regulations to prevent, reduce or control water pollution. The intent of the legislation was to eliminate the practice of discharging untreated sewage and chemicals into our nation's waterbodies. Since passage of the legislation, great strides have been made to clean up our rivers and streams. In 1997, twenty-five (25) years after passage of the ***Clean Water Act***, the Environmental Protection Agency (EPA) established the Beaches Environmental Assessment and Coastal Health Program (BEACH Program). This program was established for the purpose of reducing risks to human health due to contact with pathogens in recreational waters. These pathogens, including but not limited to bacteria and viruses, are commonly found in the surf zone, and are placed there by two (2) primary factors, stormwater and sewage discharge. Some coastal states adopted these standards shortly after they were implemented. Many beach resorts began testing the water in the surf and publish reports regarding the bacterial levels. Myrtle Beach did not immediately implement a monitoring program due to a number of factors including the availability of resources and, more importantly, the knowledge that the reporting would lag behind any pollution detected by at least twenty four (24) hours. However, in July of 1997, the National Resource Defense Council (NRDC) hosted a national press conference and, during that conference, listed Myrtle Beach, South Carolina as a "Beach Bum" due to the absence of a testing program and the potential for pathogen related health problems. As a result, the local, regional and national press produced negative articles regarding Myrtle Beach. This triggered an immediate and decisive reaction from the tourism industry. Led by the Myrtle Beach Area Chamber of Commerce, they called for implementation of a plan to set up a testing program and to publish the results. It should be noted that the number one industry for the State of South Carolina is tourism. More than 50% of the tourism revenue for the entire state comes from Myrtle Beach and the Grand Strand. As such, a reduction in the number of visitors due to the negative connotation from the designation of "Beach Bum" could have a direct negative impact on the area, region and, ultimately, the entire State. The potential for a negative economic impact was recognized by all stakeholders from the Mayor and City Council of Myrtle Beach, up to and including members of the Governor's staff.

Due to the efforts of the tourism industry, a mandatory testing program was implemented by the State through its Department of Health and Environmental Control (SCDHEC). This included a comprehensive outreach program to provide information to visitors and locals. Because a great percentage of pollution on the beach and in the surf originated from stormwater outfall pipes which discharge directly to the beach, attention immediately was focused on these areas.

Removal of Beach Outfall Pipes

The elimination of the numerous outfall pipes have long been the source of debate along the Coast of South Carolina for a number of reasons including their unsightly appearance, erosion of the beach at the outfall after significant rainfall events and the recognized potential that a recreational swimmer could potentially become ill due to exposure to the polluted stormwater from the outfall. Those against taking action to remove the outfall pipes reminded the stakeholders that there has not been a documented case of illness stemming from contact with water from these outfalls, and that the tremendous cost associated with re-routing stormwater to another area or to some distance off-shore would be a significant drain on public resources. However, the negative press and the realization that lack of action could harm the local economy brought on a rapid consensus that immediate action should be taken to eliminate as many beach outfall pipes as practical and financially feasible.

In early 1998, representatives of the City of Myrtle Beach and other municipalities along the South Carolina *Grand Strand* met to discuss the need to expedite the removal of stormwater outfall pipes from the beaches. The City of Myrtle Beach was the first of these municipalities to initiate work toward that end.

Funding

Once the decision was made to pursue removal of the beach outfalls, a myriad of new and more complex problems were brought to the forefront. As no municipality in South Carolina had taken action on this issue, there was no established funding mechanism for design, regulatory interaction, or construction. In addition, the environmental and regulatory communities were very interested in the design methodology and construction procedures which could potentially do harm to the environment, thereby creating the potential for regulatory approval problems.

In early 2001, the City Council approved a ballot referendum to be included in the fall election. The local business community invested in a public information campaign and, through this effort, the voters overwhelmingly approved the referendum which ultimately provided approximately $25 million to fund improvements in four (4) specific stormwater basins with engineering studies for potential deep water ocean outfalls in three (3) beachfront areas. The stated goal of the City was to "reduce the number of pipes on the beach, maintain high water quality standards, and to provide a reliable stormwater drainage system to alleviate flooding."

Basin Selection

The City of Myrtle Beach, like so many municipalities across the United States, had concentrated on water supply, sewage collection and roadway improvements for many years without significant consideration for stormwater management and little or no consideration for water quality. The City is bound by the Atlantic Ocean and the Atlantic Intracoastal Waterway and, as such, seventy-nine (79) pipes had been extended to the beach to drain hotels, roads, parking lots and commercial establishments as development occurred over the past forty (40) years. Overall, most areas of the City drain effectively due to the frequency of the beach outfalls coupled with the high percolation rate of the very sandy soils. However, there are a number of stormwater basins in the interior areas of the City have become landlocked due to development and are burdened with poor soil conditions, leaving these areas to flood on a frequent basis. After careful review of the potential benefits of providing relief to each of the four (4) basins, the Yaupon Basin was selected for the first project. Of these four (4) stormwater basins which flooded regularly, the Yaupon Drive basin was plagued with the higher frequency of flooding and had the best potential for a successful implementation of the deepwater outfall solution because the elevation differential within the basin provided better opportunity for gravity flow. The elevations within the basin range from 11.0 feet MSL to 26.0 feet +/- MSL. This was a very important consideration because of the City's directive that pumping stormwater should not be considered by the design team.

Yaupon Basin Existing Conditions

The Yaupon Basin is comprised of approximately 189 acres of property. The basin is highly impervious with nearly 70% covered with rooftops or pavement. The basin's single beach outfall consisted of one (1) thirty inch (30") corrugated metal pipe. This basin has been developed through the years with a variety of uses including commercial areas, multi-family, and single family neighborhoods. A very small percentage of undeveloped property is scattered throughout the basin. The vast majority of development within this basin was completed long before there were any state or local stormwater regulations and, as such, there is very little evidence of any water quantity and no evidence of water quality elements. Further, in a number of instances, development has encroached into the drainageways. The existing drainageways through the Yaupon Basin consisted of open channel and piped segments, a majority of which were installed without benefit of easements or rights-of-way and in some cases, without benefit of design as the area developed over the years. Because of this, the City was forced to acquire easements for the proposed improvements and, more importantly, for future maintenance of the system. Because of the development growth within the basin in more recent years, flooding had dramatically increased in frequency and intensity. Correspondingly, the number of complaints to City staff and to members of City Council increased.

It was decided to model the basin using Inter-Connected Pond Routing (ICPR) software under 2, 5, 10 25, 50 and 100 year storm events within the deepwater ocean outfall sized to accommodate the 50 year event, so long as the 100 year event did not create flooding beyond "acceptable" levels. A complete field reconnaissance effort was conducted throughout the basin in order to effectively model the basin under existing conditions. This effort included Courthouse research, boundary surveys, topographic surveys, and visits to the site immediately before, during, and shortly after rainfall events. Information gained by through these field visits after rainfall events proved to be extremely valuable in our effort to calibrate the existing conditions model. Through modeling the basin, it was determined that, under existing conditions, the runoff created by these storms was significant.

Table 1. Existing Conditions – Total Basin Stormwater Runoff Quantity

Storm Frequency	Rainfall Amount	Pre-Development Runoff
2 Year	4.3" / 24 hours	173 cfs
5 Year	5.7" / 24 hours	192 cfs
10 Year	6.7" / 24 hours	200 cfs
25 Year	7.6" / 24 hours	207 cfs
50 Year	8.6" / 24 hours	216 cfs
100 Year	9.7" / 24 hours	239 cfs

Even with the available storage within the basin, when one considers that the existing outfall was a 30" CMP, it is easy to understand why there were flooding problems in various areas within this basin. Under the best of conditions, this outfall pipe could pass no more than thirty (30) cfs. As such, the entire basin flooded after a rainfall event greater than a two (2) year storm.

Regulatory Interaction

It was determined early in the reconnaissance that many of the improvements that were needed within the basin would require the regulatory approval of the U.S. Army Corps of Engineers given the likelihood that the ditches and immediately surrounding areas would be considered as "jurisdictional wetlands". Because of this, a wetland delineation and a Threatened and Endangered Species Audit were commissioned and, upon completion, submitted to the Corps of Engineers and the U.S. Fish and Wildlife Service, respectively, for review and approval. Fortunately, no threatened or endangered species were identified. The wetlands study was approved by the Charleston office of the U.S. Army Corps of Engineers and, through the involvement of representatives of the Charleston District early in the project, these individuals were of great assistance in expediting the permit request through the various state and federal agencies.

Extension of the ocean outfall would require the approval of the Corps of Engineers and the United States Coast Guard, as well as a number of state agencies. The principal state agency, the South Carolina Department of Health and Environmental Control (SCDHEC) Office of Ocean and Coastal Resource Management (OCRM) is charged with review and certification of all stormwater projects in the Coastal Zone of the state. Further, SCDHEC/OCRM controls any and all construction activities on the ocean side of their critical zone line. As such, the fate of the project was ultimately in the hands of this agency. Member of the OCRM staff worked with the project design team, providing timely reviews and reasonable regulatory comments. The recognition that this was a pilot project for the City of Myrtle Beach and, potentially, other oceanfront municipalities, the agency was keenly interested in a successful engineering result with minimal adverse impact to the environment.

Goals

Recognizing that, as the first project of this nature to be attempted in the State of South Carolina, with the potential for several more following its successful completion, the Design Team set a number of goals for the design, permitting, bidding and construction. They are as follows:

- Improve drainage facilities to successfully convey stormwater from the basin through an ocean outfall under a 50-year design storm event;
- Utilize any and all available property within the basin to implement Best Management Practices (BMP's) in an effort to reduce pollutants at the outfall;
- Team with experts in the field of ocean outfall projects for structural design of the outfall, and development of the dispersion analysis;
- Work with state and federal agencies throughout the planning and design phases in an effort to ensure ultimate approval of the project;
- Set Project construction time frames to not interfere with the tourism season (May through August); and,
- Work with the City staff to develop a procedure to mandate prequalification of contractors to ensure that each contractor bidding the project could indeed construct it within the City's stated time frame.

Overcoming Restrictions and Problems

Early in the planning effort, the design team developed a clear understanding of the many obstacles in the way of the aforementioned goals. The design of the stormwater management elements to reduce flooding and carry the stormwater roughly 1,100 feet offshore was a relatively simple exercise in comparison to the environmental issues and with the contractual issues associated with bidding the project to pre-qualified contractors. The water quality improvement element of this project quickly became the greatest restrictive factor of concern by the Design Team and, as such, a majority of the design effort focused on this issue.

The location of the basin and limited availability of reasonably priced property eliminated many elements of BMP's from consideration. In addition, the existing land use encouraged many types and forms of pollution, especially domestic animal waste (dogs and cats), due to the nature of the residential communities within the basin.

With the knowledge that vegetated swales, littoral shelves and other natural methods to remove sediments and debris could not be easily implemented, the Design Team turned to structural BMP methods including sediment traps, oil/water separator devices and screening devices to remove pollutants from the system. Exhibits 1 and 2 below provide details of the sediment trap and screening devices ultimately utilized for this project. These elements are not only more expensive than utilization of natural BMP's, they are much more reliant upon regular maintenance. It was recognized that a lapse in maintenance of the screening devices may create obstructions within the drainageway, which would ultimately cause flooding and, thereby, defeat the purpose of the project. Coupled with this, the elimination of natural BMPs from consideration effectively decreased the time of concentration and time of travel within the basin, thereby increasing the peak runoff for each storm event. The Design Team had hoped to facilitate some upstream storage through construction of ponds, swales and other natural features. Unfortunately, this was not practicable due to many factors.

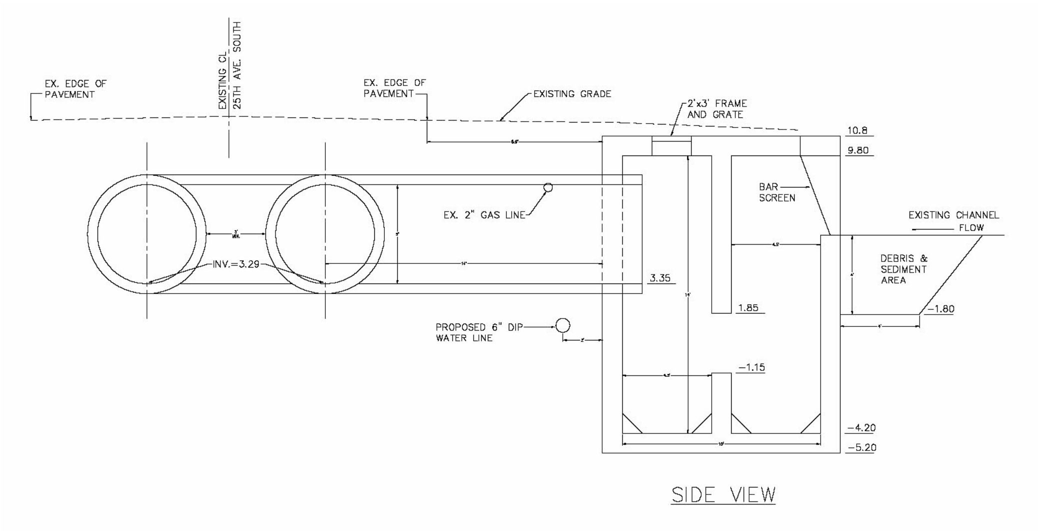

Exhibit 1.Sediment Trap (section)

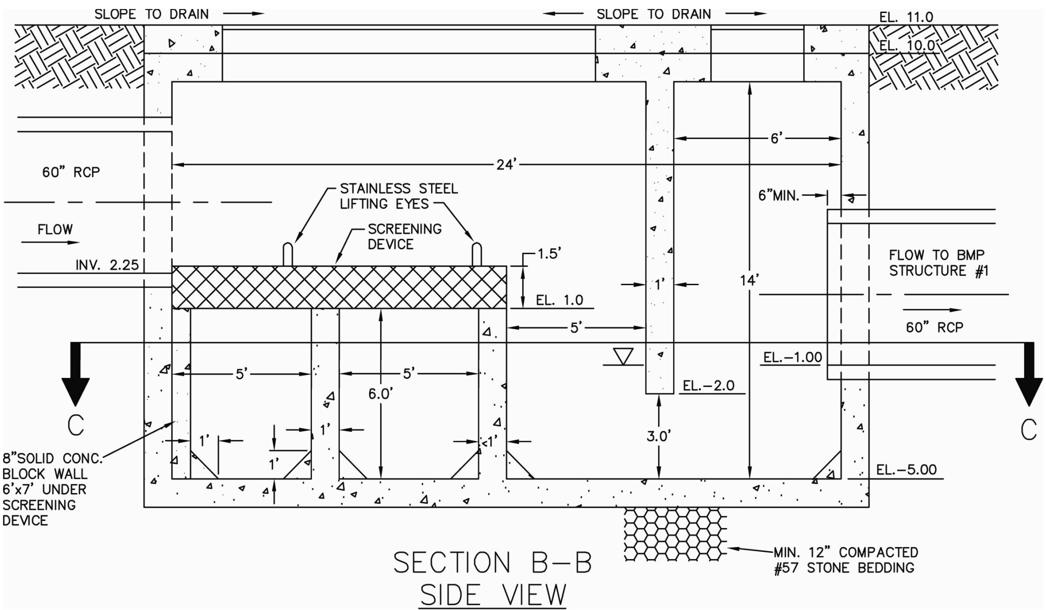

Exhibit 2.Screening (plan view)

DDC teamed with experts in the field of ocean outfalls, Dane R. Hancock, PE, Manhar Dhanak, Ph.D, and D.V. Reddy, Ph.D, PE. These experts provided the dispersion analysis required by the various agencies, predicting how the stormwater would react to ocean water and how it would dissipate. The goal was to determine the optimum distance from shoreline to extend the outfall which would allow dispersal of the stormwater, resulting in the reduction of the potential for pathogens to enter the surf zone. After determining the optimum length of the ocean outfall, the next task was to provide the burial design for the pipe. The experts work product was utilized in the regulatory approval process, as well as being incorporated into the final construction documents.

The City of Myrtle Beach procurement guidelines had no clear provisions for prequalification of contractors. As this project was a pilot program with a significant level of financial risk, the City allowed pre-qualification due to the recognition that the project must not interfere with the tourism season and, as such, the schedule could not be altered. However, the City's decision to require prequalification for the ocean outfall portion of the project was an essential part of the ultimate success of the project. After prequalification four (4) contractors were determined to be "capable" of meeting the expectations of the City and the design team. Low bid for the project, on-shore and off-shore combined, was $5,506,932.34. The project was awarded to *Greenwall Construction* for the on-shore portion and to *Misener Marine* for the ocean outfall portion.

Results and Conclusions

The Yaupon Drive Basin improvements and ocean outfall utilizing twin 60" concrete cylinder pipes was completed on schedule and on budget. The project has continued to perform as anticipated. Flooding within the basin has been eliminated for storms within the design perimeter. The sediment and trash removal elements have successfully removed floatables, as well as a high percentage of the pathogen-laden sediments which had been previously deposited on the beach. As a result, pollution advisories in this segment of the beach have been dramatically reduced. Also, the organization which labeled Myrtle Beach as a "Beach Bum" has now labeled the City as a "Beach Buddy", thereby validating the demand for action from the tourism industry and the Chamber of Commerce.

Due to the success of this pilot project, the City of Myrtle Beach has commissioned two (2) more basin improvement/ocean outfall projects and the City of North Myrtle Beach has commissioned two (2) projects of a similar nature as well.

Design and Dispersion Analysis for Upgrade and Replacement of Beach Outfalls

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[1, 2, &3] Coastal Solutions, LLC, Florida.

Abstract

Technical design considerations for an offshore outfall at Myrtle Beach for discharge of stormwater carrying undesirable bacteria are described, together with dispersion characteristics of the discharge. Hydrodynamic forces associated with a 50yr design wave are considered to determine the required burial depths for the pipes and for providing rubble protection at the outfall nozzle. Dispersion studies included laboratory experiments and mathematical models to determine the rate of dilution of the discharge water through mechanical dispersion and bacteria die-off associated with the field environment.

1. Introduction

Studies by the South Carolina Department of Health and Environmental Control (SCDHEC) and communities along the coast have shown that during and after rainstorms, stormwater discharges were responsible for high levels of enterococcus bacteria in some locations. As a result, a monitoring program was established on the beach in the late 1990s. Preemptive rainfall advisories are issued at some beaches with a history of high bacteria levels from stormwater. The beaches are reopened when monitoring shows bacteria levels are once again within the state standards. Typically, a high percentage of cases of bacteria levels exceeding required standards have been associated with stormwater.

South Carolina has had a number of storm drains that discharge to the beach, but over the last ten years state and local water controls have minimized inputs. New storm water outfalls to beaches are now prohibited. Since 1996, North Myrtle Beach and Myrtle Beach have been committed to improve water quality and extend buried stormwater outfalls 1,000 feet out into the ocean. Several pipes have been installed in the Windy Hill section of North Myrtle Beach, and Myrtle Beach has started three deep water ocean outfall projects, with one completed.

Design considerations for one of these deep water outfalls are described here, including storm water flow considerations, wave hindcasting and wave forces, pipe burial depth and other protective measures, and studies of dispersion from the outfalls. Since storm water control is mainly a seasonal and intermittent occurrence, keeping the system and design simple and fairly maintenance free was economically desirable. Minimal requirements for the pipeline design were: (1) All flows were gravity induced from the onshore collection system, (2) Offshore installation had to be designed for 50yr storm criteria. The discharge was chosen to take place from two pipelines at a location 1000ft from the beach in around 7m water depth.

2. Stormwater Flow Requirements

Historical data showed that maximum rainfalls occurred in the fall, requiring the maximum amount of water to be discharged from the inland area, included in the project collection system, to be 32.4 ft^3/s for a 10" rainfall.

This information resulted in the selection of a pipe size of 60" I.D. Due to the operating conditions and location of the system, only concrete pipe was considered. The low frictional coefficients of concrete pipe showed maximum head losses of only 0.0405 ft for the offshore discharge system. This still allowed for an offshore discharge nozzle velocity of 0.825 ft/s, which should keep suspended particles from settling within the pipe and also allow sufficient mixing of the storm water and sea water upon final discharge.

3. Hydrodynamic Forces and Pipeline Burial Design

Hindcasting resulted in a 50yr design wave with a period of 11s with an offshore wave height of H_0 = 9.3 m. Nonlinear transformation of the design wave was considered using the method described by Dally, Dean and Dalrymple (1985). This wave height transformed to 2m at the shoreline. To determine maximum wave forces at the discharge nozzle, a wave height of 6.7m was considered. Hydrodynamic forces along the route of the pipe and at the nozzle were determined at these conditions and were used as a basis for determining the required depth of pipe burial and the design of the protective rubble structure at the nozzles.

It is important to assess whether liquefaction of soil is possible around the buried pipeline. Liquefaction will occur if the cyclic strength of the soil is less than the wave-induced cyclic stress ratio of the soil. Using the method proposed by Ishihara and Yamazaki (1984) revealed that liquefaction would occur at some locations to a depth of over 1m beneath the pipeline resulting in uplift forces, including hydrodynamic, of the order 30kN/m. Due to the high pullout forces encountered, the pipe of choice was one that met AWWA C301 criteria. A typical cross-section of the buried pipe and elevation detail of the discharge nozzle are shown in Figures 1 and 2 respectively, both designed for a 50yr storm criterion.

4. Dispersion and Mixing of the Stormwater Discharge

For swimming in ocean water, EPA recommends a geometric mean of no more than 35 enterococcus bacteria per 100 ml of water, and a specified maximum number in each collected single sample. Based on these recommendations, advisories are placed at each swimming location when any single ocean water sample indicates presence of 104 or more enterococcus bacteria per 100 ml of water. Studies found typical surf bacteria densities of 10 – 178 and 10 – 2005 per 100 ml in Horry County during dry and wet periods respectively. The densities were lower during high tide than during low tide periods, presumably due to dilution effects associated with the local influx of seawater. The dispersion and mixing of the storm water discharge, with the undesirable bacteria, within the vertical discharge column from the offshore sea floor to the sea surface along with surface spreading and further dilution was the key factor in the proposed project.

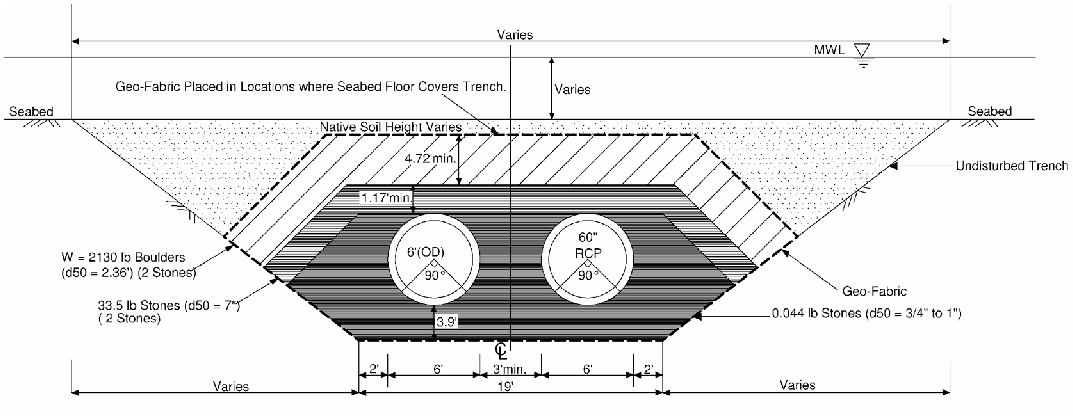

Figure 1. Typical riprap armor & filter details of Pipeline Trench

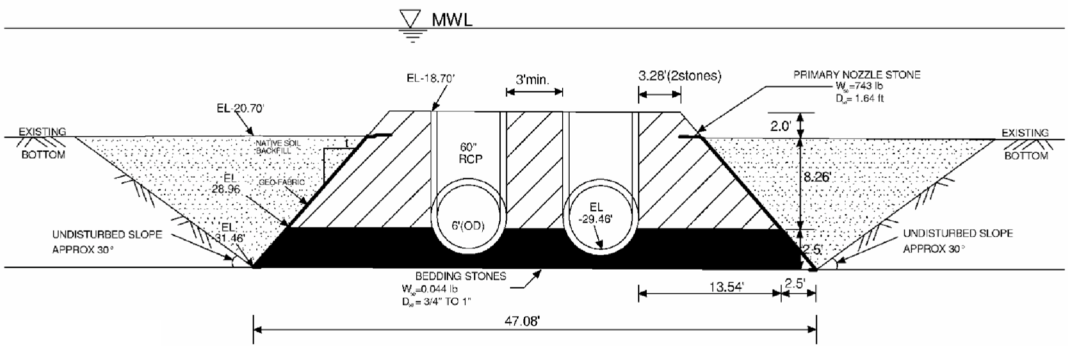

Figure 2. Nozzle Armor Elevation Detail. Gradation for armor stones:
W_{50} = 743lbs (80%), W_{max} = 2972 lbs (10%), W_{85} = 1456 lbs (10%).

A two-step approach was taken for the dispersion study. The first was a laboratory experimental study involving construction of a 1:120 scale model of the offshore region and discharge nozzle (Figure 3a). Details of the scaling are given in Table 1. The bulk of the bacteria are expected to be found in the discharge corresponding to the first 1” of rain (325,000 cu ft). Subsequent water is fresh water input with minute bacteria concentrations. This consideration is represented in the model experiment by a puff of dyed discharge, released from the nozzles over a limited time. The effluent fluid was maintained at a constant head, and the flow to the two nozzles was controlled using a single valve to provide a consistent discharge. The development of the surface spreading was monitored using video and still pictures, the latter at the rate of 0.7 pictures per second. The pictures were analyzed to determine the rate of increase of dyed surface area, *A(t)*, and the distribution of dye concentration over *A*. Various conditions were investigated, including the effects of the presence of turbulence, waves and currents on the rate of dispersion and mixing. Illustrative cases