 in of rainfall. There were five grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 1,234 – 24,196 MPN 100 ml-1, *E. coli* concentrations ranged from 3,654 – 36,540 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 5 – 492,867 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus* and *E. coli* occurred during a small peak in the hydrograph that occurred September 10, 2008 07:30. The peak Fecal *Bacteroides* spp. concentrations occurred at the beginning of the recorded hydrograph.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 1,230 gpm (2.74 cfs). The hydrograph had several quick pulses of water throughout the recorded storms, and quickly returned to base flow after each pulse. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 4.79 x 10^{10}, 7.20 x 10^{10}, and 2.26 x 10^{12} MPN or CE respectively, which equates to loads of 4.06 x 10^{8}, 6.10 x 10^{8}, and 1.92 x 10^{10} MPN or CE per h based upon examined storm length of 118 hours.

November 3-7, 2008

For the storm that occurred November 3-7, 2008, there was a total of 2.98 in of rainfall. There were seven grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 256 – 36,540 MPN 100 ml^{-1} and *E. coli* concentrations ranged from 20 – 17,329 MPN 100 ml^{-1}. No Fecal *Bacteroides* spp. samples were taken for this storm event. Maximum values recorded for *Enterococcus* and *E. coli* occurred soon after the major peak of the hydrograph.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 2,950 gpm (6.57 cfs). The total *Enterococcus* and *E. coli* and loads for this storm was 9.67×10^{11} and 4.44×10^{11} MPN or CE respectively, which equates to loads 1.01×10^{10} and 4.63×10^{9} MPN or CE per h based upon examined storm length of 96 hours.

<u>July 7, 2011</u>
During the storm of July 7, 2011 there was 1.40 in of rainfall over 24 hours. At the Soundside Street Outfall two sampling events total were conducted. Concentrations of Enterococci were above state water quality thresholds of 104 MPN 100 ml^{-1} in 9 of 11 samples. During the two sampling events *Enterococcus* concentrations ranged from 20 – 24,196 MPN 100 ml^{-1} and *E. coli* concentrations ranged from 246 – 5,570 MPN 100 ml^{-1}. High values of Fecal *Bacteroides* spp. were observed at Outfall (30,351 - 36,940 CE 100 ml^{-1}). Gull signature was observed 50 meters from outfall (range of gull signatures 5 – 80,545 CE 100 ml^{-1}). HF183 concentrations of 5 CE 100 ml^{-1} were observed in samples up to 100 meters from outfall.

<u>July 16, 2014</u>
During the storm of July 16, 2014 there was 1.02 in of rainfall over two hours. At the Soundside Street Outfall two sampling events total were conducted. Concentrations of Enterococci were above state water quality thresholds of 104 MPN 100 ml^{-1} in 7 of 18 samples. During the two sampling events *Enterococcus* concentrations ranged from 50 – 2,560 MPN 100 ml^{-1} and *E. coli* concentrations ranged from 50 – 6,450 MPN 100 ml^{-1}, with highest values of both occurring at the outfall.

<u>August 3-4, 2014</u>
During August 3-4th, there was a small rain event that dropped 0.71 in of rain. Three sampling events were conducted, in each case outfall concentrations of *Enterococci* and *E. coli* were well above the state water quality thresholds. Most other sampling points yielded *Enterococci* and *E. coli* concentrations that were at or slightly below state water quality thresholds. During the 3 sampling events *Enterococcus* concentrations ranged from 50 – 36,570 MPN 100 ml^{-1} and *E. coli* concentrations ranged from 50 - 5,335 MPN 100 ml^{-1}, with highest values of both occurring at the outfall.

<u>September 8, 2014</u>
From September 7-8th a large two pulse event dropped 2.80 in of rain. All three sampling event were taken after both rainfall pulses had passed and water flow was high. *Enterococcus* and *E. coli* concentrations were highest at the outfall. State water quality levels for *E. coli* were exceeded in all 27 samples that were collected, with exceedances occurring up to 200 meters from outfall. State water quality levels for *Enterococcus* was exceeded in 17 of 27 samples, with exceedances occurring up to 200 meters from outfall. During the 3 sampling events *Enterococcus* concentrations ranged from 75 – 4,530 MPN 100 ml^{-1} and *E. coli* concentrations ranged from 685 – 10,200 MPN 100 ml^{-1}.

Note that flow data are unavailable for the final four storms due to meter failure.

Table 30. Soundside Summary Statistics

Storm Date	# of Grab Samples	E. Coli Mean (cells/100ml)	E. Coli Range (cells/100ml)	Enterococcus Mean (cells/100ml)	Enterococcus Range (cells/100ml)	Bacteroides Mean (cells/100ml)	Bacteroides Range (cells/100ml)	HF 183 Mean (cells/100ml)	HF 183 range (cells/100ml)	Gull-2 Mean (cells/100ml)	Gull-2 Range (cells/100ml)	Total Enterococcus Load cells	Total E. Coli Load cells	Total Bacteroides Load cells	Enterococcus Load per hour	E. Coli Load per hour	Bacteroides Load per hour
6/3-4/2007	3	246	51-374	814	384-1,246	5	5	-	-	-	-	$1.78 X 10^{9}$	$7.40 X 10^{8}$	$1.39 X 10^{7}$	$5.97 X 10^{8}$	$2.49 X 10^{7}$	$4.67 X 10^{5}$
12/15-16/2007	6	152	5-668	57	5-170	23,234	7,914-79,454	-	-	-	-	$6.41 X 10^{8}$	$1.60 X 10^{9}$	$6.89 X 10^{10}$	$6.93 X 10^{7}$	$1.73 X 10^{8}$	$7.45 X 10^{9}$
4/20-23/2008	6	152	10-801	434	62-1,529	10,285	7,965-13,862	-	-	-	-	$1.55 X 10^{10}$	$6.47 X 10^{9}$	$2.26 X 10^{11}$	$2.34 X 10^{8}$	$9.77 X 10^{7}$	$3.41 X 10^{9}$
9/5-11/2008	5	14,176	3,654-36,540	9,719	1,234-24,196	147,557	5-492,867	-	-	-	-	$4.79 X 10^{10}$	$7.20 X 10^{10}$	$2.26 X 10^{12}$	$4.06 X 10^{8}$	$6.10 X 10^{8}$	$1.92 X10^{10}$
11/4-7/2008	7	3,070	20-17,329	6,894	256-36,540	-	-	-	-	-	-	$9.67 X 10^{11}$	$4.44 X 10^{11}$	-	$1.01 X 10^{10}$	$4.63 X 10^{9}$	-
7/7/2011	3	1,395	246-5,570	5,579	20-24,196	7,481	5-36,940	5	5	24,461	5-57,787	-	-	-	-	-	-
7/16/2014	2	601	50-2,560	553	50-6,450	-	-	-	-	-	-	-	-	-	-	-	-
8/3-4/2014	3	450	50-5,335	1,982	50-36,570	-	-	-	-	-	-	-	-	-	-	-	-
9/8/2014	3	2,199	685-10,200	549	75-4,530	-	-	-	-	-	-	-	-	-	-	-	-

3.7.3 Watershed Strategies

The Soundside Road watershed is the smallest (at 45 acres) of the ocean outfall watersheds. Partly because the watershed is so small, there are very few (59) building and associated septic systems located within it, and the density of these systems is relatively low (at 1.31 per acre). However, groundwater data analysis presented in Section 2.2 shows that groundwater surface elevations at the well in the eastern portion of the watershed shows that groundwater levels spend almost 95% of the time within the upper portions of the soil column in that vicinity. Even though this is true, the concentrations of Fecal *Bacteroides* spp. in this system, along with an absence of consistent measurement of the HF183 human fecal contamination marker in the outfall discharge indicate that the contamination from this outfall are likely to be non-human in nature. The storm event data for FIB shows unique and mixed patterns of loading. Some storms show a somewhat elevated signal from Fecal *Bacteroides* spp. later in storm events, but most of the data collected demonstrated relatively low levels of *Bacteroides* spp., and sometimes levels of *Bacteroides* spp. decreasing with the falling limb of the hydrograph. Perhaps the most important factor to consider with Soundside Road is that a pipe exists connecting the outfall to another outfall on the back side of the island at the west end of Soundside Road. Depending on the interaction between wind and tides, water can exchange between the two in either direction. This hydraulic variability may account for the high level of variability in the FIB loading response to different types of storms. It also should be noted that the Soundside Road outfall consistently exhibited a lower range of flows that most outfalls, and occasionally exhibited negative flow rates. Likely as a result of these factors, the upcoast/downcoast monitoring shows that the Soundside Road outfall seems to exert less impact on the surf zone FIB concentrations that it's nearby neighbors at Conch and Curlew Streets.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- The Soundside Road watershed has the relatively low count of septic systems because it is a small watershed, and because the development within the watershed is relatively low density. As a result, management that focuses on build-up, wash-off mechanisms for FIB pollution may be best suited in this watershed. These types of management strategies might include reductions in public bird feedings, and dog waste pickup strategies and enforcement.
- Should rehabilitation and improvement of the Conch Street BMP eventually produce more successful results in terms of bacterial pollutant treatment, it is important to note that the Soundside Road outfall exhibits flows that are of manageable levels and available land area suitable for application of a single BMP to treat the entire watershed.
- Opportunities for retrofitting diffuse landscape-integrated BMPs such as the high–rate infiltration sand filters discussed in Section 4.1 or other such BMPs typically associated with low impact development, such as bio-retention cells may exist. However, available sites in suitable hydrologic locations such they would treat runoff from a significant amount of impervious surface are difficult to find.
- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 be effective in reducing bacterial pollution loads, the possibility of

implementing such a system in the Conch Street watershed is aided by the presence of town-owned land immediately west of the watershed near the Jockey's Ridge State Park where the drawdown discharge could be controlled. By virtue of scale and propinquity, the Curlew Street, Conch Street, and Soundside Road watersheds lend themselves to a combined groundwater lowering system that could benefit from economies of scale by utilizing a single force main to deliver the effluent to the discharge site. That hypothetical system is illustrated in detail in Section 4.2. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIBs are extremely high whereas hydraulic flow rates are relatively low, making it readily possible to deploy pump systems capable of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.

- In conjunction with improved storm drainage asset inventories, a study deploying a sufficient number of flow gages for a period of time to understand how flow exchange between the two outfalls on either end of Soundside Road might yield useful results in terms of improving management of stormwater runoff quantities as well as FIB loads in the watershed. Of course such gages would have to be capable of measuring bi-directional flow. A study of this nature ay ultimately indicate that conditions may be improved by severing the connection.

3.8 Old Oregon Inlet Road (South Nags Head) Watershed

The Old Oregon Inlet Road watershed is comprised of an area approximately 115 acres. Land use in the area is mostly developed, with a mixture of residential and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 68**.

3.8.1 Watershed Characterization

Impervious

The Old Oregon Inlet Road watershed contains approximately 33 acres of impervious surfaces, which is approximately 28.8% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, and sidewalks. There are 307 buildings with 8.47 acres of building footprint, which is approximately 7% of the total watershed area. Buildings within the watershed area are primarily residential or commercial.

Septic Density

For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Old Oregon Inlet Road watershed is 307, which equates to an estimated density of 2.67 systems per acre. There were no documented repairs or new septic systems installed within the Old Oregon Inlet Road watershed boundary.

Soils

A summary of soils within the Old Oregon Inlet Road watershed is provided in **Table 31**. There are 54 acres of hydric soils within the watershed boundary and approximately 61 acres of non-hydric soils within the watershed. Hydric soils are generally located in the easternmost half of the Old Oregon Inlet Road watershed, with non-hydric soils located mostly in the western half. In areas where hydric soils underlay dense development, interactions between groundwater and septic systems are likely high. See **Figure 69** for Old Oregon Inlet Road watershed soils mapping.

Table 31. Old Oregon Inlet Road Watershed Soils Summary

Soil Type	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Newhan-Corolla Complex, 0-10 percent slopes	Yes	13.4	12	Excessively drained; very slow runoff; rapid permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	6.7	6	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand	Yes	25.8	22	Excessively drained; very slow runoff; rapid permeability
Beaches-Newhan Complex, 0-25 percent slopes	Yes	8.1	7	Excessively drained; very slow runoff; rapid permeability
Corolla-Duckston Complex, 0-6 percent slopes	Yes	17.4	15	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston Fine Sands	Yes	43.2	38	Poorly drained; very slow runoff; very rapid permeability above the water table.

Vegetation

The Old Oregon Inlet Road watershed contains approximately 4.6 acres of trees, with most of it occurring in the western portion of the watershed. The remaining fragmented vegetated areas within the watershed are primarily grassed. Patterns of vegetation are mapped in **Figure 70**.

Groundwater

Three groundwater monitoring wells installed by Moffatt & Nichol in 2006 are located within the Old Oregon Inlet Road watershed. B-1/B-24 is located at the shoreline end of Old Oregon Inlet Road and no groundwater levels within 0 to 3 feet of the surface for the period of collection. B-2, located alongside NC 158 (Croatan Highway) had groundwater levels within 0 to 3 feet of the surface for approximately 73% of the period of collection. It should be noted that B-1/B-24 is located on the ridge of the primary dune line, at an elevation of 20 feet above sea level, so that fact that it has no incidence of groundwater within 0-3 feet of the surface does not reflect the potential for such occurrence throughout the watershed. As a point of reference, the controlling elevation governed by the lowest point in the barrier island topography, generally occurring behind the primary dune line, or immediately west of the Beach Road, occurs at an elevations of 4-5 feet above sea level in the South Nags Head watershed. As a result, well B-2, located at an elevation of 4.2 feet is far more indicative of the potential for groundwater-septic system interaction in this watershed, and it shows a high potential. Well B-3, located at an elevation of 7 feet, showed no incidence of groundwater within the top 0-3 feet of the soil profile.

Drainage Systems and Infrastructure

The Old Oregon Inlet Road watershed contains approximately 6,410 feet of major open channel ditching and approximately 6,224 linear feet of piping. Drainage network spatial data and detailed contours of the Old Oregon Inlet Road watershed indicate that there is approximately 52 acres of the watershed drained by piping and open channel ditches. This area represents approximately 45% of the total watershed area and occurs primarily in heavily developed areas within the watershed. Stormwater runoff and pollutant loads in areas of the watershed where drainage infrastructure is well developed likely originate from built-upon areas such as parking lots and residential areas where build-up during dry periods and wash off in storm events are likely to be an important means by which pollutants are delivered to the ocean outfall. In areas without drainage infrastructure and where hydric soils are located below areas of residential development, pollutant loading is likely influenced by groundwater interactions with septic systems and is more diffuse in nature.

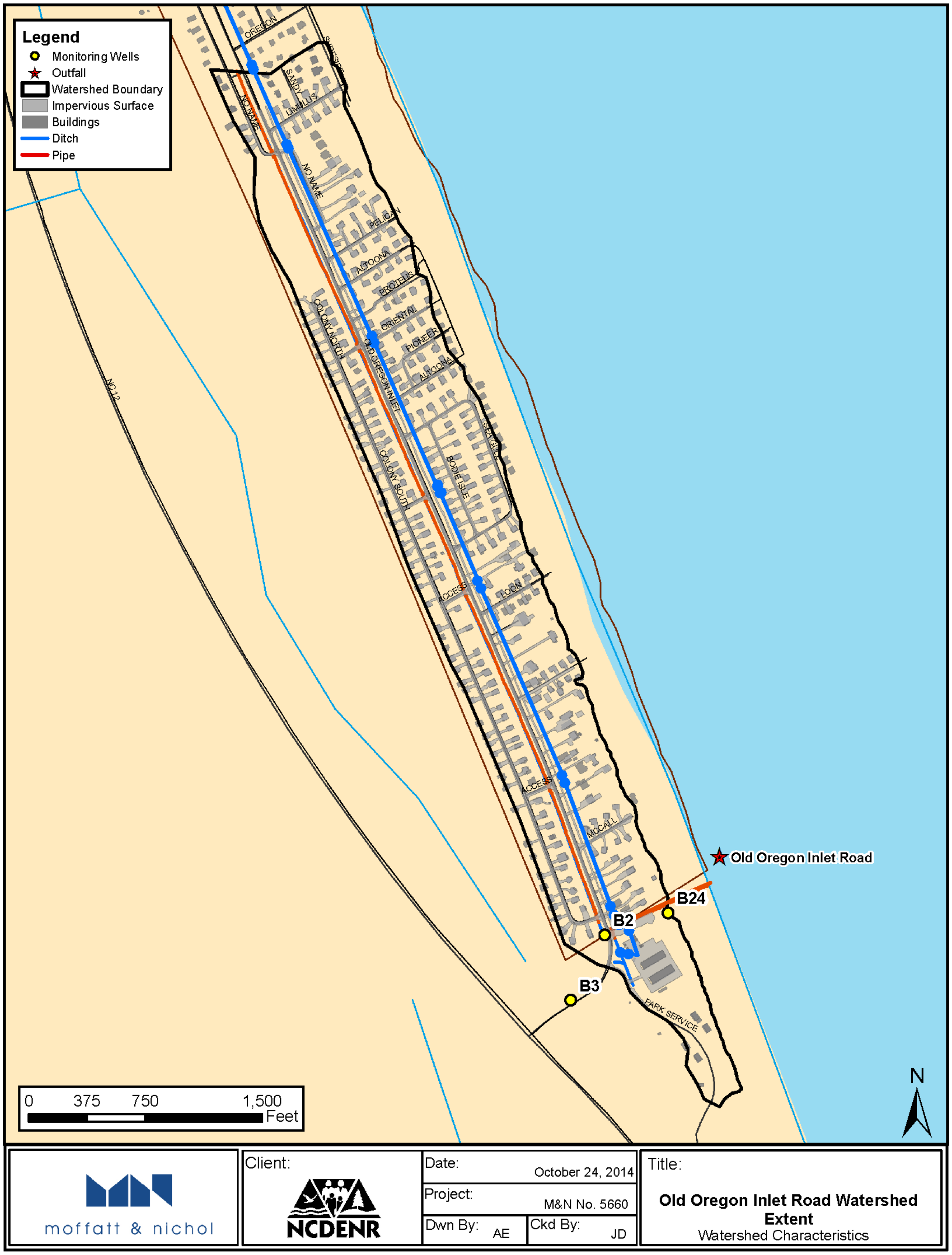


Figure 68. Old Oregon Inlet Road Watershed Extent Map

Figure 69. Old Oregon Inlet Road Watershed Soils Map

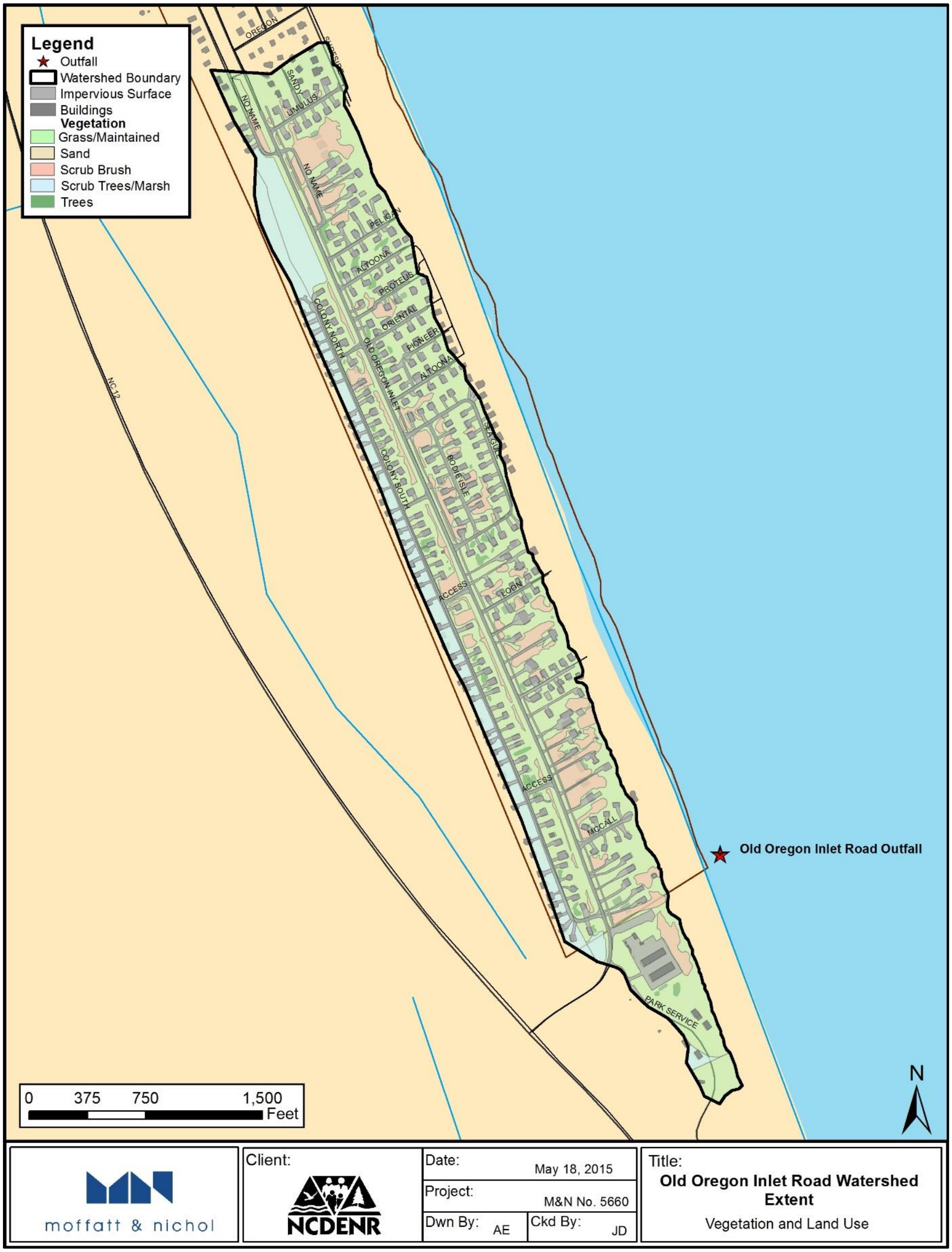


Figure 70. Old Oregon Inlet Road Watershed Vegetation Map

3.8.2 Watershed Results

S Nags Head/Old Oregon Inlet Road watershed is characterized by 115 acres of which 28.8% is impervious. The density of septic systems in this watershed is the second highest of the systems studied, with a septic density of 2.67 per acre. There is a total open channel length of 6,410 feet with a total length of drainage piping at 6,224 feet. Over the course of this project S Nags Head was monitored during 5 large storm events that occurred from summer 2007 through fall 2008. The storm summaries are presented in **Table 32**.

<u>June 3-4, 2007</u>
For the storm that occurred June 3-4, 2007, there was a total of 1.19 in of rainfall. There were three grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations recorded at 24,196 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 1,935 – 8,664 MPN 100 ml^{-1}. Maximum values recorded for *E. coli* occurred prior to the hydrograph's storm pulse. One value for Fecal *Bacteroides* spp. concentrations was recorded at 231 CE 100 ml^{-1}. This value is very close to the detection limit for the qPCR technology.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 1,483 gpm (3.30 cfs). The total *Enterococcus* and *E. coli* loads for this storm were 6.87×10^{11} and 8.62×10^{10} MPN or CE, which equates to loads of 2.22×10^{10} and 2.78×10^{9} MPN or CE per h based upon examined storm length of 29.75 hours. Similar to the data from other outfalls for this storm event, at Old Oregon Inlet Road, this event was characterized by high discharge concentrations, but very low hydraulic flow rates, so the FIB load rates were driven far more by concentration than flow.

<u>December 15-16, 2007</u>
For the storm that occurred December 15-16, 2007, there was a total of 2.68 in of rainfall. There were five grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 223 -24,196 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 5 – 1,500 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 541 – 134,133 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus* occurred at beginning of the storm event. The maximum value for *E. coli* occurred on rising limb of the discharge peak. The maximum value for Fecal *Bacteroides* spp. occurred before peak discharge.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 1,647 gpm (3.67 cfs). The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 3.20×10^{10}, 7.05×10^{10}, and 4.41×10^{11} MPN or CE respectively, which equates to loads 4.26×10^{9}, 9.39×10^{9}, and 5.88×10^{10} MPN or CE per h based upon examined storm length of 7.5 hours. Just as with the June 2007 storm event, this event was characterized by high discharge concentrations, but very low hydraulic flow rates.

<u>April 20-23, 2008</u>
For the storm that occurred April 20-23, 2008, there was a total of 3.11 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm event. *Enterococcus* concentrations ranged from 2,142 – 24,197 MPN 100 ml^{-1}, *E. coli*

concentrations ranged from 313 - 1,354 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 5 -8,945 CE 100 ml^{-1} over the course of the storm (**Figure 71**). The maximum values recorded for *Enterococcus* and *E. coli* occurred prior to rain event and the maximum Fecal *Bacteroides* spp. concentrations occurred on falling limb of first peak in hydrograph.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 3,060 gpm (6.82 cfs). The hydrograph had several pulses throughout this period. The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 1.05×10^{12}, 7.59×10^{10}, and 1.56×10^{12} MPN or CE respectively, which equates to loads of 1.59×10^{10}, 1.15×10^{9}, and 2.37×10^{10} MPN or CE per h based upon examined storm length of 66 hours.

In contrast to the examples provided in the Martin Street and Gallery Row watersheds regarding groundwater interaction, South Nags Head appears to be a system that is dominated by overland flow and tidal influence. The groundwater signal as observed in **Figure 71** is strongly tidally influenced, but the groundwater levels do not persist through the tail of the hydrographs for storms in a way similar to Gallery Row or Martin Street. In particular, it can be observed that Fecal *Bacteroides* sp. concentrations are lower in the South Nags Head system during this storm event in April 2008. Note also that when flows are decreasing from the outfall, because the tide is coming in, FIB levels have a tendency to decrease. This is likely due to increased dilution from the tidal flushing.

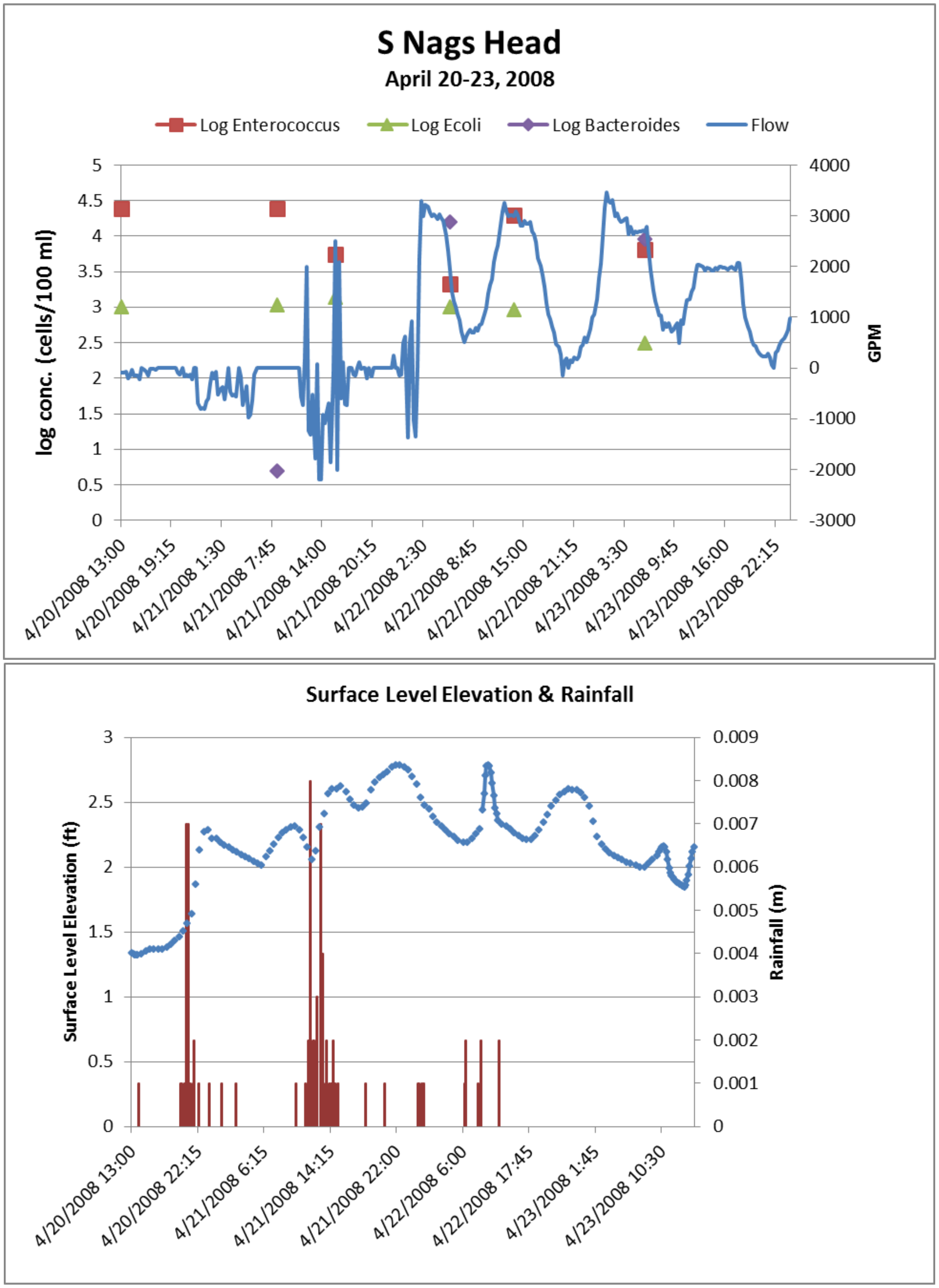


Figure 71. South Nags Head FIB Concentrations and Groundwater Surface Elevations for April 2007 Storm Event

<u>September 5-11, 2008</u>

For the storm that occurred September 5-11, 2008, there was a total of 2.40 in of rainfall. There were five grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 15,531 -51,720 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 548 – 5,172 MPN 100 ml^{-1}. Fecal *Bacteroides* spp. concentrations were not recorded for this event. It is interesting to note that the maximum values recorded for *Enterococcus* occurred at end of hydrograph, and the values measured were very high in concentration in exceedance of 50,000 MPN per 100 ml. The maximum value for *E. coli* occurred early during the storm record. The flow was measured for this storm, however no real baseline was established before this storm event. Peak measurements were recorded at 3,670 gpm (8.18 cfs). The hydrograph had several quick pulses of water throughout the recorded storms, and quickly returned to base flow after each pulse. The total *Enterococcus* and *E. coli* loads for this storm were 9.88 x 10^{12} and 8.07 x 10^{11} MPN or CE respectively, which equates to loads of 6.43 x 10^{10} and 5.25 x 10^{9} MPN or CE per h based upon examined storm length of 153.75 hours.

<u>November 4-7, 2008</u>

For the storm that occurred November 4-7, 2008, there was a total of 2.98 in of rainfall. There were seven grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 191 – 15,796 MPN 100 ml^{-1} and *E. coli* concentrations ranged from 1,178 – 3,873 MPN 100 ml^{-1}. No Fecal *Bacteroides* spp. analyses were conducted. There were several discharge peaks represented by the storm hydrograph with maximum values recorded for *Enterococcus* and *E. coli* occurring between third and fifth peaks of the hydrograph.

The flow for this storm was measured on the receding limb of the hydrograph and peak measurements were recorded at 5,710 gpm (12.72 cfs). The total *Enterococcus* and *E. coli* and loads for this storm were 2.44 x 10^{12} and 9.25 x 10^{11} MPN or CE respectively, which equates to loads of 3.40 x 10^{10} and 1.29 x 10^{10} MPN or CE per h based upon examined storm length of 71.75 hours.

Table 32. Old Oregon Summary Statistics

	# of Grab Samples	E. Coli Mean	E. Coli Range	Enterococcus Mean	Enterococcus Range	Bacteroides Mean	Bacteroides Range	Total Enterococcus Load	Total E. Coli Load	Total Bacteroides Load	Enterococcus Load	E. Coli Load	Bacteroides Load
Storm Date		(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)	cells	cells	cells	per hour	per hour	per hour
6/3-4/2007	3	4,558	1,935-,8,664	24,196	24,196	231	231	6.87×10^{11}	8.62×10^{10}	-	2.22×10^{10}	2.78×10^{9}	-
12/15-16/2007	5	334	5-1,500	9,074	223-24,196	56,103	541-134,133	3.20×10^{10}	7.05×10^{10}	4.41×10^{11}	4.26×10^{9}	9.39×10^{9}	5.88×10^{10}
4/20-23/2008	6	946	313-,.354	13,727	2,142-24,197	4,475	5-8,945	1.05×10^{12}	7.59×10^{10}	1.56×10^{12}	1.59×10^{10}	1.15×10^{9}	2.37×10^{10}
9/5-11/2008	5	2,294	548-5,172	26,594	15,531-51,720	-	-	9.88×10^{12}	8.07×10^{11}	-	6.43×10^{10}	5.25×10^{9}	-
11/4-7/2008	7	2,014	1,178-3,873	5,001	191-15,796	-	-	2.44×10^{12}	9.25×10^{11}	-	3.40×10^{10}	1.29×10^{10}	-

3.8.3 Watershed Strategies

The South Nags Head watershed is also one of the smallest four (at 115 acres) of the ocean outfall watersheds. The watershed is very narrow and centered around the Beach Road and immediate side roads, extending to the southernmost extent of Nags Head town limits where the National Park Service land begin. Land use in the watershed is dominated by medium density detached dwellings, so the watershed has a relatively high number of buildings (307), and associated septic systems, resulting in the second highest septic tank density, over 2.6 per acre. Groundwater data analysis presented in Section 2.2 indicates that one of the groundwater monitoring wells near the outfall (B-2) exhibited a high incidence of groundwater levels, dwelling 77% of the time in the top 1-3 feet of the soil profile (refer to **Table 6**). There was difficulty in qualifying the flow and pollutant behavior in this watershed, because the invert of the ditch that drains to the outfall is situated such that a free tidal exchange between the ocean and the ditch occurs through the outfall. The tidal signal can be readily seen in the monitoring results graphics presented for this outfall in **Figure 71** and Appendix D. Further complicating the hydrology of this watershed, the large ditch that runs along the Beach Road, forming the central spine of the drainage system, is connected to a pond in the marsh at the north end. Depending on the tidal influence at the south end, and the strength and direction of the wind, the majority of the ditch can flow in either direction, making the northern boundary of the watershed somewhat fluid.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- In this system, it is possible that overland ditch areas are utilized often by bird populations for feeding and resting. These high numbers of birds (and other wildlife) have been consistently observed in this area, and likely positively impact the *E. coli* and *Enterococcus* concentrations in the outfall discharge. No specific quantification of bird fecal contamination has been conducted on the discharge from this outfall to quantify the gull and seabird contributions to FIB loading, but this is a possible step for the future.
- The South Nags Head watershed has the relatively high count of septic systems for a smaller watershed because the landuse is dominated by detached residential structures, so continued diligent efforts to improve septic system maintenance and performance on the part of the Town of Nags Head's Septic Health Initiative would benefit this watershed.
- Given the importance of surface water influences in this watershed, management efforts should also focus on buildup/washoff mechanisms of FIB delivery. Retrofitting of diffuse landscape-integrated BMPs such as the high –rate infiltration sand filters discussed in Section 4.1 or other such BMPs typically associated with low impact development, such as bio-retention cells would be desirable. Almost no empty lots exist in the watershed, so retrofit sites would be limited to street right-of-ways and other tight spaces. GIS inventory data indicates the presence of a drain pipe running along the east side of the Beach Road opposite the main ditch. The right-of-way space between the road and the multi-use path on that east side is wide, such that it would likely accommodate a series of high rate sand filter (or other infiltration BMPs) that would provide treatment and break up that flow path.

- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 be effective in reducing bacterial pollution loads, the possibility of implementing such a system in the South Nags Head watershed is aided by the presence of National Park Service Land all along the western border of the watershed where the drawdown effluent could be discharged. However, discharge of stormwater effluents to these wetland areas would require consent and appropriate easements from the Park Service, and would likely involve an extensive environmental permitting process. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIBs are extremely high whereas hydraulic flow rates are relatively low, making it readily possible to deploy pump systems capable of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.
- Should rehabilitation and improvement of the Conch Street BMP eventually produce more successful results in terms of bacterial pollutant treatment, it is important to note that the South Nags Head outfall has feasible land area suitable for application of a single BMP to treat the entire watershed, but it would have to be located on land currently help by the National Park Service. Application of such a BMP would require an engineered solution to address the potential for tidal interference with the performance of the BMP (a noted challenge at Conch Street), and consent and appropriate easements or outright land acquisition from the Park Service.

3.9 Whalebone Junction Watershed

The Whalebone Junction watershed is comprised of an area approximately 61 acres. Land use in the area is mostly developed, with a mixture of residential and commercial facilities. A map illustrating the extent of the watershed and the distribution of key features and infrastructure within it is shown in **Figure 72**.

3.9.1 Watershed Characterization

Impervious
The Whalebone watershed contains approximately 22.3 acres of impervious surfaces, which is approximately 36.6% of the total watershed area. Impervious surface types consist of roads, driveways, parking lots, and sidewalks. There are 116 buildings with 5 acres of building footprint, which is approximately 8% of the total watershed area. Buildings within the watershed area are primarily residential or commercial.

Septic Density
For the purpose of this watershed characterization, the total number of buildings will be the basis for an estimation of septic density for the watershed. It is likely there are some buildings that have more than one septic system and others that have none or use other proprietary systems. Assuming that each building has one on-site septic system, the estimated septic number of septic systems for the Whalebone watershed is 116, which equates to an estimated density of 1.90 systems per acre. There were no documented repairs or new septic systems installed within the Whalebone watershed boundary.

Soils
A summary of soils within the Whalebone Junction watershed is provided in **Table 33**. There are 34 acres of hydric soils within the watershed boundary and approximately 27 acres of non-hydric soils within the watershed. Hydric soils are generally located in the easternmost half of the Whalebone watershed, with non-hydric soils located mostly in the western half. In areas where hydric soils underlay dense development, interactions between groundwater and septic systems are likely high. See **Figure 73** for Whalebone watershed soils mapping.

Table 33. Whalebone Junction Watershed Soils Summary

Soil Type	Hydric	Acres	Percent Area (%)	Drainage and Permeability
Newhan-Urban Land Complex, 0-10 percent slopes	Yes	33.9	56	Excessively drained; very slow runoff; rapid permeability
Newhan Fine Sand, 0-10 percent slopes	Yes	0.03	<1	Excessively drained; very slow runoff; rapid permeability
Beaches-Newhan Complex, 0-25 percent slopes	Yes	0.24	<1	Excessively drained; very slow runoff; rapid permeability
Corolla Fine Sand, 0-6 percent slopes	Yes	23.5	38	Moderately well and somewhat poorly drained; slow runoff; very rapid permeability.
Duckston Fine Sands	Yes	3.61	6	Poorly drained; very slow runoff; very rapid permeability above the water table.

Vegetation

The Whalebone Junction watershed contains approximately 5 acres of scrub brush, and no significant wooded habitat or clusters of trees. The remaining fragmented vegetated areas within the watershed are primarily grassed. Patterns of vegetation are mapped in **Figure 74**.

Groundwater

There are no groundwater monitoring wells installed within the Whalebone watershed.

Drainage Systems and Infrastructure

The Whalebone Junction watershed contains approximately 875 feet of open channel ditching and approximately 313 linear feet of piping. Drainage infrastructure and open channel ditching is minimal in the Whalebone Junction watershed. Drainage network spatial data and detailed contours of the Whalebone Junction watershed indicate that there is approximately 15 acres of the watershed drained by piping and open channel ditches. This area represents approximately 25% of the total watershed area.

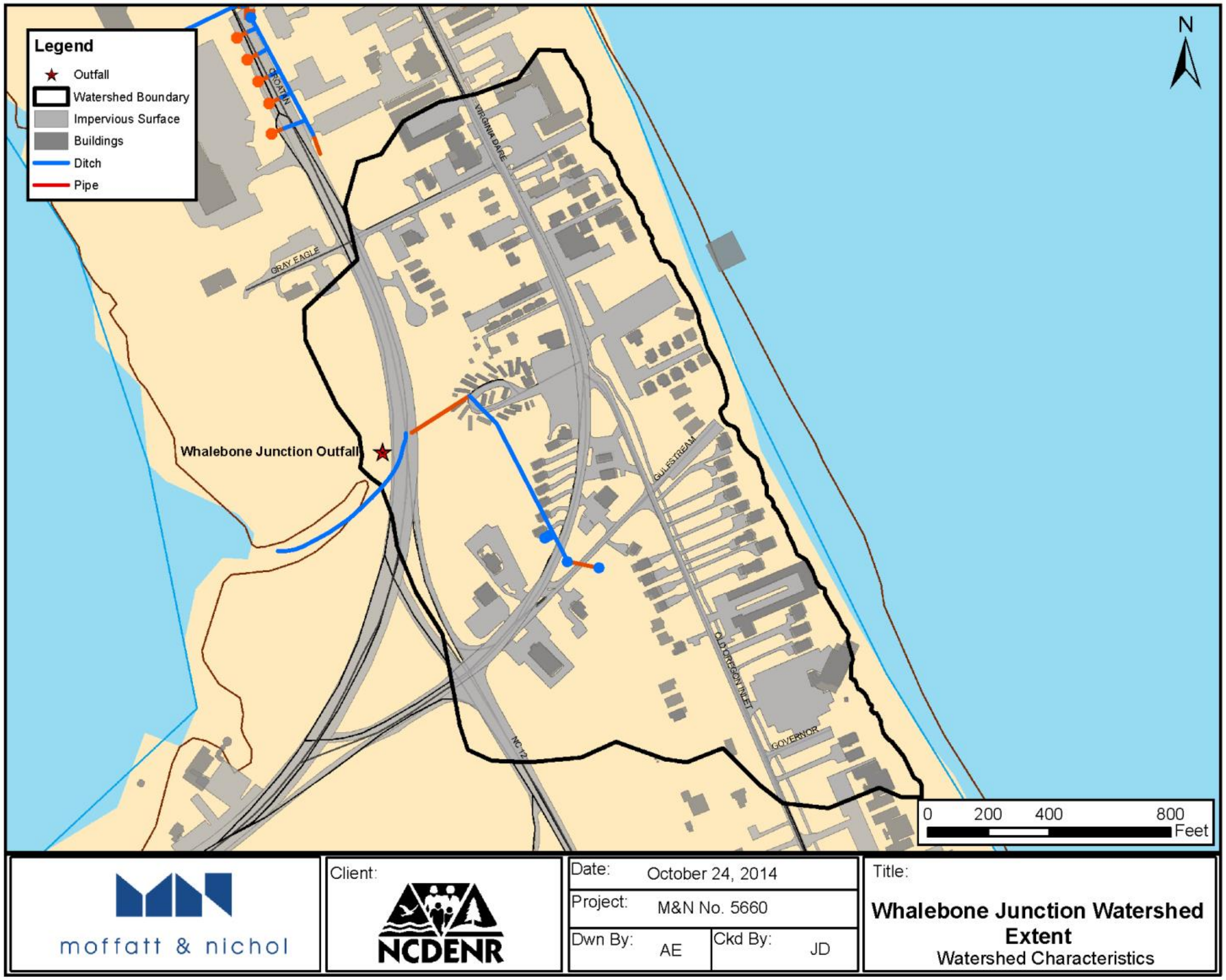


Figure 72. Whalebone Junction Watershed Extent Map

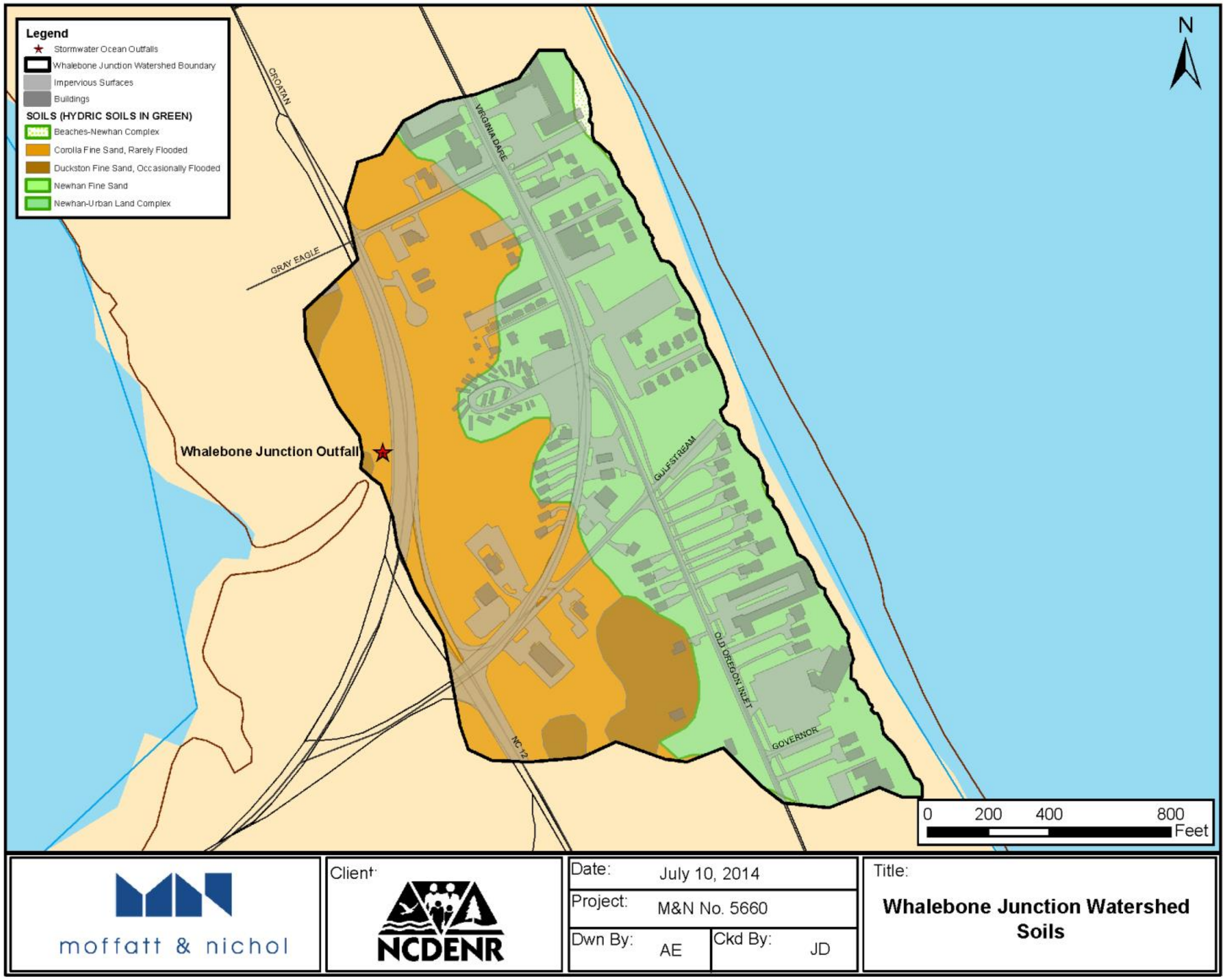


Figure 73. Whalebone Junction Watershed Soils Map

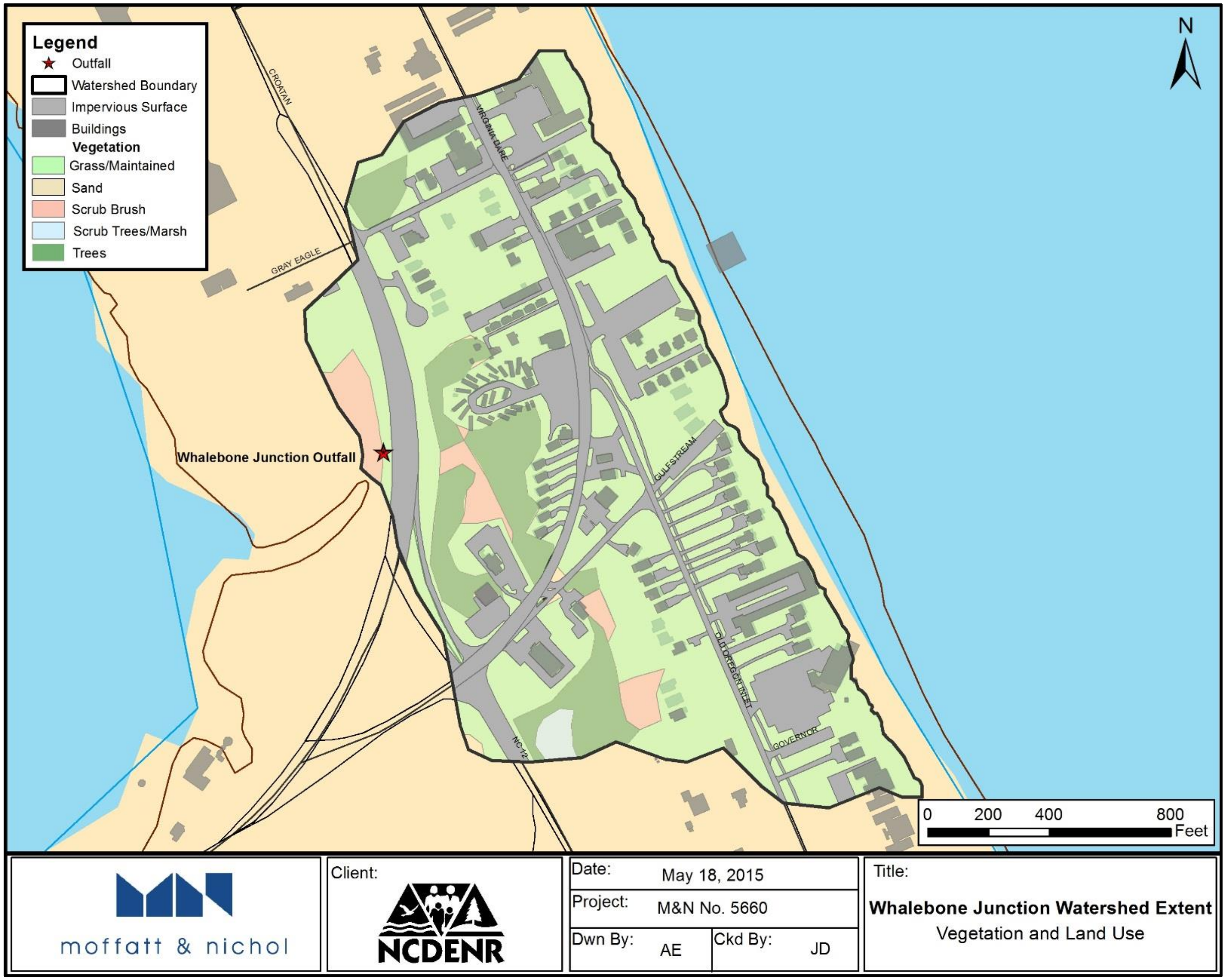


Figure 74. Whalebone Junction Watershed Vegetation Map

3.9.2 Watershed Results

Whalebone Watershed is characterized by 61 acres of which 36.6% is impervious. Septic density is 1.90 per acre. Over the course of this project Whalebone was monitored during five large storm events that occurred from summer 2007 through fall 2008. The storm summaries are presented in **Table 34**.

<u>June 3-4, 2007</u>
For the storm that occurred June 3-4, 2007, there was a total of 1.19 in of rainfall. There were three grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 1,782 – 15,531 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 650 – 1,014 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 14,544 – 52,817 CE 100 ml^{-1}. Maximum values recorded for *Enterococcus* occurred at end of storm event. The maximum *E. coli* and Fecal *Bacteroides* spp. Concentrations occurred prior to the storm's maximum discharge.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 2,557 gpm (5.70 cfs). The total *Enterococcus, E. coli* and Fecal *Bacteroides* spp. loads for this storm were 3.58×10^{10}, 6.89×10^{9}, and 1.52×10^{10} MPN or CE, which equates to loads of 1.09×10^{9}, 2.10×10^{8}, and 4.65×10^{8} MPN or CE per h based upon examined storm length of 32.75 hours.

<u>December 15-16, 2007</u>
For the storm that occurred December 15-16, 2007, there was a total of 2.47 in of rainfall. There were five grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 5 – 5,172 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 5 - 905 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. values ranged from 72,803 – 476,541 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus* and *E. coli* occurred on rising limb of hydrograph. The maximum value for Fecal *Bacteroides* spp. occurred before rising limb of hydrograph.

Flow was measured for this storm and started at a baseline measurement of 0 gpm and peak measurements were 3,380 gpm (7.53 cfs). The total *Enterococcus, E. coli* and Fecal *Bacteroides* spp. loads for this storm were 4.96×10^{9}, 3.82×10^{9}, and 1.12×10^{12} MPN or CE respectively, which equates to loads of 5.22×10^{8}, 4.02×10^{8}, and 1.18×10^{11} MPN or CE per h based upon examined storm length of 9.5 hours.

<u>April 20-23, 2008</u>
For the storm that occurred April 20-23, 2008, there was a total of 3.08 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm event. *Enterococcus* concentrations ranged from 247 – 2,382 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 110 – 6,867 MPN 100 ml^{-1} and Fecal *Bacteroides* spp. concentrations ranged from 1,891 – 40,064 CE 100 ml^{-1} over the course of the storm. The maximum values recorded for *Enterococcus* and *E. coli* occurred on falling limb of hydrograph. The Fecal *Bacteroides* spp. maximum concentration occurred prior to first peak in hydrograph.

Flow was measured for this storm and started at a baseline measurement of less than 70 gpm (0.16 cfs) and peak measurements were 3,090 gpm (6.89 cfs). The total *Enterococcus*, *E. coli* and Fecal *Bacteroides* spp. loads for this storm were 5.75×10^{10}, 1.46×10^{11}, and 9.97×10^{11} MPN or CE respectively, which equates to loads of 8.95×10^{8}, 2.27×10^{9}, and 1.55×10^{10} MPN or CE per h based upon examined storm length of 64.25 hours.

<u>September 5-11, 2008</u>

For the storm that occurred September 5-11, 2008, there was a total of 2.32 in of rainfall. There were five grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 1,076 – 17,620 MPN 100 ml^{-1}, *E. coli* concentrations ranged from 8,664 – 92,080 MPN 100 ml^{-1}. Fecal *Bacteroides* spp. was not measured for this event. The maximum values recorded for *Enterococcus* occurred prior to storm hydrograph's rising limb. The maximum value for *E. coli* occurred September 10, 2008, three days after major storm pulse.

Flow was measured for this storm and started at a baseline measurement of <50 gpm (<0.1 cfs) and peak measurements were 4,710 gpm (10.49 cfs). The total *Enterococcus* and *E. coli* load for this storm were 4.61×10^{11} and 2.90×10^{12} MPN respectively, which equates to loads of 3.19×10^{9} and 2.01×10^{10} MPN per h based upon examined storm length of 144.50 hours.

<u>November 4-7, 2008</u>

For the storm that occurred November 4-7, 2008, there was a total of 4.56 in of rainfall. There were six grab samples collected for microbial contaminant measurements over the course of the storm. *Enterococcus* concentrations ranged from 373 – 10,170 MPN 100 ml^{-1} and *E. coli* concentrations ranged from 221 – 5,794 MPN 100 ml^{-1}. No Fecal *Bacteroides* spp. was measured. The maximum values recorded for *Enterococcus* and *E. coli* occurred on hydrograph's falling limb.

Flow was measured for this storm and started at a baseline measurement of <50 gpm (<0.1 cfs) and peak measurements was 2,950 gpm (6.57 cfs). The total *Enterococcus* and *E. coli* and load for this storm were 1.59×10^{11} and 8.91×10^{10} MPN respectively, which equates to loads of 2.85×10^{9} and 1.60×10^{9} MPN per h based upon examined storm length of 55.75 hours.

Table 34. Whalebone Summary Statistics

Storm Date	# of Grab Samples	E. Coli Mean (cells/100ml)	E. Coli Range (cells/100ml)	Enterococcus Mean (cells/100ml)	Enterococcus Range (cells/100ml)	Bacteroides Mean (cells/100ml)	Bacteroides Range (cells/100ml)	Total Enterococcus Load cells	Total E. Coli Load cells	Total Bacteroides Load cells	Enterococcus Load per hour	E. Coli Load per hour	Bacteroides Load per hour
6/3-4/2007	3	884	650-1,014	7,294	1,782-15,531	1,723	187-4,135	3.58×10^{10}	6.89×10^{9}	1.52×10^{10}	1.09×10^{9}	2.10×10^{8}	4.65×10^{8}
12/15-16/2007	6	289	5-905	927	5-5,172	208,792	72,803-476,541	4.96×10^{9}	3.82×10^{9}	1.12×10^{12}	5.22×10^{8}	4.02×10^{8}	1.18×10^{11}
4/20-23/2008	6	2,155	110-6,867	1,137	247-2,382	15,171	1,891-40,064	5.75×10^{10}	1.46×10^{11}	9.97×10^{11}	8.95×10^{8}	2.27×10^{9}	1.55×10^{10}
9/5-11/2008	5	30,187	8,664-92,080	84,885	1,076-17,620	-	-	4.618×10^{11}	2.90×10^{12}	-	3.19×10^{9}	2.01×10^{10}	-
11/4-7/2008	6	1,676	221-5,794	3,926	373-10,170	-	-	1.59×10^{11}	8.91×10^{10}	-	2.85×10^{9}	1.60×10^{9}	-

3.9.3 Watershed Strategies

The Whalebone Junction watershed is the second smallest (at 61 acres) of the ocean outfall watersheds. Much of the watershed is developed with commercial land uses predominant, resulting in almost 37% impervious cover. For a small watershed, there is a relatively high number of buildings (116) and associated septic systems, and the density of these systems is relatively high (at 1.9 per acre). Because the Whalebone Junction watershed was added to the study some time after it commenced, no groundwater monitoring wells were installed in this watershed. The Whalebone Junction outfall is the only one in this study that discharges to the sound side of the barrier island. It should be noted, that due to the configuration of the outfall, wind tides often result in reverse flow. Potentially due in part to this fact, the lower portions of this watershed, predominantly along the beach road, experience frequent flooding. It is also interesting to note that the Whalebone Junction outfall exhibits unusually high flows for the second smallest watershed. The hydraulic flows may owe to somewhat dense patterns of development and a highly connected artificial drainage network. However, only limited mapping data is available to accurately characterize that network.

With these traits and patterns in mind, there are some important factors and potential opportunities which should be taken into account in the efforts to manage bacterial pollution from this outfall:

- The Whalebone Junction watershed has the relatively high count of septic systems for a smaller watershed, so continued diligent efforts to improve septic system maintenance and performance on the part of the Town of Nags Head's Septic Health Initiative would benefit this watershed.
- There are a several large on-site septic systems that serve large commercial facilities, hotels and multi-family resort properties in the watershed, and given that these systems are located in near vicinity to the outfall, improvements in their operation and performance may generate tangible benefits.
- Given the extent of impervious surfaces in this watershed, management efforts should also focus on buildup/washoff mechanisms of FIB delivery. Opportunities for retrofitting diffuse landscape-integrated BMPs such as the high–rate infiltration sand filters discussed in section 4.1 or other such BMPs typically associated with low impact development, such as bio-retention cells exist in the watershed. However, available sites in suitable hydrologic locations such they would treat runoff from a significant amount of impervious surface are difficult to find and almost no mapped inventory data for the storm drain infrastructure exists to facilitate that search.
- Should pilot tests show that groundwater drawdown systems such as those presented in Section 4.2 be effective in reducing bacterial pollution loads, the possibility of implementing such a system in the Whalebone Junction watershed is aided by the presence of land already owned by the Town of Nags Head, located immediately west of the watershed on the other side of the Bypass where the drawdown effluent could be discharged. Groundwater drawdown systems show promise as a management strategy for this outfall because discharge concentrations of FIBs are extremely high whereas hydraulic flow rates are relatively low, making it readily possible to deploy pump systems capable

of keeping up with hydraulic volumes during storm events. This suitability is discussed in greater detail in Section 4.2.

3.10 Comparison of All Watersheds

In the interest of better understanding how the metric presented in this section vary across the outfall watersheds studied, several of the key metrics are presented here for all watersheds. Individual metrics are compared and discussed below, followed by a comprehensive discussion of FIB monitoring data from all outfalls, and then all the metric and monitoring data are presented comprehensively in **Table 35** at the end of the section.

<u>Impervious</u>

Impervious cover by watershed is shown in **Figure 75**. The average percentage of impervious surfaces across all watersheds is 29.37. The East Lake Drive, Whalebone, Old Oregon Inlet Road, Baum Street, and Gallery Row "Carolinian" watersheds all contain a higher-than-average percentage of impervious surfaces, with East Lake Drive at 48.5%, which is the highest imperviousness. Martin Street and Soundside Road watersheds are only slightly below the average, and Curlew and Conch Street watersheds are well below the average, with Conch Street, at 14% impervious being the lowest.

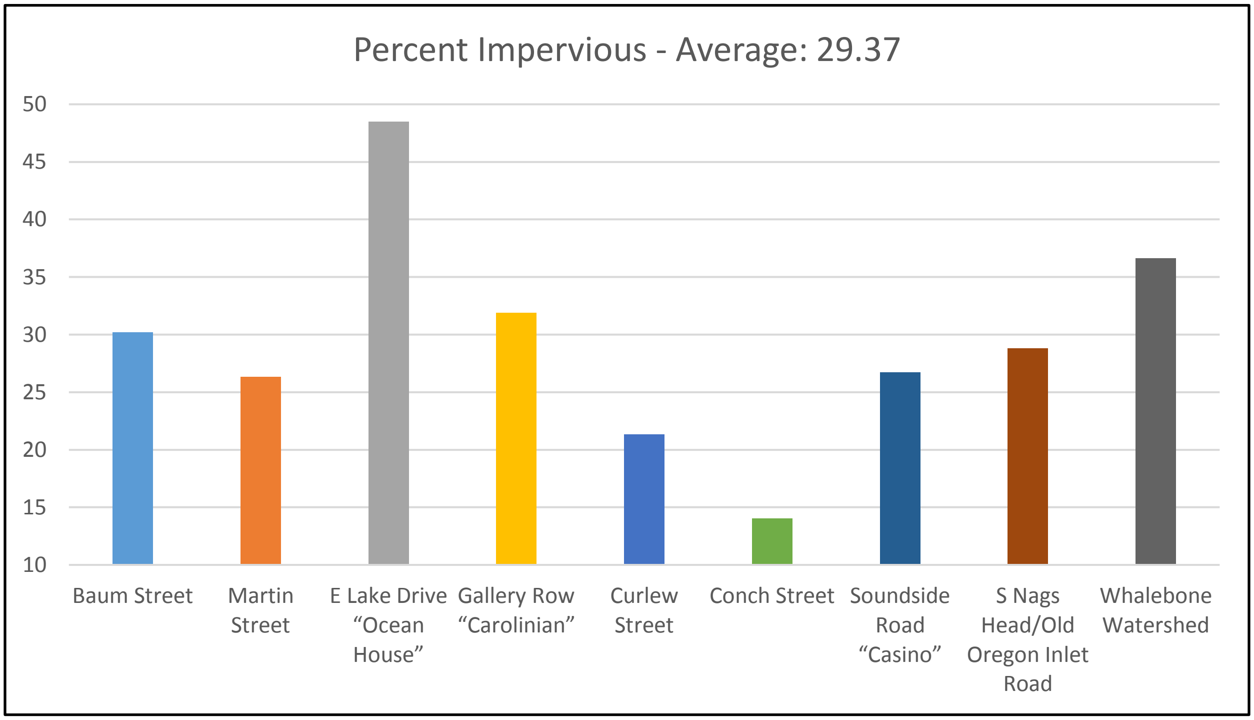


Figure 75. Percent Impervious Per Watershed

Septic System Repairs

The numbers of on-site septic system repairs per watershed are shown in **Figure 76**. The Gallery Row "Carolinian" watershed had the highest amount of septic system repairs from 2006 to 2012, with 104 repair permits issued for the watershed. These high numbers are a possibly function of a few key factors. First, the Town of Nags Head has an active Septic Health Initiative that's seeks to proactively identify poorly performing systems and affect improvements, and the Gallery Row watershed is almost entirely contained within Nags Head, The Gallery Row watershed also has a relatively high number of septic systems per acre in comparison to the other watersheds.. Poor performance of septic systems in Gallery Row may also be a function of geography. By virtue of the distribution of the developed areas of the watershed, Gallery Row has a high number and density of septic systems located in the lowest portion of the barrier island topography, the trough behind the primary dune line. The groundwater level analyses in Section 2.2 have shown that Gallery Row has the highest incident of groundwater levels in the top 3 feet of the soil profile, resulting in frequent saturation of the on-site systems with groundwater. For example, in the trough behind the primary dune line, leach fields are contained within soils that have groundwater levels within three feet of the surface 90% of the time. This is problematic because the thickness of the unsaturated soils of a leach field typically dictate the efficacy of treatment of the septic system. Of note, Gallery Row watershed did not have the highest total for new system installs. The Martin Street watershed had the highest number of new system installs with 31 new systems from 2006 to 2012. The watershed with the lowest number of repairs as well as new system installs was the Soundside Road watershed, with 11 repairs and only one new system installed from 2006 to 2012, which is mostly a function of the size of the watershed and the small number of systems within it. There were no records available or no repairs or new systems permitted for the Old Oregon Inlet Road and Whalebone watersheds.

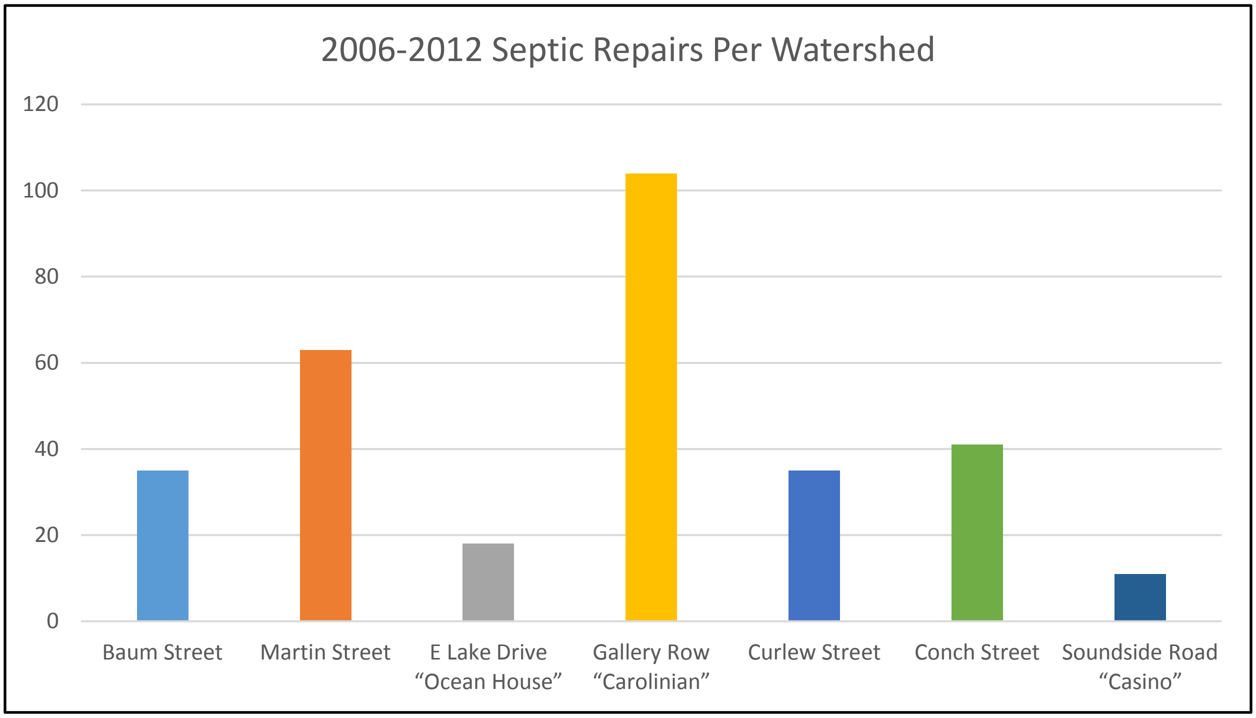


Figure 76. 2006-2012 Septic Repairs Per Watershed

<u>Soils</u>

The percentage area of hydric soils per watershed is shown in **Figure 77**. For most watersheds, the watershed area is mostly comprised of hydric soils. The Curlew Street watershed area contains only about 32% hydric soils, with the Old Oregon Inlet Road and Whalebone watersheds containing only about 47% and 56% hydric soils respectively. The potential for groundwater interaction with septic systems in these watersheds is reduced due to a lesser likelihood of groundwater being within the top foot of soil for most of the watershed area. Locations of hydric soil areas within these watersheds does matter, however, in that if hydric soil areas are located in areas of dense development, the potential for groundwater interaction with septic systems could still play a significant role in bacteria loads at the outfall site for the watershed.

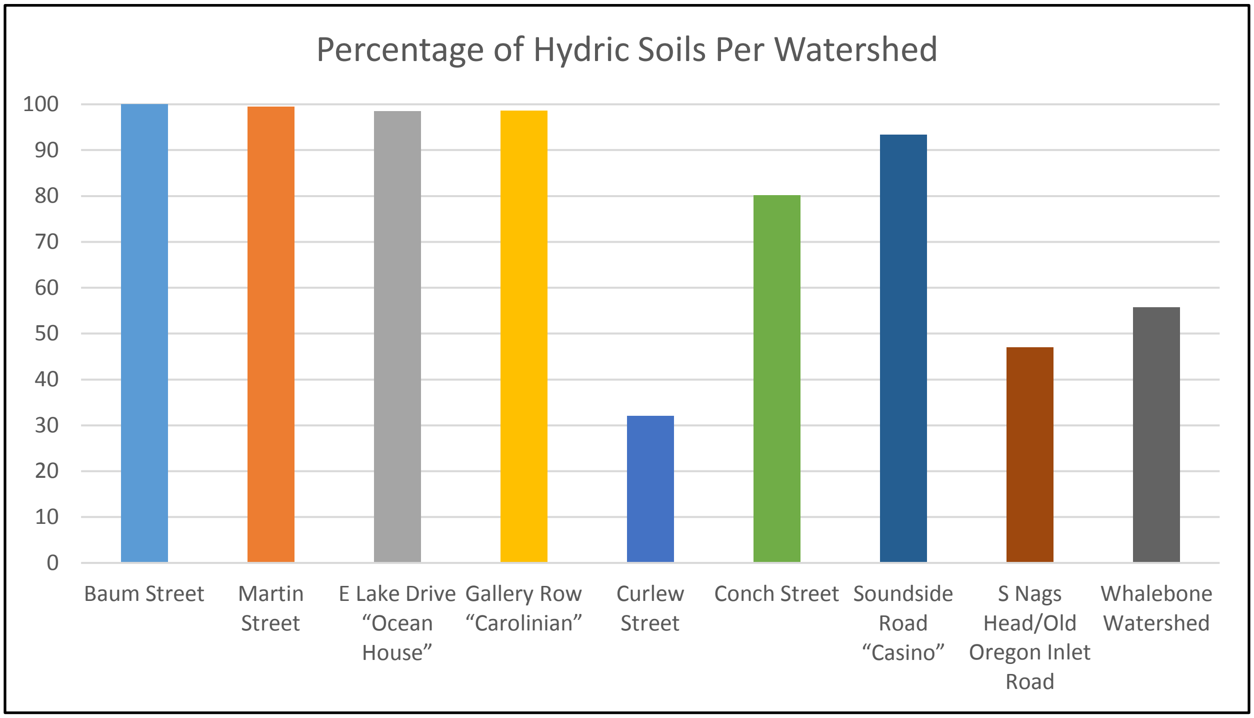


Figure 77. Percentage of Hydric Soils Per Watershed

<u>Vegetation</u>

The percent area of each watershed covered by forested (or partially forested) land is shown in **Figure 78**. Note that this data represents conditions near the initiation of this study. Aerial photography was digitized and georeferenced to create this data in the period of 2006-2007, and rapid coastal development has significantly altered the patterns of vegetative cover in several of the outfall watersheds Vegetation type within the watershed may have an effect on bacteria loads and volume of stormwater runoff in that areas of dense vegetation such as forests increase drawdown of surface water runoff by slowing flows, offering greater opportunity for infiltration and uptake of water by evapotranspiration. The watersheds with the lowest percentage of forested area compared to total watershed area are the Soundside Road (3%), Old Oregon Inlet (4%), East Lake (8%), and Baum (9%). The watershed with the highest percentage of forested vegetation relative to total watershed area is the Martin Street watershed at approximately 38% of the watershed.

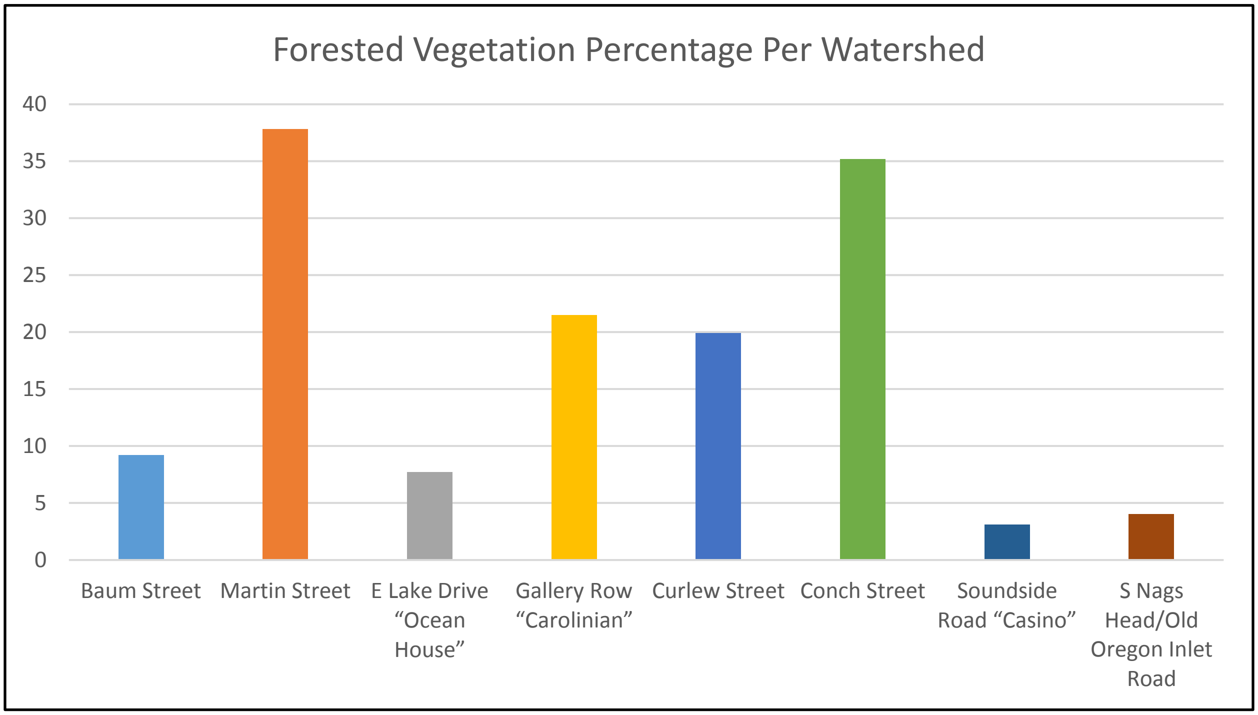


Figure 78. Forested Vegetation Percentage Per Watershed

<u>Groundwater-Septic System Interaction</u>

The percentage of groundwater monitoring data that had groundwater within 0 to 3 feet of the ground surface is shown in **Figure 79**. It should be noted that, of the two or three wells within the well transect associated with each outfall, the well with the highest incidence of groundwater within the top 0 to 3 feet of the soil profile was chosen. These worst-case scenario wells are typically located in the topographic trough behind the primary dune line that tends to be the lowest point, or controlling elevation, draining to the adjacent ocean outfall. It is the well nearest to the "bottom of the bowl" in each watershed. Soundside Road (well B-5) and Gallery Row (well B-13) had the greatest percentages of groundwater data within 0 to 3 feet of the ground surface (94.7% for Soundside Road and 89.6% for Gallery Row). Groundwater – septic system interaction would be expected to be very likely in these two watersheds, because of decreased function of the leach field associated with saturation of the soils typically relied upon to provide removal and reduction of nutrients and microbial contaminants associated with fecal contamination. The wells with the lowest percentage of groundwater monitoring data that had groundwater within 0 to 3 feet of the ground surface were the East Lake watershed (39.5% of the data) and the Martin Street watershed (39.8% of the data). Although the overall percentages were lower, it is important to note that much of the data that shows groundwater within 0 to 3 feet of the ground surface are from wells located areas of dense residential and commercial development. Therefore, the potential for groundwater – septic system is an important factor dictating loading of FIB in these watersheds. **Given the data collected as part of this project, a thorough retrospective assessment of groundwater/FIB loading interactions is possible. However, this was not a goal of the originally funded project. Conducting this assessment would be a monumental step forward**

in understanding the potential benefits to septic system retrofits and new septic system engineering requirements in this area.

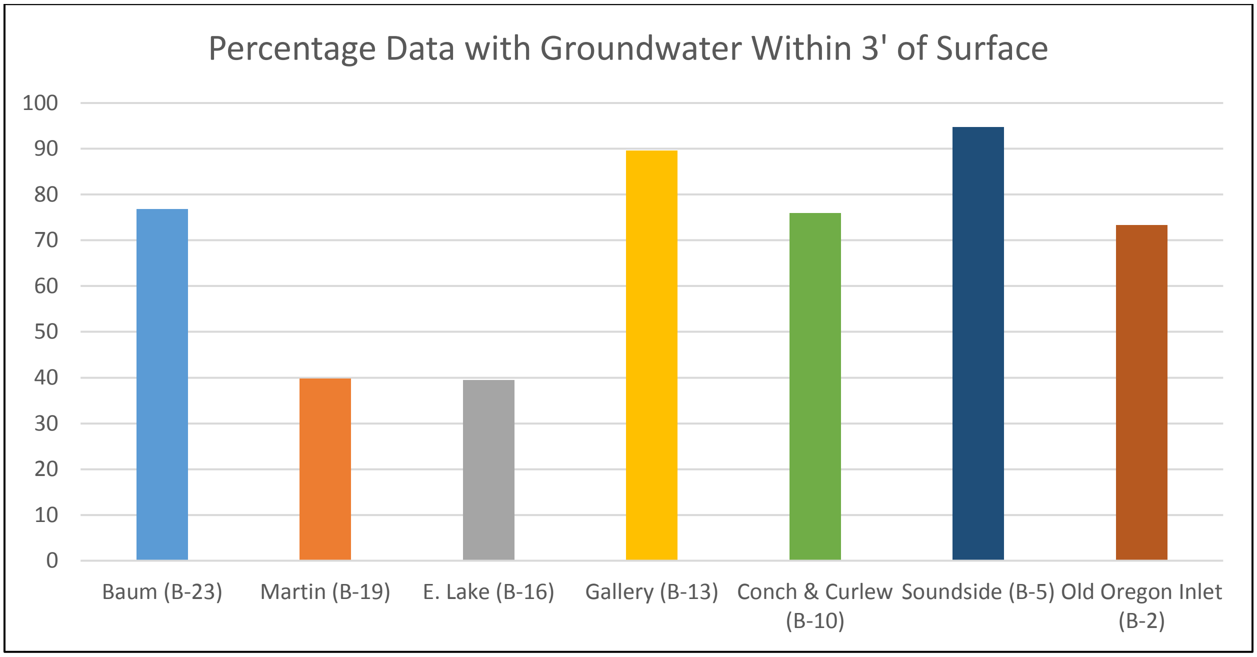


Figure 79. Percentage Data with Groundwater Within 3’ of Surface

Drainage Systems and Infrastructure

The amount of open channel ditching and drainage infrastructure in a watershed has an effect on how surface water moves or in some cases, does not move throughout a watershed. The total length of artificial drainage infrastructure (drainage ditches plus storm drain piping) per watershed is shown in **Figure 80**. The amount and location of ditching and piping may play a role in how fast and how much polluted stormwater reaches outfalls. The amount of ditching and piping will also dictate the shape of the hydrograph for different types of storms. The artificial drainage infrastructure in each of these watersheds acts to short-circuit the natural drainage patterns that would infiltrate runoff, slow its movement through the system and provide natural treatment. The watersheds with the greatest total linear feet of open channel ditch are the Baum Street (16,020 linear feet) and Gallery Row “Carolinian” (12,618 linear feet) watersheds. The watersheds with the lowest total linear feet of open channel ditch are the Soundside Road (523 linear feet), East Lake Drive (633 linear feet) and Whalebone (875 linear feet) watersheds. The Baum Street, Martin Street, East Lake Drive, and Gallery Row “Carolinian” watersheds have well-developed drainage piping with total linear footage ranging from 11,799 to 60,598 linear feet. The Martin Street watershed has the highest total linear feet of drainage piping. The watershed with the greatest combined drainage infrastructure (ditches and piping) is Martin Street (70,419 linear feet of combined artificial drainage) and the watershed with the lowest combined drainage infrastructure is the Whalebone watershed (1,188 linear feet). It should be stressed that these numbers are based on the “known” drainage infrastructure, or that which has been mapped. Much of the artificial drainage infrastructure in the ocean outfall watershed is unmapped. **A thorough asset inventory**

of artificial drainage would greatly enhance stormwater management options going forward and allow for more effective identification of BMP retrofit opportunities.

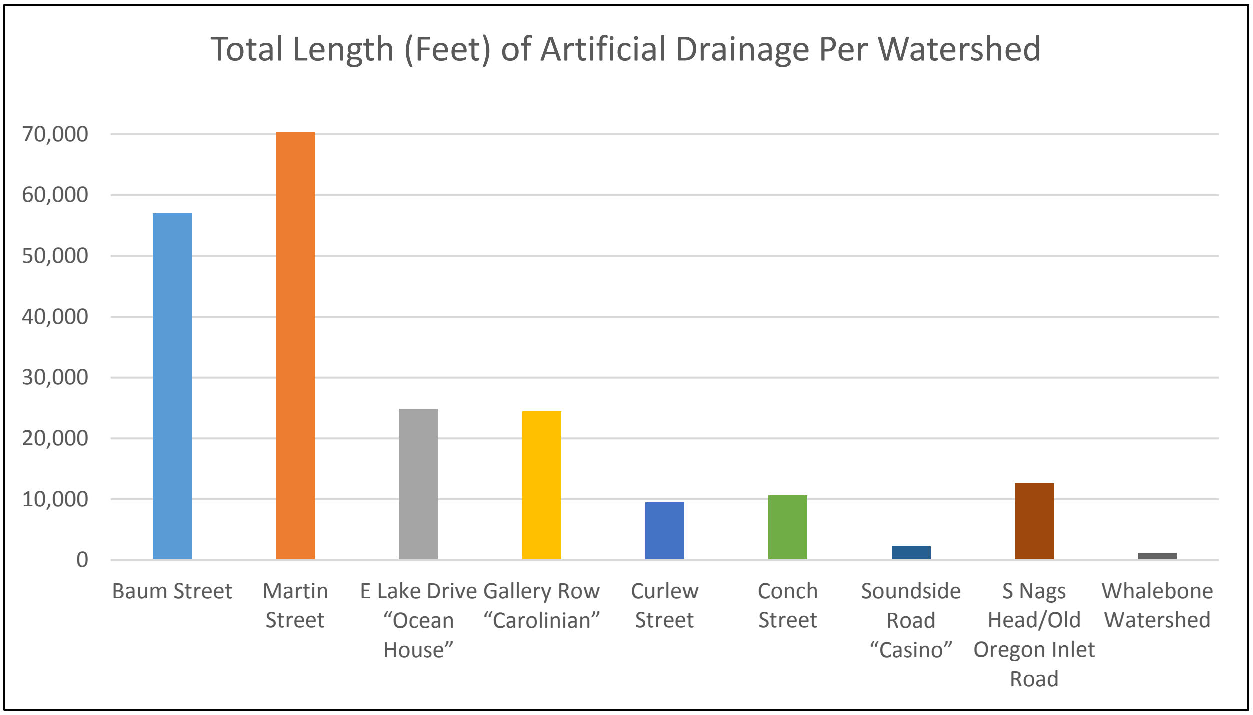


Figure 80. Total Length (ft) of Artificial Drainage Per Watershed

Summary of Outfall Findings

From 2006-2008, stormwater outfalls were characterized during storm events using a state-of-the art flow assessment and FIB/source marker study design. Briefly, during any given storm, rates of discharge (reported throughout in gallons per minute, gpm) were measured in real-time, along with environmental parameters including temperature, salinity, rainfall, and turbidity concomitantly measured. The storm event sampling response was highly adaptive, with a grab sampling approach utilized for all nine outfalls, initiated at the onset of rainfall, and continued as frequently as possible throughout the entire storm hydrograph (past the falling limb into the tail of the hydrograph). Therefore, depending on storm intensity and duration, a minimum of two grab samples were taken, with a maximum of seven grab samples collected over the duration of an event**. This project was multi-disciplinary in nature and the extensive data collected of stormwater-based microbial contaminant delivery over the duration of this project has yielded insights into the complexity of stormwater delivery mechanisms in coastal dune environments.**

Rainfall totals for the storms characterized over the duration of the study ranged from 1.19 to 3.89 inches, sometimes with multiple individual rainfall events within a longer total storm event period (up to 3 or 4 days total). Microbial contaminant concentrations in outfall discharges during storm events from all nine stormwater monitoring locations exceeded existing recreational beach water quality standards in nearly all samples collected (NC State Standard: *Enterococcus* 104 MPN or CFU per 100 ml), sometimes exceeding the standard by two orders of magnitude (e.g. >24,196 MPN per 100 ml). For example, the mean Enterococcus value exceeded the single sample recreational water quality standard across all but two storm sampling events shown on Table 34 (exceeded 95% of the time). Additionally, even though the State of NC does not utilize *E. coli* active management of marine recreational water quality, *E. coli* concentrations demonstrated similar patterns for all outfalls during all storms. Loading of *Enterococcus* spp. and *E. coli* was assessed using the combined flow and grab sample concentration data.

During longer storm events (>24 hours), loading of *Enterococcus* and *E. coli* ranged from 10^{10} - 10^{12} cells per hour (flows in exceedance of ca. 1,000 gpm or 2.2 cfs). During shorter or less intense storms, loading of *Enterococcus* spp. and *E. coli* was lower, generally ranging from 10^7-10^9 cells per hour (e.g. Gallery Row, December 2007 storm, maximum flow of 227 gpm or 0.5 cfs). Rainfall events were captured over all four seasons, and over a range of conditions, permitting an examination of conditions where groundwater levels were strongly influenced by the intensity and duration of precipitation. Concentrations of FIB, in particular *Enterococcus* spp., were very high (>10,000 MPN per 100 ml) at all outfalls for almost all of the storms measured is important. However, there are three additional salient points that can be drawn from this study that are important for future consideration of this issue.

- A "first flush" dynamic of FIB was not observed. "First flush" type delivery was not observed for concentrations or for loading patterns of FIB. At the onset of storms, FIB concentrations in outfall discharges were generally above the state standard, and either remained similar, or increased over the course of the storm. For example, at the South Nags Head outfall, during the storm from September 5-11, 2008, 2.4 inches of rain fell.

Over the duration of this prolonged storm event, flows reached a maximum of nearly 3700 gpm (8.2 cfs), with five total grab sampling events occurring over the duration of the storm. At the onset of this storm, *Enterococcus* and *E. coli* concentrations were ca. 15,000 and 4,000 MPN per 100 ml respectively. The concentrations of Enterococcus sp. over the course of these five samples collected over the duration of the storm ranged from 15,531-51,720 MPN per 100 ml. These values are over 100 times the state standard for recreational water quality use.. The total loading observed for this single storm was 9.88 x 10^{12} *Enterococcus* cells.

- Fecal *Bacteroides* spp. levels and measurements of HF183 human specific marker (where conducted) indicate the potential for human fecal contamination to be present in outfall discharges. Taken together, the FIB and Fecal *Bacteroides* spp. observed together indicate a potential risk to human health from the stormwater outfalls studied, even during some of the smaller storm events.
- Extensive groundwater, septic system, and antecedent rainfall analyses have not yet been completed. However, our initial information appears to indicate that specific watersheds (for example Martin Street, Baum Street, and Gallery Row) appear to suffer from a groundwater/surface water interaction that is exacerbated during larger storms. In these specific systems, groundwater levels increase rapidly during the rising limb of the hydrograph, and stay high through storm sampling periods and through the tail of the hydrograph. This indicates a likely connection, late in storm events, with the groundwater, possible compromising the function of septic systems in watersheds with high septic system densities. For example in Gallery Row, during the period of study, the groundwater level at one of the groundwater monitoring locations was above the ditch invert level for 90% of the study. In moving forward, it will be important for the groundwater/septic system interaction to be quantitatively assessed.

The combination of grab sampling and flow information collected throughout this prioritization period of the study permitted a ranking of the outfall systems based upon attributes such as 1) *Enterococcus* sp. concentrations observed in discharge, 2) *Enterococcus* loading, and 3) hydrological characteristics. It was this prioritization that permitted the BMP assessment and upcoast/downcoast portions of this project to focus on specific areas for more thorough evaluation.

<u>Region and Outfall Specific Findings</u>

In the interest of exploring potential relationships among data collected over the duration of this project, the key watershed characteristics discussed in this chapter are presented together with flow and FIB monitoring data in **Table 34.** Some important indications can be drawn from the aggregated data:

- Baum and Martin Street Outfalls appear to behave similarly in hydrology and microbiological contaminant delivery. Baum Street watershed regularly exhibits FIB at high concentrations for both FIB parameters, with high Fecal *Bacteroides* spp. concentrations. However, the watershed also consistently has peak hydraulic flows among the lowest of all watersheds for any given storm event. The flow phenomenon is surprising, given that it is the second largest watershed, and it has fairly high imperviousness along with a highly developed artificial drainage network. The low flows may very well result from incidental diversion of flow through the Martin Street outfall due to the connection between the two. Martin Street consistently ranks in the high range for both flow and FIB concentrations, across all FIB indicator types, especially Fecal *Bacteroides* spp. This outfall consistently ranks among the highest of all outfalls for both total loading of FIB and FIB loading rates per hour (not shown in Table 34). Taken together, Baum and Martin Street behave generally similar to one another. They are 3rd and 4th largest watersheds, with high numbers of built structures. They Martin and Baum Street watersheds have extensive drainage systems that are partially open channels. The two watersheds have also benefited from the greatest number of septic repairs as well as new septic systems.

- Gallery Row is the largest watershed, with the highest total number of impervious acres in the study. In this location, topography and groundwater well data indicate the greatest overall potential for groundwater-septic system interaction. This location is also where the greatest numbers of septic systems and septic system repairs have occurred. This outfall consistently exhibited the highest Fecal *Bacteroides* spp. concentrations. It is important to remember that high Fecal *Bacteroides* spp. concentrations can be indicative of human fecal sources. However, high fecal Bacteroides spp. concentrations have also been significantly related to human health outcomes, indicating potential public health risk for waters with high levels of these anaerobic organisms. Surprisingly, with the exception of one storm (November 2008), hydraulic flows from Gallery Row tended to be low for such a large watershed.
- Curlew and Soundside watersheds are very small, while Conch Street was the second largest in the study. All three of these watersheds are close in proximity to one another (all three together are located within a span of 5000 linear feet of beach (less than a mile). All three watersheds deliver high concentrations of *Enterococcus* and *E. Coli*. Given the relative concentrations of FIB, these three outfalls also appears to convey relatively lower concentrations of Fecal *Bacteroides* spp. For example, mean fecal *Bacteroides* spp. concentrations tended to remain in the tens of thousands per 100 ml. As expected, given the smaller watershed size and relatively low impervious coverage, hydraulic flows from these three watersheds tended to be on the lower side relative to other outfalls.
- The patterns of FIB delivery and flows at the South Nags Head (Old Oregon Inlet Road) watershed indicate that surface water dynamics are more important. This location is characterized by an extensive open ditch system that runs both parallel and perpendicular to the beach receiving waters. This can be observed by comparing the open channel length extent to the total piped drainage length, which equal one another). This location is characterized by vegetated ditches that receive tidal influx in some locations, and which are populated heavily by birds, and other forms of wildlife. This location tends to exhibit very high *Enterococcus* concentrations, but relatively low *E. coli* and *Bacteroides* spp. This is the pattern of contamination that would be expected from fecal material from wildlife and birds, and the delivery of this material to the ocean receiving waters confirms the importance of build-up, wash-off mechanisms of FIB delivery. Hydraulic flows form South Nags Head are also consistently among the highest for all outfalls for any given storm given the flows associated with those open ditch system. Furthermore, it is possible,

given the characteristics of this location, that *Enterococcus* sp. are living and growing in the ditch soils and stagnant waters. Therefore, it may be that a "legacy population" of *Enterococcus* sp., not related to recent fecal contamination, is a prominent feature at this site. This has been observed previously in other ditch locations in eastern NC (Lauer et al. 2015).

- Whalebone watershed exhibits moderate to low concentrations for all FIB indicators, but at the same time has unusually high flows for a very small watershed. The hydraulic flows may owe to somewhat dense patterns of development close to the outfall discharge location, along with a highly connected artificial drainage network. However, only limited analyses of the Whalebone watershed has been conducted for microbial contaminants in comparison to some of the other watersheds studied. In addition, limited mapping data is available to accurately characterize that network.

Table 35. Watershed Summary Comparison

Watershed	Total Acres	Impervious Acres	Impervious Percent	Total Buildings (total)	Septic Density (per acre)	Hydric soils (acres)	Hydric Soils Percent	Forested vegetation (acres)	Forested Vegetation Percent	Total open channel length (ft)	Total length of drainage piping (ft)	Total Septic Repairs 2006-2012	Total Septic New 2006-2012	Percent Time Groundwater within 3' of Surface	Storm Date	Peak Flow	E. Coli Mean	E. Coli Range	Enterococcus Mean	Enterococcus Range	Bacteroides Mean	Bacteroides Range
																(cubic ft/second)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)	(cells/100ml)
Baum Street	435	131.4	30.2	546	1.26	435	100	40	9.2	16,020	40,997	35	20	76.8	12/15/2007 - 12/16/2007	0.93	13,290	200 - 68,670	475	52 - 2,110	110,597	30,182 - 303,340
															4/20/2008 - 4/23/2008	2.38	3,625	771 - 9,208	3,240	318 - 14,136	73,704	43,908 - 91,724
															9/5/2008 - 9/11/2008	2.34	325	121 - 481	7,475	1,201 - 17,329	132,813	53,353 - 199,292
															11/4/2008 - 11/7/2008	5.15	2,730	52 - 12,997	1,648	155 - 3,873	48,164	36,690 - 64,030
Martin Street	394	103.6	26.3	861	2.19	392	99.5	149	37.8	9,821	60,598	63	31	39.8	06/03/2007 - 06/04/2007	6.38	3,386	2,382 - 5,172	13,901	5,475 - 24,196	3,321	801 - 8,081
															12/15/2007 - 12/16/2007	7.02	3,833	1,529 - 11,120	96	10 - 168	101,221	31,176 - 286,294
															04/20/2008 - 04/23/2008	4.03	854	121-2,098	1,868	460 - 5,475	59,598	55,317 - 63,571
															9/5/2008 - 9/11/2008	6.75	4,169	1,145 - 7,270	7,253	691 - 12,033	114,292	5 - 380,699
															11/4/2008 - 11/7/2008	9.78	2,753	987 - 4,106	5,942	959 - 19,863	51,604	4,867 - 168,605
E Lake Drive "Ocean House"	196	95.1	48.5	355	2.82	193	98.5	15	7.7	633	24,247	18	8	39.5								
Gallery Row "Carolinian"	488	155.7	31.9	857	1.76	481	98.6	105	21.5	12,618	11,799	104	23	89.6	06/03/2007 - 06/04/2007	2.77	3,506	323 - 5,475	15,825	888 - 24,196	11,376	10,896 - 12,065
															12/15/2007 - 12/16/2007	0.51	3,870	10 - 14,136	9,586	226 - 24,196	330,515	82,106 - 441,060
															04/20/2008 - 04/23/2008	4.03	665	318 - 1,076	986	160 - 1,968	137,631	77,072 - 255,098
															11/4/2008 - 11/7/2008	18.16	1,464	228 - 6,867	2,582	364 - 7,270	121,384	82,028 - 208,946
Curlew Street	161	34.3	21.3	345	2.14	52	32	32	19.9	6,413	3,063	35	27	76	06/03/2007 - 06/04/2007	5.18	13,571	2,382 - 24,196	19,399	9,804 - 24,196	-	-
															12/15/2007 - 12/16/2007	2.03	2,996	250 - 6,867	4,329	206 - 24,196	47,475	12,921 - 113,443
															04/20/2008 - 04/23/2008	-	3,407	581 - 9,804	2,405	749 - 7,270	39,798	24,940 - 49,550
Conch Street	438	61.3	14	323	1.35	351	80.1	154	35.2	7,020	3,642	41	5	76	06/03/2007 - 06/04/2007	2.61	1,148	657 - 1,674	2,100	1,071 - 3,130	6,129	3,320 - 9,586
															9/5/2008 - 9/11/2008	4.01	2,985	350 - 6,131	7,652	959 - 14,670	69,788	5 - 254,585
															11/4/2008 - 11/7/2008	8.4	1,783	441 - 4,352	1,083	158 - 2,310	34,032	9,521 - 69,859
Soundside Road "Casino"	45	12	26.7	59	1.31	42	93.3	1.4	3.1	523	1,759	11	1	94.7	06/03/2007 - 06/04/2007	2.56	246	51 - 374	814	384 - 1,246	-	-
															12/15/2007 - 12/16/2007	2.03	152	5 - 668	57	5 - 170	23,234	7,914 - 79,454
															04/20/2008 - 04/23/2008	3.72	152	10 - 801	434	62 - 1,529	10,285	7,965 - 13,862
															9/5/2008 - 9/11/2008	2.74	14,176	3,654 - 36,540	9,719	1,234 - 24,196	147,557	5 - 492,867
															11/4/2008 - 11/7/2008	6.57	3,070	20 - 17,329	6,894	256 - 36,540	-	-
S Nags Head/Old Oregon Inlet Road	115	33	28.8	307	2.67	54	47	4.6	4	6,410	6,224			73.3	06/03/2007 - 06/04/2007	3.3	4,558	1,935 - 8,664	24,196	24,196	231	231
															12/15/2007 - 12/16/2007	3.67	334	5 - 1,500	9,074	223 - 24,196	56,103	541 - 134,133
															04/20/2008 - 04/23/2008	6.82	946	313 - 1,354	13,727	2,142 - 24,197	4,475	5 - 8,945
															9/5/2008 - 9/11/2008	8.18	2,294	548 - 5,172	26,594	15,531 - 51,720	-	-
															11/4/2008 - 11/7/2008	12.72	2,014	1,178 - 3,873	5,001	191 - 15,796	-	-
Whalebone Watershed	61	22.3	36.6	116	1.9	34	55.7			875	313				06/03/2007 - 06/04/2007	5.7	884	650 - 1,014	7,294	1,782 - 15,531	28,744	186 - 4,135
															12/15/2007 - 12/16/2007	7.53	289	5 - 905	927	5 - 5,172	208,792	72,803 - 476,541
															04/20/2008 - 04/23/2008	6.89	2,155	110 - 6,867	1,137	247 - 2,382	15,171	1,891 - 40,064
															9/5/2008 - 9/11/2008	10.49	30,187	3,664 - 92,080	8,485	1,076 - 17,620	-	-
															11/4/2008 - 11/7/2008	6.57	1,676	221 - 5,794	3,926	373 - 10,170	-	-

4.0 Analyses of Management Alternatives

Because this study revealed both significant concentrations and significant loads of FIB during storm events throughout the study area and the performance of the pilot BMP was not found to consistently significantly reduce the loading, the project team also looked at other BMP systems for recommendations in future efforts. Given the groundwater constraints of the sites, high-rate infiltration sand filters were investigated (for areas with adequate groundwater separation) as well as groundwater lowering systems that have recently been installed in other beach communities while this study was being completed. Combining adjacent outfalls into deep-water ocean outfalls was also considered. These detailed analyses of these management alternatives and BMPs are discussed below.

4.1 Stormwater BMP Retrofitting

4.1.1 Diffuse Landscape-Integrated BMP Retrofits

The North Carolina Stormwater BMP Manual (NCDENR, 2009) gives the highest rankings for fecal coliform removal to bioretention cells, sand filters, permeable pavement, and "other infiltration devices". Bioretention cells, more commonly known as rain gardens, are commonly used in coastal North Carolina and have been shown to have fecal coliform removal rates as high as 89-92% for bioretention cells monitored in Charlotte, NC (Hathaway, et al, 2009). However, the same study showed bioretention cells in coastal Wilmington, NC having lower removal rates, with one shallow cell found to have higher effluent FIB that was found in the influent. As a result of such findings, bioretention cells were not utilized as the example BMP in this analysis. By the same token, permeable pavement was not considered a viable alternative for retrofitting in already built landscape due to the high costs and levels of disruption associated with replacing large areas of existing pavement.

High rate infiltration sand filters offer distinct advantages over bioretention cell as a retrofit BMP for the scenario at hand on the northern Outer Banks of North Carolina. First they tend to be more compact, which is allows for them to be constructed in the limited land areas available in a resort community where land area is often limited and expensive. In many instances, they can be constructed in the existing right of way along the streets within the community. Second, there is no need to vegetate the catch basin for high rate sand filters, which lowers the potential for attracting wildlife which could contribute additional bacteria to the treatment process. Although minimal vegetation, such as grass to stabilize the catch basin or a ring of low shrubs around the edge to prevent pedestrian and dog traffic though the catch basin may be desired. Lastly, they are relatively comparable in cost to traditional bioretention, but reported cost numbers vary widely for bioretention cells). The predictive cost model generated by Hunt & Wossink (2003) based on examining the construction costs of numerous bioretention cells put the cost of treating one acre with bioretention at approximately $21,000. The Low Impact Development Center in Beltsville, MD puts the cost of retrofitting bioretention cells in developed commercial and institutional landuse settings at $10-40 per square foot (http://www.lid-stormwater.net/bio_costs.htm). Assuming each bioretention cell would an area approximately 5% the size of the treated watershed, the cost for treating one acre at the lower end of the LID center cost range at just over $21,000.

Average costs on the Outer Banks are likely to be slightly lower due to lack of need for underdrain systems and limited distribution of hard infrastructure such as curb and gutter. Direct quotes from NC product suppliers put the cost of high rate infiltration sand filters at $20,000 per acre including $15,000 for the customized filter media and $5000 for construction of the catch basin, and outlet structures and minimal landscaping.

While such high rate infiltrations are propriety systems, they are readily available from suppliers with offices in North Carolina. **Figure 81** and **Figure 82** illustrate the design of one such system, called Focal Point, available from ACF Environmental. **Figure 81** shows a cutaway diagram of the Focal Point System and **Figure 82** shows a Focal Point treatment system being constructed.

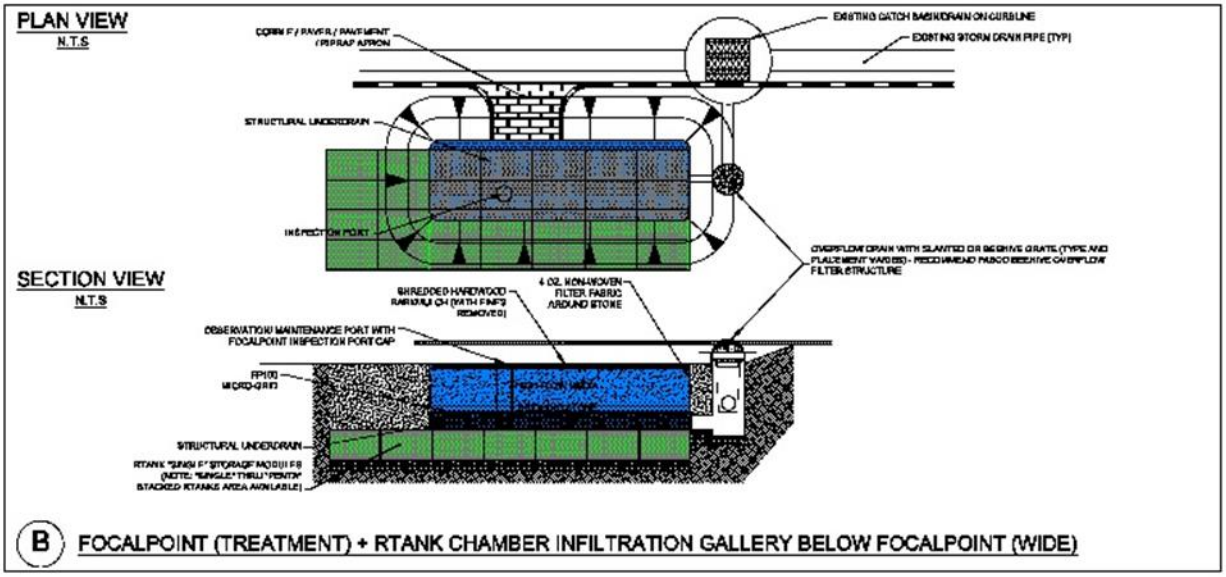


Figure 81. High Rate Infiltration Sand Filter Design (courtesy of FabCo Industries)

Figure 82. High Rate Infiltration Sand Filter Design (courtesy of FabCo Industries)

High rate infiltrations are propriety systems do present some constraints. First, they are not recommended for treatment of areas greater than one acre, so watersheds the size of those associated with the ocean outfalls in this study would require numerous installations to render them effective. Second, and most important, per supplier's guidance and the design drawings above, the devices require 2.5 feet (ideally 3 feet) of separation between the land surface and the groundwater table during most of the time. Periodic rises of groundwater into the storage chamber at the bottom of the device are not problematic. The same constraint also exists for bioretention cells and other infiltration BMPs in general.

With the advantages and constraints in mind, and exercise was performed utilizing desktop GIS analysis and actual field reconnaissance to identify hypothetical locations to retrofit high rate infiltrations and filters in the East Lake Drive watershed. East Lake Drive was selected for this "straw man" retrofitting exercise because it is in the middle of the range in terms of watershed size; it reflects a level of development intensity comparable to most of the watersheds for the other outfalls, and it is a watershed for which one of the richest GIS datasets of storm drainage infrastructure was available. Several criteria were use in the selection of locations for potential sand filter retrofits which included:

- Approximately 1 acre treatment watersheds.
- Sufficient separation between the land surface and the groundwater table.
- Landscape position – BMP sites situated to receive drainage from surrounding areas.
- Integration within existing rights-of way – maximize utilization of existing public space.
- Integration with existing storm drain infrastructure, such as drop inlets and curb inlets.
- Co-location across the street from each other when possible for ease of maintenance.
- Co-location with undeveloped lots to facilitate acquisition of easements where necessary.

The straw man retrofitting exercise began with a GIS analysis of land use, surface topography, ground water elevations, which determined that 29 acres of the watershed's 246 acres are undeveloped and did not require retrofitting. Of the remaining 217 acres, 91 acres, or 42 percent of the developed portion of the watershed is untreatable by surface retrofits due to insufficient separation between the land surface and the groundwater table. Within the remaining 126 acres, 116 viable BMP retrofit sites were identified, which are projected to treat approximately 93% of that 126 acres deemed eligible for treatment. The retrofits are mapped in **Figure 83**. Based on the suppliers cost estimate of $20,000 per one-acre treatment installation the total cost for 116 installations comes to $2,318,400. With a 25% contingency allowance for cost variability, the projected cost for retrofitting the East Lake Drive watershed with surface BMPs becomes $2,898,000.

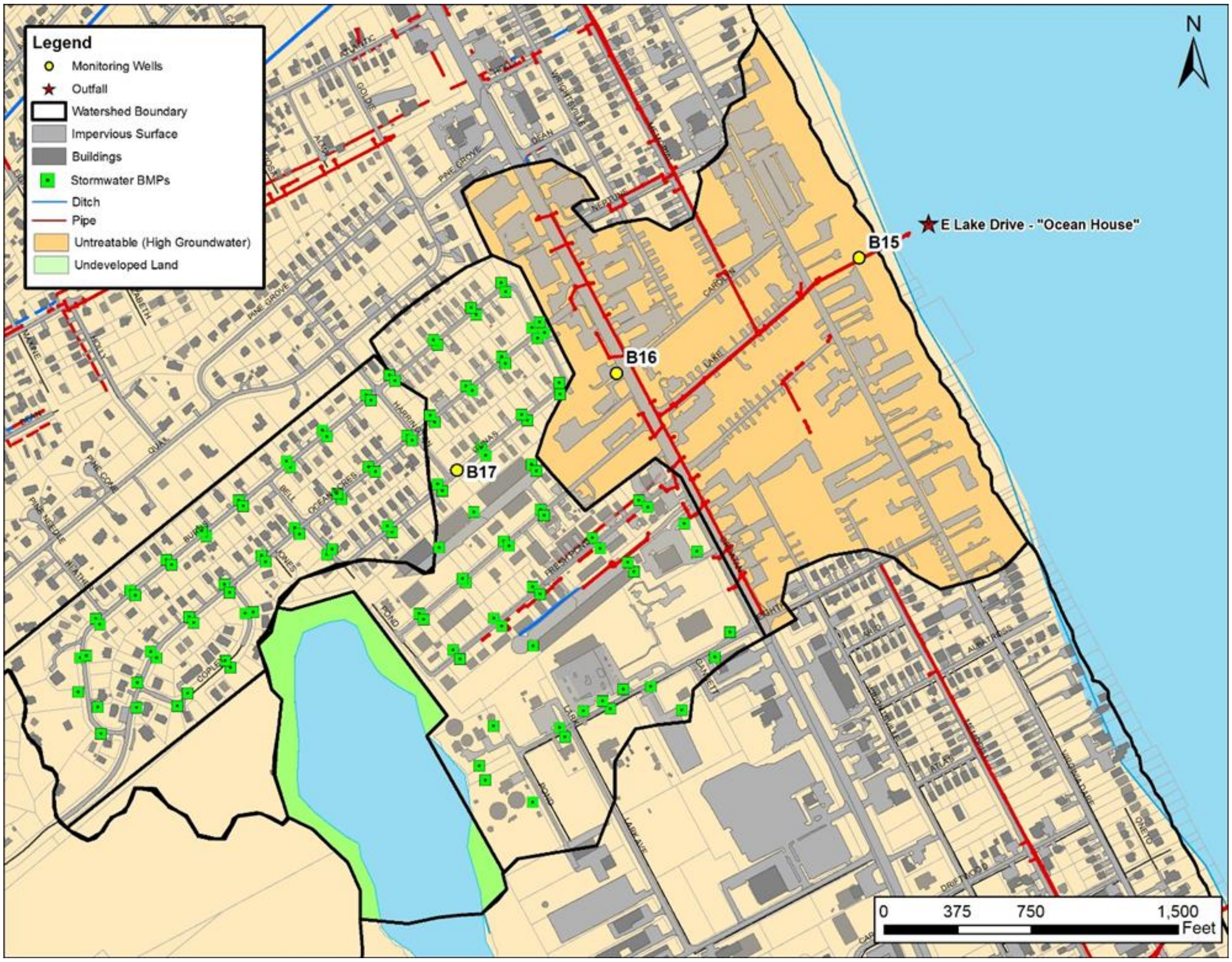


Figure 83. East Lake Drive Watershed BMP Retrofit Scenario

Based on the same set of assumptions, the analysis of surface BMP retrofit potential for East Lake Drive was extrapolated out to all the outfall watersheds in the study area. While specific BMP retrofit locations were not mapped for each watershed, it was assumed that suitable locations for BMPs could be found such that 93% of the watershed area deemed to have sufficient groundwater separation to be suitable for retrofits. The projected numbers of retrofit BMPs and predicted costs are shown in **Table 36**. As shown in **Table 36**, the analysis of groundwater elevations rendered significant portions of each watershed are rendered untreatable by surface retrofits due to high groundwater tables. At best, 76% of the developed area in the Conch Street watershed was eligible for retrofits, leaving only 24% untreated, but in the worst case scenarios the Curlew Street and the Old Oregon Inlet Road watersheds were rendered completely untreatable due to low surface elevations and limited separation from the prevailing groundwater elevations.

Table 36. Project BMP Numbers and Costs for Ocean Outfall Watersheds

Watershed	Size (acres)	Undeveloped (acres)	Developed (acres)	Untreatable (acres)	Treatable (acres)	Treatable (%)	BMPS Required	Total Cost	Cost plus 25% Contingency
Baum Street	435	73	362	272	90	25%	83	$1,656,000	$2,070,000
Martin Street	344	27	317	128	188	59%	173	$3,459,200	$4,324,000
E Lake Drive	246	29	217	91	126	58%	116	$2,318,400	$2,898,000
Gallery Row	488	73	415	181	234	56%	215	$4,305,600	$5,382,000
Curlew Street	161	0	161	161	0	0%	0	$0	$0
Conch Street	438	258	180	43	137	76%	126	$2,520,800	$3,151,000
Soundside Road	45	17	28	17	11	39%	10	$202,400	$253,000
Old Oregon Inlet Rd	115	0	115	115	0	0%	0	$0	$0
Whalebone Junction	61	0	61	41	20	33%	18	$368,000	$460,000

Table 36 also shows that the projected costs for retrofitting surface BMPs to treat stormwater range from $253,000 for the smallest watershed (Soundside Road) to $5,382,000 in the largest watershed (Gallery Row). Given the high numbers of installations required and the projected cost, it is unlikely that this management approach alone would be viable to address fecal bacterial pollution on a large scale in the ocean outfall watersheds, especially when one considers the large portions of the watershed that would remain untreated, and that such retrofits would have little or no impact on bacterial pollution loads delivered through groundwater pathways. However, it is likely that surface BMP retrofits of this nature could produce tangible water quality benefits when used in conjunction with other treatment and management options, particularly in smaller watersheds.

4.1.2 Regional BMP Retrofits

Given the limited amounts of available open space and the high costs of land in a beach resort community, identifying suitable locations for regional scale BMPs is a challenging exercise, just as the project team found in the efforts to identify a suitable site for the pilot BMP which was built at Conch Street. The exercise is further complicated by the need to have the BMP is an advantageous hydrologic location where an appreciable amount of flow could be intercepted for treatment. A detailed search through undeveloped parcels of land throughout the study area and their positions relative to larger drainage networks yielded only 2-3 possible sites, the most suitable of which is located in the watershed for the Martin Street Outfall.

Just west of the Croatan Highway, there is a cluster of undeveloped parcels where are large BMP could potentially be sited (**Figure 84**). The effort would require substantial land acquisition, but that effort might be aided by the fact that Fox Street has never been extended through the block in which the parcels are located. The right of way for Fox Street still exists within the BMP site area. As can be seen in Figure 56, by virtue of the network of ditches and pipes, the BMP could be configured to treat an area of up to 112 acres in the northwestern quadrant of the Martin Street watershed, which amounts to about a third of the entire watershed's 344 acres (adjusted for recent drainage installations).

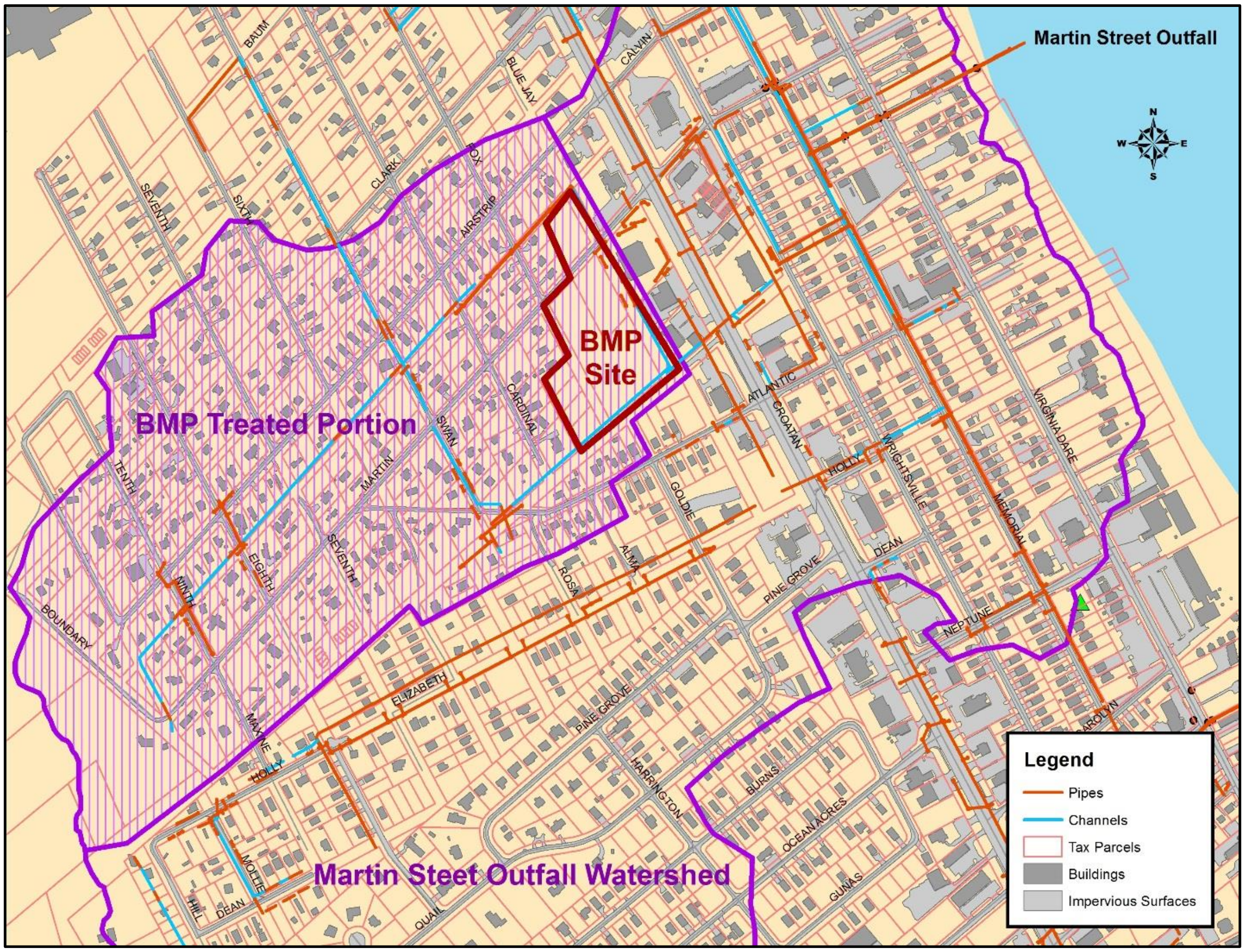


Figure 84. Martin Watershed Regional BMP Retrofit Scenario

Given that conventional BMPs capable of being scaled up to treat a watershed of this size, namely detention basins (wet or dry) and stormwater wetlands, are not rated particularly well for their capacity to treat FIB, a BMP retrofit in this location would most likely rely on an approach similar to that taken with the Conch Street BMP. It would involve construction of a chamber or vault that used proprietary treatment media to reduce microbial pollution. The vault structure would need to be large enough to effectively capture and treat the first flush from the contributing watershed. Without the aid of a detailed hydrologic and hydraulic modeling analysis to examine topographic relief and the differential head pressure available to move flow through the treatment media, it is nearly impossible to estimate the size of vault that would be necessary in this case. However, in looking to the Conch Street example, a conceptual-level estimate of the costs that may be associated with such a device can be surmised.

The pilot BMP at Conch Street was designed to maximize treatment of the first flush from the watershed, while not causing excessive ponding on the roadway immediately upstream. The costs for the Conch Street BMP were approximately $750,000 for the vault and $250,000 for the propriety treatment media for a system designed to treat 16 cfs. Flow predictions from the updated MIKESHE/MIKE11 modeling framework developed this study indicate that the peak flow from this portion of the Martin Street watershed for the two-year, 24-hour rainfall event would be approximately 4 cfs, so a vault sized to capture 5 cfs would allow for a margin of safety in capturing well above the first flush from the treated subwatershed. In other words, a smaller vault could be utilized in this hypothetical application. Assuming the vault needed to be approximately one third the size of the BMP at Conch Street, and some fixed costs for construction are taken into account as we scale down, the vault in the Martin Street location would cost approximately $500,000, plus the price of media.

While only a limited degree of success was achieved in terms of load reductions for FIB with the Conch Street BMP, the difficulties with that device cannot be solely assigned to the performance of the Smart Sponge treatment media. Several aggravating factors including, but not limited to, tidal interference, sediment accumulation, and high incoming FIB loads acted together to impede the performance of the device. With that in mind, the real-world trials and evaluations of similar proprietary treatments systems should not be ruled out at this time. Since the time when the treatment system was selected for the Conch Street vault, numerous new types of treatment systems targeting bacterial pollution have been developed. For example, FabCo Industries has achieved high rates of bacterial pollutant removal (as high as 99%) with the helical configured contact media illustrated in **Figure 85** and **Figure 86** below. As with this helical treatment system, most of the new media types developed since implementation at Conch Street are lighter, easier to handle, and less expensive than the Smart Sponge media. However, data from closely monitored real-world applications remains to be very rare for all treatment media types. Prior to the selection of any new propriety treatments system, it is recommended that a full literature review on the availability and performance of such systems be conducted, as was conducted when the media for the Conch Street BMP was selected.

Figure 85. Example of Recently Developed Proprietary FIB Treatment Media

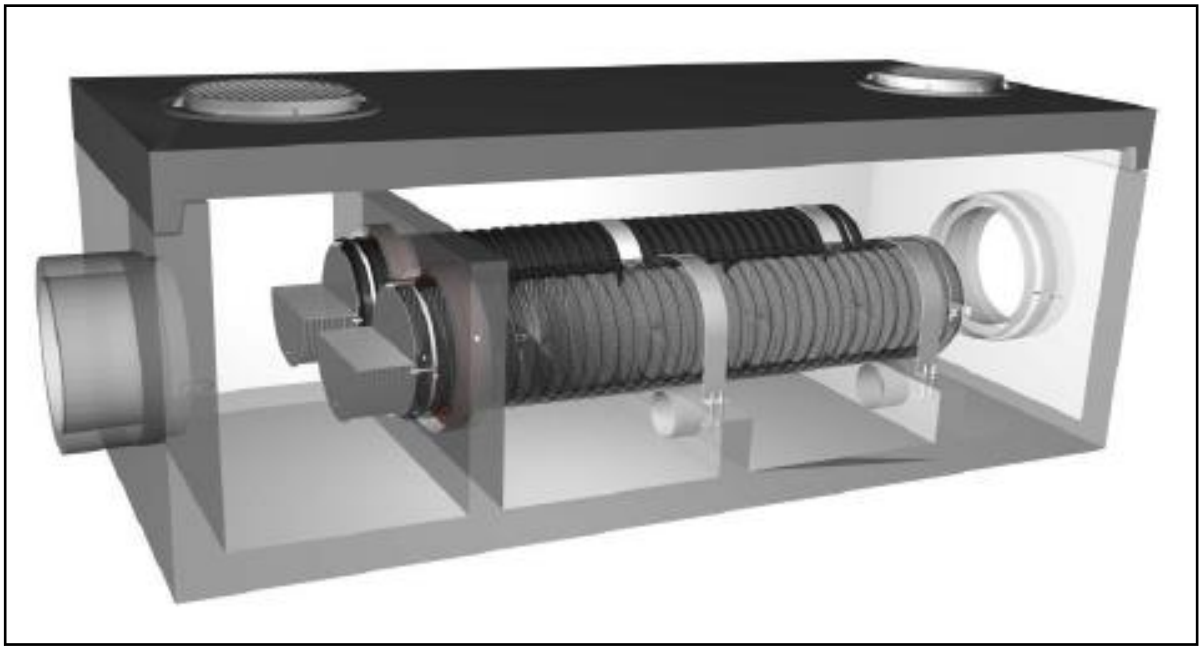


Figure 86. Possible Vault Configuration of Helical Treatment Media

4.2 Groundwater Drawdown Systems

Engineered groundwater drawdown systems were also evaluated as a potential management alternative for the ocean outfall watersheds. Such systems work by using infiltration galleries consisting of perforated pipe buried below ground at strategic depths in layers of gravel which are connected to wet wells with relatively large pumps. Given the high permeability of the sandy coastal soils, such systems are capable of lowering the groundwater table by several feet when the pumps are running. The pumps would be connected to force mains that direct the water to the back side of the island where it can be sheet flowed off and infiltrated into undeveloped areas of land. Systems of this nature have been completely installed and successfully operated in North Carolina barrier island locations for several years now in Emerald Isle and recently in Corolla. By lowering the groundwater levels substantially, these systems create greater levels of subsurface hydraulic storage capacity and promote much higher levels of infiltration of stormwater runoff, which dramatically reduces the incidence in which peak groundwater elevation reaching the surface or the upper part of the soil profile where septic system interaction occurs. While the systems already installed in NC were envisioned and implemented for the purposes of reducing nuisance flooding in low lying areas where development has occurred, water quality monitoring on those systems has shown them to have very low effluent levels of fecal coliform bacteria.

After construction of the drawdown system in Emerald Isle, repeated water quality sampling of the effluent from the system outfall has consistently shown very low levels of fecal coliform with 6 of 9 samples reporting results of <1 CFU/100ml and 3 samples reporting countable results of 2, 31, and 161 CFU/100ml (M&N, 2010(1)). The water quality monitoring results (including fecal coliform) for the effluent from the Emerald Isle groundwater drawdown system are shown in **Table 37**.

In Corolla, no monitoring on the system effluent has been performed but water quality samples collected from groundwater wells in the vicinities and at depths where the infiltration galleries were to be installed have demonstrated non-detectable levels of fecal coliform while adjacent samples of ponded surface runoff showed regularly detectable concentrations of fecal coliforms that exceeded 2000 CFU per 100ml (M&N, 2010(2)). It is likely that these drawdown systems are creating natural *in-situ* sand filter capacity by allowing stormwater to be percolated though the emptied soil column in the affected area, resulting in reduction of FIB. Even if no reduction is occurring by virtue of treatment within *in-situ* soils, the systems could substantially reduce ocean outfall discharge volumes by promoting infiltration and by intercepting and redirecting substantial volumes of water that would otherwise be discharged to the surf. Initial field measurements and anecdotal accounts from the resident communities have also indicated that the drawdown systems perform very well in terms of their original intended purpose of flood reduction.

Table 37. Water Quality Monitoring Results from the Emerald Isle Drawdown System

Date	Time	COLIF, FEC col/100ml	TKN (ppm)	NO3+NO2-N (ppm)	TN (ppm)	TP (ppm)	CU/T/ICP (ppm)	ZN/T/ICP (ppm)
2/14/07	12:30 PM	<1	1.390	<0.1	1.390	0.851	<0.002	0.013
2/28/07	12:30 PM	<1	1.960	0.405	2.360	2.040	0.005	0.030
5/16/07	1:45 PM	161	1.300	<0.1	1.300	0.554	0.007	<0.005
7/24/07	12:00 PM	31	0.568	1.170	1.710	0.484	1.380	0.021
11/30/07	2:25 PM	<1	1.900	<.1	1.900	1.950	<.002	0.577
1/29/08	12:00 PM	<1	1.160	<.1	1.160	1.070	0.036	0.055
3/31/08	12:10 PM	2	0.762	<.1	W	0.822	0.103	0.058
5/30/08	11:00 AM	<1	0.948	<.1	0.948	1.280	0.085	0.054
7/31/08	1:00 PM	<1	<.1	<.1	<.1	0.272	0.274	0.080
9/30/08	1:00 PM	No Flow						
2/28/09	8:30 AM	<1	0.621	<.1	0.621	0.744	<.005	0.006

Groundwater drawdown systems show promise as a management strategy for reduction of FIB from ocean outfalls because discharge concentrations of FIB are very high not only at the onset of a storm, but also throughout the storm and well through the tail period of the hydrograph. This presents a particular challenge to BMP success aimed at achieving reductions through removal of contaminants. Even with 90% removal efficiency of any BMP, when the discharge concentration is in excess of 10,000 MPN 100 ml^{-1}, the resulting FIB concentration is still nearly 10-times the single sample standard for recreational water quality. Conversely the hydraulic flow rates across all outfalls are relatively low, with maximum recorded flows during the 2006-2008 monitoring period ranging from 6-20 cfs, making it readily possible to deploy pump systems capable of keeping up with hydraulic flow rates and associated volumes during most storm events other than tropical storms and nor'easters.

Given the success of these groundwater drawdown systems in other locations, preliminary designs were developed as a potential management alternative to reduce flow volumes and discharge levels of FIB from the ocean outfalls. In the interest of hydraulic efficiency and achieving economies of scale, the systems were designed such that some adjacent watersheds, where feasible were combined into single aggregate drawdown systems. The concept-levels systems were designed such that all infiltration galleries and wet wells could be constructed within existing public right-of-ways, and force mains would be routed along public right of ways each of the conceptual designs are described in the following.

Drawdown System Design

The Baum/Martin Street Groundwater Drawdown System is a good example of the conceptual design approach used for the drawdown systems, and it is illustrated in **Figure 87**. It begins with 4 pumps at the Martin Street ocean outfall with two pumps each located where the outfall line crosses Virginia Dare Street and Memorial Drive. Each pump and wet well installation would service 500 feet of infiltration gallery running north and south along Virginia Dare and Memorial. A force main from the Martin Street pump array runs up Virginia Dare for one block and then doglegs along Martin to Memorial. The force main runs north on Memorial to Baum where it intersects another array of 4 pumps and infiltration galleries similarly situated along Virginia dare and Memorial at Baum Street. The force main continues west on Baum Street until turning north and running along Croatan Highway (The Bypass) for one block, and then it turns west again and traverses Town of Nags Head property before running along Veterans Drive within the First Flight schools campus. After passing through the campus, the outfall would terminate on Town-owned land on the Albemarle Sound side of the island. The force main would be equipped with a forebay and outlet control structures that would cause the effluent to be release in a dispersed sheet-flow fashion across a significant area of land so as to avoid harmful erosion.

The remaining groundwater systems are designed in a similar fashion allowing for localized variability in topography and available space for the structures (**Figure 88**- **Figure 92**). The structures were also designed to target the infiltration galleries to strategic locations in their respective watersheds where the groundwater level monitoring data (see **Figure 13**-**Figure 16**) and anecdotal evidence has indicated the greatest propensity for ponding water during storm events. The systems were all designed such that the necessary infrastructure could be constructed within existing right of ways and already publicly-owned land to minimize the need for easement acquisition. All discharge locations are also planned for existing publicly-owned land (mostly property the Towns of Kill Devil Hills and Nags Head), and they would be equipped with outfall forebays and outlet control structures to release the effluent in a dispersed, sheet-flow, manner. Typical design details for key elements of these drawdown systems are presented in Appendix E.

Costs for the groundwater drawdown systems were calculated for each watershed in order to make an effective cost comparison to the other management measures considered. In order to calculate costs by watershed, the costs of infrastructure common to two or more watersheds (namely the sections of force main traversing the barrier island and the outlet structures) was apportioned to each watershed according to the their share of the total count of infiltration galleries and pumps connected to the system in order to reflect the proportion of flow volume contributed by each watershed. The cost results are shown in **Table 38**, and vary in cost from $2.3 million for Old Oregon Inlet Road to $8.3 million for the combined system to manage the Curlew, Conch and Soundside watersheds. Detailed opinions of probable are presented in Appendix E.

Table 38. Groundwater Drawdown System Costs for Ocean Outfall Watersheds

Watershed	Preliminary Cost	Cost plus Design & 25% Contingency
Baum & Martin	$5,250,000	$7,400,000
E Lake Drive	$4,206,250	$5,900,000
Gallery Row	$3,737,500	$5,300,000
Curlew, Conch & Sounside	$5,875,000	$8,300,000
Old Oregon Inlet Rd	$1,612,500	$2,300,000
Whalebone Junction	$1,706,250	$2,400,000

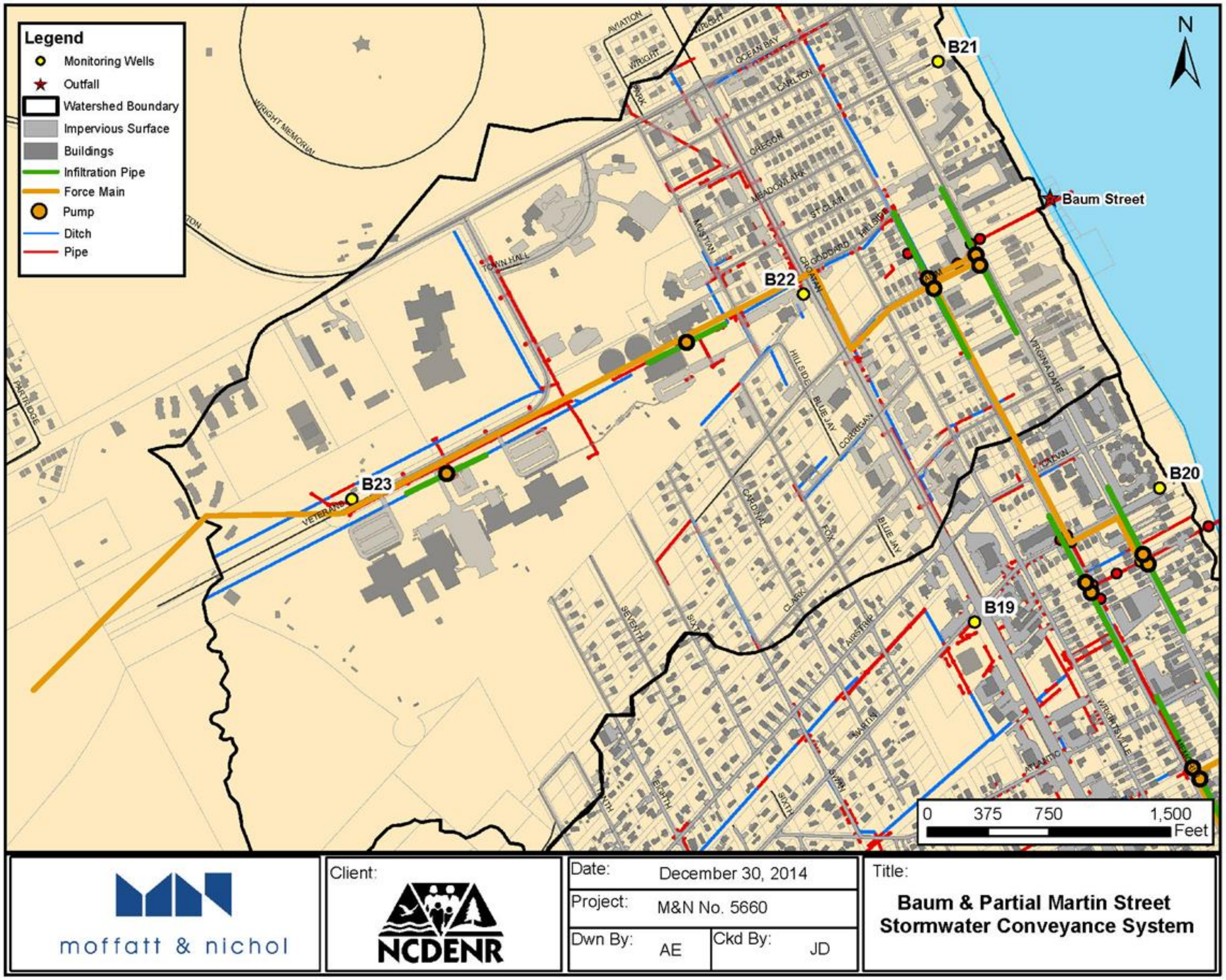


Figure 87. Baum/Martin Street Groundwater Drawdown System

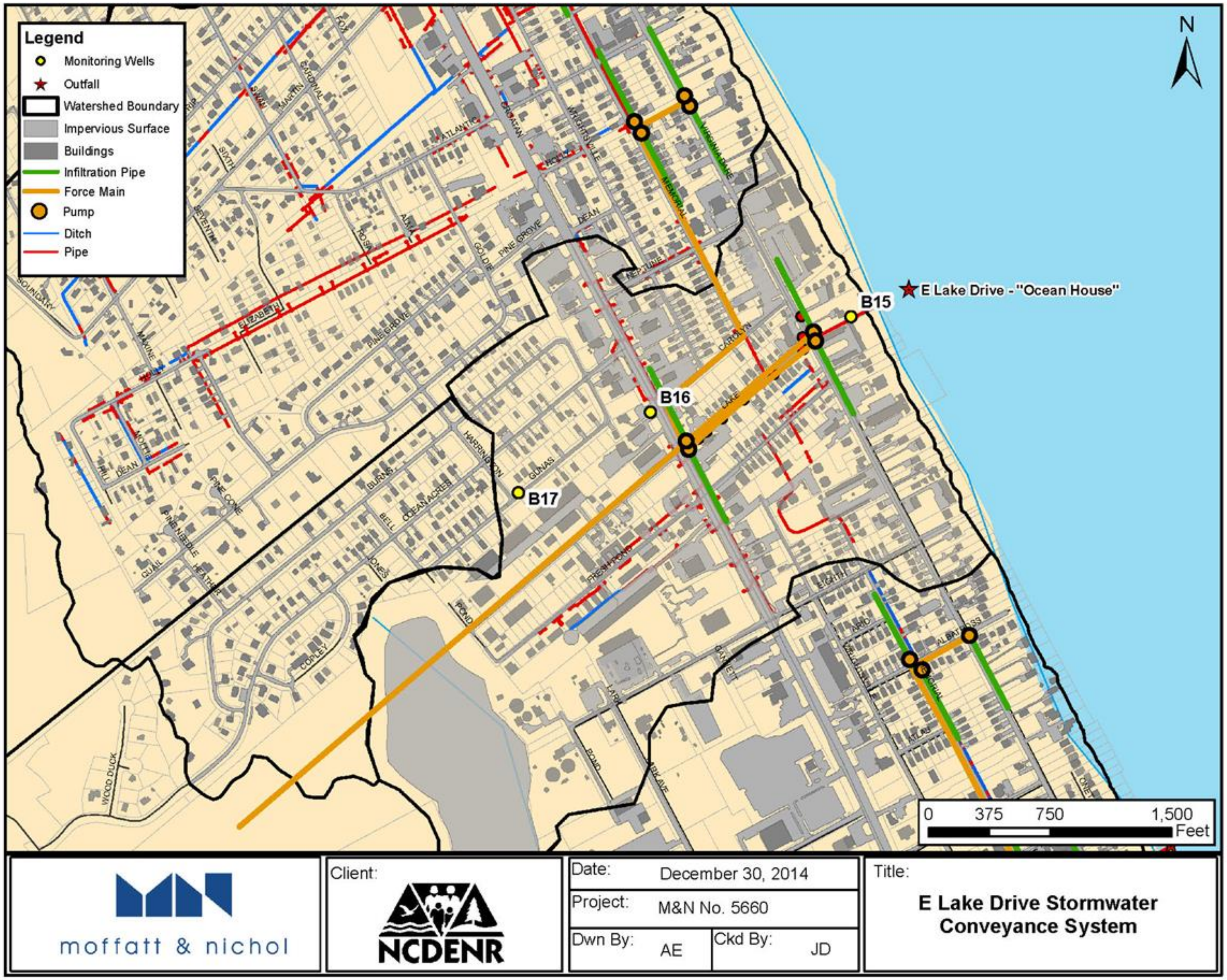


Figure 88. East Lake Drive/Martin Street Groundwater Drawdown System

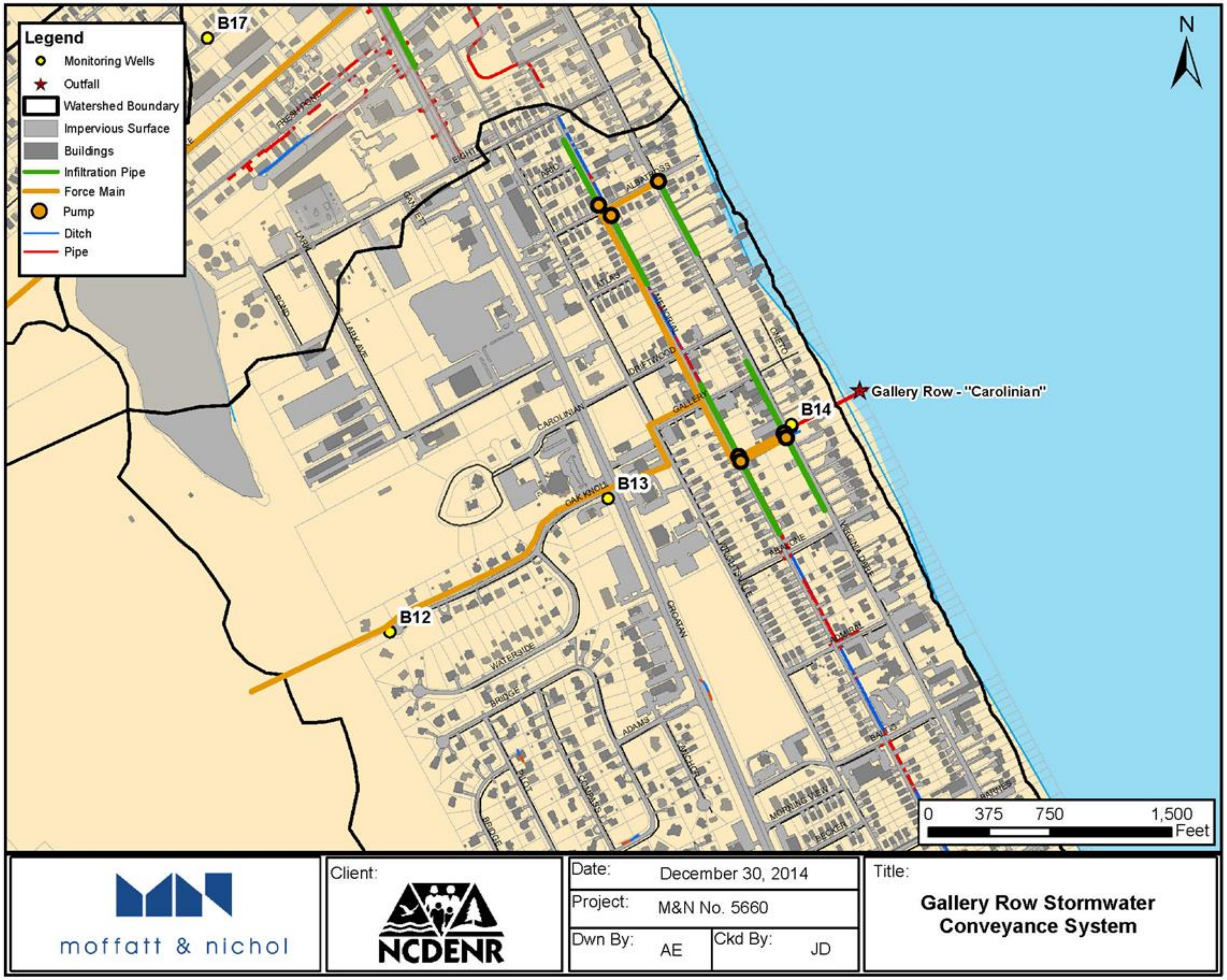


Figure 89. Gallery Row Groundwater Drawdown System

Figure 90. Curlew/Conch/Soundside Groundwater Drawdown System

Figure 91. Whalebone Junction Groundwater Drawdown System

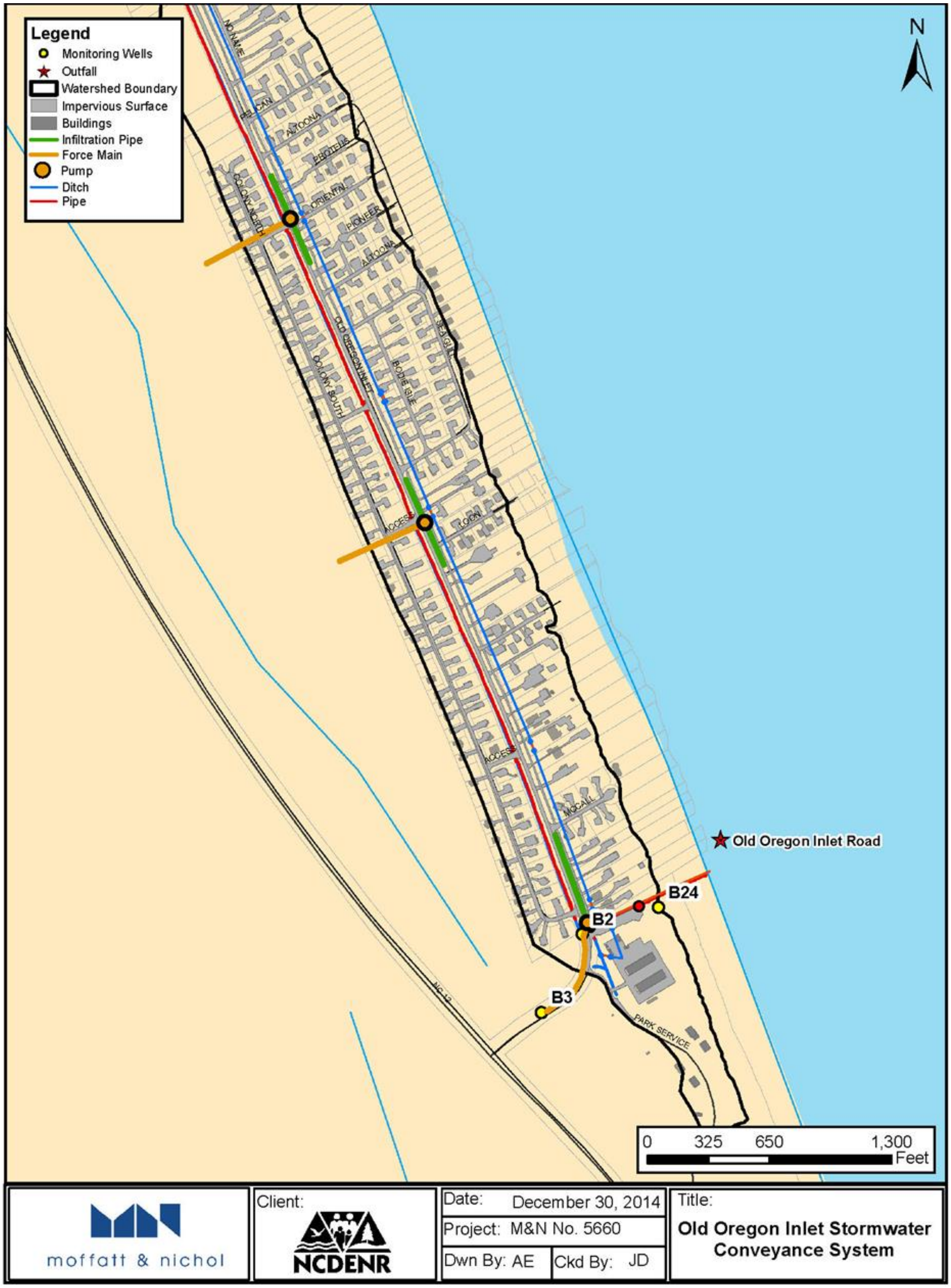


Figure 92. Old Oregon Inlet Road Groundwater Drawdown System

4.3 Deep Water Extension of Ocean Outfalls

One potential management alternative to reduce the risk of human exposure to high FIB concentrations for recreational users of the surf zone is to extend the outfall lines to discharge points further offshore. Extending outfalls would allow the discharges to access a much larger mixing zone and remove the most concentrated FIB levels in the near field discharge plumes away from the zones of immediate human contact. North Carolina law and regulations currently do not allow for the permitting of new ocean discharges of wastewater or stormwater. However, given that the Dare County Ocean Outfalls are essentially already existing discharges to the ocean, the permitting hurdles may be overcome.

Even if the hurdles could be overcome, acquiring environmental permits would be an extensive and prolonged process with no guarantee of a permit being granted. The permitting will require direct coordination with NCDCM. This scenario will incur impacts to the Ocean Hazard System AEC. Permitting for oceanfront outfalls would require a Major Permit from NCDCM as well as concurrence from both USACE and the NCDEQ Division of Water Resources. A project of this nature would likely receive considerable comments from both the regulatory community and the general public. USACE can authorize certain outfall structures under Nationwide Permit (NWP) # 7 if the proposed effluent is regulated under the National Pollutant Discharge Elimination System (NPDES) program. However, NCDCM will likely remain the lead regulatory agency and will oversee the regulatory requirements.

Permitting challenges aside M&N design staff performed the engineering analyses necessary to generate preliminary designs of deep water outfalls as a management alternative for consideration. Examination for the depth contours of the immediate continental shelf for the northern NC Outer Banks reveals that in order to reach a point where the outfalls could discharge at a depth 30 feet or more, they would have to be extended approximately 3000 feet off shore. The 30 feet discharge depth is desirable because it is expected that currents at this depth would tend to pull the discharged effluent further offshore, rather than moving it toward the shore. It should be noted that the City of Virginia Beach, Virginia employed this very approach to a major stormwater ocean outfall immediately north of their most heavily used tourist beaches. In the case of Virginia Beach, the outfall in question was extended to 2000 feet offshore.

For consideration here, the hypothetical outfall extensions were designed to be buried under the sea floor, which is desirable to avoid the often rigorous wind and wave conditions of the Outer Banks. A conceptual illustration of the potential configuration of the outfalls is shown in **Figure 93**. The outfall designs were considered at lengths of 2000 and 3000 feet to evaluate cost variability. The map in **Figure 94** shows the relative distance scale of outfalls extended to 3000 feet off shore.

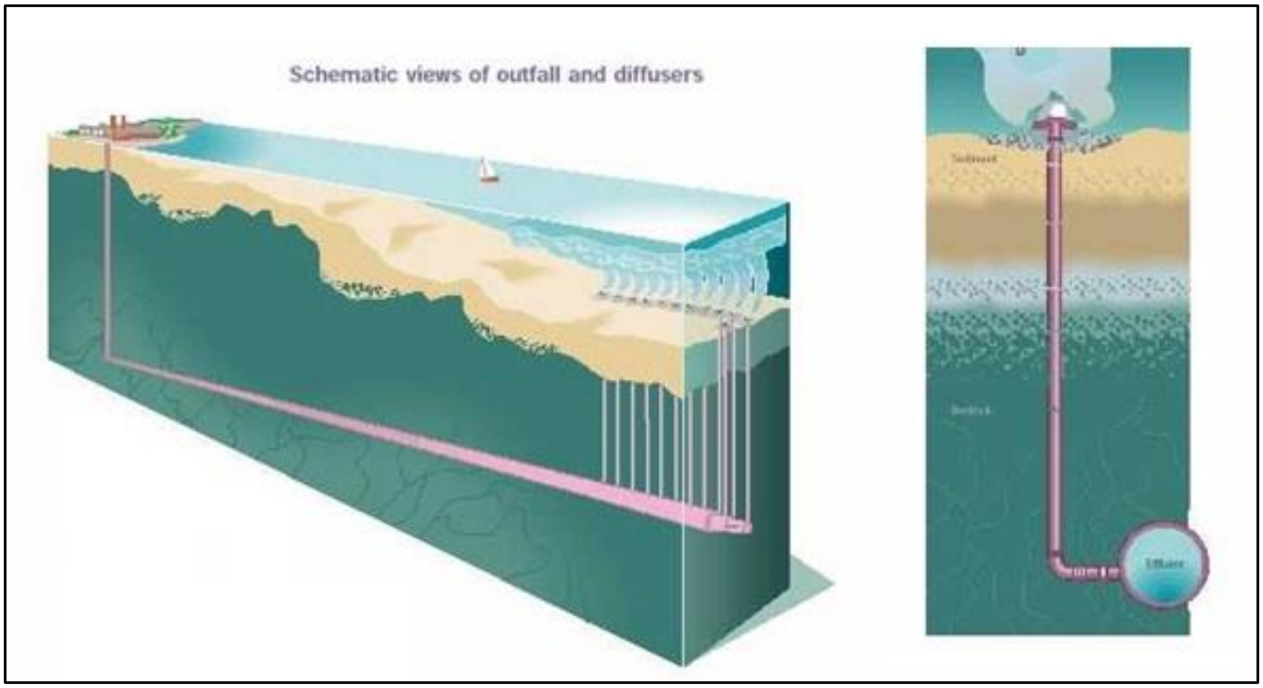


Figure 93. Conceptual Illustration of Deep Water Ocean Outfall

In order to deliver the projected peak hydraulic volumes the hypothetical outfalls for Baum, Martin, East Lake, Gallery Row, and Curlew were each configured with dual 72 inch diameter outfall lines. Inclusive of outfall piping, anchoring and diffuser materials, construction costs and a 25% contingency, the conceptual-level cost for each of these outfalls was estimated to be $27.2M each for extensions of 3000 linear feet off shore. Reducing the distance of the extension to 2000 feet reduced the projected cost to $19.1M each. By virtue of having smaller peak hydraulic volumes, the Conch Street and Soundside Road outfalls could be combined into a single 72 inch outfall line estimated to cost $24.0M at 3000 feet, and $18.0M at 2000 feet. The sound side outfall at Whalebone Junction could be rerouted to discharge off shore and conveyed though a single 72 inch diameter outfall line at a projected cost of $19.5M at 3000 feet, and $13.5M at 2000 feet. The outfall at Old Oregon Inlet Road could be also be effectively conveyed though a single 72 inch diameter outfall line at a projected cost of $18.7M at 3000 feet, and $12.6M at 2000 feet.

While it may be feasible to address challenges related to permitting, and potentially public perception, for this management option, it proves to be, by far, the most costly of all the alternatives considered in this study. However, if urban growth continues to result in greater population densities and higher numbers of tourists using beach, available resources and practical demands may ultimately render the option desirable.

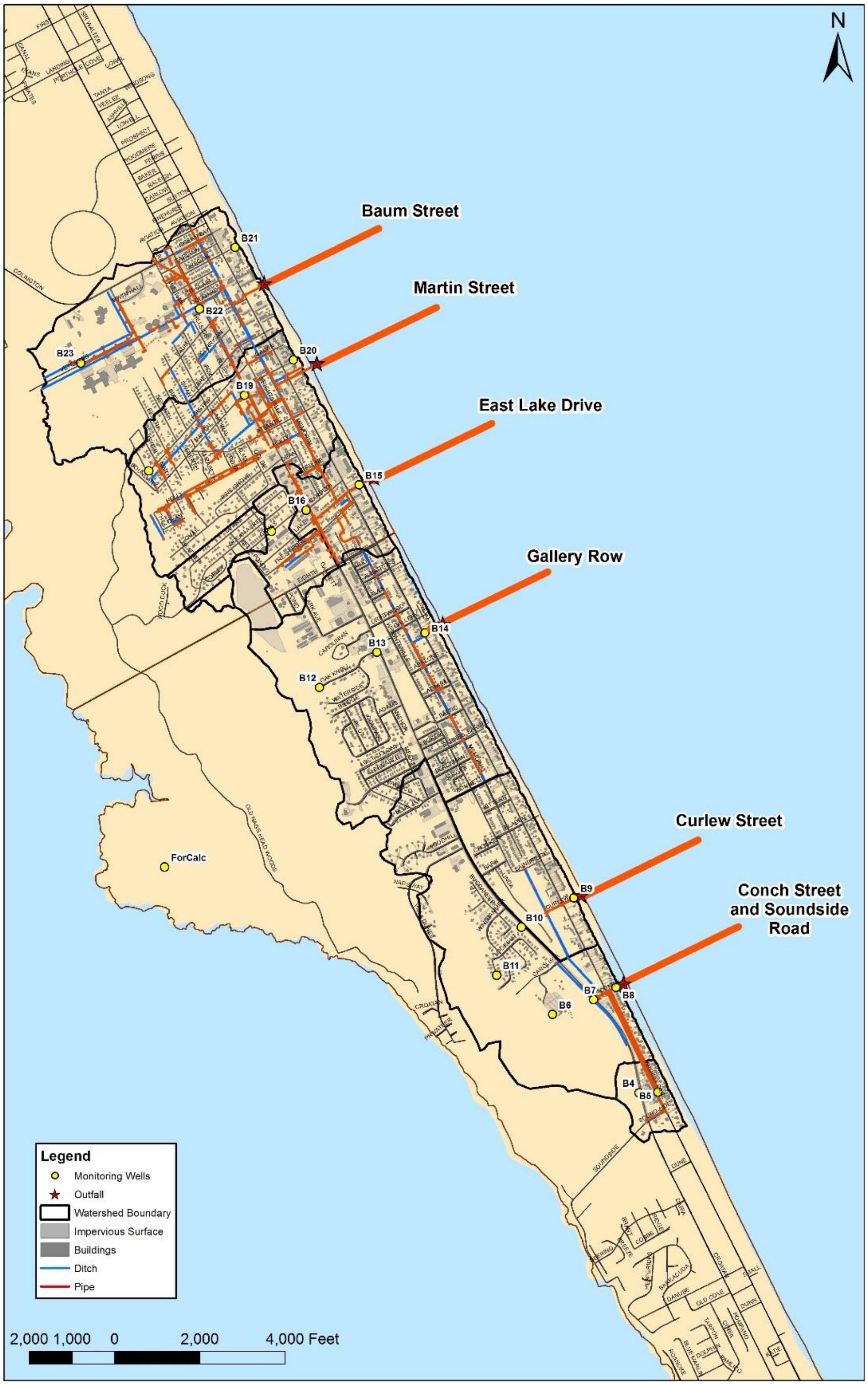


Figure 94. Geographic Extent of Deep Water Ocean Outfalls

4.4 Centralized Wastewater Treatment Systems

While the loading mechanisms and the specific delivery pathways are not completely defined in this study, it is clear that shallow groundwater interaction with leach fields from on-site septic systems are a significant source of FIB contamination in the ocean outfall discharges. That bacteria source could be drastically reduced or eliminated through the installation of sanitary sewer collection systems and centralized wastewater treatment facilities. However, such public, centralized systems often have high price tags, especially when installing them in already developed landscapes. As an example, in a similar NC Coastal geographic and physical setting, and similar size of community, the Town of Oak Island recently installed a town-wide wastewater collection and treatment system. The final cost of that system was approximately $150 Million. In addition to the high costs, such systems require a discharge site for the large volume of treated wastewater, or large land areas suitable for spray irrigation or subsurface injections. Given the limited availability of suitable land on the Outer Banks, this requirement represent a significant hurdle for the feasibility of any such system. It should also be noted that such large public systems are typically financed with municipal bonds which require the facilitation of higher levels of growth and development to generate the revenue to service the bonds while continuing to maintain existing services and operate the new infrastructure. Lastly, it should be noted that this type of system would provide no treatment for birds and other wildlife sources which also contribute to the issue.

The feasibility hurdles associated with large-scale centralized wastewater systems could potentially be overcome with an alternative approach of targeting the development of smaller scale collection and treatment systems in areas of higher intensity development that are known the be active sources of FIB loading in shallow groundwater. Systems of this nature can also take advantage of the existing on-site septic systems by piping the treated wastewater back out through the community and distributing it to the subsurface though the existing leach fields. Challenges to these targeted small treatment systems would be the high cost of installing parallel collection and distribution lines to send the treated effluent back and small satellite treatment plants that don't have permanent on-site staff which are prone to inconsistent treatment performance. The examination of the economics and feasibility of targeted small systems would require a detailed engineering alternatives study beyond the scope of this endeavor.

4.5 Potential Funding Alternatives

While some clear distinctions may exist, all of the alternatives set forth in this section are both expensive and challenging to implement. To varying degrees they all require acquisition and/or use of significant areas of land and implementation of substantive new infrastructure. Many of these approaches will require public funding resources beyond those available within the local communities most impacted by these ocean outfalls. Effective solutions are likely require assistance in the form of state and federal grant and loan funding for implementation. In that light, a brief overview of potential funding sources is set forth below.

Clean Water Act Section 319 Nonpoint Source Management Program

From the USEPA website, "Section 319 addresses the need for greater federal leadership to help focus state and local nonpoint source efforts. Under Section 319, states, territories and tribes receive grant money that supports a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects." Section 319 grants are awarded to states (and tribal authorities) by the USEPA, and the states, in turn, can use some portion of the funding (up to 20%) to support their own nonpoint source management programs and TMDL development. The states then award the remaining funds directly to local communities and non-profit organizations for projects that result in tangible reductions in non-point source pollution and improvements to water quality. Section 319 grants require 40% local matching to receive federal funding, but "in-kind" services, such as local community staff time associated with the project can be counted toward the match. More information can be found at:

http://www.epa.gov/polluted-runoff-nonpoint-source-pollution/319-grant-program-states-territories-and-tribes

http://portal.ncdenr.org/web/wq/ps/nps/319program

Federal Emergency Management Agency (FEMA) Hazard Mitigation Assistance Program

FEMA's Hazard Mitigation Assistance (HMA) grant programs provide funding for eligible mitigation activities that reduce disaster losses and protect life and property from future disaster damages including the Hazard Mitigation Grant Program (HMGP), Pre-Disaster Mitigation (PDM), Flood Mitigation Assistance (FMA). Eligible applicants include states, territories and tribes, local communities, and private non-profit organizations. While some programs require that communities have been subject to a Presidential Declaration of Major Disaster for eligibility (specifically HMGP), not all sections are subject to the requirement. Projects and associated programmatic management efforts can be 100% supported by grant moneys (no match required). However, funded projects are required to undergo rigorous Benefit Cost Analyses, and to in order to proceed beyond Schematic (30%) Design, must be shown to have a benefit/cost ratio greater than one. More information can be found at:

http://www.fema.gov/media-library/assets/documents/103279

National Disaster Resilience Competition (NDRC) Grant Program

In 2015, the US Department of Housing and Urban Development (HUD) used the usual Community Development Block Grant (CDBG) funding to team with the Rockefeller Foundations to sponsor the NDRC. The NDRC is currently in the process of awarding $1 Billion dollars in funds for programmatic efforts and specific projects to achieve disaster recovery and improvement of long-term community resilience. States and local communities which were subject to Presidential Declarations of Major Disasters in 2011, 2012, or 2013 are eligible applicants and the second phase of the two-phased 2015 competitive application process is now ongoing. At this juncture, it is officially unknown whether the NDRC will continue as the ongoing framework for CDBG funds, but a 2016 cycle is anticipated. More information can be found at:

https://www.hudexchange.info/programs/cdbg-dr/resilient-recovery/

North Carolina Clean Water State Revolving Fund (CWSRF)

The CWSRF was established to replace the earlier Construction Grants program by amendments to the Clean Water Act in 1987. With those amendments Congress provided funds for states to establish revolving loan programs for funding of wastewater treatment facilities and projects associated with estuary and nonpoint source programs (including stormwater BMPs). The program makes low interest loans (1/2 of market rates) available with a limited amount of principle forgiveness loans and some 0% interest loans for Green Projects and rehabilitation projects for certain local units of government. The CWSRF is operated by the NCDENR Division of Water Infrastructure and has two funding cycles annually. More information can be found at:

http://portal.ncdenr.org/web/wi/cwsrf

North Carolina Clean Water Management Trust Fund (CWMTF)

The CWMTF was established in 1996 to provide grant assistance to conservation non-profits, local governments and state agencies for the protection of surface waters in North Carolina. The CWMTF funds projects that (1) enhance or restore degraded waters, (2) protect unpolluted waters, and/or (3) contribute toward a network of riparian buffers and greenways for environmental, educational, and recreational benefits, (4) provide buffers around military bases to protect the military mission, (5) acquire land that represents the ecological diversity of North Carolina, and (6) acquire land that contributes to the development of a balanced State program of historic properties. The CWMTF is no longer authorized to fund conventional stormwater projects (having deferred that program to the Division of Water Infrastructure and the State Water Infrastructure Authority (which administers the CWSRF above). However, the CWMTF still maintains the capacity to fund stormwater projects deemed innovative, which is likely to apply to the potential improvements set forth to address ocean outfalls.

http://www.cwmtf.net/#home.html

Obviously the challenges presented by the ocean outfalls and the potential solutions fall across the nexus of water quality improvement efforts, hazard mitigation and community resilience, and as a result, would be eligible to take advantage of funding programs and mechanisms aimed at any of these three arenas. The purpose of this section was to highlight a few of the largest, most applicable, and most readily available funding sources to support improvements to address fecal bacteria contamination from ocean outfalls. A more comprehensive list of funding sources for water resource and related projects is hosted by NCDENR (now NCDEQ) at:

http://portal.ncdenr.org/web/wq/ps/bpu/urw/funding

5.0 Recommendations

This project was both spatially and temporally intensive and yielded tremendous quantities of valuable data. Here we attempt to distill our technical findings into recommendations. Conclusions from the findings presented in Chapters 2 and 3 directly impact recommendations stated here. For context, conclusions are restated with the relevant recommendation.

5.1 Recommendations to Improve Stormwater Management

5.1.1 Improve Stormwater Infrastructure Asset Inventories

Stormwater BMP retrofitting is a primary avenue through which FIB loads can be reduced in ocean outfall watersheds. In addition, stormwater BMP retrofits can reduce pollutant loads for a wide array of other pollutants, and reduce stormwater quantities to address nuisance flooding, if sited and designed for those objectives. However, identifying opportunities to site stormwater BMPs in already-built landscapes can be challenging, particularly in beach communities where available land for implementation is scarce and costly.

The conceptual analysis of retrofitting opportunities present in Chapter 4 were based on the knowledge of stormwater infrastructure representing the best available information at the time of this study. The data was compiled by partial surveys of infrastructure conducted for this study (primarily in areas east of the US 158 Bypass), and piecemeal mapping data on infrastructure obtained from the Towns. Known recent installations of new storm drain pipes, and rerouting of some existing drainage system have already significantly altered drainage patterns in some outfall watersheds. Any future efforts to identify candidate sites for implementation of stormwater BMPs will require a thorough and accurate inventory of the drainage networks already in place. Such asset inventories will allow for effective optimization of drainage areas and hydraulic treatment volumes for BMP retrofits.

It should be noted that the benefits of collecting the necessary data and developing a comprehensive inventory of existing stormwater infrastructure go well beyond that of enabling BMP retrofits to address ocean outfalls. A thorough and data-rich inventory would facilitate numerous efforts including master planning and effective management related to flood hazard reductions. The inventory data collection process would also allow for a system wide assessment of the conditions of existing structures, and it would facilitate cooperative efforts between the Towns.

5.1.2 Analyze Existing Data to Better Understand Shallow Groundwater Delivery of FIB Contamination

The results from this project indicate that there is a potential for human fecal contamination to be present in stormwater runoff from ocean outfalls. In addition, the groundwater well monitoring data show that during storms of higher total precipitation and longer duration, there is a high frequency of interaction between groundwater and septic system drain fields. The tide also plays an important role in the delivery of microbial contaminants over the duration of longer storms due to pooling of contaminated water, and subsequent release during falling tides. Together, these watershed and coastal hydrology factors have increased the potential for delivery of human-derived fecal contamination to the surf. At this time, even though trends have been observed over the course of this study among groundwater, septic system densities, and microbial contaminant profiles, no formal hydrological data analysis has been conducted to inform Town Managers of the range of scenarios that might be most effective in mitigating this problem. This phenomenon has been observed and documented previously in coastal NC systems (Line et al. 2006). A major recommendation of this project is to utilize the wealth of data that is available to develop both correlative and causal assessments of sources of microbial contaminants and overall loading to the system. In addition, the recommendation is to assess the severity of this groundwater interaction, and to utilize the developed information to guide any further consideration of groundwater drawdown technologies in specific areas.

5.1.3 Utilize Proactive Groundwater Drawdown

As discussed in Section 4.2, the Town of Emerald Isle, NC and the Whalehead Community on the outer banks of Currituck County, NC have experienced success in controlling excessive stormwater volumes and reducing the frequency, magnitude and duration of flooding events though the use of engineered groundwater drawdown systems. By engaging such systems, 24-48 hours prior to the arrival of major storms to reduce groundwater levels locally, these communities have been able to create substantial areas of available subsurface storage capacity to avert or reduce flooding. The pump systems then convey and discharge that infiltrated groundwater to areas on the sound side of their respective barrier islands where its impacts are reduced relative to having it discharged in the surf. Monitoring data have also indicated that such systems have very low levels of FIB present in their discharge. In that light, drawdown systems show promise as a means to reduce the levels of FIB currently discharged from ocean outfalls, by potentially achieving treatment of those floodwater volumes as they filter through the increased depth of the soil column made available by drawdown (essentially utilizing the *in-situ* soils as a sand filter). At the very least, the current level of understanding warrants the installation of such a system on one outfall on a pilot basis to closely evaluate performance.

5.1.4 Town and NCDOT-Specific Strategies

Results from this project provide detailed information regarding water volumes in storms, loading of FIB, timing of delivery of FIB within storms, and fate of FIB in receiving waters that can be effectively utilized to guide the towns and NCDOT through improvements in stormwater management efforts and plans. Additionally, watershed assessments including land cover and stormwater infrastructure allow the stormwater data to be analyzed in a site-specific context for each of the storm drains in this study. This information is a tremendous asset that can be used to conduct feasibility assessments in each watershed and, where tenable, design watershed-specific stormwater plans. At the outset, a major goal of this study was providing empirical information to improve stormwater management. Data and information generated by this study are well suited for application in a variety of efforts to enhance the efficacy of stormwater pollution mitigation efforts. The watershed boundaries break neatly along the border between the Towns of Nags Head and Kill Devil Hills, with the northernmost three watersheds, Baum Street, Martin Street and East Lake Drive, located entirely or predominantly (East Lake Drive) Kill Devil Hills, and the remaining watersheds located within the bounds of Nags Head. The sometimes distinct geographic settings and some observations from the vast array of data and assessments lend themselves to some recommendation for town-specific strategies as follows:

Town of Kill Devil Hills

Our analysis of reported on-site septic system repairs showed that in the period 2006 to 2012, the proportion of septic systems in any given Nags Head watershed which had experienced some repair or upgrade varied from 10-24% of all septic systems in that watershed, whereas, the proportion of existing septic systems affected by reported repairs or upgrades ranged from 5-7% in Kill Devil Hills watersheds. There are some watershed-specific hydrologic characteristics that explain some variability from watershed to watershed in failure rates and the occurrence of problems with these systems. However the larger geographic setting is similar enough that similar failure and problem rates might be expected from town to town. The discrepancy in repairs and upgrades is more likely a function of the Town of Nags Head's Septic Health Initiative and the fact that they have set forth a Decentralized Wastewater Master Plan. The Town of Kill Devil Hills may wish to consider devoting resources to a developing a program and more proactive stance on inspection, maintenance and upgrade of on-site wastewater systems.

In terms of watershed priorities, there is a case to be made for focusing management efforts on the Martin Street watershed. Of all the ocean outfalls in this study, for any given storm Martin Street most consistently delivers among the highest three in terms of hydraulic flow and FIB loads, and this holds true in terms of bold total storm load and load rates per hour for both *Enterococcus* spp. and *E. coli*. Partly by virtue of being large watershed, but also due to fairly high levels of urbanization, the Martin Street watershed has the most developed system of artificial drainage. Any efforts to reduce, interrupt, infiltrate or divert the storm flows moving through that system will likely have positive impact on pollutant loads. Martin Street offers diverse management opportunities, including the potential for development of a combined groundwater drawdown system in conjunction with the Baum Street outfall, and the potential for a regional stormwater BMP retrofit.

Upcoast/downcoast monitoring data have indicated that there is likely some interaction between the outfalls at Soundside Road, Conch Street, and Curlew Street in terms of the transport and dispersion of their FIB pollutant loads along the shore. While there are merits to focusing efforts on Martin Street, it would be advantageous to keep in mind that three outfalls within Kill Devil Hills are spread over a distance similar in scale to those three Nags Head outfalls. Given that they are collectively a larger set outfalls in terms of combined flow and FIB loading, and that they serve a more urbanized landscape than the other outfalls, they should be viewed as having as strong a potential for interaction of their pollutant loads in the surf.

Town of Nags Head

The Town has clearly experienced some success with the Septic Health Initiative by increasing awareness and facilitating higher rates of repair and improvement of on-site septic systems. There is obvious merit to increasing the resources devoted to this program and to exploring potential mechanisms to cause on-site systems to move more rapidly and in greater numbers to higher level of technology and performance among on-site systems within the jurisdiction. The analysis of potential groundwater-septic system interaction herein has point to a high potential for such interaction in the South Nags Head watershed, and especially Gallery Row. Efforts aimed at moving onsite septic systems in these watershed over to new mounded systems could be of obvious benefit.

The Soundside Road, Conch Street, and Curlew Street outfalls together could be viewed and managed in a comprehensive fashion. Should groundwater drawdown systems be proven to be effective for FIB reduction loads from the ocean outfalls, these outfalls readily lend themselves to opportunities to capitalize on economies of scale by implementing a combined drawdown system. Should any single phase or portion of that system be implemented, there is obvious advantage in designing and implementing it so as to account for subsequent phases.

Given the investment already made and the lessons learned at Conch Street, The Town of Nags Head may wish to consider entering into a more deliberate partnership with NCDOT to affect recommended improvements and regular maintenance of the Conch Street BMP. Since the time the BMP was envisioned and implemented, more cost-effective treatment technologies have advanced and expanded, and designers and practitioners have learned a great deal regarding the operation, maintenance, and performance of such devices. Any efforts to improve the operation and performance of the BMP should be accompanied with sufficient monitoring efforts to gage effectiveness and support an ongoing cycle of adaptive management.

NCDOT

Unlike the Town of Nags Head and Kill Devil Hills, whose jurisdictions each include the watersheds for some of the outfalls, NCDOT has jurisdiction over roadways and other facilities which generate runoff that flows to all of the Dare County Ocean Outfalls. In addition, a considerable amount of the drainage infrastructure connected to the outfalls is located within NCDOT right-of ways and is under their domain. As such, effective management of stormwater and the related infrastructure will require active cooperation between the towns and NCDOT. Any efforts to retrofit green infrastructure BMPs to capture and treat stormwater from already built landscapes would offer obvious opportunities for partnerships. Groundwater drawdown systems, should they be used, will require portions of that infrastructure to be installed within NCDOT right-of-ways as well.

The most obvious opportunity for partnership would be to engage the effort to make improvements to the Conch Street BMP, or to work together in the effort to decommission it if that is the path chosen. It should be noted that both the Town of Nags Head and NCDOT contributed personnel and equipment in the collaborative effort to perform the maintenance that has occurred on the Conch Street BMP.

5.1.5 Consider Limited Applicability of End-Of-Pipe Solutions In Challenging Settings

The monitoring results for the pilot BMP study at Conch Street have shown that limited levels of success have been achieved with the device with some level of reduction in FIB concentrations observed during ideal conditions, predominantly consisting of periods with measurable advective flow through the device and tides low enough to eliminate tail water interference on the downstream end. Unfortunately, such conditions do not occur frequently in this setting along the northeastern NC Outer Banks. Simply put, the very limited amount of topographic relief on this barrier island places severe hydraulic limits on such devices in that the change in elevation from the lowest point of drainage system on the upstream side to the outlet below sea level on the downstream side does not always allow for sufficient head pressure to effectively move water through the device. Large structural BMP retrofit devices of this nature are much more likely to be suitable for treating portions of the outfall watersheds where space is available and hydraulic conditions are suitable, such as in the large BMP retrofit example presented in Section 4.2.

It should also be noted that a set of recommendation has been set forth to improve the performance of the Conch Street BMP (Section 2.5) including improved pretreatment to improve sediment trapping, retrofitting of a solar pump to reduce tidal interference, and a full change-out with new treatment media. Given the investment of public resources already made at Conch Street, it would be worthwhile to make the investments to give the device ample opportunity to produce more successful results.

5.1.6 Improve Public Education on Recreational Water Quality

Based upon the results observed in this study, there is significant FIB delivery during storms. Delivering this technical finding in a context that resonates with stakeholders is essential. Improved public education forums and approaches can contribute to meeting this challenge. Examples of effective public education approaches to consider include: incentive-based programs for septic system pump-out and septic system improvements, educational efforts on issues related to FIB, programs describing the connections between FIB and human health, demonstrations of the limitations and sensitivities of FIB based water quality management, programs outlining remedial options ranging from watershed management to end of pipe BMP, presentations detailing what individuals can do to help prevent stormwater pollution, and educational programs on the economic value of clean recreational waters.

Two specific examples of areas where water quality management and public education intersect are public education regarding feeding of wild birds (seagulls) and proactive pet waste pickup and disposal practices. While a dog waste pickup program is in place in Dare County, NC, there is a need to formalize this program, and provide specific locations for bags for dog waste, and enforcement of dog waste pickup practices. In the case of seagulls, while a program is very generally in place in coastal NC, it may be necessary to incentivize and to put in place a system to more specifically enforce rules and regulations regarding this issue, including the feeding of birds at restaurants and in parking lots, and proper covers and closures to all trash receptacles and dumpsters.

5.2 Recommendations for Public Notification and Protection of Public Health

5.2.1 Consider the development of proactive rainfall-based advisories for beaches

Prior to this study, many local stakeholders were uncertain that Dare County beaches had stormwater-driven FIB issues. This study clearly demonstrated the presence of stormwater delivery of FIB and provides detailed information to craft protective rainfall-based advisories. It is clear from the upcoast/downcoast monitoring portion of this study that even short duration, small storms can result in stormwater contamination in swimming waters. The results from this study indicate that rainfall/FIB relationships exist. Other recent studies in coastal North Carolina have identified significant relationships between rainfall and *Enterococcus* sp. concentrations. In order to conduct a full data analyses for the development of a presumptive rainfall advisory, it will be necessary for stakeholder interaction with the project team, this is necessary to determine whether any rainfall advisories would be town, region, or state issued, and this information will directly dictate the data that are included in the analyses.

Rainfall-based advisories are used in many coastal states to effectively manage water quality. Rainfall-based thresholds are derived by simply relating the FIB contamination observed at the beach of interest to either the total amount of rainfall, or rainfall related parameters such as rainfall per hour. Rainfall-based advisories are one of the most established water quality management techniques used for recreational waters, and they are also part of the most recent (2012) and a new version of EPA-based guidance on the development of real-time predictive tools for water quality management. They are based on the assumption that as rainfall increases FIB concentrations (and therefore public health risk associated with water contact) in beach waters and loading of FIB from stormwater runoff also increases. Many states develop their rainfall-based advisories using the single sample thresholds that are already in place for their beaches (e.g. *Enterococcus* sp. concentrations of 104 MPN or CFU/100 ml would be the established threshold of interest for NC beaches). By identifying a beach notification threshold or target FIB concentration, managers can predict exceedances of the threshold using cumulative precipitation amount, and/or storm duration and/or intensity.

Should presumptive rainfall-based advisories be implemented for the affected Dare County beaches, in the event that an advisory were issued, rapid and frequent sampling could be utilized to enhance public safety and reopen beaches for recreational swimming again, as soon as possible. For instance, the Town of Wrightsville Beach has considered a system of rain-fall based advisories, under which, when an advisory was issued, FIB sampling would just six hours after the rainfall event ceases, and would occur again every six hours until the advisory was lifted, in the interest of minimizing the period of time under the advisory.

As an alternative to a pre-determined presumptive rainfall triggers and advisories, more detailed predictive modeling could be utilized, such as the multiple linear regression tool called "Virtual Beach" that is an EPA product. National guidance is available from the USEPA for the use of predictive models in the form of the new document entitled "Five Key Steps for Developing and Using a Predictive Model at Your Beach", to be released shortly.

5.2.2 Consider improved signage at major outfalls

Alerting the public to the extent of stormwater runoff based contamination at the beach may require consideration of location and number of signs. Currently, permanent signs are placed at the stormwater outfalls and alert the public to contamination that extends to 200 feet from the stormwater outfalls. These signs are typically placed at the outfall pipe itself. The upcoast/downcoast monitoring results from monitoring of outfalls from this study, conducted over a wide range of storm events, clearly indicate that *Enterococcus* sp. levels along beaches impacted by outfall discharge consistently exceed water quality standards throughout and well after a storm event. Furthermore, the impact of the *Enterococcus* sp. contamination appears to extend to distances in exceedance of 100 meters up and down the beach from outfall pipes. In the summer, it has been noted that these events are relatively short in duration and while contamination along the beach appears to extend further than previously speculated, that the pulse of contamination is likely relatively short lived. A previous experiment conducted with a team of water quality managers in 1999 in southern California indicated that signs are not visible to the public at distances in exceedance of 25 feet (Noble et al. unpublished data). This means that, beyond a distance of 25 feet from the outfall pipe, the public are neither aware of, nor responding to signage that exists at the outfall pipe. As indicated previously some states are using rainfall-based advisories in order to alert the public to issues related to stormwater contamination at beaches. Many of those states are also implementing rapid resampling efforts following storms so as to quickly reopen beaches because contamination events can be short lived. Rapid molecular methods such as those approved by EPA for *Enterococcus* sp. can offer an avenue to provide results within 2 hours from sampling, providing a mechanism to rapidly reopen high use beach areas that were impacted by short-lived rainfall events. The levels of FIB measured in these study beaches indicate that human health risks exist in NC recreational waters at distances far from the outfall pipe and perhaps in areas not currently indicated by existing signs. To improve in the protection of public health at recreational beaches in NC that are impacted by major outfalls, it is recommended that the State water quality management agencies utilize the data collected as part of this project to develop an improved approach. An example of a possible outcome might be that the public be alerted to risk using a web-based map tool based on precipitation. Since summer storm events during the height of the beach season are often short in duration, it is likely that no one measure or solution will offers the promise of addressing this matter effectively when taken alone. It is far more likely that an array of management efforts and engineered solutions, including those presented here, will be required to effectively address the FIB discharge stemming from the ocean outfalls.

Given this, the major recommendations include the following, scaled in order of short-term to long-term priority:

a. Consider, on the permanent signage, increasing the indicated distance of caution to the public when stormwater is actively discharging from pipes, along with improved placement of signs to promote visibility to the public. Our data indicate that a warning extending to 300-400 feet from the outfall pipe is warranted.

b. For storms of short duration, consider implementation of improved permanent signage along at more visible beach locations, along with the usage of a web based notification system for rainfall-based advisories.

c. Consider a combination of rainfall-based advisory and rapid resampling of recreational waters using available USEPA-approved rapid methods following storm events to improve protection of public health while minimizing adverse impacts on beach visitation and economies.

5.3 Stakeholder Interaction to Improve Performance of On-Site Wastewater Systems

In the fall of 2000, after a decade of grass roots septic system based initiatives conducted by members of the town, the Town of Nags Head formally implemented the "Septic Health Initiative". This initiative included public education, detailed septic inspections, and pump-outs, and monitoring of ground and surface water quality. Since, then, the data collected have been utilized to develop the Decentralized Wastewater Master Plan. Today this plan is Nags Head's long-term strategy in protecting water quality while allowing the continued use of on-site septic systems. As part of this project, extensive groundwater data has been collected, as well as information on drainage and septic system placement that are relevant to patterns of FIB contaminant at beaches during storms. There is a wealth of information that can be utilized to guide and improve a septic health program, and this information should be utilized to the full extent possible. For example, at specific outfalls, and in specific towns there is a trend toward stormwater runoff containing human fecal contamination late in storms, coinciding with increasing groundwater levels. It may be that these areas could be of the highest priority for groundwater drawdown systems as a means of stormwater runoff mitigation. Second, the Town of Nags Head is to be lauded for their forward thinking efforts, and additional stakeholder interaction with other towns to promote the development of such programs should be initiated. Finally, it will be of interest to promote and incentive based program for owner-based efforts to improve septic system operation and reporting. While it is often determined that at the individual scale, that septic system retrofits are expensive. However, it may be of interest to the individual towns to offer home-owner based incentives on new, state-of-the-art septic systems in the interest of stormwater runoff treatment practices.

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Appendix A – Conch Street BMP Assessment

Appendix B – Ocean Monitoring Results

Appendix C – Hydrologic and Hydraulic Modeling and Results

Appendix D – Outfall Monitoring Results 2006-2008

Appendix E – Design Typicals and Cost Estimates for Engineering Alternatives

Appendix F – Responses to Questions and Comments Submitted