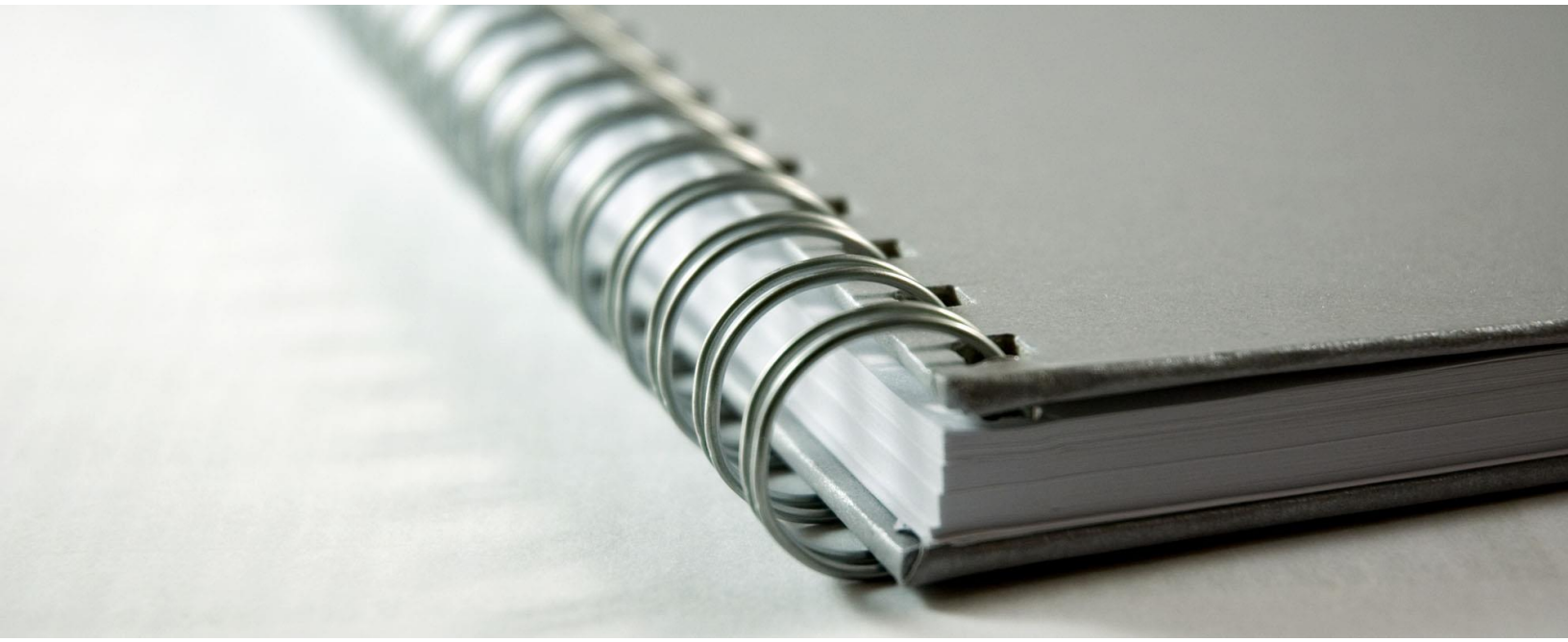

City of Rehoboth Beach

Stormwater Preliminary Engineering Report

May 2016

This report: has been prepared by GHD for City of Rehoboth Beach and may only be used and relied on by City of Rehoboth Beach for the purpose agreed between GHD and the City of Rehoboth Beach as set out in this report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared

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Appendices

Appendix A – Hydrodynamic and Water Quality Modeling of Stormwater Discharges

1. Introduction

1.1 Project Background

In December 1998, Delaware Department of Natural Resources and Environmental Control (DNREC) issued a Total Maximum Daily Load (TMDL) with the requirement that "all point source discharges which are currently discharging into the Indian River, Indian River Bay, and Rehoboth Bay and their tributaries shall be eliminated systematically" (DNREC 1998). The City of Rehoboth Beach Wastewater Treatment Plant (WWTP) currently discharges treated effluent to the Lewes-Rehoboth Canal, which discharges into Rehoboth Bay. Thus, the City of Rehoboth Beach (City) had to find an alternate method to discharge their treated wastewater effluent.

From 2010 to 2012, GHD and the City developed an Environmental Impact Statement (EIS) which investigated six alternative methods of effluent disposal for the Rehoboth Beach WWTP. During the development of the EIS, DNREC, other review agencies, and the public were provided copies of various drafts of the report, and a public hearing was held. Comments received during the review process and public hearing were integrated into the Final EIS, published on January 27, 2013. As stated in the Final EIS, the "most technically feasible, cost effective and environmentally friendly alternative for the City of Rehoboth is a dedicated ocean outfall". The Record of Decision (RoD), issued by DNREC in January 2015, stated that:

> *The factors and considerations identified in the Final EIS warrant approval of Alternative 6, Ocean Outfall, as described and analyzed in the Final EIS for the wastewater disposal method for the City of Rehoboth Beach and in this Record of Decision. All practical means to avoid and minimize environmental harm from implementation of the selected alternative have been incorporated, as described in the final EIS and this Record of Decision.* (DNREC 2015)

As water quality is a priority to DNREC and the City of Rehoboth Beach, the RoD stated that:

> *… [A]s a condition of this Record of Decision, the City will conduct a storm water evaluation of its catchment areas and collection system that are associated with the existing five (5) outfalls which discharge directly to the Atlantic Ocean. The City will submit a planning-level report to the Department which identifies nonpoint sources of stormwater effluent and options for controlling those sources in order to minimize potential impacts to swimmers, surfers, and other water users within the nearshore area. The report shall include cost effective alternatives for improving stormwater quality, reducing stormwater volume within the collection system, and an evaluation of disposal options, including possible reorientation, reconfiguration, extension, or· other upgrades to the outfalls. The stormwater evaluation shall include Engineers Estimates of Probable Construction Costs of the various approaches for improving stormwater quality, reducing quantity, and improving disposal methods. The report shall be completed and provided to DNREC by January 1, 2016.* (DNREC 2015)

This report details the results of the stormwater evaluation that has been completed in accordance with the requirements of the RoD.

1.2 Scope

The scope of this Preliminary Engineering Report is primarily to meet the requirements of the RoD as defined above. In order to minimize impact to swimmers, surfers, and other water users within the nearshore area, a twofold approach is required. First, low cost Best Management Practices (BMPs) must be investigated and implemented on shore to reduce the total enterococcus within the City's runoff. BMPs can include non-structural practices, such as public awareness campaigns and operation/maintenance strategies, or structural practices such as infiltration or filtration devices. Second, alternative configurations of the stormwater ocean outfalls must be investigated to redirect stormwater away from the surf zone and improve dilution within the ocean. The scope includes evaluation of up to three discharge scenarios.

The scope and purpose of this PER is to:

- Summarize the existing data available in relation to stormwater management within the City
- Detail existing stormwater management achieved by the City
- Develop an uncalibrated EPA SWMM model
- Evaluate alternative BMPs available to the City
- Evaluate alternative outfall configurations
- Provide recommendations for further evaluation

As detailed within the RoD, this study is limited to the drainage areas that lead to the five existing stormwater ocean outfalls within the City of Rehoboth. Portions of the City and surrounding land that drain to other discharge points, such as the Lewes-Rehoboth Canal, Silver Lake, or directly into the ocean, are excluded. Similarly, possible reconfiguration of the Silver Lake outfall, located at the southern extent of East Lake Drive, is not included within the scope.

Data collection within the City's stormwater system on enterococcus concentration and flow rates was excluded from this analysis. As such, for the purposes of this PER, estimates, assumptions, and approximations were made from existing data and literature review. While this has allowed for a qualitative assessment and development of preliminary recommendations, detailed data collection and analysis will be needed prior to the recommendation of any specific alternative. Refer to Section 7.1 for addition information on recommendations for future studies.

2. Data Review

2.1 City of Rehoboth Beach History

The City of Rehoboth Beach is an incorporated City located adjacent to the Atlantic Ocean in Sussex County, DE. The City, consisting of approximately 1,051 acres of land, was originally incorporated in 1891 and developed throughout the 20th Century. See Figure 1 for a map of the City of Rehoboth Beach city limits.

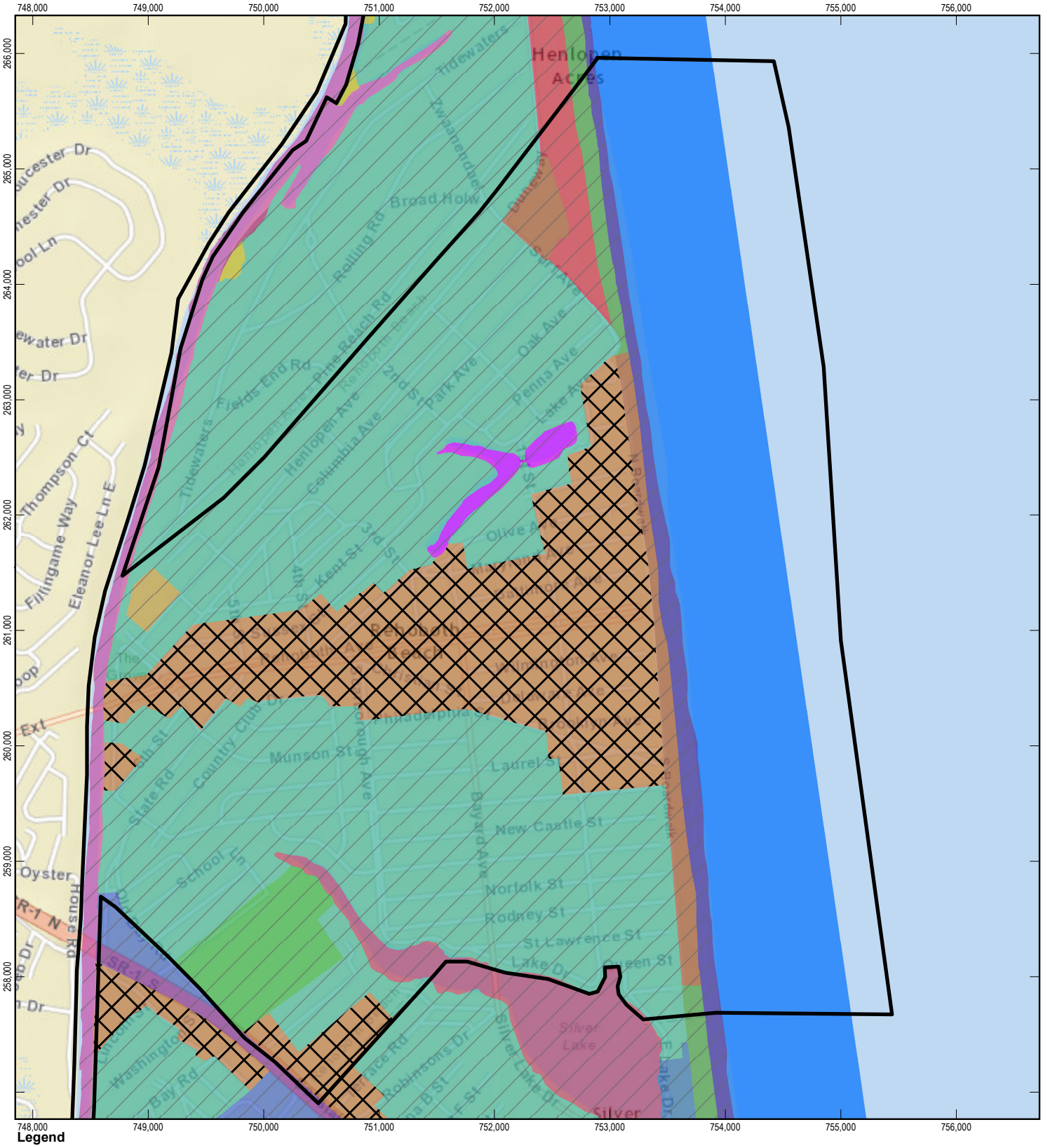
As stated in the Final Environmental Assessment for Alternative Sand Sources and Stormwater Outfall Extensions for the Rehoboth Beach and Dewey Beach Storm Damage Reduction Program:

> *Land uses within Rehoboth Beach are primarily composed of beachfront properties (residences, retail businesses, lodging), boardwalks, and undeveloped portions. The beachfront properties consist primarily of three distinct areas of development. The southern-most section of Rehoboth Beach consists of single-family homes and a boardwalk fronts the properties on the ocean side of the properties north of Prospect Street. Above that area, a commercially developed area consisting of hotels, restaurants, retail stores, condominium, and an arcade is located from Philadelphia Street to Lake Street. A boardwalk fronts the ocean side of this area. The northern section of Rehoboth Beach from Lake Avenue to Henlopen Avenue consists of single-family homes. Henlopen Acres and North Shores located north of Rehoboth Beach are private residential developments.* (USACE 2002)

According to the 2010 census, the current, permanent population of Rehoboth Beach is 1,327 persons (U.S. Census Bureau 2010). However, as a seasonal resort community, seasonal population expands to over 25,000 during the peak summer season (City of Rehoboth Beach 2015). The beach is heavily populated during the summer months along the entire length of the boardwalk, with the highest density of beach goers centered around Rehoboth Ave.

Every year, the Natural Resources Defense Council (NRDC) annually rates beaches based on water quality as established by monitoring for public health standards. Over the past six years, Delaware has consistently ranked among the nation's best in beach water quality, and has ranked first four times (Dorfman and Haren 2014). The City of Rehoboth Beach has won several water quality awards, including a 5-star rating from NRDC multiple times.

Due to the exemplary water quality within the City, the City is under no regulatory requirements to improve stormwater management. Improvements to stormwater management within the City are voluntary and not the result of new development, new regulations, or any lawsuits.



Legend

- City of Rehoboth Beach Municipal Limits
- Commercial Land
- Residential Land

Landuse

- Bays and Coves
- Beaches and River Banks
- Highways/Roads/Access roads/Freeways/Interstates
- Inland Natural Sandy Areas
- Institutional/Governmental
- Man-made Reservoirs and Impoundments
- Mixed Urban or Built-up Land
- Multi Family Dwellings
- Natural Lakes and Ponds
- Other Urban or Built-up Land
- Recreational
- Retail Sales/Wholesale/Professional Services
- Single Family Dwellings
- Tidal Emergent Wetland
- Tidal Open Water
- Tidal Shoreline
- Waterways/Streams/Canals

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City of Rehoboth Beach City Limits

Figure 1

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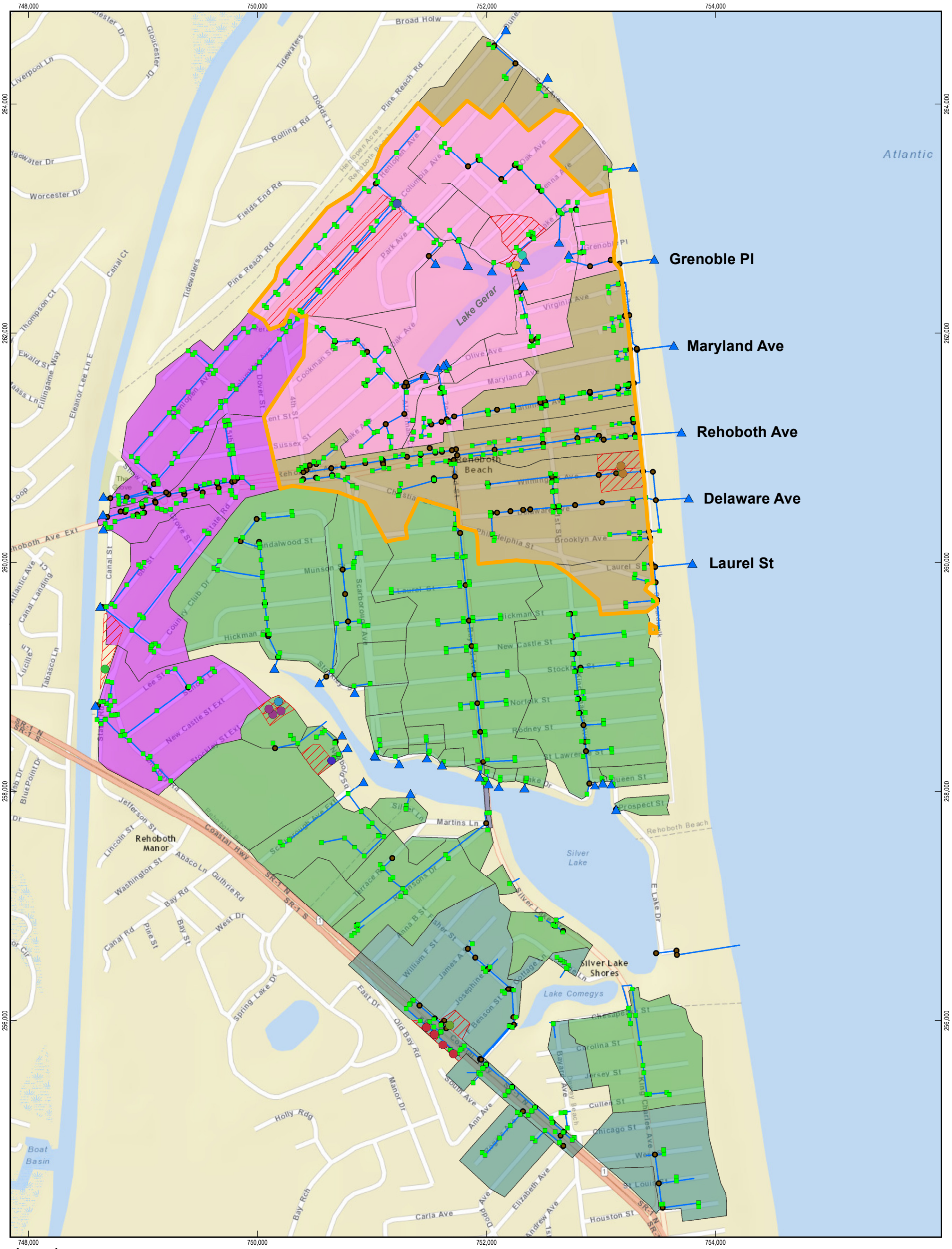

Legend

- OUTFALL_location
- SWM_INLETS
- SWM_MANHOLES
- SWM_PIPES
- SWM_FACILITY_TREATMENT_AREA
- Study Area

STMWATER_FACILITY

- 24" PERF UNDERDRAIN
- MICRO BIORETENTION
- SAND BOTTOM CHANNEL DRAIN
- SAND BOTTOM INFILTRATION STRUCTURE
- SAND BOTTOM STEEL TOP CHANNEL DRAIN
- SWM INLET/SAND BOTTOM UNDERDRAIN
- SWM MANHOLE SEDIMENT TRAP
- SWM MANHOLE SEDIMENT TRAP stormceptor
- SWM POND
- SWM SEDIMENT AND TRASH TRAP

SWM_DRAINAGE_AREA

- ATLANTIC OCEAN
- CANAL
- LAKE COMEGYS
- LAKE GERAR
- SILVER LAKE
- SILVER LAKE INCOMPLETE DATA

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Horizontal Datum: North American 1983
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Data Provided in Beacon Geodatabase

Figure 2

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2.2 GIS Geodatabase

The City retained Beacon Engineering, LLC (Beacon) to develop a GIS geodatabase of the City's stormwater collection system. The GIS geodatabase was developed from field data collected by Beacon, historic City data, and as-built drawings provided by the City. The final geodatabase was provided on October 30, 2015. See Figure 2 for a map of the data provided in the geodatabase. As noted in Section 1.2, the study area of this report is limited to the drainage areas that contribute to the five ocean outfalls, as delineated in orange on Figure 2.

The following stormwater management features were included:

- SWM_INLETS – Stormwater catch basins
- SWM_MANHOLES – Stormwater manholes
- SWM_PIPES – Stormwater pipes
- OUTFALL_location – Outfalls of storm drain system into a water body
- SWM_DRAINAGE_AREAS – Drainage areas to each outfall, including outfalls into the Atlantic Ocean, Lake Gerar, Lewes-Rehoboth Canal, Silver Lake, and Lake Comegys.
- STMWATER_FACILITY – Existing stormwater treatment device including ponds, sediment traps, micro-bioretention basins, and other infiltration practices
- SWM_FACILITY_TREATMENT_AREA – Drainage area to each stormwater treatment device

The geodatabase contained five ocean outfalls, consistent with the number identified in the scope:

- Laurel Street
- Delaware Avenue
- Rehoboth Avenue
- Maryland Avenue
- Grenoble Place

A pipe was identified by Beacon at the intersection of Lake Avenue and Surf Avenue (north of the Grenoble Place Outfall). The pipe does not reach the water and regularly becomes covered with sand. However, the water pressure from the surcharged inlets is usually sufficient to wash the sand away, allowing the stormwater to run across the beach.

The delineated drainage areas end around the boardwalk and only include areas draining into a catch basin. Areas of sheet flow directly into the ocean are not captured.

2.3 Lake Gerar

As shown in Figure 2, approximately half of the study area drains to Lake Gerar. The lake overflows into an inlet located at the eastern extent of the lake and discharges at the Grenoble Place outfall. As shown in Figure 3, the inlet structure consists of a metal grate sloping up from the water elevation of the lake. Water quality data on the lake is not available.

Figure 3 Lake Gerar Overflow Inlet

Although Lake Gerar has no functional forebays and is heavily silted in due to about a century of runoff from land disturbances, it is considered a superior fishery and of high ecological significance (Fritchman 2015).

2.4 Impervious Data and Topography

Impervious land cover within the study area was determined from the Sussex County (East), DE, 2007 Impervious Surface Coverage GIS Raster file obtained from Delaware Office of State Planning Coordination. The raster file is a 1 meter by 1 meter grid, with each grid identified as either pervious or impervious. Based on this data set, approximately 60% of the study area is impervious.

Sussex County 2-foot contours were obtained from the Delaware Geological Survey and are based on 2005 LIDAR data.

2.5 Rainfall

The total precipitation for 24-hour design storms of various return periods was obtained from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Point Precipitation Frequency Estimates for Lewes, Delaware, Station ID 07-5320 (38.7756° N, 75.1389° W). The rainfall associated with each of the design storms is presented in Table 1.

Table 1 NOAA Precipitation Frequency Estimates

Average Reoccurrence Interval	24-hour Duration Rainfall (in)
1-year	2.81
2-year	3.42
5-year	4.45
10-year	5.33
100-year	9.22

Daily rainfall was obtained from data provided online by Delaware Environmental Observing System (DEOS), accessible at http://www.deos.udel.edu/monthly_retrieval.html (University of Delaware 2015). Rainfall data was collected at the Rehoboth Beach, DE-Boardwalk Station, ID DRHB (38° 43' N, 75° 5' W). Daily rainfall from April 2010 to June 2015 is presented in Figure 4, with the rainfall associated with each of the 24-hour return period storms shown for comparison.

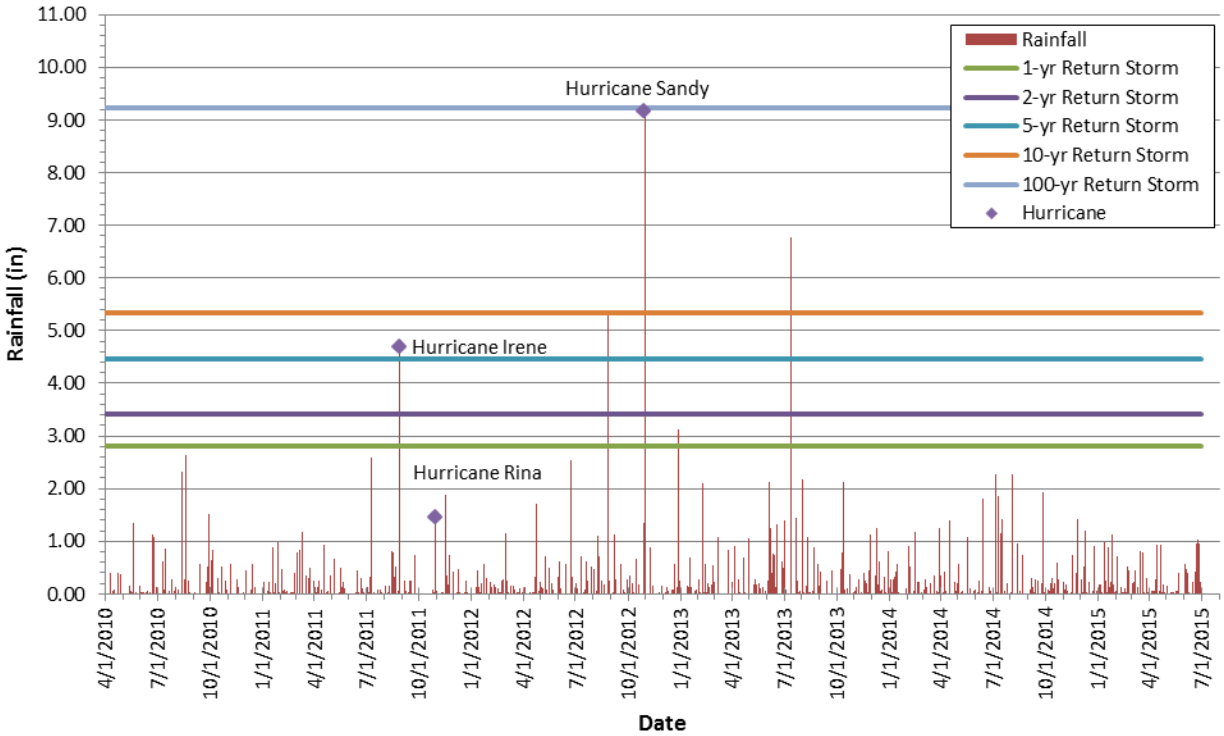

Figure 4 Daily Rainfall Recorded

The vast majority of daily rain totals are less than the rainfall associated with a 24-hour 1-year storm. Days with rainfall greater than the 1-year storm (2.81 inches) are summarized in Table 2.

Table 2 Daily Rainfall above 24-hour 1-year Design Storm

Date	Return Period Storm
8/27/2011 (Hurricane Irene)	Between 5-year and 10-year
8/25/2012	Between 5-year and 10-year
10/29/2012 (Hurricane Sandy)	Between 10-year and 100-year
12/26/2012	Between 1-year and 2-year
7/12/2013	Between 10-year and 100-year

2.6 Water Quality

2.6.1 Enterococcus as an Indicator Bacteria

Water contaminated by fecal pollution can contain a variety of pathogens that can affect human health. Since specific pathogens vary seasonally and geographically, monitoring for all disease-causing microorganisms from fecal contamination is infeasible. For more than a century, protection of public health for those using recreational waters has been accomplished through the use of fecal indicator bacteria (FIB) such as *E. coli* and enterococcus. The presence of FIBs have been shown in numerous epidemiology studies to be predictive of the potential for human infectious disease, especially gastrointestinal illness. For marine water, the EPA has recommended since 1986 the use of enterococcus as indicators of fecal contamination, and therefore, assessment of water quality in this report is primarily based on enterococcus concentration (USEPA 2014).

Enterococcus, like all FIB, are naturally found in the guts of warm-blooded animals (including humans) and therefore are excreted in high densities in the feces of such animals (NRC 2004). They provide an estimation of the amount of feces (or degree of contamination) and, indirectly, the presence and quantity of fecal pathogens in the water. However, extensive research has also shown that enterococcus is widely distributed in a variety of environmental habitats, such as soil and sediments, beach sand, aquatic and terrestrial vegetation, and ambient waters (rivers, streams, and creeks), even when there is little or no input from human and/or animal fecal sources (Byappanahalli, et al. 2012).

2.6.2 Collected Ocean Water Quality Data

The water quality of Delaware beaches is assessed based on the concentration of indicator bacteria, specifically enterococcus. Since 2009, the criteria for water quality on Delaware beaches was 104 enterococcus colony-forming units per 100 milliliters (cfu /100 mL), based on the state's daily maximum bacterial standard for primary contact recreation marine waters as detailed in the *State of Delaware Surface Water Quality Standards As Amended, October 11, 2014* (DNREC 2014). “Primary Contact Recreation” refers to any water-based form of recreation, such as swimming, where there is a high probability for total body immersion or ingestion of water.

In 2012, the EPA suggested in *Recreational Water Quality Criteria* (USEPA 2012) that states use the more conservative Beach Action Value (BAV) of 60 cfu /100 mL for making beach notification decisions. DNREC will adopt the BAV as part of its Surface Water Quality Standards Regulations prior to the 2017 swimming season. Therefore, for the purposes of this report, the criteria for water quality on Delaware beaches is assumed to be 60 enterococcus cfu /100 mL in anticipation for the adoption of the BAV.

Water quality data from May 2010 to early June 2015 was collected by DNREC in the surf zone at four Rehoboth Beaches under the Recreational Water Program. See Figure 5 for a map of sample locations. Frequency of sampling varied, but typically, grab samples were taken once or twice per week at each location throughout the summer months (May to September).

Samples with observed enterococcus concentrations greater than 60 cfu /100 mL were observed on 11 days as summarized in Table 3.

Table 3 Observed Enterococcus Concentrations Greater than 60 cfu /100 mL

Date	Daily Rainfall (inches)	DE133779 Rehoboth-Virginia Ave Beach (cfu / 100 mL)	DE133780 Rehoboth-Queen St Beach (cfu / 100 mL)	DE133781 Rehoboth-Rehoboth Ave Beach (cfu / 100 mL)	DE734395 Deauville Beach (cfu / 100 mL)
7/12/2010	0.00	5	**97**	5	---
6/20/2011	0.31	---	10	---	**74**
5/14/2012	0.00	20	**63**	41	5
6/4/2012	0.07	5	5	5	**74**
7/9/2012	0.71	---	**63**	---	5
8/8/2012	1.10	---	---	**199**	---
6/3/2013	2.12	**183**	10	**703**	**74**
6/10/2013	0.77	**63**	10	5	31
7/29/2013	0.00	30	20	30	**85**
6/11/2014	0.07	---	---	**98**	---
8/25/2014	0.00	**63**	5	10	**74**

The percentage of sampling days where observed enterococcus concentrations was greater than 60 cfu /100 mL is presented in Table 4.

Table 4 Percent of Days with Observed Enterococcus Concentrations Greater than 60 cfu /100 mL

Sample Location	Number of Days Exceeding 60 cfu /100 mL	Total Days of Sampling	Percent of Days Exceeding 60 cfu /100 mL
DE133779	3	95	3.16%
DE133780	3	102	2.94%
DE133781	3	199	1.51%
DE734395	5	77	6.49%
Overall	11	204	5.39%

Legend

- Bacterial Data Collection Points
- Study Area
- Stormwater Pipes

Paper Size ANSI A
1:12,000
0 155 310 620 930 1,240
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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Bacterial Data Collection Points

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Figure 5

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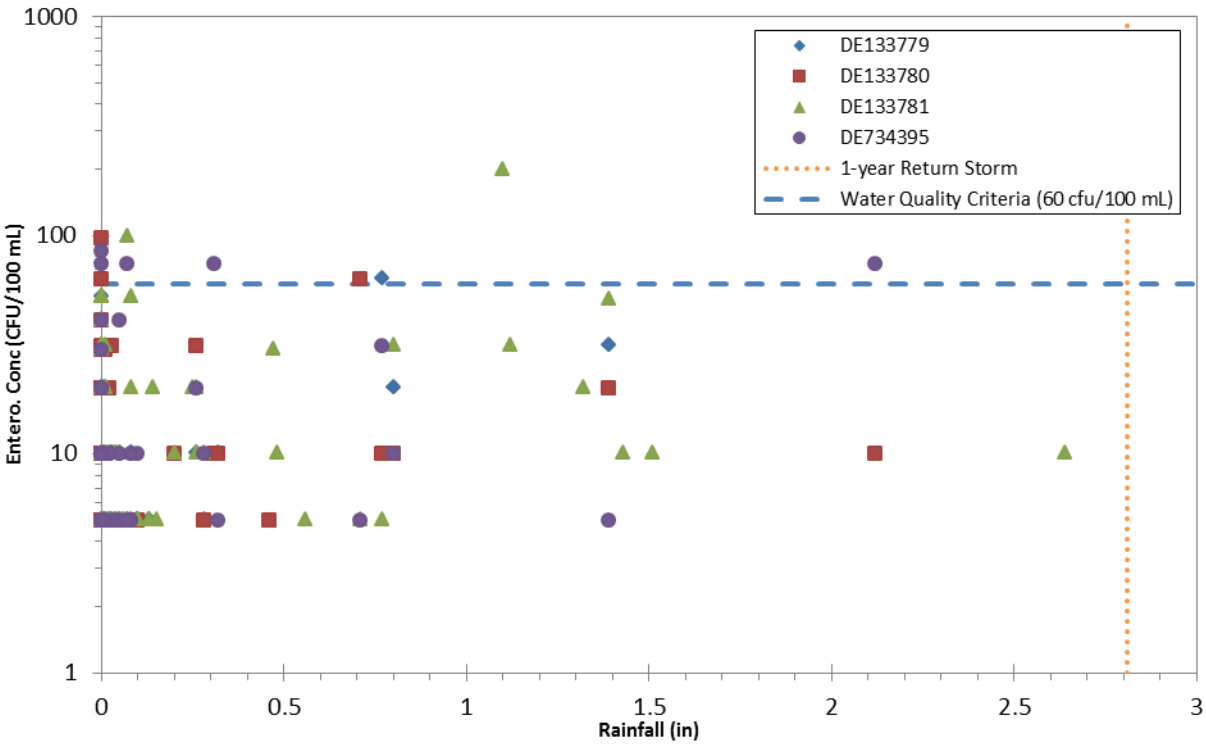
Observed enterococcus concentration was graphed against daily rainfall as shown in Figure 6. As shown, there does not appear to be any correlation between the bacterial concentration in the grab-sample data provided and daily rainfall total. There was similarly no apparent correlation when observed enterococcus concentrations were compared to the preceding day's daily rainfall or to the average daily rainfall over the preceding three days (including the sample date). Observed enterococcus concentrations vary between non-detectable levels and 100 cfu / 100 mL on days with no rainfall as well as on days with up to one inch of rainfall.



Notes: No samples were taken on days with greater than 3 inches of rainfall.
The limit of detection of the enterococcus sampling equipment is 10 cfu/100 ml. A value of 5 cfu/100 ml was recorded when sample concentrations were lower than the limit of detection.

Figure 6 Daily Rainfall vs. Enterococcus Concentration

The 1990 report *Evaluation of Microbial Indicator Levels at the Beach in Rehoboth Beach, Delaware* also investigated the relationship between rainfall and enterococcus concentrations in the ocean, stating:

> *The data collected by the State of Delaware indicated a relationship between the levels of indicator microorganism and rainfall. A more detailed analysis confirms the relationship but because of the many variables involved with rainfall, storm flow and microbial sources, concludes that the relationship is of little predictive value. Similar conclusions were reached in most of the stormwater studies over the last 20 years.* (Olivieri 1990)

2.6.3 Enterococcus Concentration in Stormwater Pipes

Nationwide, stormwater runoff is the most commonly identified cause of beach closings and swimming advisories (Dorfman and Haren 2014). While it is assumed that the high enterococcus concentrations observed in the ocean within Rehoboth Beach are the direct result of stormwater runoff, the exact source has not been identified. As detailed within

Section 2.6, observed enterococcus concentrations were obtained from grab samples in the surf zone, after stormwater has mixed with the ocean. Furthermore, the samples were taken intermittently, and no correlation with rainfall was observed.

In order to confirm that stormwater is the source of enterococcus observed within the surf zone, and to quantify the enterococcus concentrations within the City's stormwater runoff, detailed stormwater surveying will need to be performed. Refer to Section 7.1 for additional information.

In the absence of recorded data within the City of Rehoboth Beach, a literature review was conducted to approximate the concentration of stormwater at each ocean outfall. The literature review revealed that enterococcus concentration within stormwater can vary significantly over several orders of magnitude (Wildey 2006) (Boehm and Sassoubre 2014). For example, one study in Monmouth County, NJ (Selvakumar and Borst 2006) recorded enterococcus concentrations between 1,000 and 8,500 cfu /100 mL, whereas another study in Baltimore, MD recorded enterococcus concentrations between 20,000 and 120,000 cfu /100 mL (USEPA 1999).

The concentrations reported in the Monmouth County, NJ report were observed to be "similar to those reported in the stormwater NPDES database (Pitt et al. 2003) … [and] … of the same order found by other investigators (Oliveri et al. 1977; Qureshi & Dutka 1979)." (Selvakumar and Borst 2006). Therefore, the enterococcus concentrations from this report were utilized. The Monmouth County, NJ study investigated six different outfalls, divided into three land use categories: high-density residential (65% imperviousness), low-density residential (17% imperviousness), and landscaped commercial (85% impervious). The highest concentration reported from a high-density residential drainage area was 6,800 cfu / 100 mL, and the highest concentration reported from a landscaped commercial drainage area was 8,500 cfu / 100 mL.

The enterococcus concentrations assumed for the purposes of this report are reported in Table 5.

Table 5 Assumed Enterococcus Concentration by Land Use

Land Use	Assumed Enterococcus Concentration (cfu / 100 mL)
Commercial Area	8,500
Residential Area	6,800

3. Existing Stormwater Management

Due to low permanent population, the City of Rehoboth Beach is not currently regulated as a Municipal Separate Storm Sewer System (MS4), and as such, has not been required to develop or implement a stormwater management program per EPA requirements. However, beach water quality is of extreme importance to the City, and thus the City has taken many proactive steps to manage stormwater and improve beach water quality.

3.1 Good Management Practices / Public Outreach

3.1.1 Pet Waste Management

Improperly disposed pet waste can be picked up by stormwater runoff and washed into the surf zone, increasing bacteria pollution.

Dogs are prohibited from the beach and boardwalk, where stormwater runs off directly into the surf, between May 1 and September 30 per Section 88-16 of the City Code (City of Rehoboth Beach 2015a). A “pooper scooper” law requires pet owners to have in their immediate possession appropriate devices to scoop and dispose of dog waste while on public or private land throughout the City, and failure to clean up pet waste can subject the owner to fines, per Section 88-14 and 88-15 of the City Code (City of Rehoboth Beach 2015a).

Signs, such as that shown in Figure 7, are located throughout the city to inform the public of pet waste management laws and the impact of pet waste on water quality. In addition, the City’s Rules and Regulations on the City’s website lists the aforementioned laws (City of Rehoboth Beach 2015).

Figure 7 Pet Waste Sign

3.1.2 Trash and Debris Management

Floating trash and debris in waterways not only causes severe aesthetic impacts but can pose choking hazards to wildlife and bacterial impacts to humans. Trash can also clog stormwater inlets and collection systems.

As shown in Figure 8, public trashcans along the boardwalk and Rehoboth Ave. are covered and emptied regularly by City staff, minimizing the potential for trash to be picked up by stormwater.

Figure 8 Covered Public Trashcans

Strict City Ordinances minimize the locations where smoking is allowed, and signs, such as that shown in Figure 9 are posted to inform the public. Where smoking is allowed, cigarette butt receptacles are provided as shown in Figure 9.

Figure 9 Smoking Area and Cigarette Receptacle

3.1.3 Street Sweeping

Trash, debris, and other pollutants can accumulate on City streets, resulting in polluted stormwater runoff, inlet clogging, and decreased aesthetics. To combat this, the City has developed a robust street sweeping program. Under this program, street-sweeping vehicles, such as that shown in Figure 10, collect accumulated debris for disposal in landfill. Street sweeping is performed by the City every day during the summer and every other day during the winter off-season.

Figure 10 Typical Street Sweeper (Elgin 2015)

Street sweeping programs require access to shoulders and curbs to be most effective. This can be difficult during the summer months when the majority of city streets are crowded with street parking. As shown in Figure 11, the commercial portion of the City, where debris accumulation is anticipated to be relatively higher, consists of metered parking. Street sweeping is performed very early in the day, when the majority of these spots are empty and access to the curb is mostly unobstructed.

Outside of the metered area, many vehicles are parked long term, and street sweepers frequently have to avoid parked cars. It is anticipated that there would be extreme public resistance to any program requiring vehicle movement for street sweeping. However, pollutant accumulation within the residential areas is assumed to be much less than that within the commercial portion of the City, and the current street sweeping program has been successful in keeping streets throughout the City clean.

Figure 11 City Metered Parking Map

3.2 Structural Best Management Practices

3.2.1 Sand Filters

Two sand filters are located within City of Rehoboth, both along the first block of Wilmington Ave., east of 1st St. See Figure 12 for a photograph.

Figure 12 Existing Sand Filter along Wilmington Ave

The sand filters are of the Delaware sand filter design, consisting of two parallel underground chambers / trenches. A typical cross section is shown in Figure 13. Stormwater first enters the sedimentation chamber through a grated cover and then overflows into the filtration chamber, where it filters through a layer of sand before entering the outfall pipe. The sand filters are designed to treat the first inch of rainfall, when pollutants are highest. During larger storm events, runoff overflows the sand filter system into adjacent catch basins.

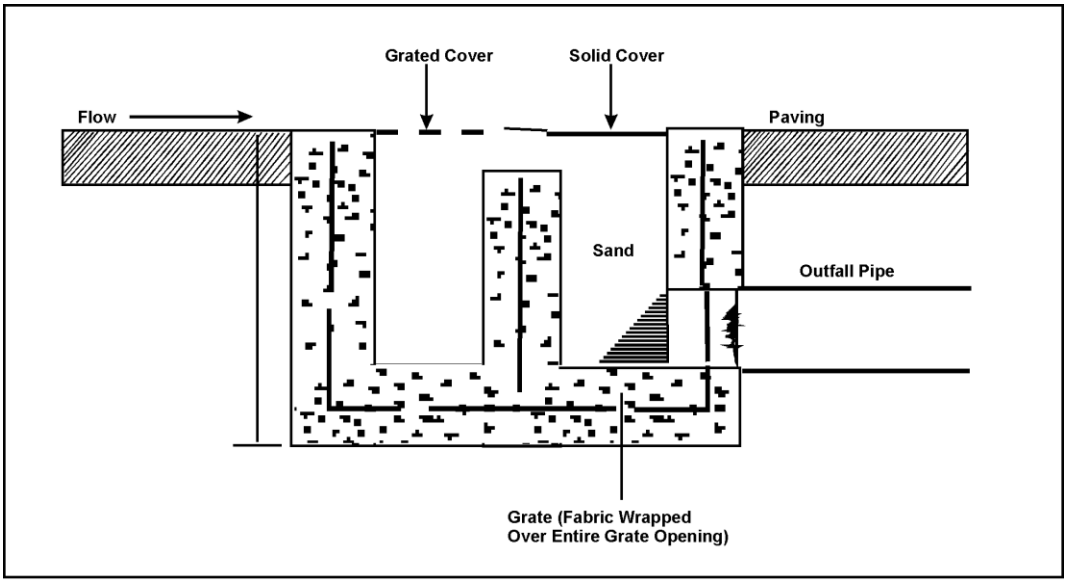


Figure 13 Typical Delaware Sand Filter Cross Section (USEPA 1999b)

Both sand filters were constructed in 1992, are maintained annually, and are reported as still being in good condition by City staff. Maintenance consists of cleaning out the filter and replacing a small portion of sand.

Each sand filter is approximately 67 feet long, and combined, the two sand filters treat approximately 2.88 acres of drainage area. Reported bacteria removal rates for Delaware Sand Filters vary in the literature, but typical removal efficiency is around 76% (USEPA 1999b).

3.2.2 Perforated Pipe Infiltration

The storm drain pipes along either side of Columbia Ave between Gerar St. / 3rd St. and 2nd St., approximately 2,400 linear feet of 12" pipe, are perforated, allowing stormwater to infiltrate back into the ground after entering the collection system.

The perforated pipe was installed in 2003. No maintenance is performed on the perforated pipes.

3.2.3 Sediment / Trash Traps

Multiple sediment / trash traps are located in the Lake Gerar watershed, one at the intersection of Columbia Ave. and 2nd St., and two more on Lake Ave. adjacent to Lake Gerar. The typical design of a Stormceptor®, one type of sediment / trash trap installed within the City, is presented in Figure 14. The primary purpose of the sediment / trash

traps is to collect debris, oil, and other large pollutants prior to stormwater entering the environment.

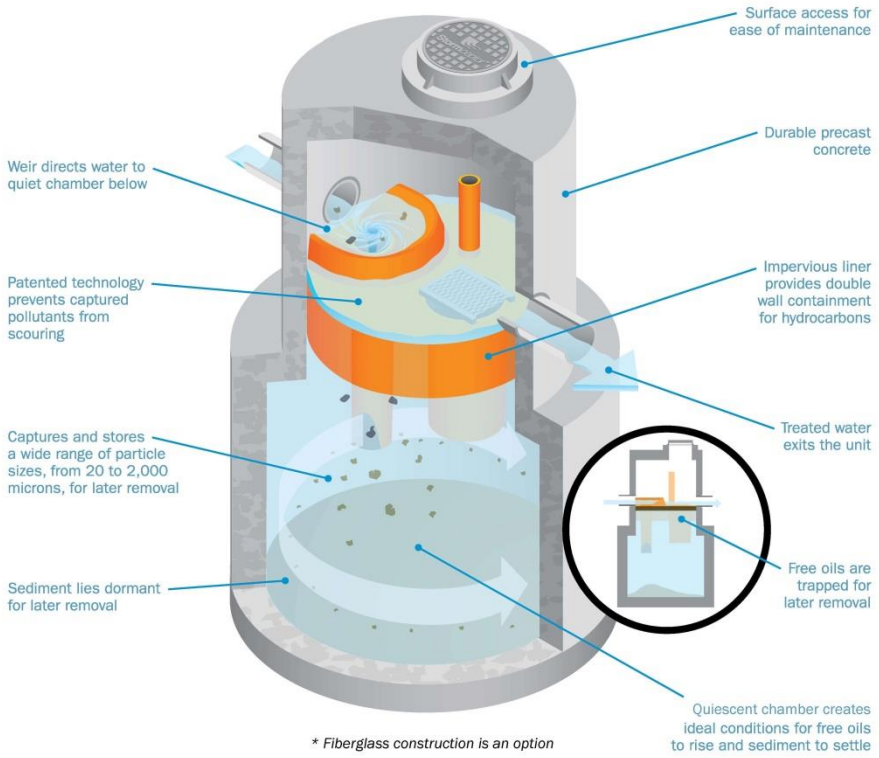


Figure 14 Typical Sediment / Trash Trap Design (Imbrium 2015)

The sediment / trash traps were constructed in 2003, are maintained annually, and are reported as still being in good condition by City staff. Maintenance consists of removing accumulated debris with a standard vacuum truck.

Combined, the three sediment / trash traps in the Lake Gerar Watershed treat approximately 10.30 acres of drainage area. As the devices are designed to trap large particulates, bacteria removal is minimal to nonexistent.

3.3 Lake Gerar Waterway Restoration and Management Plan

In the early 2000s, owners of property along and near Lake Gerar contacted the Save Our Lakes Alliance 3 (SOLA3), due to concern over the poor water quality of the lake. Stormwater runoff and an over-population of resident Canada geese had caused the lake to become eutrophic, resulting in frequent fish kills, rampant algae, and emission of noxious odors (SOLA3 Board of Directors 2013). In an effort to improve the water quality of the Lake, the City of Rehoboth Beach, with funding from the State of Delaware and USDA, contracted with Envirotech Environmental Consulting Inc. to design and implement a Waterway Restoration and Management Plan for the lake (Fritchman 2015). The plan included many features, including:

- A 10-foot wide riparian buffer of native plants to stabilize the shoreline, filter pollutants and sediments, and provide a habitat for wildlife.
- A water quality enhancement plan including cyanobacteria control, algae and pond weed control (aquatic herbicides application), and air diffusion system.

- Installation of monofilament to control the Canada goose population
- Educational outreach, including installation of signs around the lake detailing the purpose of the buffer strip and good management practices citizens can engage in to improve water quality.
- Illicit discharge monitoring and response.

Refer to Figure 15 for photographs of the Lake Gerar Waterway Restoration and Management Plan. The lake is now transparent, no fish kills have been observed since the restoration, and the Lake is listed as prime fishing spot for bass and carp (SOLA3 Board of Directors 2013).

It is assumed that the riparian buffer removes approximately 60% of bacteria (NRCS 2015) from drainage areas draining directly to the lake, approximately 27 acres. Maintenance is performed by Envirotech Environmental Consulting Inc.

Figure 15 Lake Gerar Waterway Restoration and Management Plan

Clockwise from top left: riparian buffer, lake aeration system, conservation area public awareness sign, and citizen good management practices public awareness sign

3.4 Silver Lake Management Plan

A management plan for Silver Lake is currently under development and design by DNREC. The management plan is anticipated to include similar features to the Lake Gerar Waterway Restoration and Management Plan, including dredging, buffer plantings, and an outreach program.

3.5 Potential Stormwater Hotspot Locations

GHD conducted a field visit with City staff to identify potential hotspots. GHD's observations and discussions with City staff confirmed that the commercial portion of the City is a potential pollutant hotspot, in that it is relatively more likely that enterococcus is entering stormwater in high numbers in this area than in the City as a whole. City staff have observed restaurants along Rehoboth Ave. disposing of wash water onto the adjacent streets (Baltimore Ave. and Wilmington Ave.). In addition, dumpsters are located behind many of the commercial establishments in this area, and this area is subjected to the greatest amount of foot traffic by residents and guests.

In addition to collecting samples within the surf zone (See Section 2.6), DNREC's Recreational Water Program also conducts onsite surveys to identify potential sources of bacterial pollution. The major consistent sources of potential pollution at Rehoboth Beach identified by the Recreational Water Program (Bott 2015) are:

- Discharges from Silver Lake (outside study area) and Lake Gerar, since both lakes are maintained as waterfowl sanctuaries
- Seagulls feces on the boardwalk and associated streets
- Dog waste from residential properties or areas adjacent to the lakes
- Foot wash stations located on the boardwalk
- Trash pickup locations on the streets, which can leak into storm drains or cause congregations of seagulls

Without detailed sampling, the relative impact of the above constituent sources is hard to identify. Water sampling within Silver Lake and Lake Gerar is recommended to quantify the enterococcus concentration entering the surf zone from these lakes.

Foot wash stations along the boardwalk are located over inlets into underground chambers, as shown in Figure 16. Wash water must filter through hundreds of feet of beach sand before entering the ocean, and therefore enterococcus pollution from the foot wash stations is assumed to be minimal.

Figure 16 Foot Wash Station Along Boardwalk

4. EPA SWMM Model

4.1 Model Development

The GIS geodatabase developed by Beacon, as detailed in Section 2.2, was used to develop a Stormwater System Model. This model includes the inlets, manholes, pipes, and drainage areas within the City of Rehoboth Beach. The model was developed in CivilStorm Version 8i by Bentley Systems, Inc utilizing the EPA SWMM calculation engine. This analysis allows for an Extended Period Simulation (EPS) of the stormwater system over the duration of a storm with varying rainfall intensity.

Based on the rainfall data provided by NOAA (refer to Section 2.5), three scenarios were developed in the model corresponding to 24-hour design storms of differing reoccurrence intervals. The three storms selected were:

- 1-year 24-hour storm (2.81 inches)
- 5-year 24-hour storm (4.45 inches)
- 10-year 24-hour storm (5.33 inches)

The rainfall distribution of the design storms was based on the dimensionless SCS TYPE II 24-hour duration storm curve. The hyetograph for a 10-year return period 24-hour duration storm following this curve is presented in Figure 17. Although the average intensity over the entire 24-hour storm duration is 0.22 in/hr, the intensity during the peak hour is 2.418 in/hr (with a peak intensity of 7.310 in/hr for a 6-minute period).

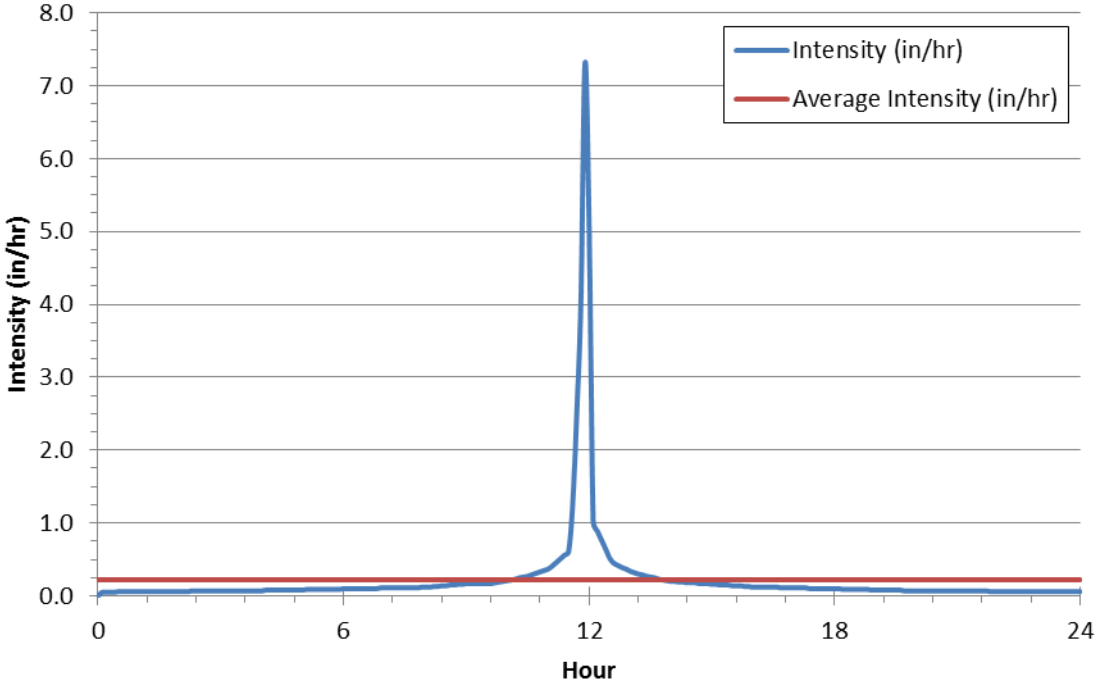


Figure 17 10-year SCS TYPE II 24-hour Hyetograph

Required model inputs are summarized in Table 6.

Table 6 Stormwater System Model Inputs and Assumptions

Model Input		Assumptions	Source
Stormwater system data including manholes, catch basins, pipes, and outfalls		n/a	GIS geodatabase provided by Beacon Engineering (Beacon)
Drainage areas (DAs)	Size and extents	Estimated based on 2-ft LIDAR contours	Overall drainage area to each outfall provided by Beacon
	Percent Impervious	n/a	*Sussex County (East), DE, 2007 Impervious Surface Coverage* 1 meter by 1 meter grid GIS Raster file
	Manning's n (pervious & impervious)	Manning's n (Impervious): 0.011 Manning's n (Pervious): 0.150	*TR-55* Table 3-1
	Slope	Average slope within DA calculated through GIS "Zonal Statistics" tool	Sussex County 2-ft LIDAR contours
	Characteristic Width	Square root of DA area	Assumption
	Depression Storage	No depression storage	Assumption
	Infiltration Method	Curve Number (CN) Method will be used - Curve Number: Weighted average based on cover and soil hydrologic soil group (HSG). All pervious assumed to be good condition grass cover - Drying Time: Not used in analysis; however, a value is needed for the model to run. Assumed to be one day.	- Curve Number: ○ HSG: NRCS Web Soil Survey ○ Land use: see "Percent Impervious" above. ○ CN: TR-55 - Drying Time: assumption
Rainfall	Total Rainfall Depth	24-hour Storm	Point Precipitation Frequency Estimates for Lewes, DE (Station ID: 07-5320) from NOAA Atlas 14, Volume 2, Version 3
	Distribution	SCS Type II 24-hour Storm	Industry standard for DE

4.2 Model Calibration

Model calibration / verification is not within the scope of this Preliminary Engineering Report and would not be possible without detailed rainfall and flow data collection throughout the stormwater collection system. It is recommended that this data be obtained as part of the detailed stormwater surveying further detailed in Section 7.1. Once this data is obtained, the model can be loaded with actual rainfall distribution recorded, and assumed variables within the model can be adjusted in order for the observed and modeled flow patterns to match throughout the stormwater system. The calibrated / verified model would be a useful tool for the City for current and future management of their stormwater system.

4.3 Preliminary Model Results

The uncalibrated model was utilized to approximate the hydrograph at each outfall for input into the Hydrodynamic and Transport Model (refer to Section 6.4 for additional information).

5. Best Management Practices Evaluation

One approach to improve the water quality in the surf zone at Rehoboth Beach is to implement Best Management Practices (BMPs) on shore to reduce the total enterococcus within the City's runoff. BMPs projects can be implemented individually or combined to improve effectiveness. The feasibility of implementing various BMPs within the City of Rehoboth was investigated.

5.1 Non-Structural Alternatives

5.1.1 Public Education & Outreach

Public Education & Outreach is a cost-effective management practice that can be easily implemented across the City.

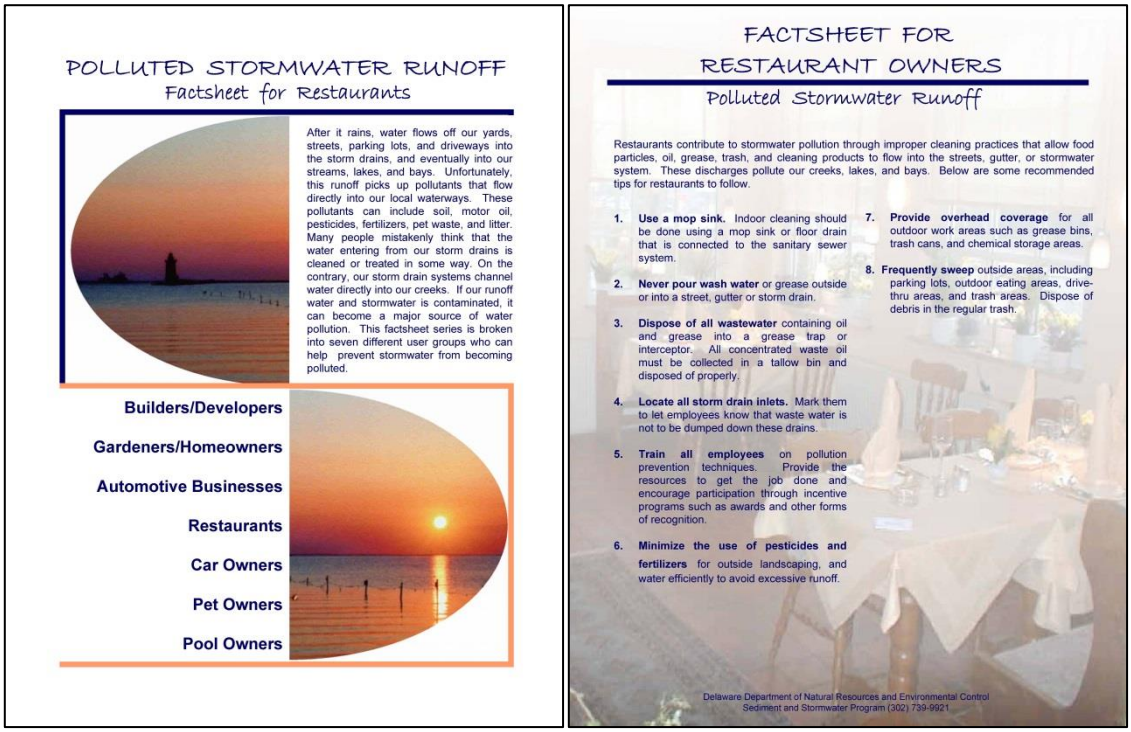
The City of Rehoboth Beach is not currently regulated as an MS4, but it is recommended that the City meet the Public Education & Outreach requirements of MS4s. Per EPA:

> *Phase II MS4s are required to educate their community on the pollution potential of common activities, and increase awareness of the direct links between land activities, rainfall-runoff, storm drains, and their local water resources. Most importantly the requirement is to give the public clear guidance on steps and specific actions that they can take to reduce their stormwater pollution-potential.* (USEPA 2014d)

As a resort community, many inhabitants of the area are not year-round residents, which limits the effectiveness of some public outreach methods. For example, implementing classroom education on stormwater at local schools would not be an effective method of reaching seasonal guests.

Focus should thus be on public education and outreach that takes into account the seasonal nature of the City of Rehoboth community. Distribution of brochures and fact sheets to local businesses would spread awareness in the commercial portion of the City, where enterococcus generation is anticipated to be the highest. Coordination with hotels and rental agencies can help spread awareness to vacationers. For example, brochures and fact sheets can be posted and made available in hotel lobbies or magnets can be designed for placement on refrigerators in rental units. Visitor's guides and maps can also be utilized to spread awareness to City guests. The City's website and community bulletin boards can be updated to include information on stormwater and runoff.

Many brochures and fact sheets already exist. For example, simple two-page fact sheets such as that shown in Figure 18 have been developed by DNREC for restaurants, pet owners, pool owners, and other groups. The City can also develop their own guides to suit their specific needs.



POLLUTED STORMWATER RUNOFF
Factsheet for Restaurants

After it rains, water flows off our yards, streets, parking lots, and driveways into the storm drains, and eventually into our streams, lakes, and bays. Unfortunately, this runoff picks up pollutants that flow directly into our local waterways. These pollutants can include soil, motor oil, pesticides, fertilizers, pet waste, and litter. Many people mistakenly think that the water entering from our storm drains is cleaned or treated in some way. On the contrary, our storm drain systems channel water directly into our creeks. If our runoff water and stormwater is contaminated, it can become a major source of water pollution. This factsheet series is broken into seven different user groups who can help prevent stormwater from becoming polluted.

Builders/Developers
Gardeners/Homeowners
Automotive Businesses
Restaurants
Car Owners
Pet Owners
Pool Owners

FACTSHEET FOR RESTAURANT OWNERS
Polluted Stormwater Runoff

Restaurants contribute to stormwater pollution through improper cleaning practices that allow food particles, oil, grease, trash, and cleaning products to flow into the streets, gutter, or stormwater system. These discharges pollute our creeks, lakes, and bays. Below are some recommended tips for restaurants to follow.

1. **Use a mop sink.** Indoor cleaning should be done using a mop sink or floor drain that is connected to the sanitary sewer system.
2. **Never pour wash water** or grease outside or into a street, gutter or storm drain.
3. **Dispose of all wastewater** containing oil and grease into a grease trap or interceptor. All concentrated waste oil must be collected in a tallow bin and disposed of properly.
4. **Locate all storm drain inlets.** Mark them to let employees know that waste water is not to be dumped down these drains.
5. **Train all employees** on pollution prevention techniques. Provide the resources to get the job done and encourage participation through incentive programs such as awards and other forms of recognition.
6. **Minimize the use of pesticides and fertilizers** for outside landscaping, and water efficiently to avoid excessive runoff.
7. **Provide overhead coverage** for all outdoor work areas such as grease bins, trash cans, and chemical storage areas.
8. **Frequently sweep** outside areas, including parking lots, outdoor eating areas, drive-thru areas, and trash areas. Dispose of debris in the regular trash.

Delaware Department of Natural Resources and Environmental Control
Sediment and Stormwater Program (302) 739-9921

Figure 18 Polluted Stormwater Runoff Factsheet for Restaurants (DNREC 2006)

5.1.2 No Dumping Storm Drain Marking

Storm drain marking programs are “effective, inexpensive, and easy to implement” (USEPA 2014e) and a useful practice to discourage illicit discharges into the stormwater system and improve public awareness.

Some storm drains within the system already have small placards or text cast into grate covers with statements such as “No Dumping Drains to Ocean”, but these are intermittent and in some locations small or difficult to read. See Figure 19 for photos of existing markings.

Figure 19 Existing Storm Drain Marking

It is recommended that the City enact highly visible storm drain markings throughout the entire community but with particular attention in the commercial portion of the City. Not only is this area assumed to be the location of most illicit discharges, but high foot traffic would lead to higher visibility of the signage and greater public awareness.

Costs vary depending on the method of marking. Stenciling painted signs on curbs is the least expensive option, with reusable plastic stencils costing $40 to $50[1] (Stencilease 2015). Partnering with volunteer groups can not only reduce labor costs but also improve public awareness and buy-in. Plastic or ceramic tile markers are slightly more expensive, but are more durable. Four-inch plastic markers with adhesive cost around $7[1] each (Berntsen 2015), and thus a campaign to mark the approximate 300 inlets within the study area, including labor, would cost approximately $2,800[1].

5.1.3 Storm Drain System Cleaning / Flushing

Stormwater pipes, due to steady nutrient concentrations and dark environments protected from ultraviolet radiation, are well suited for bacteria regrowth. Studies show that concrete pipes, which make up the vast majority of the City of Rehoboth's stormwater system, provide particularly hospitable environments for bacteria and microbe growth (Roberts 2012). During storm events, the increased flow can dislodge built up bacteria and increase bacteria within the stormwater discharge. Regular cleaning of the storm drain systems can not only reduce bacteria regrowth but can also remove clogged trash and debris.

Stormwater pipe cleaning is most effective on pipes smaller than 36" in diameter, which includes all pipes within the City of Rehoboth Beach. Pipes with flat grades and low flows are particularly important to flush as they rarely achieve high enough flows to flush themselves (USEPA 2014f).

The cost to perform storm drain system cleaning is approximately $4[1] per foot (USEPA 2014f). Therefore, the cost to clean the entire City of Rehoboth stormwater system, consisting of approximately 36,000 linear feet of pipe, would be approximately $144,000[1]. After detailed data collection on enterococcus generation within the City of Rehoboth, specific pipes and areas of the system can be prioritized for storm drain cleaning.

5.2 Structural Alternatives

A variety of structural BMPs were investigated. Overall, the literature reveals that filtration and bioretention are the most effective at bacteria removal (Hathaway 2008) (Clary, Leisenring and Jeray 2010). However, other practices such as infiltration can reduce the volume of stormwater runoff; thus, reducing the total amount of enterococcus.

Due to the micro-scale of these recommendations and the associated complexity of assessing their impact, quantifying the water quality benefits for these recommendations was excluded from the scope of this PER.

5.2.1 Sand Dune Infiltration Systems

Sand Dune Infiltration Systems (SDIS) employ infiltration to capture and treat stormwater pollutants before they reach the ocean. The Town of Kure Beach, North Carolina, is the

[1] Costs include 40% contingency

only beach in North America that has fully implemented a SDIS. The SDIS at Kure is a gravity-fed system due to Kure's somewhat unique topography: Kure's dunes are 14-16 feet above sea level and the existing stormwater sewer network has a shallow depth (approximately 12-15 feet above sea level) (Burchell, Hunt III and Chescheir 2008). This allows for the SDIS to be located at an elevation between the terminus of the stormwater sewer system and the groundwater. Rehoboth Beach has a flatter topography, which results in little room to place a SDIS.

The Kure Breach SDIS built in 2006 had a capital cost of $25-30,000; the system consisted of 200 linear feet of 48-inch diameter Stormchamber™ pipe serving an 8-acre watershed. A more complicated system or a pumping system would add significant cost. The main reason that Kure Beach SDIS was relatively inexpensive is that it is gravity feed. A SDIS at Rehoboth Beach would likely be more complex and would require significant earthwork and a pump station.

SDIS may be effective at bacteria reduction, with the ability to achieve a "3 log reduction in fecal coliform indicator bacteria and a 2 log reduction in enterococci indicator bacteria" (Bright, et al. 2011), which was found to result in a "97% difference between the stormwater and groundwater bacteria median concentrations" (Price, et al. 2010). However, poorly-designed or -maintained SDIS may be susceptible to accumulation or regrowth of bacteria in the sand filter. Due to their topography, the Kure Beach SDIS are generally dry and not conducive to bacteria growth. A NCSU Study of the Kure Beach SDIS (Burchell, Hunt III and Chescheir 2008) did not find significant difference of bacteria count between SDIS dune sand and control sand. However, the bacteria removal performance can diminish over time without regular maintenance, such as replacing clogged layers of sand (Price, et al. 2010).

5.2.2 At-grade Infiltration and Bioretention Practices

Rain gardens, micro-bioretention basins, landscape infiltration, dry wells, and other at-grade infiltration and bioretention practices can provide significant bacteria removal (Hathaway 2008) (Clary, Leisenring and Jeray 2010). As shown in Figure 20, these practices are simply landscaped features developed by directing stormwater into retention devices where the water can infiltrate into the ground or be taken up by vegetation. This makes these practices relatively inexpensive and easy to maintain. Soil borings and infiltration tests must be performed to determine if the infiltration capacity of the soil and depth to water table is sufficient for these practices.

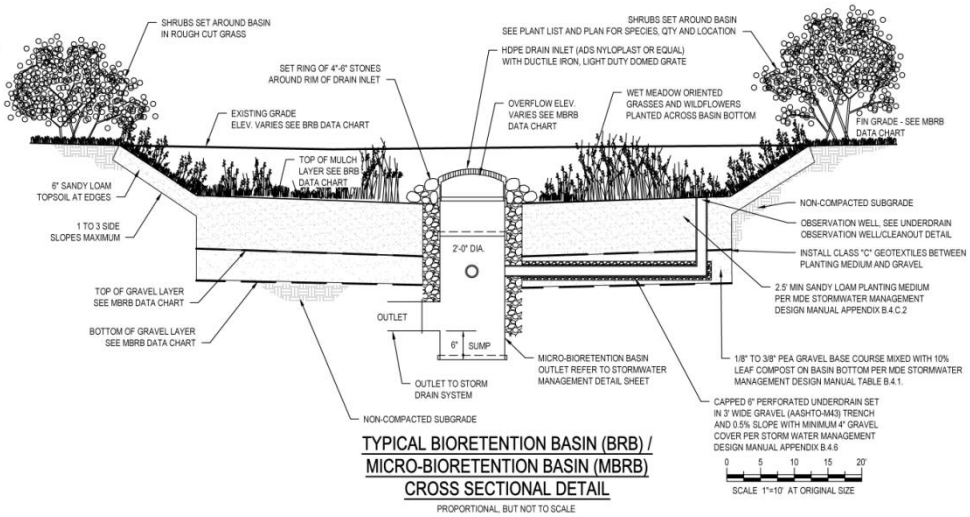


Figure 20 Typical bioretention basin / micro-bioretention basin cross sectional detail

These practices typically require a significant footprint located directly adjacent to the impervious surface to be treated. These practices are thus not practical for the commercial portion of the City where little land is available for construction of these devices. Even in the residential areas, land within the road right-of-ways is limited and typically used by residents for vehicle parking.

The only area where these practices would be feasible is within privately owned property within the City's residential areas. To implement these practices, the City could work out an agreement with the homeowners to allow the City to construct green infrastructure on private property. However, maintenance would still be the responsibility of the homeowner, and it may be difficult to get homeowners to agree to such an arrangement. Many MS4s have thus instead developed incentive programs to encourage homeowners to install approved green infrastructure practices themselves. These incentive programs can include funding, tax credits, or reimbursements.

To meet the requirements of their MS4 permit, Montgomery County, Maryland developed the RainScapes Rewards program in 2008, which has since resulted in over 800 approved projects treating about 11 to 12 acres of impervious area (Water Environmental Federation 2013). Rebates are calculated based on the type, size, and depth of devices installed, with a maximum rebate of $2,500 per household. The rebate for construction of a rain garden, for example, varies from $5 to $9 a square foot based on the depth of media (Montgomery Co, MD 2015).

5.2.3 Sediment / Trash Traps

As detailed in Section 3.2.3, the City currently has numerous sediment / trash traps installed. However, the devices are designed to trap large particulates; therefore, bacteria removal is minimal to nonexistent. Construction of additional sediment / trash traps would therefore not be expected to have a noticeable impact on improving enterococcus concentrations within the surf zone. Furthermore, there is no indication that trash or debris is a significant pollutant in the City's runoff. Therefore, additional sediment / trash traps are not recommended at this time.

5.2.4 Delaware Sand Filters

As detailed in Section 3.2.1, two Delaware-style sand filters are currently installed along the first block of Wilmington Ave. Delaware-style sand filters are well suited for further implementation within the City, as they are entirely underground and have relatively high bacteria removal efficiency around 76% (USEPA 1999b). Delaware sand filters are very shallow, typically only 30 inches deep, allowing minimal headloss within the stormwater system and reducing construction costs (USEPA 1999b). One limitation on Delaware sand filters is that they must be constructed on flat grade, but this is not an issue in the City, where slopes are very shallow. Delaware Sand filters are typically designed for drainage areas of one to five acres.

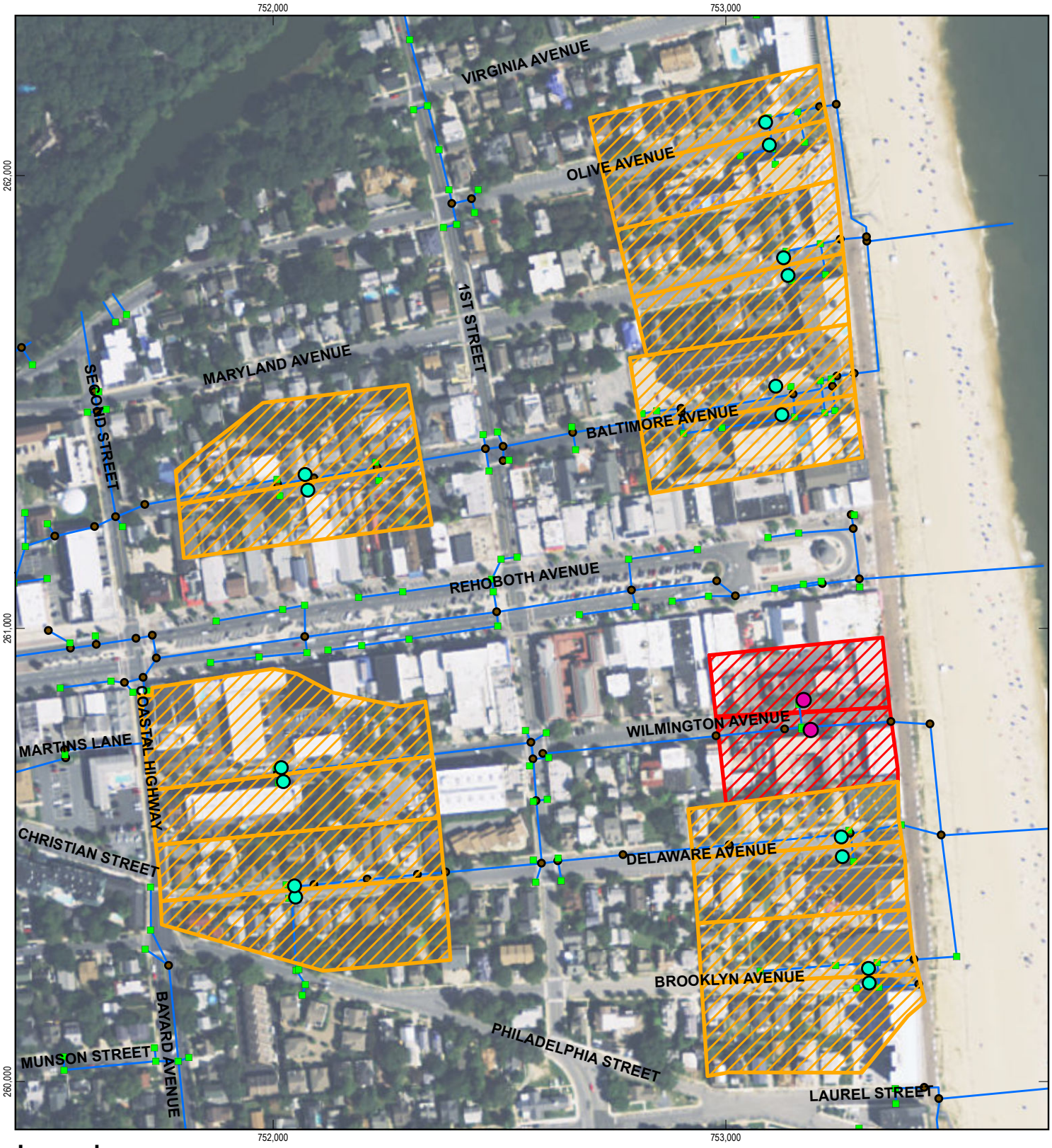
Some potential locations for sand filters and the associated drainage areas are shown in Figure 21. Other locations within the City can be further investigated during detailed design. Each proposed sand filter shown has a drainage area of around two acres.

Construction cost for a Delaware sand filter is typically around $23,000[2] per acre of treatment (USEPA 1999b). Therefore, each of the sand filters shown would cost approximately $46,000[2]. Construction of the 16 filters shown in Figure 21 would cost approximately $736,000[2]. Annual O&M costs are approximately 5% of the initial construction cost (USEPA 1999b), or about $2,300[2] per year for each device.

5.2.5 Engineered Biofiltration Devices

As detailed in Section 5.2.2, due to the large land requirement, at-grade infiltration and bioretention practices are primarily infeasible except on private property. However, engineered biofiltration devices, such as Contech's™ Filterra® system and Rotondo's BioPod system contain components similar to bioretention but in a smaller footprint (Contech 2015). In an engineered biofiltration device, stormwater runoff enters the system through a curb inlet, travels through the filter media and exits to the stormwater system through an underdrain. See Figure 22 for the cross section of a typical engineered biofiltration device. With the use of filter media optimized for bacteria removal, engineered biofiltration devices have shown to have bacteria removal rates between 77% and 99% (Coffman and Ruby 2008).

[2] Costs include 40% contingency



Legend

- Existing Sand Filters
- Potential Sand Filters
- SWM Inlets
- Existing Sand Filter Drainage Areas
- Potential Sand Filter Drainage Area
- SWM Manholes
- SWM Pipes

Paper Size ANSI A
1:3,600
0 45 90 180 270 360
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

GHD
CLIENTS|PEOPLE|PERFORMANCE

City of Rehoboth Beach
Stormwater PER

Job Number 86-18689
Revision A
Date Nov 19, 2015

Potential Locations for Delaware Sand Filters

Figure 21

16701 Melford Blvd Ste 330 Bowie MD 20715 USA T 240 206 6810 F 240 206 6811 E bowmail@ghd.com W www.ghd.com

G:\86\18689\GIS\- Figures - 18689 - SW PER\PER Figure 21 - Potential Locations for Delaware Sand Filters.mxd

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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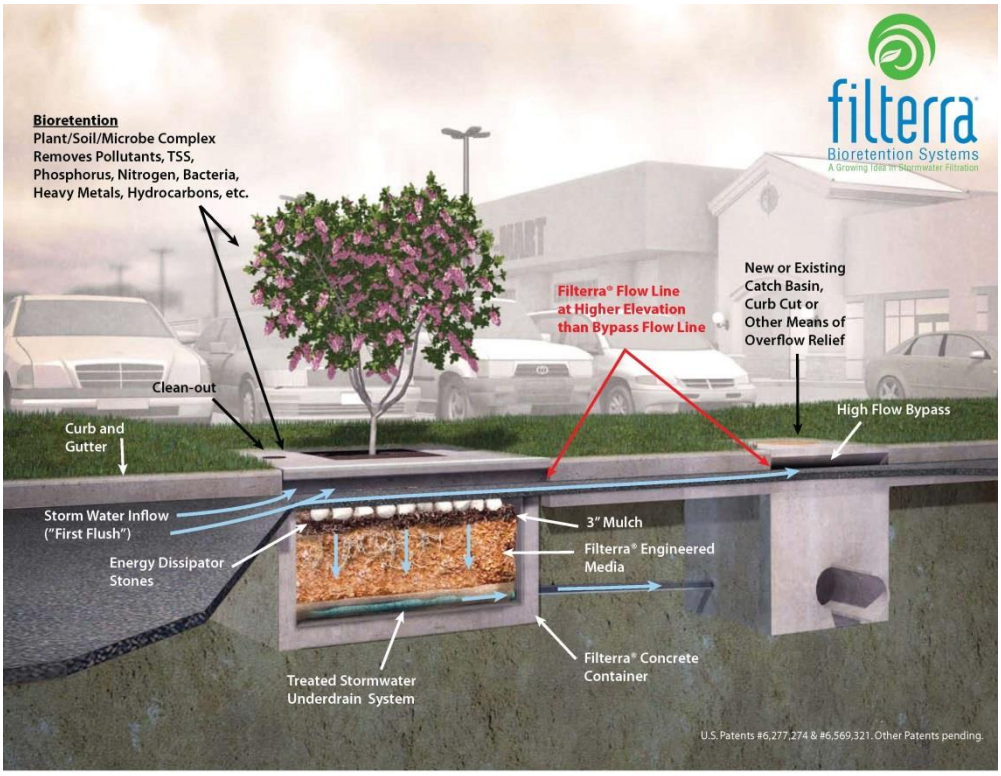


Figure 22 Typical Engineered Biofiltration Devices (Contech 2015)

Even with the smaller footprint, it is doubtful that sufficient space is available for engineered biofiltration device within the commercial portion of the City. Many storm inlets within the residential portion of the City are located within the road or within the shoulder where cars are parked and are thus infeasible for conversion into an engineered biofiltration device (see Figure 23). However, other storm inlets, located in or next to grassed areas between the road and sidewalk, as shown in Figure 24, would be ideal for conversion.

Figure 23 Storm Drain in Shoulder on Henlopen Avenue (Microsoft 2015)

Figure 24 Storm Drains outside of road on Oak Avenue and Penna Avenue in Lake Gerar watershed (Microsoft 2015)

5.2.6 Perforated Pipe Infiltration

As detailed in Section 3.2.2, approximately 2,400 linear feet of 12" storm drain pipes along either side of Columbia Ave between Gerar St. / 3rd St. and 2nd St. are perforated, allowing stormwater to infiltrate into the ground. While this practice does not treat stormwater, it does reduce the volume of stormwater runoff, thus, reducing the total amount of enterococcus entering the surf zone.

Replacing other stormwater pipes with perforated pipes within the City could further reduce volume of runoff and total enterococcus. Some potential locations for installation of perforated pipes are shown in Figure 25. Prior to installation of any perforated pipe, soil borings and infiltration tests should be performed to determine the depth of the water table and the suitability of local soil to infiltration practices.

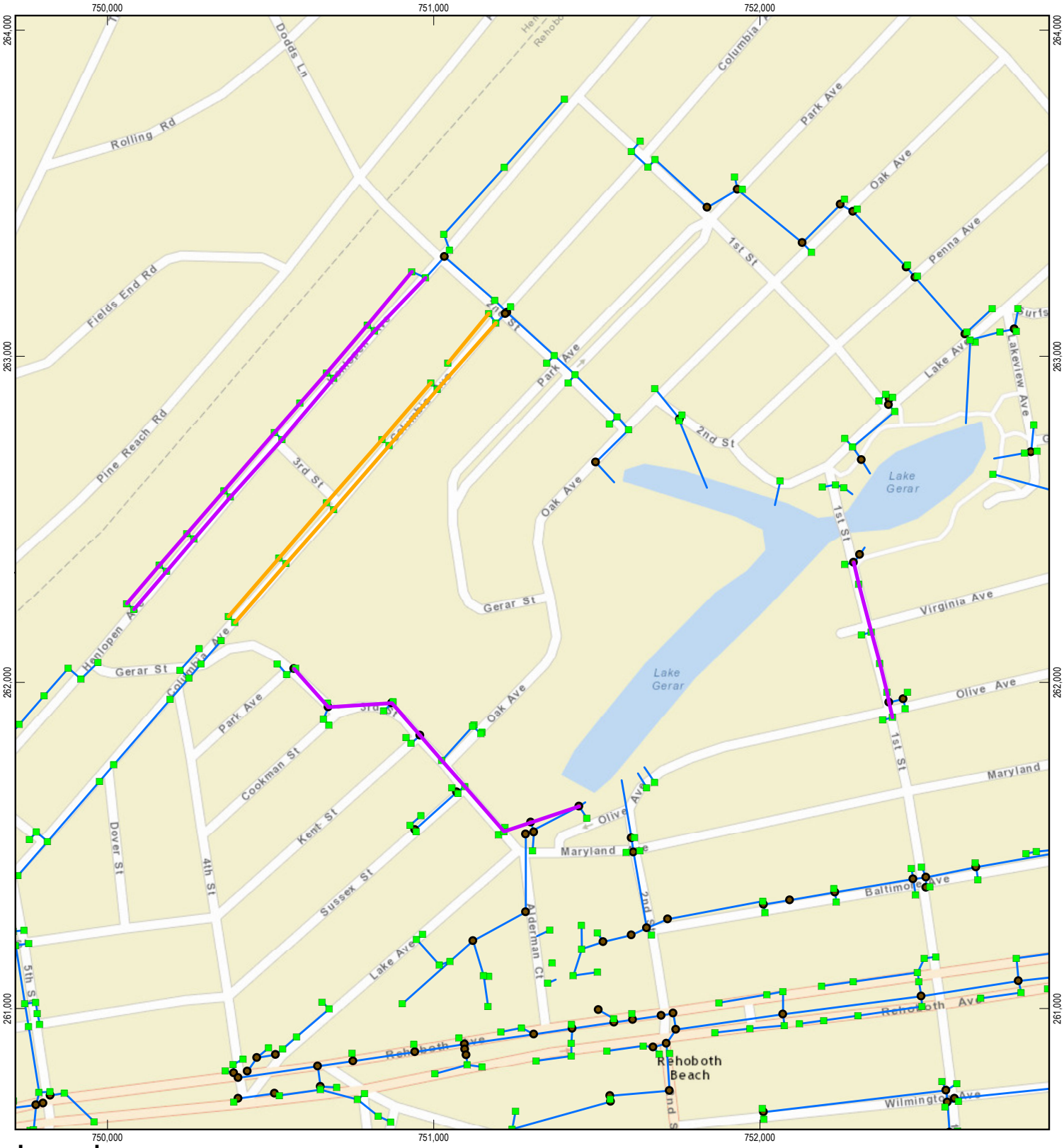
One of the most promising locations is along Henlopen Ave between Gerar St. / 3rd St. and 2nd St. This is directly adjacent to the existing perforated pipe installation and street layout and topology is very similar to Columbia Ave. In addition, it is anticipated that the proposed Rehoboth Beach Ocean Outfall project will include construction of a new force main along Henlopen Ave. This project will already require excavation, pavement removal and replacement, and temporary traffic disturbance. Significant cost savings could be achieved by combining a project to install perforated stormwater pipe with that project.

Elsewhere in the City, perforated pipe can be installed when infrastructure replacement is required due to aging or failing pipes to minimize costs.

5.2.7 Permeable Pavement

Permeable pavement is pavement engineered to allow rain to pass through it, filtering the runoff and allowing infiltration into the surrounding area. In general, permeable pavement may be divided into three types: porous asphalt, pervious concrete, and permeable interlocking concrete pavement. The permeable pavement surface is placed over a highly permeable layer of open-graded stone base/subbase or sand drainage system. The voids within the sub-base provide storage for runoff prior to filtration and infiltration (USEPA 1999a).

Provincetown, Mass, a coastal community at the tip of Cape Cod, recently implemented an extensive project to replace approximately 147,000 square feet of asphalt road with porous asphalt. The project was driven by a significant number of beach closures due to observations of high enterococcus concentrations. After implementation of the first two phases of this project (approximately 70% of the overall project), the number of beach closures went down significantly (Tripp, et al. 2015). A photo of the recently installed porous asphalt is presented in Figure 26.



Legend

- Existing Perforated Pipe
- Proposed Perforated Pipe
- SWM Inlets
- SWM Manholes
- SWM Pipes

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Potential Locations for Perforated Pipe Infiltration

Figure 25

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Figure 26 Porous asphalt after construction in Provincetown, MA (Tripp, et al. 2015)

The first two phases of the project, consisting of approximately 103,000 square feet of porous asphalt, drainage improvements, and sidewalk reconstruction, totaled approximately $3.4 million.

Permeable pavement is well suited for the commercial portion of the City, especially along Rehoboth Ave, where land availability for other structural practices is limited. If implemented, permeable pavement would replace existing pavement and not require any additional land use outside of the paved roads. Rehoboth Ave contains many types of impervious surfaces, including asphalt, concrete, and brick, as shown in the Figure 27. By replacing each existing pavement with the associated permeable pavement, the existing aesthetics of this corridor can be maintained.

Figure 27 Asphalt, concrete, and brick pavement along Rehoboth Avenue (Microsoft 2015)

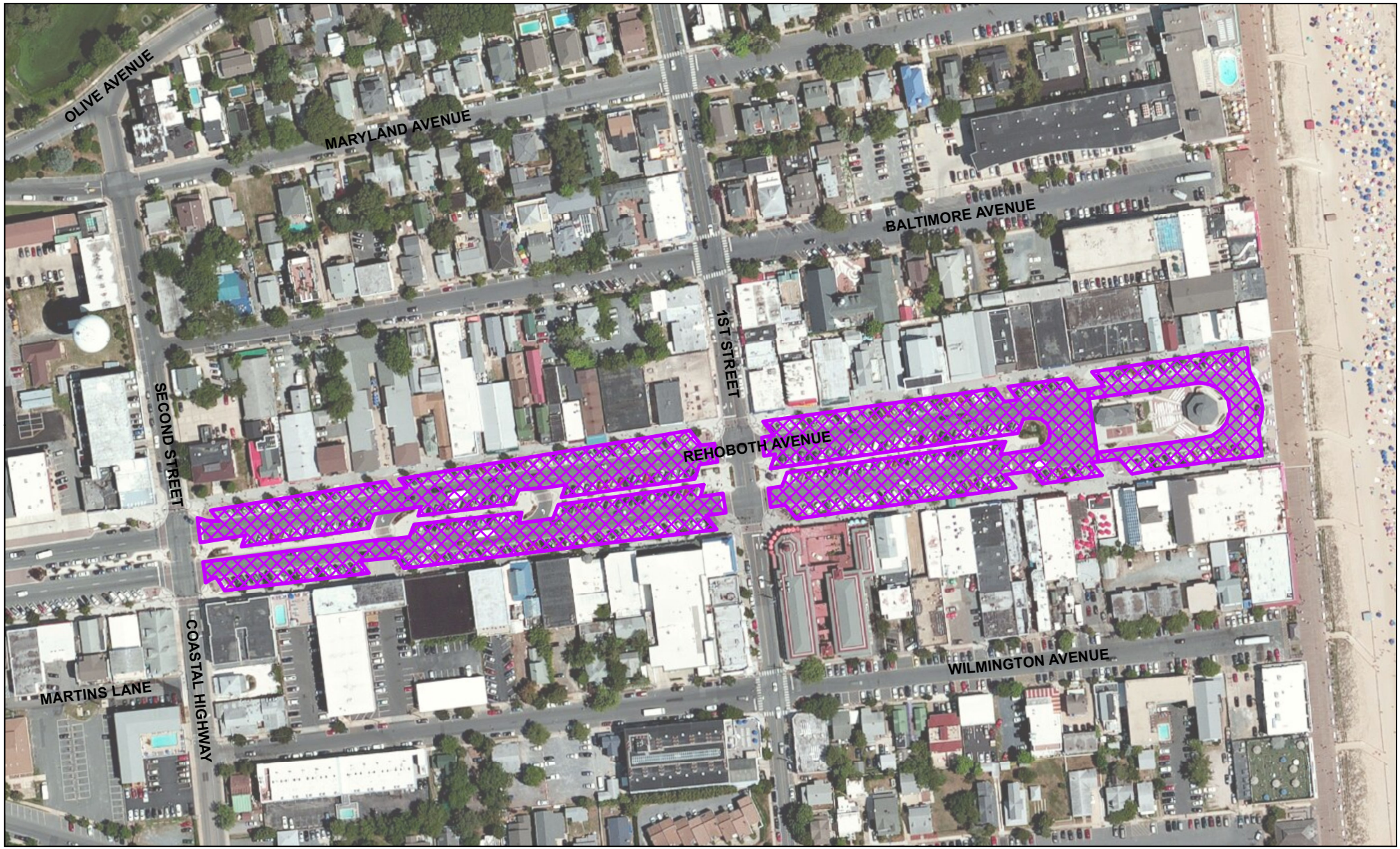
The effectiveness of permeable pavement can vary based on the hydrologic soil group (HSG) of the nearby soil. The majority of the City is located on Type B soil, which is well suited for permeable pavement (NRCS 2014). However, prior to installation of permeable pavement, soil borings and infiltration tests must be performed to determine if the infiltration capacity of the soil and depth to water table is sufficient.

Pavement replacement is typically a significant disruption to local businesses and traffic, but within the City, construction can be phased and limited to the off-season, significantly minimizing the impact.

Permeable pavement is recommended along Rehoboth Avenue, where site conditions are not favorable for other structural BMPs. Potential locations for installation of permeable pavement are shown in Figure 28. Other locations within the City can be further investigated during detailed design.

Permeable pavement costs are typically around $15[3] per square foot (USEPA 2014c) (USEPA 2014b) (GHD 2013). Therefore, the approximately 175,000 square feet of permeable pavement shown in Figure 28 would cost about $2.63 million[3]. Although some cost savings can be achieved by installing a large amount of permeable pavement at once, for the most part, as much or as little permeable pavement can be installed at one time.

[3] Costs include 40% contingency



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Potential Locations for Permeable Pavement

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Potential Locations for Permeable Pavement

Figure 28

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Maintenance of permeable pavement is crucial; otherwise the pores within the pavement will clog over time, reducing the permeability back to that of a typical impervious surface. Monthly visual inspection during rain events is typically recommended to confirm infiltration. In addition, vacuum sweeping should be done twice a year at a minimum (Tripp, et al. 2015).

5.3 Summary of Feasible Best Management Practices

Non-structural alternatives are comparatively the least cost to implement and the benefits would be City-wide. Therefore, it is recommended that the feasible non-structural alternatives be implemented within the City as soon as possible.

After implementation of feasible non-structural alternatives, it is recommended that the City implement structural BMPs throughout the City. Since structural BMPs can be relatively expensive and the enterococcus treatment localized to the drainage area of the BMP, detailed stormwater surveying (as further detailed in Section 7.1) is recommended to be performed prior to implementation. This will help to ensure that the most enterococcus is treated or removed from the stormwater at the lowest cost.

Estimated costs for feasible BMPs are summarized in Table 7. It is not anticipated that all feasible BMPs will need to be implemented.

Table 7 Estimated Costs of Feasible BMPs.

BMP Type	BMP	Assumed Scope of Implementation	Estimated Cost
Non-Structural	Public Education & Outreach	City-Wide	Minimal
	No Dumping Storm Drain Marking	300 inlets	$2,800
	Storm Drain System Cleaning / Flushing	36,000 linear feet of pipe	$144,000
Structural	At-grade Infiltration and Bioretention Practices	Rebate provided per household	$2,500 per household
	Delaware Sand Filters	16 sand filters	$736,000
	Engineered Biofiltration Devices	As needed	Varies
	Perforated Pipe Infiltration	Used instead of typical pipe for replacement of aging or failing pipe	Minimal
	Permeable Pavement	175,000 sq ft along Rehoboth Avenue	$2.63 million

6. Outfall Reconfiguration Evaluation

A second approach to improve the water quality in the surf zone at Rehoboth Beach is to reconfigure the stormwater ocean outfalls to redirect stormwater away from the surf zone and improve dilution within the ocean. An assessment of the potential impacts on the receiving waters from discharge of the stormwater under existing and proposed outfall reconfiguration alternatives was carried out using the existing hydrodynamic and transport model, developed in 2010 for the needs of the City of Rehoboth Beach EIS. Detailed information on the modeling is presented in the Hydrodynamic and Water Quality Modeling of Stormwater Discharges Report, included within Appendix A.

6.1 Examples of Nearby Stormwater Ocean Outfalls

Two examples of stormwater ocean outfalls in the Mid-Atlantic region can be found in the City of Virginia Beach, VA and the City of Myrtle Beach, SC.

The stormwater ocean outfall project in Virginia Beach, VA is currently under construction. The project is planned to consist of a 48-inch concrete pipe buried below the ocean floor for a distance of 1,200 feet, as well as a 45,000 gpm pump station. The combined construction cost of the outfall and pump station is estimated to be $20.8 million USD (City of Virginia Beach 2013a). During this project, the City of Virginia Beach will also make improvements to the stormwater collection system along two miles of Atlantic Avenue (the City's main throughfare), costing approximately $23.6M for design and construction (City of Virginia Beach 2013). The project driver for the City for the stormwater improvements and ocean outfall was flood mitigation rather than pollution prevention. According to the City, floods would occur even during minor storms, and large storms would render Atlantic Avenue impassable.

Unlike the project in Virginia Beach, the stormwater ocean outfall project in the City of Myrtle Beach, SC was implemented primarily to improve water quality along the beach. Prior to the outfall project, the City had 79 stormwater outfall pipes discharging onto the beach (Sanford and Wooten 2006). Although the City received complaints related to the pollution, erosion, and unsightliness of the outfalls, no action was taken for several years because there was perceived to be no immediate threat to human health, and city officials were hesitant to spend significant amounts of funds to fix a problem of undefined scope.

In 2001, Myrtle Beach voters overwhelmingly passed a ballot referendum to invest $25 million USD to implement stormwater management improvements and perform engineering studies for deep-ocean outfalls. Structural BMPs were considered and constructed but not on a wide scale due to the lack of available sites. The City constructed two outfalls for a cost of approximately $13 million USD. The first outfall, serving a 100-acre 70% impervious watershed (Schroeder, et al. 2014), consisted of two parallel 84" diameter pipes extending 1,400 ft into the ocean and is estimated to cost $10 million (Orion Marine Group 2014). The second smaller outfall will be constructed at a cost of $3 million.

6.2 Concentration to Each Outfall

In the absence of recorded enterococcus concentrations, the assumed enterococcus concentration at each outfall was determined based on the land use within the drainage area and assumed enterococcus generation for residential and commercial land use.

Since all drainage areas include both residential and commercial land, a weighted geometric average was calculated for each outfall's drainage area. The concentrations assumed at each outfall for the evaluation are summarized in Table 8.

Table 8 Assumed Enterococcus Concentration at Each Outfall

Outfall	% Commercial Area	% Residential Area	Enterococcus Concentration (cfu / 100 mL) - weighted geometric average
Grenoble Pl	18.18%	81.82%	7,080
Maryland Ave	99.38%	0.62%	8,490
Rehoboth Ave	99.08%	0.92%	8,480
Delaware Ave	92.85%	7.15%	8,370
Laurel St	86.00%	14.00%	8,240

6.3 Outfall Reconfiguration Alternatives

The scope of this PER included analysis of up to three outfall reconfiguration scenarios. The three scenarios investigated in detail in the hydrodynamic and transport model are as follows:

1) Existing Outfalls – Discharge from each drainage area loaded into the model at the location of the existing outfalls, approximately 300 feet offshore from the closest manhole.

2) Rehoboth Ave Extension – Discharge from the Rehoboth Ave drainage area moved an additional 1,000 feet (300 meters) offshore, approximately 1,300 feet offshore from the nearest manhole. Discharge from all other drainage areas still loaded into the model at the location of the existing outfall.

3) Combined Outfall Extension – Discharge from Grenoble Pl drainage area moved an additional 1,000 feet (300 meters) offshore, approximately 1,300 feet offshore from the nearest manhole. Discharge from Maryland Ave, Rehoboth Ave, Delaware Ave, and Laurel St combined and loaded into the model 1,000 feet (300 meters) offshore from the existing Rehoboth Ave outfall, approximately 1,300 feet offshore from the nearest manhole.

The three scenarios are shown in Figure 29.

Transporting the stormwater through the use of a pumping station was seen as infeasible due for a number of reasons:

- High cost. Pump stations in general have significantly higher capital and operation and maintenance costs than gravity systems (CDOT 2004)

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- Existing / Proposed Outfalls
- Proposed Connection to Existing System
- Proposed Pipe

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Outfall Reconfiguration Alternatives

Figure 29

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- Low land availability. No land already owned by the City was identified as feasible for construction of a pump station. Land in close proximity to the beach is expensive, and a pump station would detract significantly from the aesthetics of the beach front, which would be unacceptable to the City, City residents, and City guests.
- High pump rate. Based on the peak hour intensity of a 10-year 24-hour storm as detailed in Section 6.2, the assumed peak hour flow rate for all five drainage areas analyzed totals around 260,000 gpm or 374 MGD. A pump station or pump stations to handle this flow is unrealistic.

Based on a preliminary hydraulic analysis, both of the scenarios proposed are feasible using large gravity pipes, similar to the Myrtle Beach and Virginia Beach examples detailed in Section 6.1.

In order to increase the length of the outfall pipes without increasing the hydraulic headloss, the diameter of the outfall pipes must be increased. The diameter and length of new outfall pipe required so that the headloss of a 10-year 24-hour storm does not increase is summarized in Table 9 for each scenario.

Table 9 Required Outfall Pipe Diameter

Scenario	Required Pipe
Existing Outfalls	n/a
Rehoboth Ave Extension	1,300 feet of 48-inch HDPE pipe
Combined Outfall Extension	1,300 feet of 96-inch Concrete pipe (combined outfall) 1,300 feet of 42-inch HDPE (Grenoble Pl outfall)

6.4 Hydrodynamic and Transport Model

As detailed in Appendix A, the existing hydrodynamic and transport model, developed in 2010 for the needs of the City of Rehoboth Beach EIS, was refined to simulate the stormwater discharge in the City. The model extent, boundary conditions, driving forces and mixing coefficients were not changed from the 2010 model; however, the spatial resolution of the model near the Rehoboth Beach coast was substantially increased.

6.4.1 Evaluation

For the evaluation, a hydrograph at each outfall was determined from the results of the EPA SWMM Model (refer to Section 4). The peak flow from the large Grenoble Pl catchment has been attenuated through Lake Gerar, extending over a duration of 18 hours. The other four catchments do not experience attenuation (no ponds or lakes), and hence exhibit higher peaks, but over a much shorter duration of 6 hours. The hydrographs used in the hydrodynamic model are presented in Figure 30.

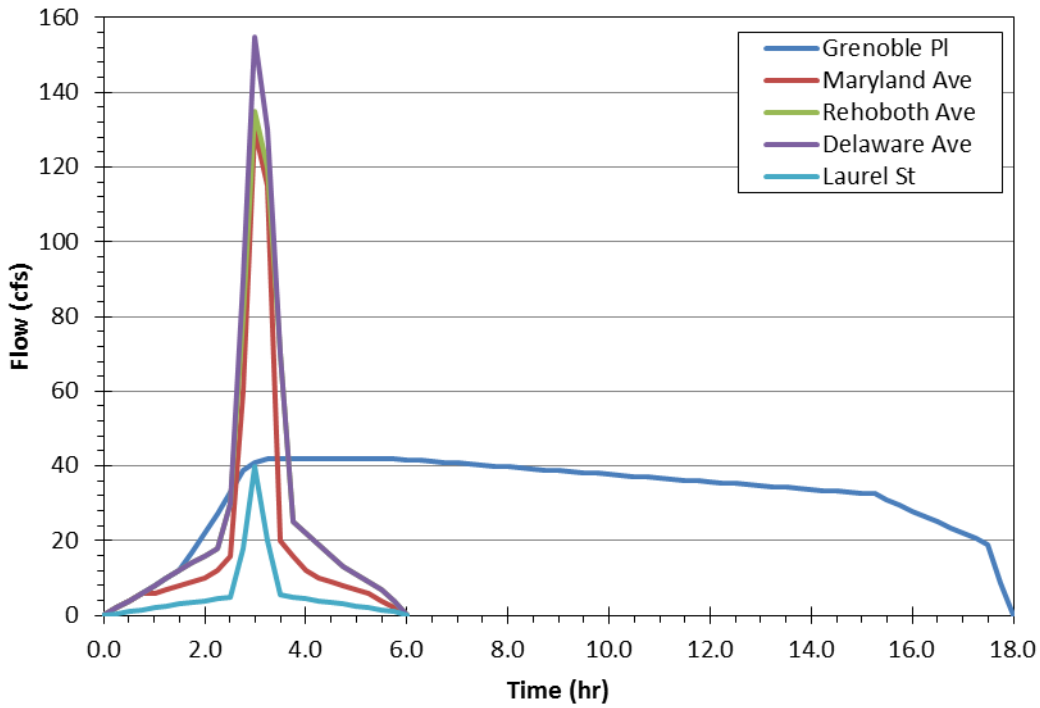

Figure 30 Input Hydrographs for Hydrodynamic Model

Stormwater flow and associated enterococcus loading from other sources besides the five outfalls was excluded from the analysis per the scope. Excluded flow includes surface flow directly into the ocean and flow from the Silver Lake outfall pipe.

The results of the evaluation are presented in the Hydrodynamic and Water Quality Modeling of Stormwater Discharges Report in Appendix A. The evaluation observed that:

- Concentrations are greatly reduced by the beginning of the second day (24 to 30 hours after start of stormwater discharge). Under the Existing Conditions and Rehoboth Ave Extension scenarios, a small plume of concentrations higher than the Beach Action Value (60 cfu/100 mL) remains at the beginning of the second day, but concentrations do not exceed 75 cfu/100 mL and the concentrations are below the Beach Action Value by the third day. Under the Combined Outfall Extension, concentrations have been reduced to below the Beach Action Value on the second day.
- Extension of the Rehoboth Avenue outfall alone would appear to offer only a minor benefit. Concentrations and plume extents are comparable between the Existing Conditions and Rehoboth Ave Extension scenarios on Day 1 and Day 2.
- Aggregating four of the existing outfalls into a single outfall an additional 1,000 feet offshore and extending the Grenoble Pl outfall an additional 1,000 feet offshore allows a substantial reduction in predicted peak concentrations at the beach (relative to the predictions corresponding to the existing outfall configuration) to occur within the first day after the discharge. During the period of discharge (first 6 hours), concentrations are frequently 2,001 - 5,000 cfu / 100 mL along the shoreline during existing, but less than 100 cfu / 100 mL along the shoreline with extended outfalls.

- By Day 3, the beneficial impact of the outfall extension appears to have effectively vanished, with all concentrations below the be

The Hydrodynamic and Water Quality Modeling of Stormwater Discharges Report concluded that purely from a water quality perspective, the optimal outfall configuration is the Combined Outfall Extension scenario.

6.5 Additional Considerations

Extension of the outfalls would have other benefits in addition to potentially improving water quality within the surf zone. The current location of the ocean outfalls are highly visible, detracting from the aesthetics of the beach. Since they pose a significant hazard to swimmers and others within the surf zone, swimming is not allowable in their vicinity. A typical existing stormwater ocean outfall within the City is shown in Figure 31.

Figure 31 Typical Existing Stormwater Ocean Outfall within the City

The aesthetic impacts and potential hazards of the existing ocean outfalls are especially of concern when the beach becomes eroded following storm events. A storm in early October 2015 washed away a significant portion of sand, exposing the stormwater outfall pipes along almost the entire width of the beach. One of the exposed stormwater ocean outfalls is shown in Figure 32. Historically, erosion has also directly impacted stormwater ocean outfalls by reducing the structural support of the most seaward portion of the pipe. Without the support, the ends of the pipes break or must be cut, decreasing the distance from shore to the discharge point.

Figure 32 Existing Ocean Outfall after October 2015 Storm

Extended ocean outfalls would also minimize conflict with beach replenishment projects. Due to erosion, the beaches within the City must be replenished with additional sand every couple of years. Given the current location of the stormwater ocean outfalls, beach replenishment projects can interfere with their successful operation. For example, after a beach replenishment project in February of 2012, sand from the beach replenishment frequently partially filled in the outfall pipes, resulting in a few instances of flooding within the City. To prevent this, an excavator had to be kept on call to regularly clear the outfall pipes for the majority of the summer until the sand filling the outfall pipes completely eroded. Excavation had to be performed at low tide during daylight hours when the beaches could potentially be crowded with guests (Mavity 2012).

6.6 Outfall Extension Budgetary Cost Estimate

Budgetary cost estimates from multiple marine contractors are summarized in Table 10. Based on the provided cost estimates, directional drilling is a more cost effective option when it is feasible based on diameter and material, approximately 50% of conventional trench construction. If directional drilling is utilized for all HDPE construction, the cost would be approximately $7.7 million for Alternative 1 and $22.6 million for Alternative 2 ($16 million for the 96-inch concrete pipe and $6.6 million for the 42-inch HDPE pipe).

Table 10 Stormwater Outfall Budgetary Cost Estimates

	Contractor 1 (Conventional Cut-and-Cover Trenching)	Contractor 2 (Conventional Cut-and-Cover Trenching)	Contractor 3 (Directional Drilling)
Alternative 1 – Rehoboth Ave Extension:			
1,300 feet of 48-inch HDPE	$18,200,000	$15,400,000	$7,700,000
Alternative 2 – Combined Outfall Extension:			
1,300 feet of 96-inch Concrete pipe	$22,000,000	$16,000,000	n/a
1,300 feet of 42-inch HDPE	$11,600,000	$15,100,000	$6,600,000

Note: All costs include 40% contingency.

7. Conclusion / Recommendations

7.1 Recommendations for future studies

As discussed in Section 1.2, data collection within the City's stormwater system on enterococcus concentration and flow rates was excluded from this analysis. Estimates, assumptions, and approximations were made from existing data and literature review in order to provide a qualitative assessment and develop preliminary recommendations. However, before significant investment is made by the City into their stormwater system, detailed stormwater surveying should be performed. Such a survey should include:

- Rainfall data
- Flow data collection at multiple points throughout the stormwater system
- Enterococcus sampling performed during storm events at multiple points throughout the stormwater system, including upstream and downstream of existing stormwater management devices, such as the Delaware sand filters
- Grab samples within Lake Gerar during dry and wet weather

If budget allows, the stormwater survey can be expanded to include not only the 5 outfalls investigated for this analysis, but also the portion of the City and surrounding land within the Silver Lake watershed, including Silver Lake's outfall to the ocean. It is also recommended that the small drainage area discharging onto the beach near the intersection of Lake Ave and Surf Ave be investigated and rerouted to the Lake Gerar watershed, if feasible.

The stormwater surveying will provide the data necessary to:

- Calibrate the stormwater system model and the hydrodynamic and transport model
- Confirm stormwater as the source of enterococcus within the surf zone
- Correlate storm events and enterococcus concentration in runoff
- Identify drainage areas and sub-drainage areas with relatively higher enterococcus generation.

This will allow for prioritization of future stormwater management projects including construction of new BMPs and modifications to the stormwater pipe system.

7.2 PER Recommendation

Based on the assessment performed in this PER, the following recommendations are proposed:

1. As soon as possible, implement public education & outreach (refer Section 5.1.1) and storm drain marking (refer Section 5.1.2).
2. Perform detailed stormwater surveying as outlined in Section 7.1.
3. Based on the results of the detailed stormwater surveying, further investigate the feasible structural BMPs alternatives, including
    - Development of a program to incentivize homeowners for construction of at-grade infiltration and bioretention practices (refer Section 5.2.2).

- Construction of additional Delaware sand filters within the commercial portion of the City (refer Section 5.2.4).
- Construction of engineered biofiltration devices within the residential portion of the City (refer Section 5.2.5).
- Replacement of existing stormwater pipes with perforated pipe to allow for infiltration (refer Section 5.2.6).
- Replacement of impervious along Rehoboth Avenue with permeable pavement (refer Section 5.2.7).

4. Develop a small scale pilot program consisting of construction of one or a few of the feasible structural BMPs. Collect detailed data before and after to analyze the effectiveness of the device. If deemed a cost effective method of enterococcus removal, construct addition BMPs as needed and as budget allows.
5. Based on the results of the detailed stormwater surveying, and the effectiveness of implemented structural and non-structural BMPs, further investigate outfall reconfiguration alternatives. Implement outfall extensions and modifications as necessary to improve water quality within the surf zone.

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Appendices

Appendix A – Hydrodynamic and Water Quality Modeling of Stormwater Discharges

GHD (Pty) Ltd

Rehoboth Beach: Stormwater PER TO12

Hydrodynamic and Water Quality Modelling of Stormwater Discharges

May 2016

Scope and limitations

This report: has been prepared by GHD for GHD (Pty) Ltd and *may only be used and relied on by GHD (Pty) Ltd for the purpose agreed between GHD and the GHD (Pty) Ltd as set out in Section 1.1 of this report.*

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

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Appendix A – Maps of 95th Percentile Enterococci Concentration

1. Introduction

1.1 Purpose of this report

This report informs (and hence forms part of) the "City of Rehoboth Beach Stormwater Preliminary Engineering Report".

The purpose of the report is to describe tasks undertaken in assessing (through hydrodynamic modelling), the relative benefit to recreational water quality of extending one or more existing stormwater outfalls offshore. The report provides an overview of scope, model development, and assumptions. The report ends with a presentation of key results and associated conclusions and/or recommendations.

1.2 Background

The storm drainage system for the City of Rehoboth Beach discharges to the Atlantic Ocean through a series of stormwater beach outlets. An assessment of potential impacts on the receiving waters from the discharge of stormwater, and subsequently the assessment of whether extending one or more outfalls offshore may provide a benefit, forms part of the requirements of the Rehoboth Beach Record of Decision (RoD).

In particular, the requirement for hydrodynamic modelling is indicated within Section 2.2 (Dispersion Modelling) of Task Order 12, which is reproduced below.

> *"The storm drainage system of the City of Rehoboth Beach discharges to the Atlantic Ocean via 5 stormwater beach outlets. An assessment of the potential impacts on the receiving waters from the discharge of the stormwater is required as part of the Rehoboth Beach RoD. It is proposed to carry out the assessment using the existing hydrodynamic and transport model, developed in 2010 for the needs of the EIS. With bacteria (e.g. Enterococci) the main indicator for the health of the receiving waters in the near-shore zone and assuming an adequate understanding of bacteria die-off rates in the region can be built from existing literature, it is proposed that the current model would be used "AS IS" and would provide a first estimate of advection and dispersion of the effluent and its biological component for conceptual design. To achieve the latter objective, the model would be operated with a constituent decaying at the adopted Enterococci decay rate."*

1.3 Project Scope

The scope pertaining to receiving water analysis can be summarised as follows:

- Carry out a numerical assessment in order to identify an improved, optimal configuration of the existing stormwater outfalls using the existing hydrodynamic and transport model, developed in 2010 for the needs of the EIS.
- Upgrade the model with capability of predicting the temporal and spatial concentration of enterococci discharged to the ocean by the stormwater over critical periods of operation of the outlets. Adopt bacteria (e.g. enterococci) as the main indicator for the health of the receiving waters in the near-shore zone.
- Provide numerical predictions of plume extent in statistical format and time histories of enterococci concentration at nominated locations to assist in the decision making process.

- Present the results of runs involving stormwater hydrographs determined through hydrologic modelling coupled with a best guess of pollutant loading.

1.4 Format of Report

Chapter 2 of this report provides a summary of data utilised for the study.

Chapter 3 describes the development (updating) of the hydrodynamic model previously developed for this area (refer GHD 2011).

In Chapter 4, a brief discussion is provided in relation to the representation of indicator bacteria, and the section/determination of an appropriate decay rate.

Modelling scenarios are described in Chapter 5, while results and conclusions as to the relative merits of considered outfall options are presented in Chapter 6 (with spatial plots provided as Appendix A).

Collectively, the chapters of this report form a key input to the overall Preliminary Engineering Report.

1.5 Assumptions

Background concentration

The study has been undertaken with the agreed assumption of zero background concentration of enterococci in the ocean, given a relative paucity of measurements across the entire model domain. Results are presented with this in mind, noting that the primary focus was a comparison of options. That is, the modelling undertaken allows (i) an assessment of the relative benefit of options when compared to existing conditions, and (ii) the magnitude of dilution that can be achieved (against which the required dilution can be measured). Where it is desired that a background concentration be included, then either the target dilution, or the target concentration, can be lowered accordingly.

Other assumptions are detailed in Section 5.4.

2. Project Data

2.1 Outfall Locations

The location of the five existing stormwater outfalls is indicated in Figure 1. Each of these locations has been included within GHD's existing hydrodynamic model of the region, with the release of stormwater in the numerical model simulated at these locations. Co-ordinates are provided in Table 1 and Table 2 (in units of feet and metres respectively).

Table 1 Existing Outfall Locations (ft), Delaware State Plane

Name	Latitude	Longitude	Northing (ft)	Easting (ft)
Grenoble Pl	38° 43' 14.531" N	75° 4' 32.373" W	262,647.81	753,462.79
Maryland Ave	38° 43' 7.058" N	75° 4' 30.465" W	261,892.43	753,616.84
Rehoboth Ave	38° 42' 59.603" N	75° 4' 29.438" W	261,138.47	753,701.06
Delaware Ave	38° 42' 53.896" N	75° 4' 28.668" W	260,561.36	753,764.25
Laurel St	38° 42' 48.261" N	75° 4' 28.108" W	259,991.43	753,810.74

Table 2 Existing Outfall Locations (m), Delaware State Plane

Name	Latitude	Longitude	Northing (m)	Easting (m)
Grenoble Pl	38° 43' 14.531" N	75° 4' 32.373" W	80,055.21	229,655.92
Maryland Ave	38° 43' 7.058" N	75° 4' 30.465" W	79,824.97	229,702.87
Rehoboth Ave	38° 42' 59.603" N	75° 4' 29.438" W	79,595.17	229,728.54
Delaware Ave	38° 42' 53.896" N	75° 4' 28.668" W	79,419.26	229,747.80
Laurel St	38° 42' 48.261" N	75° 4' 28.108" W	79,245.55	229,761.97

To simplify reporting, each outfall has been assigned a short name; for example "G" for Grenoble Place, "M" for Maryland Avenue, "R" for Rehoboth Avenue and so on. The short names are used when appearing in tables.

2.2 Coordinate Geo-reference System

All modelling work has been carried out using the Transverse Mercator projection, North American 1983 horizontal datum and NAD 1983 State Plane Delaware FIPS 0700 meter grid. All GIS work has been converted to NAD 1983 State Plane Delaware FIPS 0700 feet grid.

2.3 Outfall Discharges

While establishing the updated model, it was necessary to adopt a steady 5m^3/s discharge over a seven day period, at a constant 1 g/L concentration for each outfall. These conditions were used for all preliminary (also termed "reconnaissance") simulations. Additional detail is provided in Section 5.2. This approach was adopted while more accurate estimates of the discharges from each of the five catchments were determined.

For operational simulations (i.e. those investigating the impacts of proposed changes to outfall locations on plume extent and behaviour), realistic stormwater runoff hydrographs and pollutant loadings have then been adopted, as indicated in Table 3. The adopted hydrographs equate to the predicted runoff volume from the hydrologic model, but have been truncated. The peak flow from the large Grenoble catchment has been attenuated through Lake Gerar, extending over a duration

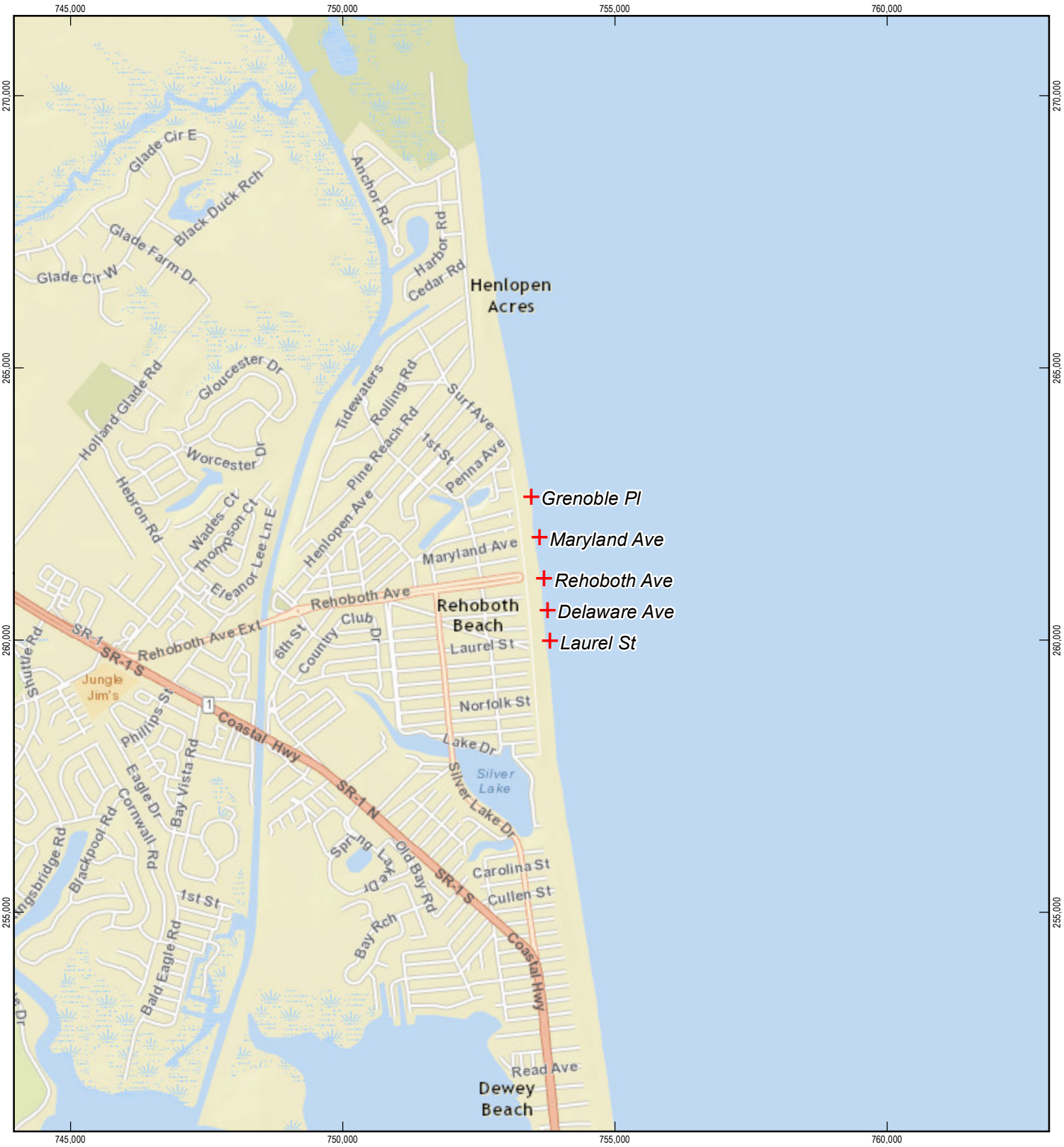
of 18 hours. The other four catchments do not experience attenuation (no ponds or lakes), and hence exhibit higher peaks, but over a much shorter duration of 6 hours.

Details of the derivation of both the enterococcus concentrations and hydrographs are provided in Sections 2.6.3, 6.2 and 6.4 of GHD (2015). Other supporting information may be found in Section 2.4, Chapter 4 and Section 5.4 of this report.

Table 3 Flow Rates and Concentrations

Name	Catchment Area (acres)	Peak Flow Rate (ft^3/s)	Peak Flow Rate (m^3/s)	Concentration (cfu/100 mL) – weighted geometric average	Scenario used / description
G	144.8	42	1.19	7,080	Existing and extended 300 m offshore
M	22.5	130	3.68	8,490	Existing configuration
R	30.5	135	3.82	8,480	Existing configuration or individual outfall extended 300 m offshore
D	33.0	155	4.39	8,370	Existing configuration
L	6.6	40	1.13	8,240	Existing configuration
R1	92.6	460	13.0	8,426	Scenario R1 involves the aggregation of outfalls M+R+D+L and extended 300 m offshore

Source: Table 8 and Figure 30 of PER (GHD, 2015)



LEGEND

+ Existing Outfall

Paper Size ANSI A

0 1,500 3,000

Feet

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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City of Rehoboth Beach
Stormwater PER

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Revision	A
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Location of Existing Stormwater Outfalls

Figure 1

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2.4 Water Quality Objectives

The US EPA has developed water quality criteria for application to recreational waters for protection of human health in coastal waters designated for primary contact: "*2012 Recreational Water Quality Criteria*". These water quality criteria recommendations are not regulations as States are able to adopt criteria that may be different from that developed by the US EPA. These criteria are based on *E. coli* and enterococci concentrations and their relationship between human gastrointestinal illness and faecal contamination. Table 4 shows the recommendations of the US EPA for water quality criteria.

Table 4 Recreational Water Quality Criteria (EPA 2012)

Criteria Elements	Recommendation 1 Estimated illness rate 36/1,000		Recommendation 2 Estimated illness rate 32/1,000	
Indicator	GM* (cfu/100mL)	STV** (cfu/100 mL)	GM (cfu/100mL)	STV (cfu/100 mL)
Enterococci (marine and fresh)	35	130	30	110
E. coli (fresh)	126	410	100	320

*GM = geometric mean, **STV = statistical threshold value

Definitions

The State of Delaware uses the following definitions for recreational contact:

"Primary Contact Recreation" means any water-based form of recreation, the practice of which has a high probability for total body immersion or ingestion of water (examples include but are not limited to swimming and water skiing).

"Secondary Contact Recreation" means a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of water (examples include but are not limited to wading, boating, and fishing).

The State has previously adopted the GM for enterococci for marine water of 35 cfu/100 mL and a single sample value of 104 cfu/100 mL for primary contact in marine water as shown in Table 5 (http://regulations.delaware.gov/AdminCode/title7/7000/7400/7401.shtml). Secondary recreational contact water quality criteria were 520 cfu/100 mL for a single sample value and 175 cfu/100 mL as a geometric mean.

Table 5 Recreational Water Quality Criteria (Delaware 2014)

Marine water	Enterococci Single sample value (cfu/100 mL)	Enterococci Geometric mean (cfu/100 mL)
Primary contact recreation	104[#]	35
Secondary contact recreation	520	175

[#] Superseded by Beach Action Value

Beach Action Value

In order to more fully safeguard public health, 60 cfu / 100 mL has been selected as the EPA's new Beach Action Value (BAV). This is applied to Delaware's beaches under the Beach Water Quality Monitoring Program. Adopted values are based on the following information provided by the Delaware Department of Natural Resources and Environmental Control (DNREC):

6. Water quality criteria

a. DNREC still uses the 1986 regulations, which require notification if samples exceed 104 cfu / 100 mL. The 2012 regulations, which require notification if samples exceed 60 cfu / 100 mL will go into effect in 2016,

Accordingly, the PER evaluates water quality based on the 60 cfu / 100 mL requirement as specified by DNREC and as recently used to assess beach water quality under the Delaware Beach Water Quality Monitoring Program.

Reference can also be made to Section 2.6 of GHD (2015).

3. Hydrodynamic Model

3.1 Description

In 2011, GHD developed a large-scale finite volume hydrodynamic model of the Delaware Estuary and adjacent coastal waters in order to investigate the feasibility of a new waste water ocean outfall for the City of Rehoboth Beach (GHD, 2011). The hydrodynamic model, calibrated to the best data available at the time, was subsequently coupled to a dispersion model and applied to (1) predict the advection and dispersion of the effluent released from the outfall and (2) assist in determining the potential for impacts on environmentally sensitive areas.

The 2011 modelling effort yielded a modelling system capable of resolving coastal hydrodynamic and dispersion processes or, in other words, describing the spatial and temporal evolution of currents along the coast together with the inherent mixing processes.

With the focus of the current investigation set on the optimisation of stormwater releases along the Rehoboth Beach coastline, the 2011 hydrodynamic and dispersion modelling system has been applied without any change to model extent, boundary conditions, driving forces and mixing coefficients. However, the spatial resolution of the model near the Rehoboth Beach coast has been substantially increased (section 3.2) with microbial modelling capabilities using a decaying substance as a proxy added (section 4.1).

The aim of the adopted approach has been to:

- preserve the quality of the calibration achieved in 2011
- ensure that the numerical solution remains unchanged in terms of flow patterns and resulting long-term transport trends, and
- provide an efficient engineering solution with respect to outfall configuration with added microbial modelling capabilities at relatively low time and computational cost.

A brief summary of the key modelling features follows. Additional detail is provided in GHD (2011).

3.2 Model Extent

The simulation domain (Figure 2) includes the entire Delaware estuary and 233 miles (375 km) of the adjacent continental shelf extending some 65 miles (105 km) offshore to maximum depths of approximately 328 ft (100 m). The included section of continental shelf stretches from the mouth of the Delaware estuary 99 miles (160 km) north past Bamegat Bay reaching Point Pleasant Beach and 134 miles (215 km) to the south ending at Cape Charles at the mouth of Chesapeake Bay.

3.3 Resolution and Numerical Time Step

The model (or numerical) mesh is an implementation of the flexible (unstructured) mesh concept available within the Mike 21 suite of models developed by the Danish Hydraulic Institute (DHI). For the 2015 study, the mesh has been refined to provide the spatial resolution necessary to resolve the hydrodynamic and dispersion processes near the Rehoboth Beach coast. By way of example, the key result of the refinement is an improved representation of wave induced currents and the associated near-shore transport in the coastal waters in the immediate vicinity of the outfalls.

The new flexible mesh contains 32704 elements (up from 12730 elements in the 2011 version) and 17480 nodes (up from 7247 nodes in the 2011 version).

The resolution of the mesh is approximately 30-35 m (significantly finer than the original 150 m). This resolution has been implemented along the coast over a distance of 17 km centred on the location of the existing stormwater outfalls and in cross-shore direction over a distance of approximately 1.3 km extending well beyond the surf zone.

3.4 Calibration

In 2011, the model was operated in a series of calibration scenarios involving the three most significant driving forces governing the ocean hydrodynamics of the area - the tide, freshwater inflows from the Delaware River, and offshore winds. The importance of these forces was established following a review of the existing scientific literature with some of the reviewed documents going back to the 1980s. Further details on model calibration can be found in GHD (2011).

3.5 Driving Forces

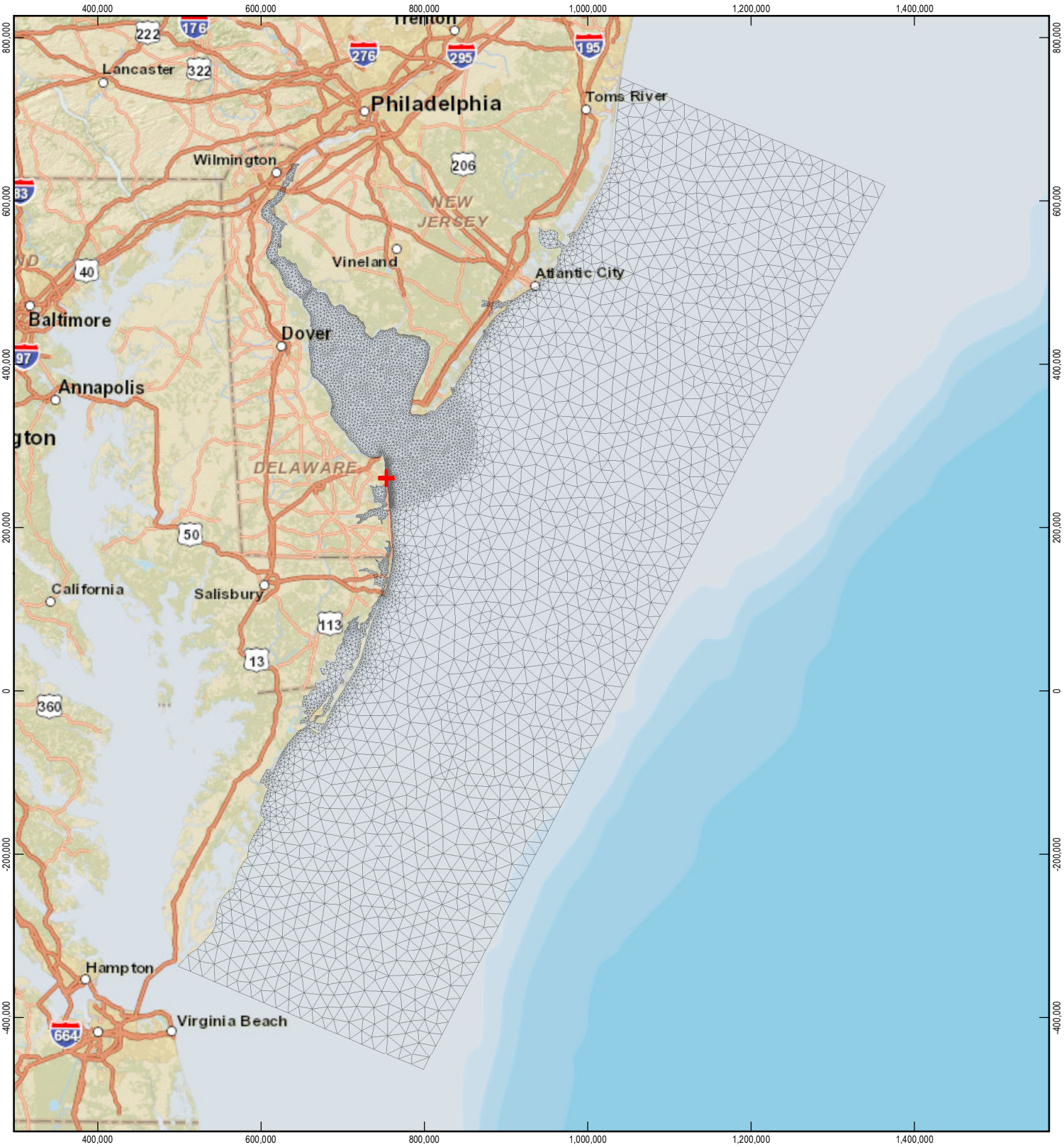
The primary forcing factors included in the analysis remain as previously indicated: tides, winds, waves and the Delaware River discharge. Excluded from direct consideration in the analysis are seasonal changes of salinity and temperature, heat transfer processes through the water surface, precipitation, evaporation and large-scale shelf circulation. However, the effects of salinity, temperature and solar radiation are indirectly accounted for in the decay rate of the non-conservative substance used as a proxy to model bacteria (refer section 4.5).

*Forcing of Hydrodynamic M*odel

Tidal elevations are imposed along the offshore boundaries of the model by specifying amplitude and phase for each of the following 8 major tidal constituents: Q1, O1, P1, K1, N2, M2, S2 and K2. These are obtained from the DHI global tidal model which is an integral part of the adopted modeling system.

Forcing of Wave Model

The wave model is forced by offshore winds applied to the free-surface of the model and offshore open boundary conditions comprising significant wave height, spectral peak wave period, mean wave direction and a directional spreading index.



LEGEND

+ Existing Stormwater Outfalls

Model Elements

Paper Size ANSI A

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Feet

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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Extent of the Model
used for Far-Field Analysis

Figure 2

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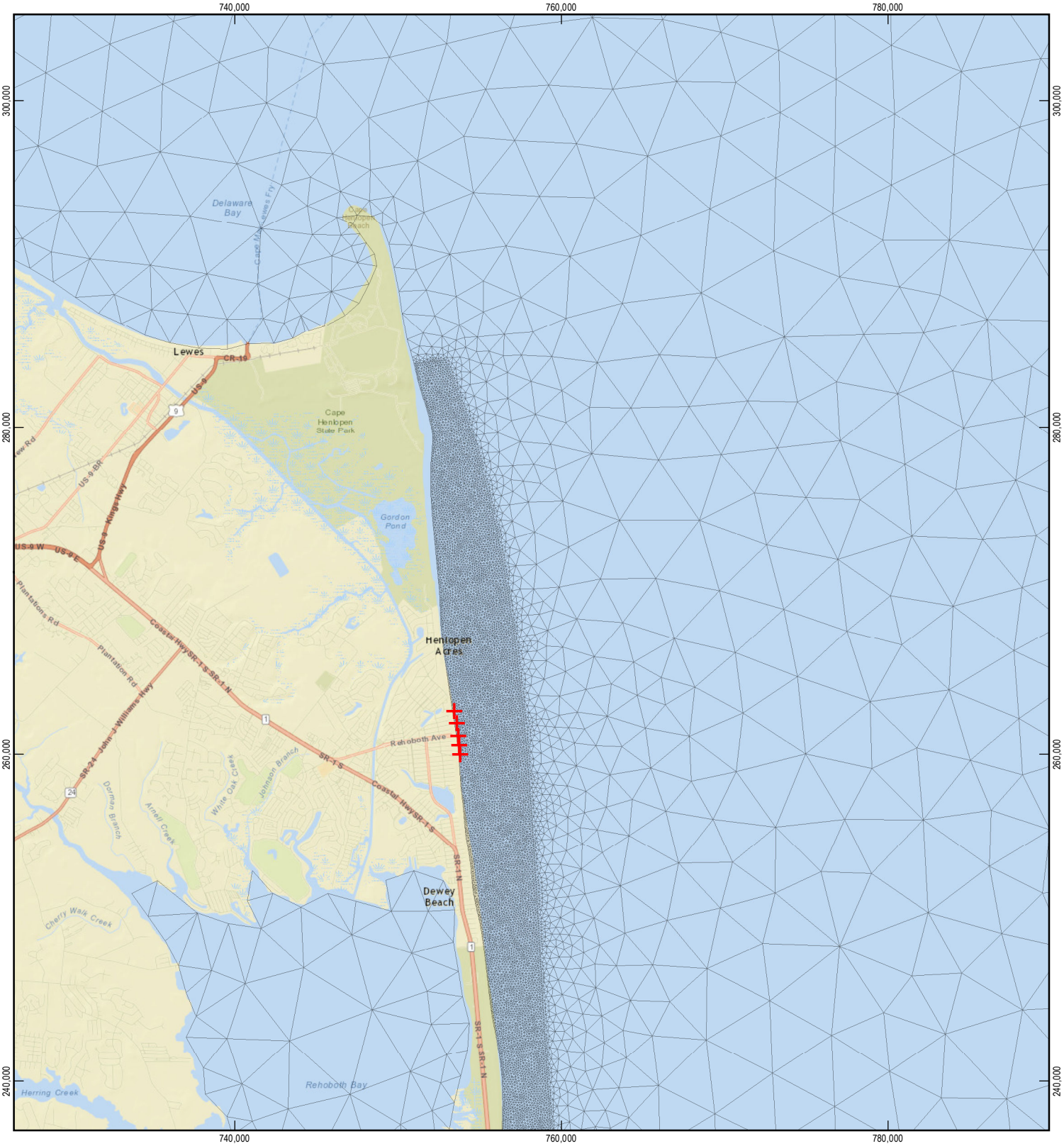

LEGEND

Existing Stormwater Outfalls

Model Elements

Paper Size ANSI A

0 5,000 10,000

Feet

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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City of Rehoboth Beach
Stormwater PER

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Magnified view of model mesh along coast

Figure 3

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4. Indicator Bacteria

4.1 Proxy Representation of Bacteria in Model

The adopted modelling approach does not directly represent bacteria and the associated biological processes. Instead, it adopts a non-conservative (decaying) substance or constituent with a specific decay rate and uses the constituent as proxy for representing bacteria and the constituent decay rate as a die-off rate that links bacteria survival rates in ocean waters with the behaviour of the constituent. By doing so (e.g. adopting a constituent as proxy), a larger number of modelling scenarios can be completed at relatively low time/computational cost without detailed representation of the effects of salinity, temperature and solar radiation in the modelling process.

Clearly, it is important to choose an adequate (e.g. site-representative) yet reasonable (with respect to the impact assessment viewpoint) bacterial die-off rate to model accurately the decay of the constituent and hence the die-off of bacteria in the field. Availability of bacteria die-off data to support the selection process is thus a key factor in determining the quality of the predictions.

The following sections (1) describe commonly used bacteria indicators, (2) designate the most reliable indicator of health risk in salt water, (3) define some of the specific terminology in bacterial studies and finally (4) review a range of die-off rates prior to (5) selecting a corresponding decay rate to be applied to the decaying constituent.

Following from the adopted approach for representing bacteria in the model, the term “die-off rate” traditionally used to estimate bacteria inactivation is substituted by the term “decay rate” when referring to the proxy constituent.

4.2 Indicators

The following summary, sourced from http://water.epa.gov/type/rsl/monitoring/vms511.cfm, lists commonly used bacteria indicators, makes recommendations for the selection of these in different receiving water environments and designates enterococci as the best indicator of health risk in salt water.

The most commonly tested faecal bacteria indicators are total coliforms, faecal coliforms, Escherichia coli or E. coli, faecal streptococci, and enterococci. All but E. coli are composed of a number of species of bacteria that share common characteristics such as shape, habitat, or behaviour; E. coli is a single species in the faecal coliform group.

***Total coliforms** are a group of bacteria that are widespread in nature. All members of the total coliform group can occur in human faeces, but some can also be present in animal manure, soil, and submerged wood and in other places outside the human body. Thus, the usefulness of total coliforms as an indicator of faecal contamination depends on the extent to which the bacteria species found are faecal and human in origin. For recreational waters, total coliforms are no longer recommended as an indicator. For drinking water, total coliforms are still the standard test because their presence indicates contamination of a water supply by an outside source.*

***Faecal coliforms**, a subset of total coliform bacteria, are more faecal-specific in origin. However, even this group contains a genus, Klebsiella, with species that are not necessarily faecal in origin. Klebsiella are commonly associated with textile and pulp and paper mill wastes. Therefore, if these sources discharge to your stream, you might wish to consider monitoring more faecal and human-specific bacteria. For recreational waters, this group was the primary bacteria indicator until relatively recently, when EPA began recommending E. coli and enterococci as better indicators of*

health risk from water contact. Faecal coliforms are still being used in many states as the indicator bacteria.

E. coli *is a species of faecal coliform bacteria that is specific to faecal material from humans and other warm-blooded animals. EPA recommends E. coli as the best indicator of health risk from water contact in recreational waters; some states have changed their water quality standards and are monitoring accordingly.*

Faecal streptococci *generally occur in the digestive systems of humans and other warm-blooded animals. In the past, faecal streptococci were monitored together with faecal coliforms and a ratio of faecal coliforms to streptococci was calculated. This ratio was used to determine whether the contamination was of human or nonhuman origin. However, this is no longer recommended as a reliable test.*

Enterococci *are a subgroup within the faecal streptococcus group. Enterococci are distinguished by their ability to survive in salt water, and in this respect they more closely mimic many pathogens than do the other indicators. Enterococci are typically more human-specific than the larger faecal streptococcus group.* ***EPA recommends enterococci as the best indicator of health risk in salt water used for recreation and as a useful indicator in fresh water as well.***

4.3 Decay Rates

Bacteria reduction rates are traditionally expressed as either log reduction or percent reduction. A quick guide to log reduction (source http://www.healthyfacilitiesinstitute.com) and its relationship with percent reduction is presented in Table 6. "Log" stands for logarithm, which is the exponent of 10. For example, 2 Log represents 10^2 or 100. Log reduction stands for a 10-fold (one decimal) or 90% reduction in numbers of live bacteria.

Another way to consider the reduction is as follows: 1 Log reduction would reduce the number of bacteria 90% (e.g. 100 bacteria would be reduced to 10). A 3 Log reduction on a coastal body with 1,000,000 bacteria would leave 1,000 bacteria which equates to a 99.9% reduction in potentially harmful organisms.

Table 6 Quick Guide to Log Reduction

Log Reduction Factor	Number of Bacteria Times Smaller	% Reduction of Original Population
1 Log reduction	10	90
2 Log reduction	100	99
3 Log reduction	1000	99.9
4 Log reduction	10000	99.99

Other ways of expressing decay rates would include the time it takes for bacterial concentration to decrease by 90% (for example).

4.4 Literature

Data relating to die-off of enterococci bacteria in coastal environments (and for the Delaware coast in particular) are not readily available to support the schematization of the process of inactivation of enterococci.

However, a literature review has been undertaken yielding several documents of relevance to the current study. These documents are listed below together with the key reasons for their selection. The key findings from each document are then summarised in the following sections.

Microorganisms Die-off Rates in Urban Stormwater Runoff (US EPA 2007)

- Content is stormwater specific
- Compares die-off rates for enterococci, *E. coli*, faecal coliforms, faecal streptococci
- Provides guidance to the range of discharge concentration for each organism in stormwater runoff

Brisbane River Pathogen Modelling Study (GHD 2011)

- previous in-house experience,
- review of data on faecal coliform bacteria,
- list of pathogen parameters for growth and decay set by a project specific Microbiology Review Panel,
- multiple references to and summaries from a review undertaken by The University of Western Australia's Centre for Water Research (CWR) who have previously completed a major study for the American Water and Wastewater association investigating the hydrodynamic distribution of pathogens in lakes and reservoirs.

Water Research 39 (2005)

- Enterococci die-off rates in estuarine and coastal waters, temperate climate.

Journal of Environmental Protection 5 (2014)

- Indication of a wide range of reported enterococci die-off rates.

4.4.1 Microorganisms Die-Off Rates in Urban Stormwater Runoff (US EPA, 2007)

The study confirms the importance temperature, sunlight, dissolved oxygen and salinity as key environmental factors affecting die-off rates in stormwater runoff. Other key findings from the study are:

Stormwater discharges can have significant negative impacts on receiving water bodies and create human health concerns. They release pathogenic bacteria, protozoans, and viruses as well as a number of potentially toxic, bio-accumulative contaminants. The reported concentration range in stormwater runoff for total coliforms is 42,000-190,000 CFU/100mL, concentrations of faecal coliforms and faecal streptococci vary in between 5,600 and 22,000 CFU/100mL and 350 - 3,200 CFU/100mL, respectively. Concentrations of enterococci are reported in the 1,000 - 6,600 CFU/100mL range and concentrations of *E. coli* in the 1,500 -8,500 CFU/100mL range.

In general, the survival of microorganisms is prolonged at low temperatures with organism persistence remaining higher at 10°C than similar samples at 20°C.

Much of the early work on bacterial removal assumed that temperature was the most important factor controlling the removal mechanism. Recent investigations consider bacterial removal as a more complex mechanism involving interactions between the physical, chemical and biological systems present in the wetlands and retention ponds although temperature clearly remains an important parameter.

Studies of inactivation in sunlight of faecal coliforms and enterococci from sewage and meat works effluent conclude that the die-off rate of faecal coliforms is 2 - 4 times that of enterococci and inactivation is generally slower at lower light intensities. However, experimental evidence also exists indicating that die-off rates of *E. coli* and enterococci from exposure to light could be similar.

In experiments, enterococci had a die-off rate due to temperature of 0.095 ± 0.038 (1/h) at 19.87°C whereas *E.coli* had a die-off rate of 0.085 ± 0.033 (1/h) and faecal coliforms of 0.01 ± 0.14 (1/h). These are equivalent to durations of 10.5, 12 and 100 hours or respectively 0.43, 0.49 and 4.2 days.

Conclusion

The die-off rate for enterococci has been found to be substantially higher than that referenced in the pathogen study (refer below), with shorter inactivation durations.

4.4.2 Brisbane River Pathogen Modelling Study (GHD, 2011)

The study, undertaken by GHD Pty Ltd in 2006 for Brisbane Water, investigated the discharges of non-disinfected effluent from two wastewater treatment plants (WWTP) into the lower reaches of the Brisbane River located in southeast Queensland, Australia. The study (1) designated enterococci as one of the key pathogen indicators to be used for monitoring compliance with water quality objectives and (2) mapped the predicted 95th percentile concentration and spatial distribution of enterococci according to the Australian National Health and Medical Research Council's guidelines.

Excerpts from the study with relevance to the estimation of faecal coliforms and enterococci die-off rates are presented below.

With respect to faecal coliforms:

A summary of many values from sources in the literature for faecal coliforms, yields the familiar power-law dependence in which the loss or die-off rate is represented as:

$$k_{dT} = k_{d20}\theta^{T-20} \quad (1)$$

where T is temperature, k_{d20} is the observed natural mortality or dark death rate at 20 °C(day^{-1}) and θ controls the sensitivity of k_{dT} (day^{-1}) to the temperature change. Across the literature there is a large amount of variation in the values assigned to these parameters which is not surprising considering the large range of environmental conditions covered by these studies.

Using the method of least-squares, the study found that the best fit of Equation (1) to the full set of data described in the report (section 2.2.1 Natural Mortality, Figure 1) was achieved for k_{d20} = 0.71 and θ = 1.07.

With respect to enterococci:

Data in the literature tend to suggest the enterococci are notably more robust than the coliform bacteria…. This data suggests that an appropriate value of k_{d20} in Equation (1) would fall between 0.4 and 0.7.

Conclusion - Summary of Die-off Estimates from this Source

Under the assumption that actual maximum water temperatures vary between 20°C and 22°C, the predicted range for the loss rate k_{dT} falls between 0.71 to 0.81 (1/day). This is equivalent to a period for bacteria inactivation of 1.23 and 1.4 days, respectively.

When setting k_{d20} to 0.4 and accounting for the resilience of enterococci relative to Coliform bacteria, the loss rate k_{dT} reaches 0.46 (1/day) or an equivalent 2.2 days for bacteria inactivation.

4.4.3 Water Research 39 (2005)

The paper reports the results of irradiated microcosm experiments using simulated sunlight to investigate the die-off of intestinal enterococci in relatively turbid estuarine and coastal waters collected from the Severn Estuary and Bristol, Channel, UK.

Die-off rates in the paper are estimated in terms of T_{90} defined as the time for bacterial concentration to decrease by 90%. T_{90} is equivalent to a Log reduction factor of 1 (refer section 4.3).

One of the key findings is that the received dose of irradiance from sunlight is the principal driver for enterococci survival. High-turbidity estuarine waters produced a T_{90} value of 39.5 hours. Low-turbidity coastal waters produced a much shorter T_{90} value of 6.6 hours. In experiments receiving no irradiation, high-turbidity estuarine waters also produced a longer T_{90} of 65.1 hours compared with corresponding low-turbidity coastal waters, T_{90} 24.8 hours.

4.4.4 Journal of Environmental Protection 5 (2014)

Culturable faecal coliform, epidemic, clinical, faecal and recreational beach enterococci strains possessing putative virulence genes were enumerated over the course of 5 weeks to comparatively assess their persistence in tropical marine and fresh waters. For the clinical and epidemic strains tested, it took 2.38 ± 0.45 days for a 1-log reduction (T90) in marine water. A higher T90 average of 2.51 ± 0.08 was observed for the commensal and environmental strains. Generally, lower T90 values of 2.14 ± 0.26 and 2.15 ± 0.16 days respectively were observed for hospital and community acquired enterococci strains in fresh water mesocosms subjected to tropical ambient temperature.

Beach water enterococci and enterococci recovered from faeces of humans survived for up to 20 days and 23 days respectively in fresh and marine waters.

4.4.5 Estimates using a Die-off Model

The die-off model used to assess enterococci die-off rates was originally developed for *E. coli* by Jensen (1999) and later adopted by Erichsen et al. (2006). As described by the Danish Hydraulic Institute (DHI) Mike 21 scientific documentation, the model results can be customised to estimate die-off rates for enterococci. DHI further note that enterococci die-off is slower than *E. coli* die-off, the existing documentation for determining enterococci die-off is still not fully matured and the corresponding estimates are uncertain.

Using the DHI die-off model, *E. coli* die-off rates during light (as opposed to dark) conditions are estimated as:

$$KL = S_m\,(b_T\,T + KL_0)/(a\,S_m - (a-1)\,S) \qquad (2)$$

where

T	actual water temperature (C°)
S	actual salinity (psu)
S_m	a reference salinity of 34.5 (psu)
a	1.54
b_T	0.133 E-03 (m^2/(W day °C))
KL_0	2.124 E-03 (m^2/(W day))

In the case of dark conditions, the die-off rate KM (1/day) is determined from:

$$KM = a_T\ T - KM_0$$

where

T actual water temperature (C°)

a_T 0.002425 (1/ (day °C))

KM_0 0.00826 (1/day)

From (2) and using actual water temperature of 24 C°, salinity of 34.5 (psu) and an estimate of the average light available in the entire water column of the order of I_{avg} = 200 (W/m^2), a die-off rate of 1.07 (1/day) is obtained for light conditions. Applying a factor of 0.5 (value suggested in DHI documentation) to convert the estimated die-off rate from *E. coli* to enterococci yields an approximate enterococci die-off rate of 0.5 (1/day) or the equivalent of 2 days of inactivation period for enterococci in coastal waters.

The amount of light available to the water column has an important role in the assessment. For example, halving I_{avg} = 100 (W/m^2) has the potential to increase the inactivation period to approximately 4 days.

4.5 Adopted Enterococci Die-Off Rates for Modelling Purposes

It can be difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens including enterococci. In addition, the range of reported (in the literature) die-off rates for enterococci in coastal waters is significant (2-20 day range).

Accordingly, based on the review of existing scientific literature and estimates from a die-off model, the die-off rate of enterococci in coastal waters has been adopted as 0.5/day or the equivalent of 2 days of inactivation period.

The selection of inactivation period is justified as follows:

- A 2-day inactivation period is considered to represent a plausible value judging from the reviewed sources. In the absence of site-specific enterococci die-off rates, the current selection has been supported using a mix of in-house experience from a previous study (mouth of the Brisbane River, QLD, Australia) and estimates from a die-off model developed by the Danish EPA for early warning systems in bathing water quality studies.
- Keeping the selected value (for the inactivation period) constant across all modelling scenarios allows the plume footprints generated from a number of stormwater discharge configurations (combining existing and proposed (extended offshore) outfalls) to be compared efficiently. Emphasis is thus on the relative impacts on beach health associated with each stormwater discharge configuration and ultimately optimisation of the existing structures at minimal cost.
- Within the current context,
    - using a literature based die-off rate value has little consequence on the selection of an optimal discharge configuration, however
    - a die-off rate value determined for local conditions will be most relevant for the assessment of beach closure times once an optimal discharge configuration has been selected.

It has been already noted that the model in its current implementation does not directly account for the effects of salinity, temperature and solar radiation. However, the adopted inactivation period (respectively decay rate of the non-conservative substance used as a proxy to model bacteria) has been determined with these effects taken into consideration. The resulting engineering predictions of plume dispersion and decay presented in the current document can thus be considered to adequately represent the conditions in the field.

5. Modelling Scenarios

5.1 Introduction

Analysis has been carried out for the conditions and scenarios described in Section 1.3 and Section 5.3 respectively. This has been based on the use of data available at the start of the project with reasonable assumptions applying to key parameters in the analysis. Conservative assumptions were not applied to all parameters, as this would compound the level of conservatism (i.e. the likelihood of all parameters being at their "worst" at the same time is extremely low).

5.2 Reconnaissance Simulation Scenarios

A number of preliminary simulation scenarios were completed as part of a broader reconnaissance survey aimed at enhancing the understanding of local receiving water conditions and plume behaviour while providing insight into the potential for optimisation of the outfall configuration. A representative selection of these scenarios is presented in Table 7.

The first six scenarios were characterised by a uniform shift of all five outfalls some distance offshore (e.g. 0, 100, 200 or 300 m) from the existing outfall locations, a constant flow discharge of 5 m^3/s, constant concentration and 7-day discharge duration.

Scenarios 7, 8 and 9 explored a more individualised outfall configuration. For example, in the case of scenario 8, the Grenoble Place outfall was extended 300 m offshore in isolation, with all other outfalls remaining at their existing locations.

Similarly for scenario 9, the Rehoboth Avenue outfall was extended 300 m offshore while all other outfalls were modelled at their existing locations.

In scenarios 7, 8 and 9, flow rates for each of the five individual outfalls were customised and determined on the basis of an approximate estimate of the catchment areas associated with each outfall. Assuming a total flow rate of 100 %, the adopted proportions of flow rate for each outfall were approximated as: G (50% of total flow rate), M (15%), R (15%), D (15%) and L (5%).

Actual hydrographs were subsequently derived using hydrologic software (GHD, 2015).

Table 7 Summary of Preliminary (Reconnaissance) Simulation Scenarios

#	Scenario ID	Distance from existing Location	Die-off (decay) rate (1/d)	Comments
1	1640	250-300 m	No die-off	01 January 2010
2	1650	250-300 m	0.5	01 June 2010
3	1652	0 m or existing location	0.5	01 June 2010, refined mesh size
4	1654	100 m	0.5	01 June 2010, refined mesh size
5	1656	200 m	0.5	01 June 2010, refined mesh size
6	1658	300 m	0.5	01 June 2010, refined mesh size

#	Scenario ID	Distance from existing Location	Die-off (decay) rate (1/d)	Comments
7	pd_ex	0 m or existing location	0.5	
8	pd_10	300 m	0.5	Grenoble outfall extended 300 m offshore, all others at existing locations
9	pd_20	300 m	0.5	Rehoboth outfall extended 300 m offshore, all others at existing locations

For all simulation scenarios under this section, all five outfalls were simultaneously operated adopting: (i) a numerical time step of 15 seconds, (ii) zero background concentration, (iii) a seven day discharge, and (iv) a constant concentration in the outfall pipe of 1 kg/m^3.

5.3 Operational Simulation Scenarios

Using the insight gained from the preliminary analysis, operational simulation scenarios were conceived in which each outfall was represented with a distinct discharge and corresponding concentration. Scenario characteristics have been summarised in Table 8. Scenario 1 considers all five outfalls at their existing locations. Scenario 2 introduces an option with only one outfall extended offshore (in this case, the outfall at Rehoboth Avenue), while Scenario 3 involves the aggregation of outfalls M, R, D and L as a new aggregated R1 outfall, coupled with extension of outfall G.

As noted in Section 2.3, discharges were determined on the basis of the size of drainage areas associated with each outfall. Concentrations were estimated on the basis of consideration (adoption) of specific water pollution controls (denoted as BMP "best management practice") for each drainage area and an assumed percent removal associated with each type of BMP.

Expected concentrations (refer Table 3) were coupled with modified hydrographs, calculated using SWMM software. The receiving water (ocean) was assumed to have zero background concentration of enterococci.

Table 8 Summary of Operational Simulation Scenarios

#	Scenario ID	Arrangement of outfalls
A1	PER_ex	Existing location (5 outfalls at existing locations)
A2	PER_20	Five outfalls: R outfall extended 300 m offshore. All others at existing locations.
A3	PER_30	Two outfalls at a distance offshore of 300m. Outfalls G and R1, with R1 representing the aggregation of outfalls M, R, D and L.

Notes:

Die off (decay) rate of 0.5 (1/d) for all scenarios.

Peak flows as summarised in Table 3.

5.4 Key Assumptions

Further to the assumption of zero background concentration, several other assumptions have been made. These are described in the following sections.

5.4.1 Non-conservative Constituent

A non-conservative (decaying) substance has been used as a proxy for bacteria representation

In the absence of a site-representative effective bacteria die-off rate or range of such, a decay rate accounting for the effects of salinity, temperature and light intensity has been applied to the non-conservative constituent to simulate bacteria die-off processes in the field.

5.4.2 Stormwater Flow Rates

Flow rates allocated to each outfall have been adopted as defined in Table 3.

5.4.3 Indicator Bacteria

The following assumptions have been made in relation to indicator bacteria:

- Bacteria are subject to first-order die-off (alternatively decay)
- There is a constant die-off rate (e.g. no daily variation)
- Adoption of constant average light intensity (e.g. no variation in cloud cover) for duration of stormwater discharge and ensuing plume tracking period
- A 2-day bacteria inactivation period or the equivalent of 0.5/day bacteria die-off rate has been applied to all scenarios associated with the optimisation of the proposed outfall configurations.

5.4.4 Simulation Period

The simulation period (early June) has been selected as representative of the receiving water conditions encountered during the summer period when the beaches are most frequented.

5.4.5 Modelling Scenarios

Modelling scenarios were operated using a constant die-off rate (refer section 5.4.3) with the aim of achieving an optimised configuration of the proposed outfalls (i.e. a configuration that achieves the lowest concentration and/or the shortest duration relative to alternative/existing configurations). Any potential inaccuracy in evaluating the most appropriate bacteria die-off rate value (converted into the decay rate of a decaying substance for modelling purposes) has little consequence on the selection of an optimal outfall configuration.

By retaining the selected die-off rate value as a constant across all modelling scenarios, it is possible for plume footprints generated from the various outfall configurations (combining existing and proposed (extended offshore) outfalls) to be compared efficiently.

Emphasis of the analysis is thus on the relative impacts on beach health associated with each stormwater/outfall discharge configuration, supporting optimisation of a preferred solution.

5.5 Simulation Duration and Period

All operational scenarios were simulated for a sufficiently long period to allow concentration of bacteria in the receiving waters to decrease owing to bacteria die-off and dilution below a threshold value of 35 cfu/100mL.

As a result, operational simulation scenarios were terminated after 12 days. Included in this 12-day simulation period was a five-day model warm-up period during which the outfall flow rate was zero.

All scenarios commenced at midnight on June 1st. Outfalls commence discharging stormwater six days later at midnight of June 6th.

6. Results

6.1 Introduction

This chapter provides a summary of modelled results in graphical form, along with a brief summary of findings and observations.

The full set of mapped results are presented in Appendix A.

6.2 Definitions

Spatial plume maps have been presented as 95th percentiles. The 95th percentile is the value below which 95% of all predicted values (of enterococci concentration in the current context) occur. Use of the 95th percentile of concentration is considered to provide an estimate of the upper bound (or worse case) of risk.

6.3 Presentation of Results

The results from the analysis are presented as:

- Time histories of enterococci concentration
- Percentile maps of enterococci concentration generated using instantaneous snapshots of plume concentration results extracted at 15 minute intervals for a period of six hours. These have been presented for the first six hour period of each day.

Result maps should be considered from a relative, rather that absolute perspective. It must be recognised that the actual values of concentration plotted are not exact. However, consideration of the relative concentrations (e.g. when comparing the difference between the existing and PER30 scenarios) yields a more accurate assessment of the benefit of the various outfall configurations that have been investigated).

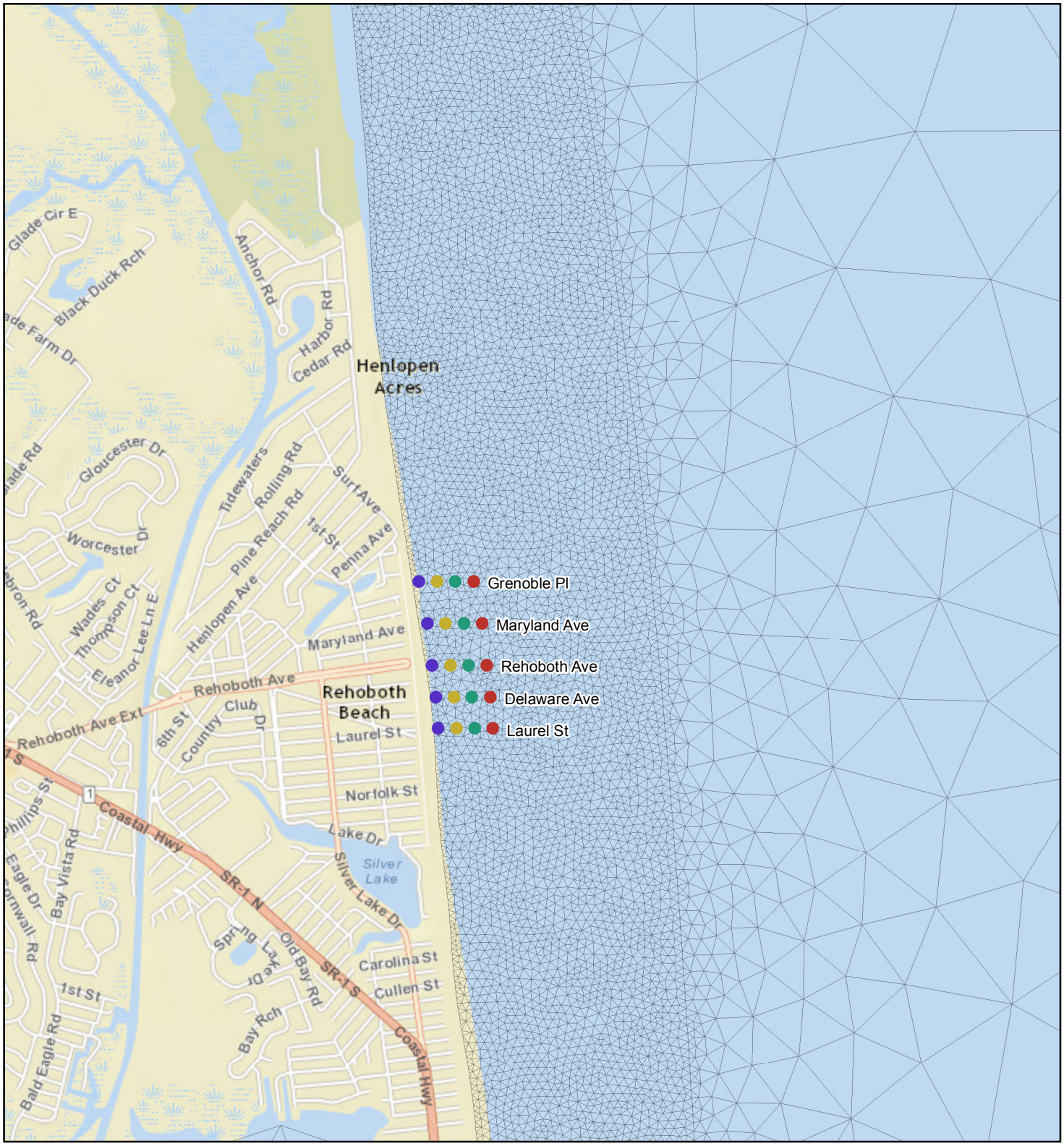
Note that in the assessment of percentiles of concentration, the choice of the assessment window can play an important role in determining the quality of the overall results. The main role of the window is to eliminate the effects of the initial conditions and warm-up stages of the modeling exercise from consideration, thus setting the focus of the analysis on developed conditions alone. In the current analysis, the assessment window has been set to coincide with the duration of discharge for the four outfalls discharging directly into the ocean (six hours).

The 95th percentile of enterococci concentration has been used to generate the maps for each scenario.

6.4 Time Histories

6.4.1 Locations of results

Time histories of enterococci concentration have been predicted for each operational modelling scenario at twenty numerical monitoring stations distributed uniformly at 100 m (328 ft) interval along five cross-shore profiles starting from each existing outfall location. Each profile has thus been associated with four numerical monitoring stations. The locations of the monitoring stations are plotted in Figure 4 with the coordinates of the stations listed in Table 9.



LEGEND

Numerical Modelling Station

- Existing
- 100m Offshore
- 200m Offshore
- 300m Offshore

Model Elements

Paper Size ANSI A

0 1,500 3,000
Feet

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

City of Rehoboth Beach
Stormwater PER

Job Number 86-18689
Revision A
Date Nov 09, 2015

Numerical monitoring stations for the recording of results for enterococci concentration along the Rehoboth Beach coast

Figure 4

G:\41\28960\GIS\Maps\Deliverables\Plumes

16701 Melford Blvd Ste 330 Bowie MD 20715 USA T 240 206 6810 F 240 206 6811 E bowmail@ghd.com W www.ghd.com

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By way of example, there are four pairs of coordinates in row G of Table 9 corresponding to the four numerical monitoring stations allocated offshore from the Grenoble Place outfall. The coordinates of the existing outfalls are placed in columns 2 and 3, the coordinates of the first set of numerical monitoring stations positioned 100 m offshore from the existing outfalls are found in columns 4 and 5 and so on.

Table 9 Coordinates of Numerical Monitoring Stations (m)

(1) Profile ID	(2) Existing Northing	(3) Existing Easting	(4) 100m Northing	(5) 100m Easting	(6) 200m Northing	(7) 200m Easting	(8) 300m Northing	(9) 300m Easting
G	80,055	229,656	80,055	229,756	80,055	229,856	80,055	229,956
M	79,825	229,703	79,825	229,803	79,825	229,903	79,825	230,003
R	79,595	229,729	79,595	229,829	79,595	229,929	79,595	230,029
D	79,419	229,748	79,419	229,848	79,419	229,948	79,419	230,048
L	79,246	229,762	79,246	229,862	79,246	229,962	79,246	230,062

Time histories of enterococci concentration (cfu/100mL) have been plotted in Figure 5 to Figure 7 for each of the three operational modelling scenarios (defined in Table 8).

Each figure consists of five panels, one panel per profile passing through outfall starting from top panel (outfall at Grenoble Place) to bottom panel (outfall at Laurel Avenue)

Each panel in the figures shows four lines – one line per monitoring station.

The black line corresponds to a station allocated at the existing location of the outfall. The blue line corresponds to a station 100 m offshore, the red line corresponds to station 200 m offshore and the green line corresponds to a station 300 m offshore.

6.4.2 Observations

The following observations and comments apply to the presented time histories. The emphasis of the following discussion is on the relative benefit (reduction) offered by extending one or more outfalls offshore. Spatial concentration maps are presented in Appendix A.

General Observations

- The discharge period is clearly identified by a section of elevated concentration within the first 6 hours. This is evident in each of Figure 5, Figure 6 and Figure 7.
- Under the adopted simulation conditions (a time varying combination of the effects of freshwater from the Delaware Estuary, tide, wind and waves) concentration peaks appear relatively independent of discharge duration.
- All simulations have been based on a stormwater release commencing at midnight. If a different time of release (say 9 hours later) were to be simulated, the timing and patterns of concentrations will vary in comparison to those presented here. This is due to the complex, time-dependent interaction of the applied driving forces (freshwater from the Delaware Estuary, tide, wind and waves). Peak values however would largely be expected to remain the same magnitude.

- Periods of zero values such as those predicted shortly after the release of stormwater indicate that the plume has moved along the coast away from the source and should not be interpreted as constituting the end of bacterial pollution at this point in time.
- Subsequent concentration peaks, like those shown 12 hours after discharge, are due to tidal oscillations bringing the plume back towards the monitoring stations.

When reviewing Figure 5 to Figure 7, it should be noted that results are plotted at four numerical monitoring stations for each of the five profiles (G, M, R, D and L). These numerical monitoring stations are located at 100m intervals commencing at the existing outfall location.

Existing Conditions (Figure 5)

- Under existing conditions, the peak concentration at the shore occurs in the vicinity of the Maryland Ave outfall, with a value of 2,700 cfu/100mL.
- Values at the other outfalls are closer to 1,600 to 1,700 cfu/100mL at Grenoble Place and Delaware Avenue, falling away to 200 cfu/100mL at Laurel Avenue.
- Concentrations drop significantly with distance offshore. A location 100m offshore from Grenoble Place sees a concentration of 430 cfu/100mL (only 25% of that at the shoreline), whilst that at Maryland Avenue reduces by a slightly larger percentage to 620 cfu/100mL.
- At 200m offshore, concentrations have reduced to no more than 100 cfu/100mL.

PER_20 Scenario (Figure 6)

- Under the PER_20 scenario, significant improvements (around 50% reduction in concentration) are evident at the shoreline for the three northern outfall locations (Grenoble, Maryland, Rehoboth), whilst those for Delaware Avenue and Laurel Avenue are relatively unchanged.
- 100m offshore, values reduce by a smaller percentage than under the existing outfall configuration, with concentrations in the range of 200 to 300 cfu/100mL at Grenoble, Maryland, and Rehoboth.
- At 200m offshore, the concentrations are generally less again.
- However, at 300m offshore, some increases (compared to 200m offshore) are evident. In particular, a concentration of 160 is evident offshore of Maryland Avenue, and 260 cfu/100mL offshore of Rehoboth Avenue. Values remain lower than those at the shoreline.

PER_30 Scenario (Figure 7)

- Concentration peaks are substantially reduced owing to dilution when the release occurs in deeper waters
- At the shoreline, peak concentrations reduce uniformly to less than 100 cfu/100mL. This represents a reduction in concentration of over 95% for all locations other than Laurel Avenue.
- At a distance of 100m offshore, values remain below 100 cfu/100mL for all sites, reinforcing the benefit of this option within the recreational area.
- A similar observation can be made 200m offshore, with only the point offshore of Grenoble Place exceeding 100 cfu/100mL.

- At 300m (i.e. closer to the source for the PER_30 scenario), concentrations peak around 400 cfu/100mL for Grenoble Place, 500 cfu/100mL for Maryland Avenue, and 700 cfu/100mL for Rehoboth Avenue.
- However, each of these concentrations remains a substantial improvement at the shoreline over those associated with the existing scenario (outfall at existing locations).

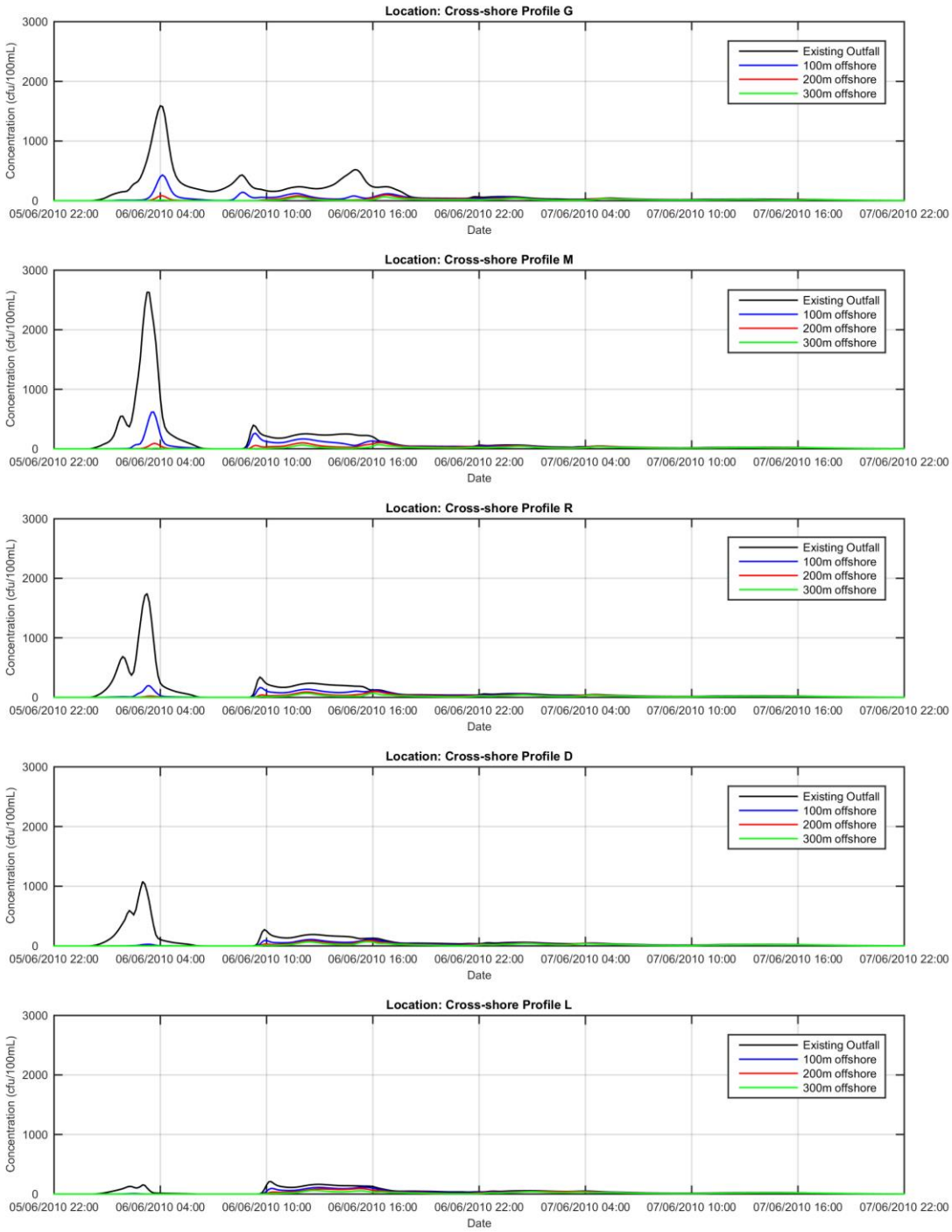

Figure 5 Time Histories of Enterococci Concentration (cfu/100mL) for existing outfall locations

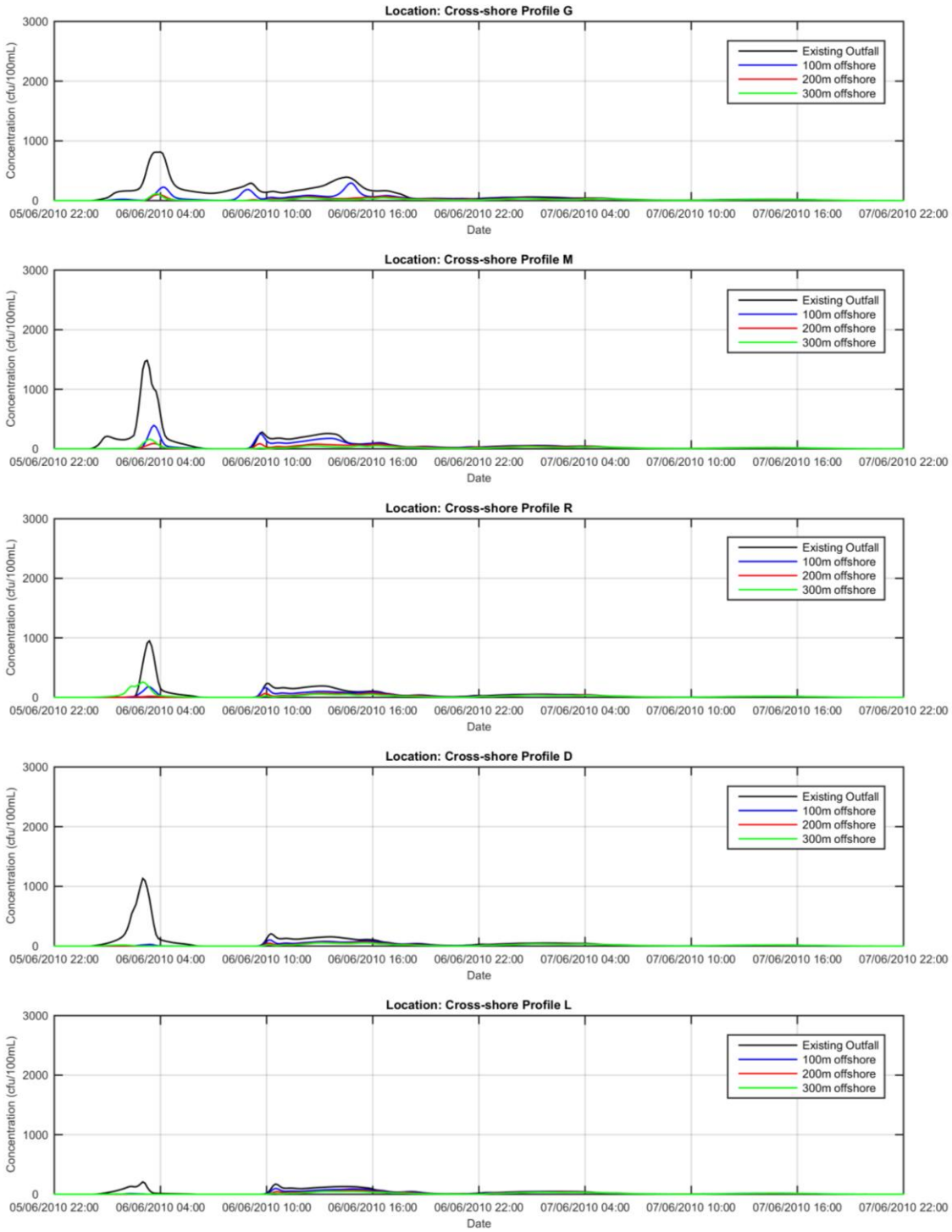

Figure 6 Time Histories of Enterococci Concentration (cfu/100mL) for Scenario PER20 (R outfall extended 300 m offshore)

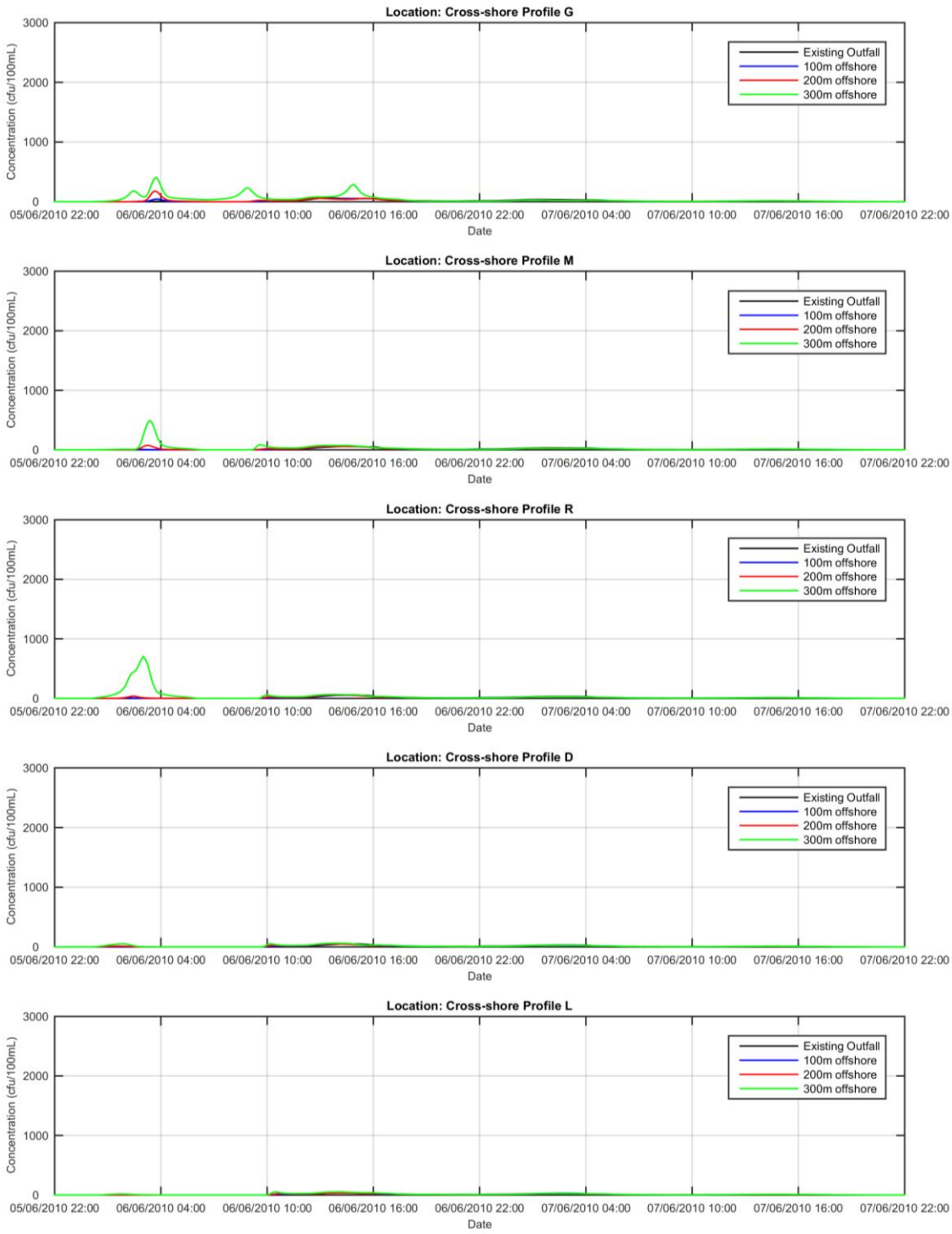

Figure 7 Time Histories of Enterococci Concentration (cfu/100mL) for Scenario PER30 (Outfalls G and R1 extended 300 m offshore)

6.5 Maps

Maps of enterococci concentration (95th percentile) have been generated for a series of 6-hour periods. Maps are produced for the first 6 hours of each of five successive days. This allows a rapid assessment of how quickly stormwater concentrations may decrease for each of the three scenarios:

- PER Ex All outfalls at existing locations
- PER 20 R outfall extended 300 m offshore with remaining 4 outfalls at existing locations
- PER 30 Outfalls G and R1 extended a distance of 300 m off-shore, where R1 comprises an aggregation of outfalls M, R, D and L.

Fifteen maps are presented in Appendix A as follows:

Table 10 List of Maps

Figure Numbers	Maps
Figures A1 to 5	Existing (5 maps)
Figures A6 to 10	PER 20 (5 maps)
Figures A11 to 15	PER 30 (5 maps)

6.6 Discussion

6.6.1 Review of Spatial Maps

Examination of the maps presented in Appendix A allows the following observations to be made:

For the existing outfall configuration, reference to Figure A1 indicates relatively high concentrations occurring in the first 6 hour period centred on the Maryland Avenue and Rehoboth Avenue outfalls. In terms of concentration, the centre of the plume is close to the coastline – that is, in close proximity to recreational areas.

Figure A6 (PER 20 scenario) demonstrates a similar northwards extent for the plume, but with a slight reduction in maximum concentrations. The width of the plume has increased, in keeping with the extended outfall for Rehoboth Avenue. Overall however, the plume remains in close proximity to the coastline, and hence to recreational areas.

Figure A11 represents the PER 30 Scenario, which involves aggregating four of the existing outfalls (i.e. R1=M+R+D+L) into a single outlet and extending both this and the Grenoble Place outfall 300 m offshore. The figure indicates a substantial reduction in predicted peak concentrations at the beach (relative to the predictions corresponding to the existing outfall configuration) to occur within the first day after the discharge.

Of particular note is the relocation of the centre point of the plume offshore, with low concentrations (0 to 35 range) now evident at each of the four bacterial data collection points. It should be noted that the plume footprint will continue to move with tide, and hence there will be short periods where the 35 cfu/100 mL threshold is exceeded at one or more of these points.

The following additional observations are noted:

- Twenty four hours after the end of the discharge (refer Figure A2, A7, A12), the plume has significantly dispersed. This is most pronounced for the PER 30 scenario, with only a small band in the 35 to 60 cfu/100 mL evident.
- Clearly, releases from the extended and aggregated outfalls have experienced intense mixing.
- Comparing the predictions associated with scenarios PER_ex and PER_20 suggests that the extension of the Rehoboth Avenue outfall alone would appear to offer only a minor benefit.
- Beyond Day 2, the benefits of the aggregated and extended offshore releases are no longer evident, with all scenarios indicating concentrations below the 35 cfu/100 mL threshold.

6.6.2 Comparison to Design Intent

The design intent was to reduce high concentrations close to recreational areas by discharging further out to sea. By definition, this also means that the plume can spread further, as dispersion is not constrained by the shoreline. Key observations are as follows:

- PER-30 tends to generate a slightly larger footprint than for existing conditions, but consequently offers a reduced extent of high concentrations across the entire domain, and in particular, close to recreational areas.
- This is consistent with expectations, and is a function of the proximity of the outfalls to the coastline. That is, the plume can spread further (in all directions) if discharged offshore, whereas when discharged nearshore (existing outfall locations), the plume cannot expand beyond the coastline.
- When conservation of mass is considered, no pollutants should be “lost” through the process of discharging offshore. Rather, changes are attributable to better dilution (in accordance with the design intent).
- More importantly, the concentrations of enterococci are lower in the vicinity of recreational areas.

6.7 Advice on Interpretation

Results are consistent with the coastal bathymetry data sourced from the C-Map database but could change should the near-shore bathymetry data be found to be significantly different from the one modelled owing to survey accuracy, or as a result of storm events.

6.8 Conclusion

On the basis of the limited number of investigated scenarios detailed in this report, the results indicate that purely from a water quality perspective, the optimal outfall configuration is Scenario PER_30. This involves the aggregation of four outfalls into a single outlet extended some distance offshore, e.g. 300 m eastward from the existing location of the Rehoboth Avenue outfall, potentially coupled with the extension of Outfall G.

However, this benefit is experienced for a relatively short period of time (less than 48 hours), and takes no consideration of the cost to achieve the solution, nor the relative cost/benefit of implementing other measures (for example, source based controls).

7. References

Ahmad et al (2014). Ahmad, A., Dada, A.C., Usup G., Survival of Epidemic, Clinical, Faecal and Recreational Beach Enterococci Strains with Putative Virulence Genes in Marine and Fresh Waters, Journal of Environmental Protection, 2014, 5, 482-492.

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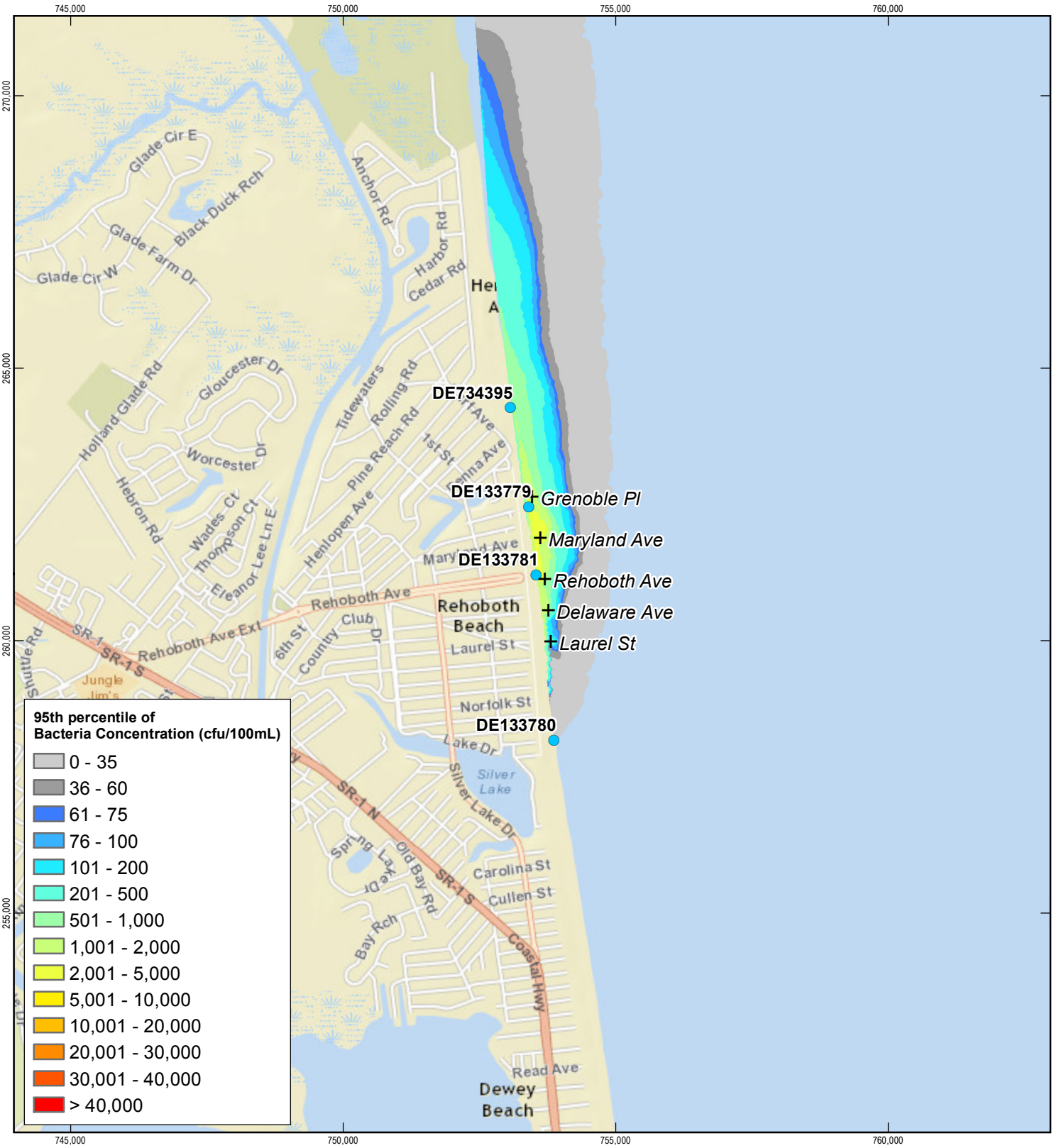
USEPA (2007). Selvakumar, A., Borst, M., Struck, S., Microorganisms Die-Off rates in Urban Stormwater Runoff.

Appendices

Appendix A – Maps of 95th Percentile Enterococci Concentration



LEGEND

+ Existing Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 06 June 00:00 to 06 June 06:00 AM
Existing outfall configuration
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

City of Rehoboth Beach
Stormwater PER

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Figure A1

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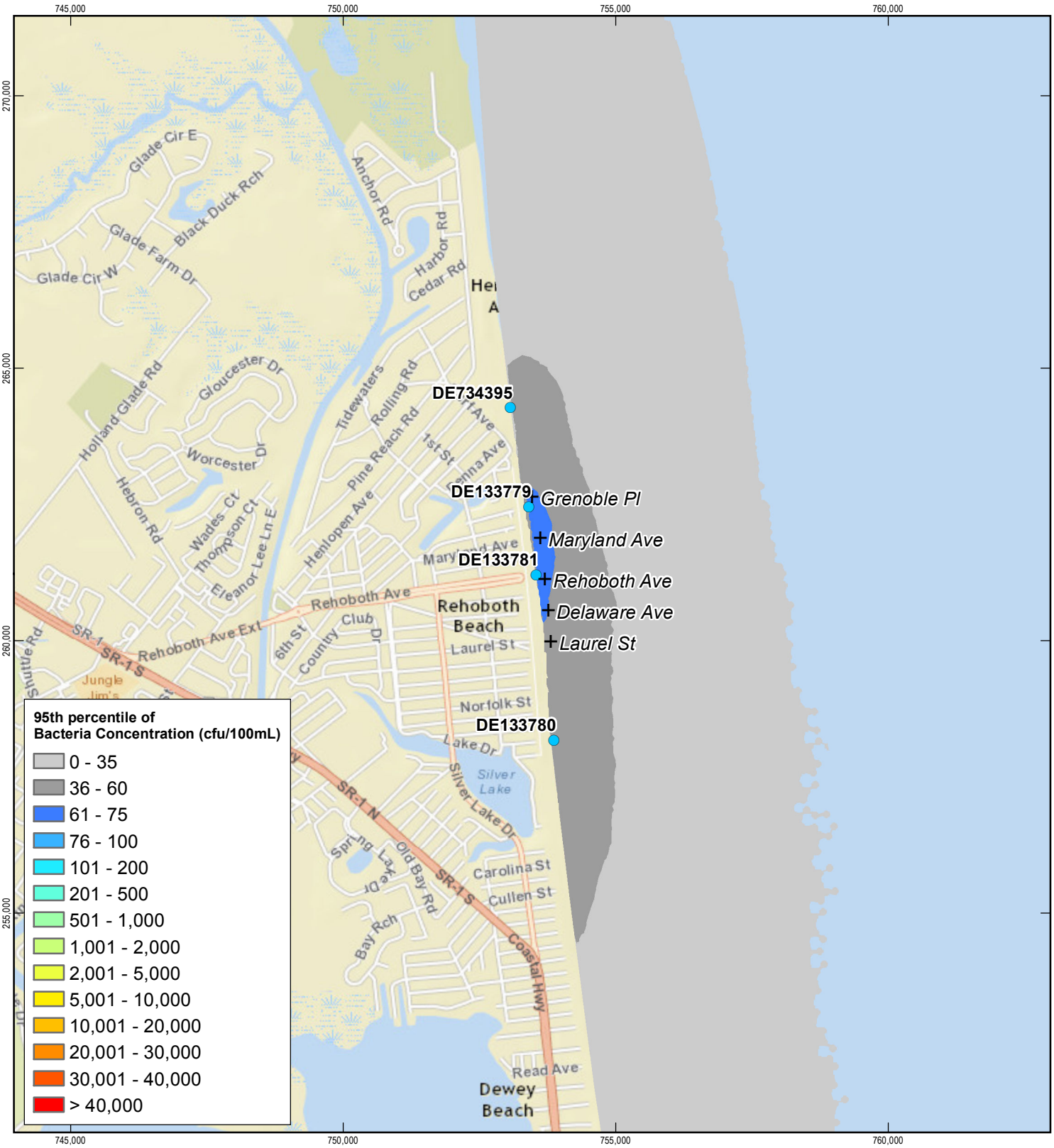

LEGEND

+ Existing Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 07 June 00:00 to 07 June 06:00 AM
Existing outfall configuration
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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City of Rehoboth Beach
Stormwater PER

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Revision	A
Date	Dec 23, 2015

Figure A2

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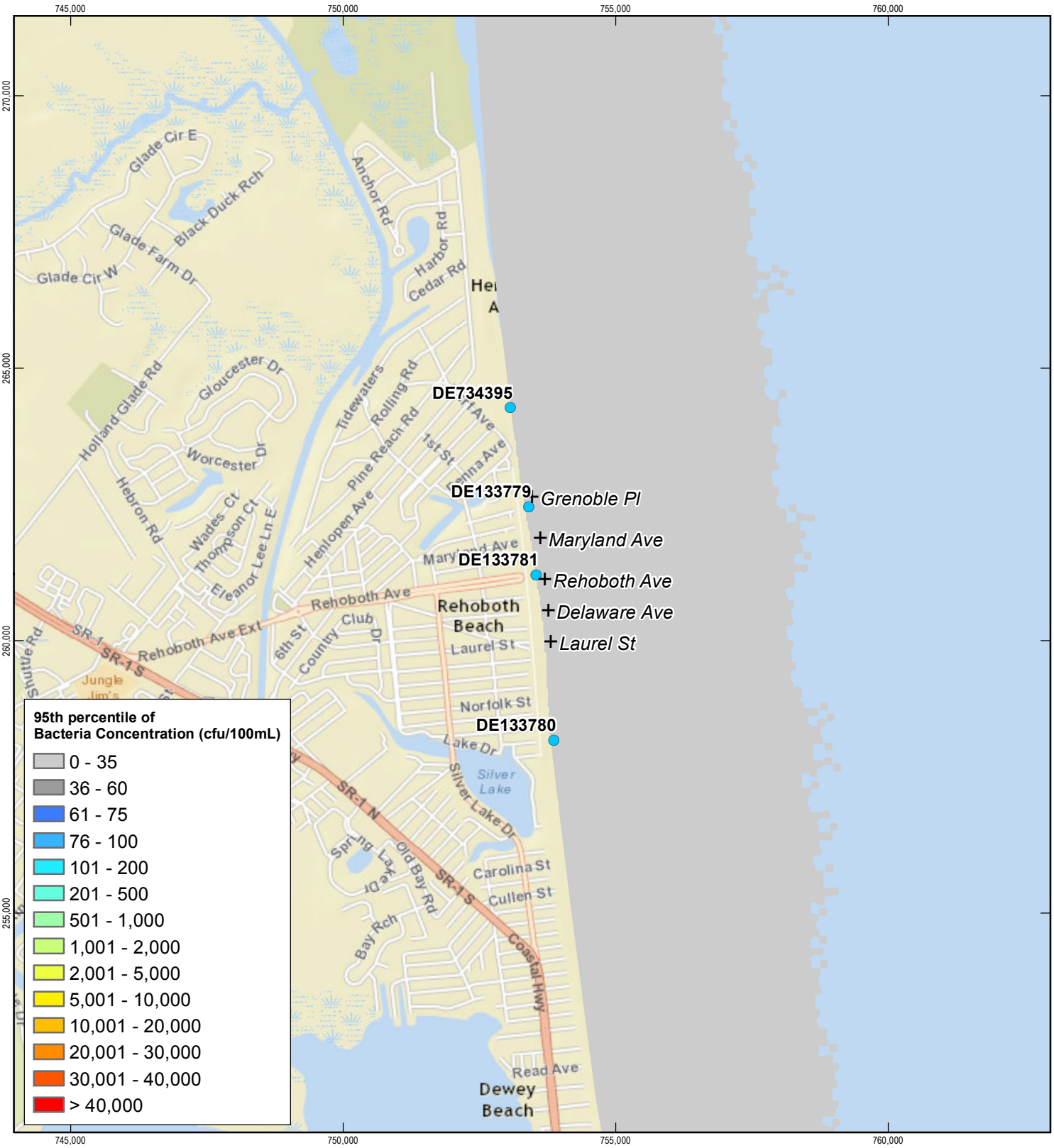

LEGEND

+ Existing Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 08 June 00:00 to 08 June 06:00 AM
Existing outfall configuration
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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City of Rehoboth Beach
Stormwater PER

Job Number	86-18689
Revision	A
Date	Dec 23, 2015

Figure A3

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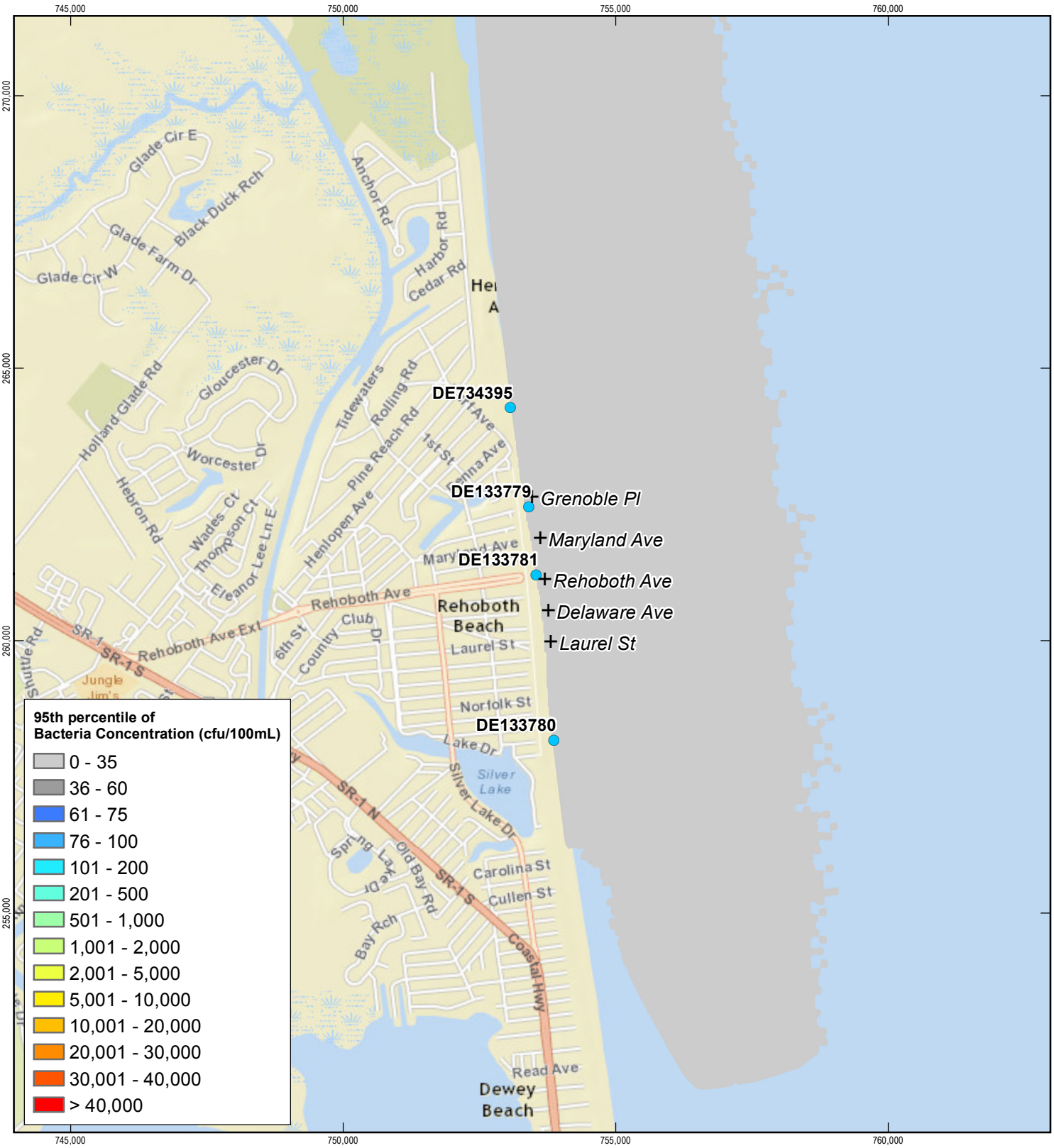

LEGEND

+ Existing Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 09 June 00:00 to 09 June 06:00 AM
Existing outfall configuration
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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City of Rehoboth Beach
Stormwater PER

Job Number	86-18689
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Figure A4

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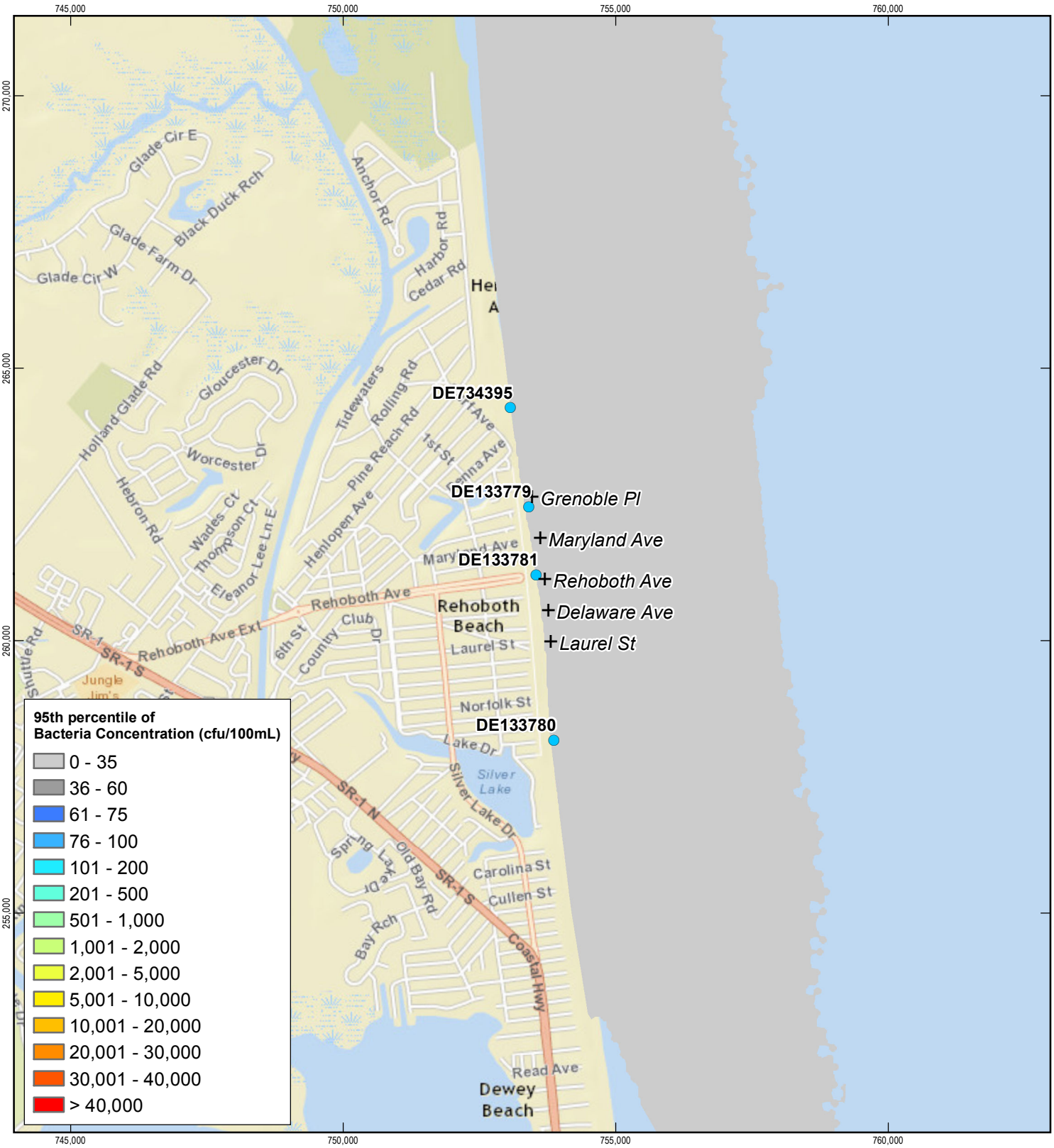

LEGEND

+ Existing Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 10 June 00:00 to 10 June 06:00 AM
Existing outfall configuration
Baseline Condition

Paper Size ANSI A
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Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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City of Rehoboth Beach
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Figure A5

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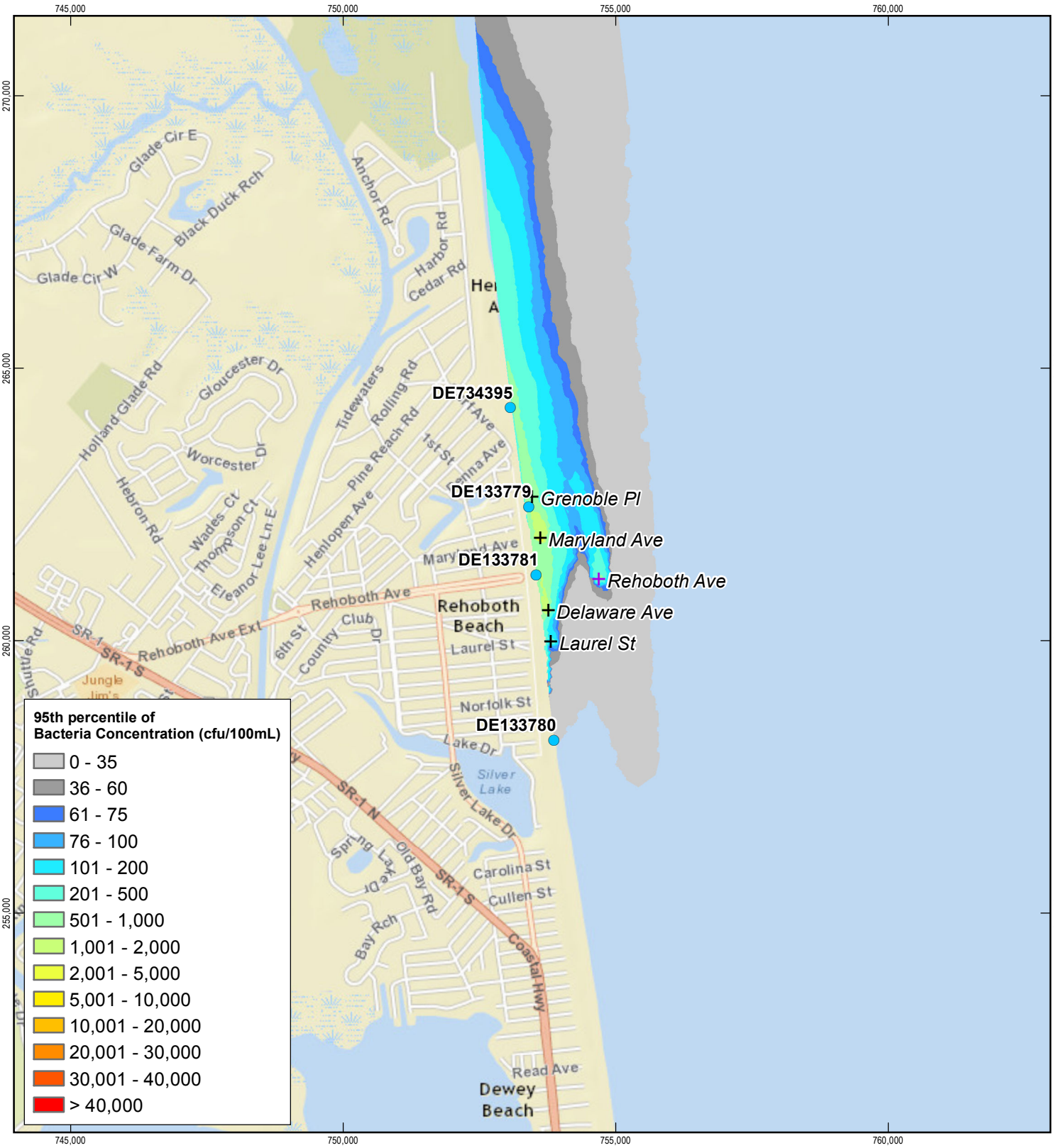

LEGEND

- Existing Outfall
- Proposed Outfall
- Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 06 June 00:00 to 06 June 06:00 AM
PER 20 - R Outfall Shifted 300m offshore
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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City of Rehoboth Beach
Stormwater PER

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Figure A6

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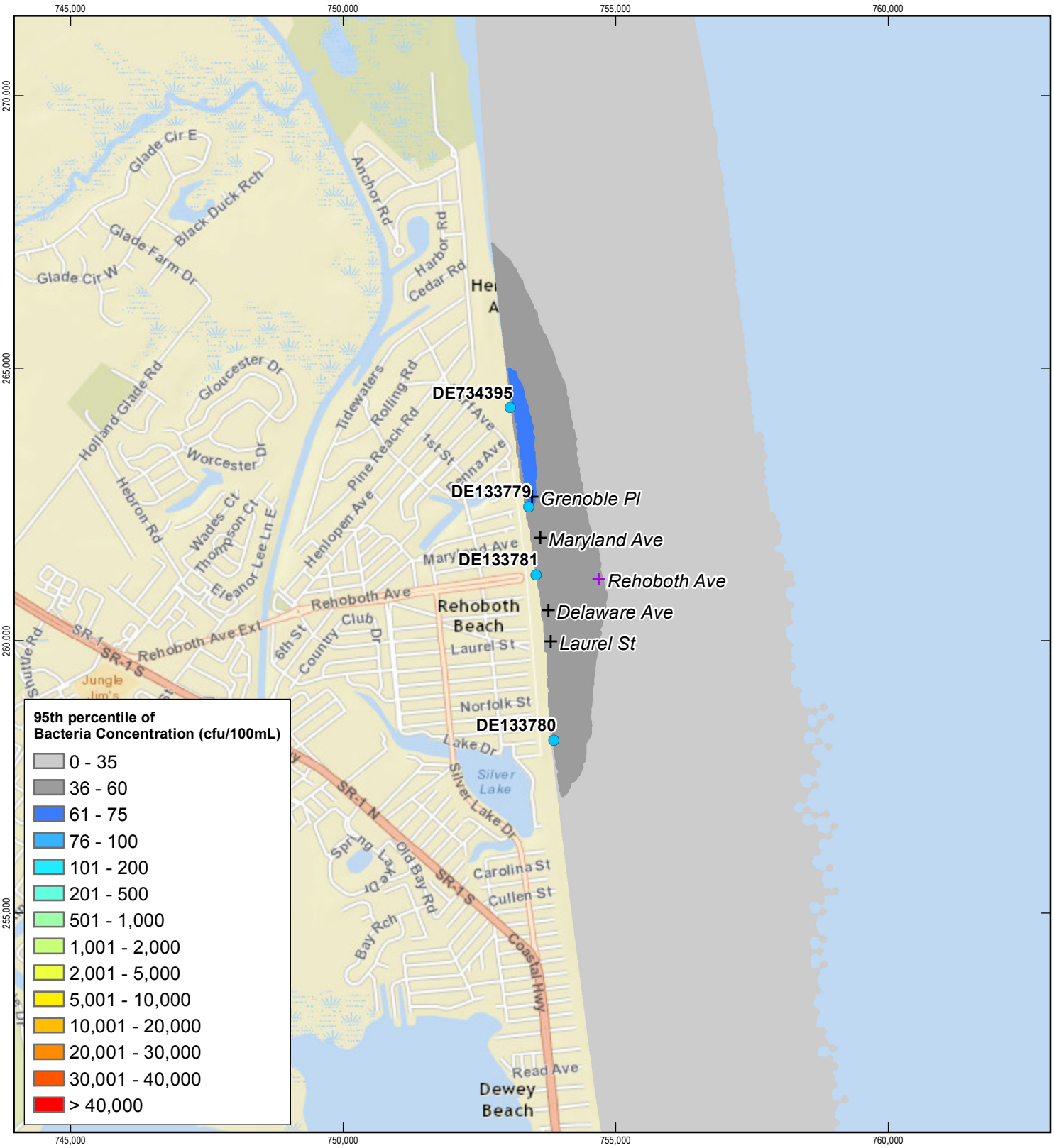

LEGEND

- Existing Outfall
- Proposed Outfall
- Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 07 June 00:00 to 07 June 06:00 AM
PER 20 - R Outfall Shifted 300m offshore
Baseline Condition

Paper Size ANSI A
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Feet
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Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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Stormwater PER

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Figure A7

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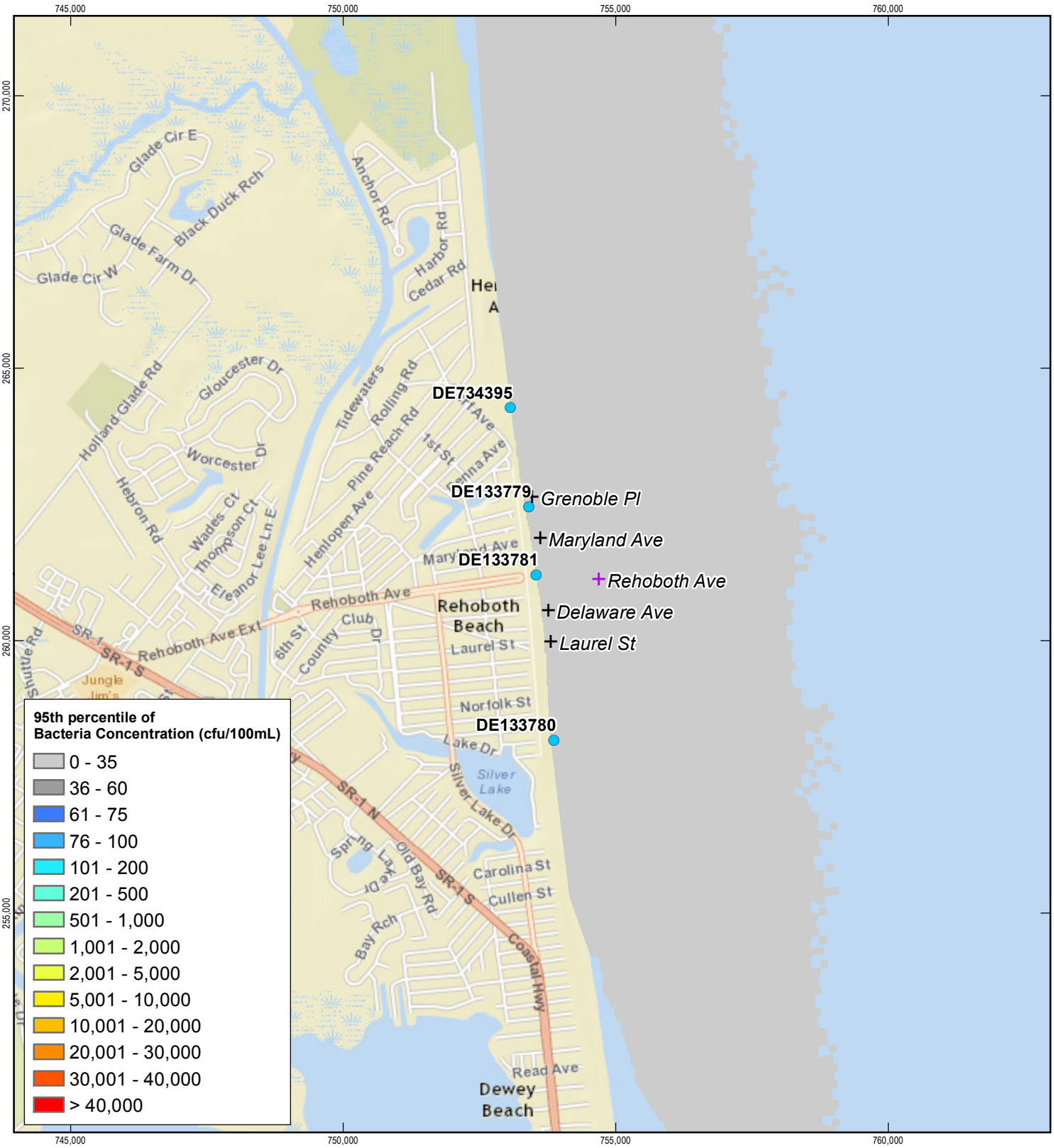

LEGEND

- Existing Outfall
- Proposed Outfall
- Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 08 June 00:00 to 08 June 06:00 AM
PER 20 - R Outfall Shifted 300m offshore
Baseline Condition

Paper Size ANSI A
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Feet
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City of Rehoboth Beach
Stormwater PER

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Figure A8

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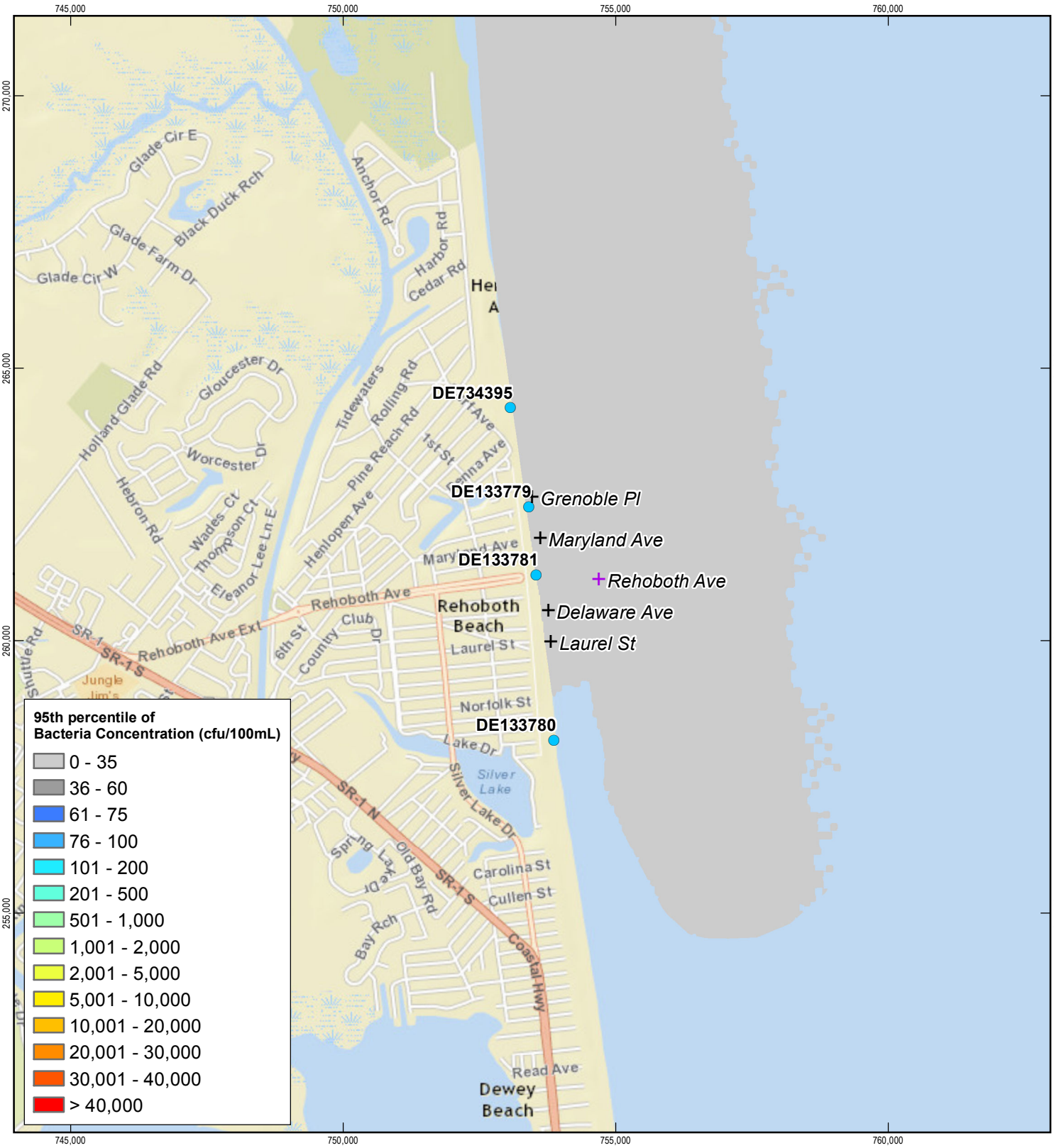

LEGEND

- Existing Outfall
- Proposed Outfall
- Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 09 June 00:00 to 09 June 06:00 AM
PER 20 - R Outfall Shifted 300m offshore
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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Stormwater PER

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Figure A9

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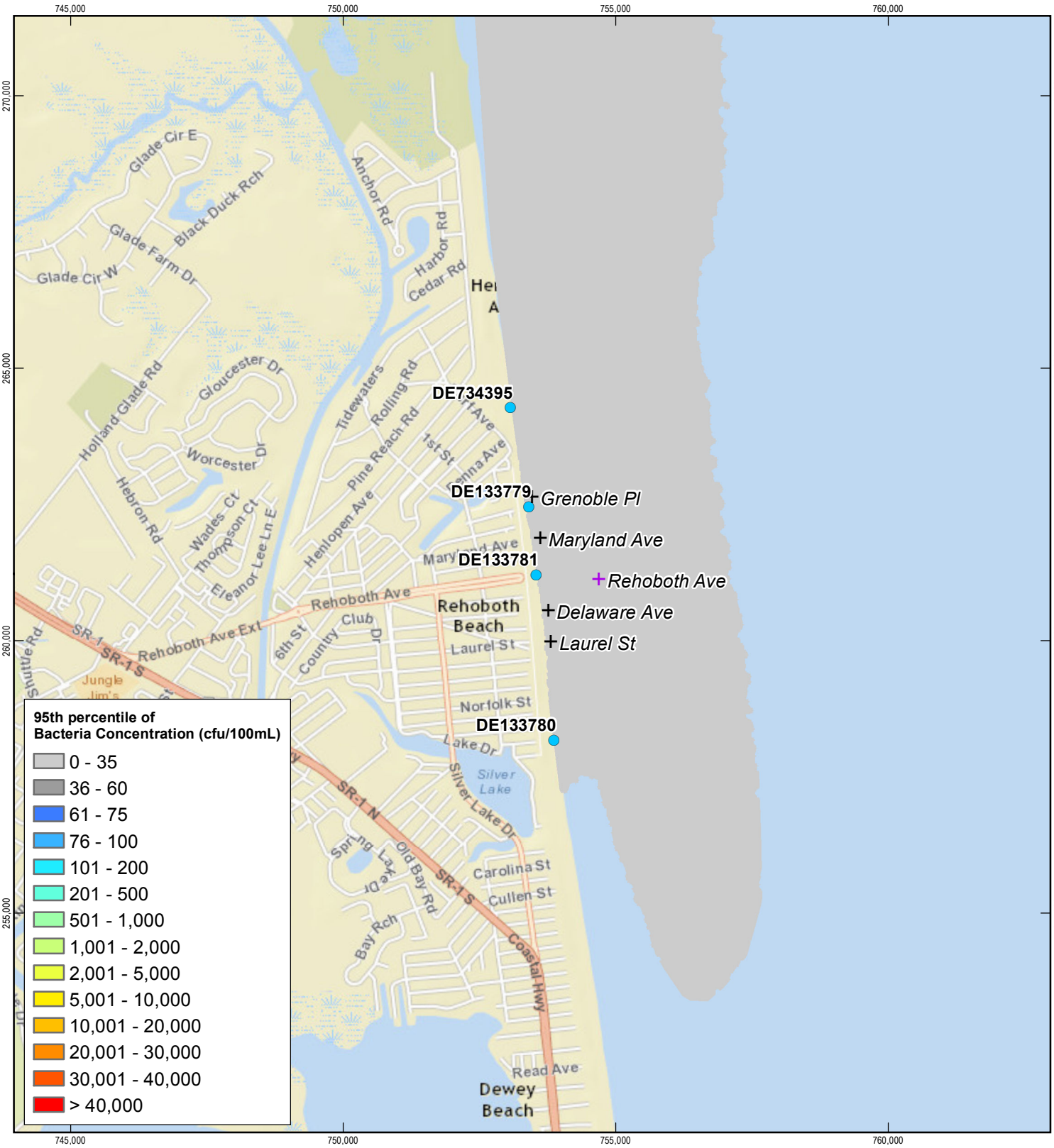

LEGEND

- Existing Outfall
- Proposed Outfall
- Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 10 June 00:00 to 10 June 06:00 AM
PER 20 - R Outfall Shifted 300m offshore
Baseline Condition

Paper Size ANSI A
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Feet
Map Projection: Transverse Mercator
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Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

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Figure A10

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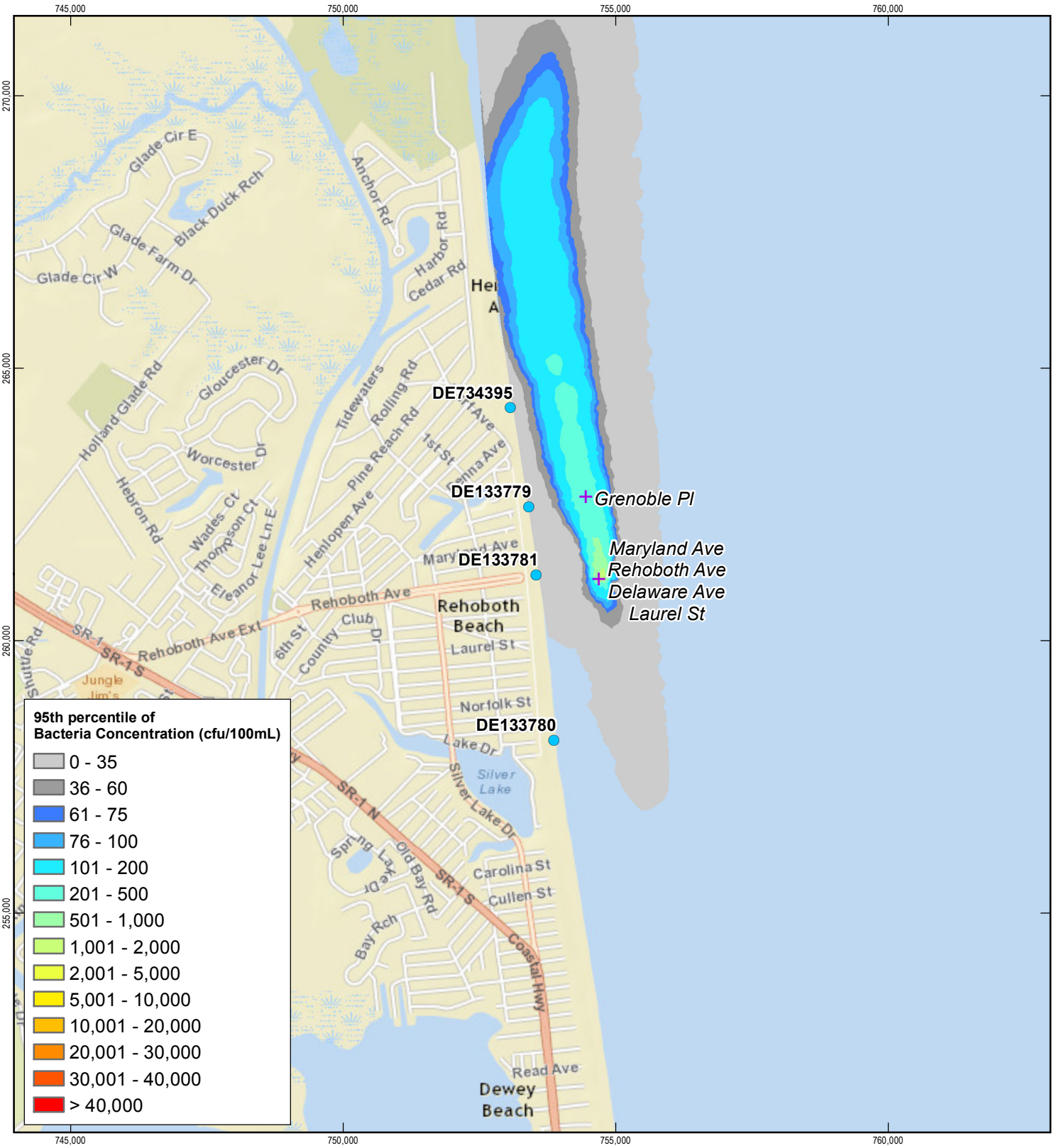

LEGEND

+ Proposed Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 06 June 00:00 to 06 June 06:00 AM
PER 30 - Two Outfalls: G&R1,shifted 300 m offshore
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

City of Rehoboth Beach
Stormwater PER

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Figure A11

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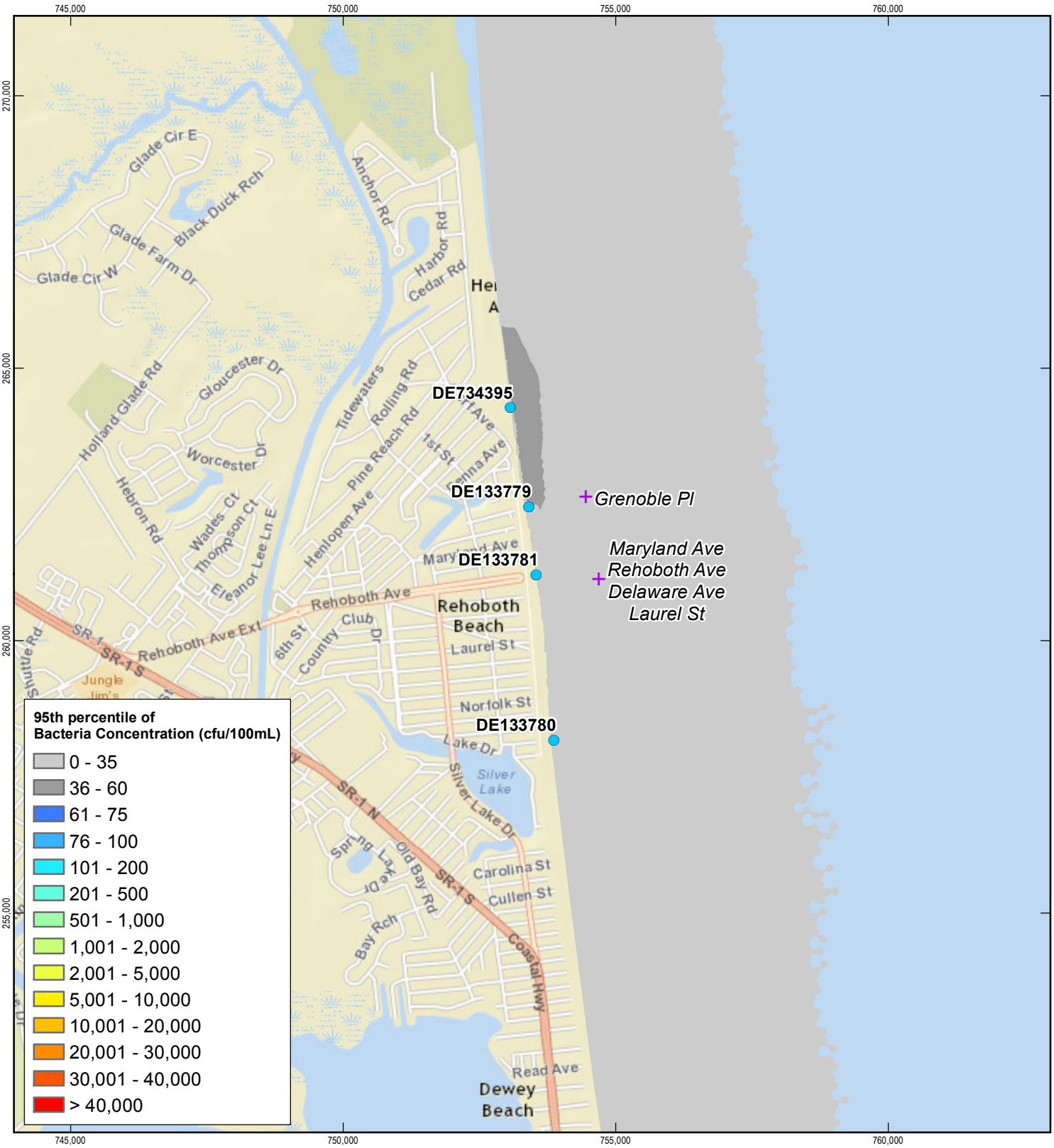

LEGEND

+ Proposed Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 07 June 00:00 to 07 June 06:00 AM
PER 30 - Two Outfalls: G&R1,shifted 300 m offshore
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

City of Rehoboth Beach
Stormwater PER

Job Number	86-18689
Revision	A
Date	Dec 23, 2015

Figure A12

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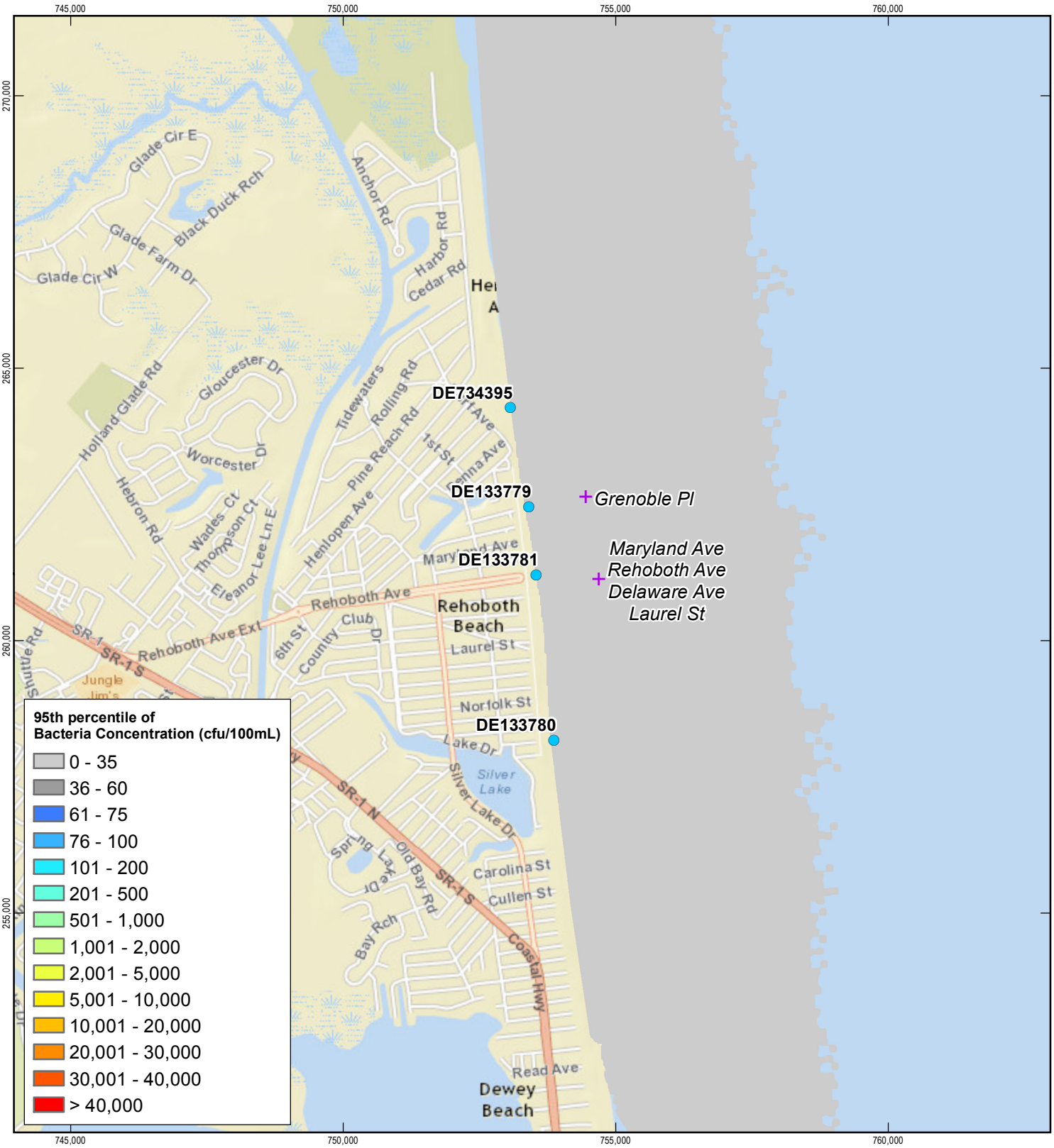

LEGEND

+ Proposed Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 08 June 00:00 to 08 June 06:00 AM
PER 30 - Two Outfalls: G&R1,shifted 300 m offshore
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

City of Rehoboth Beach
Stormwater PER

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Figure A13

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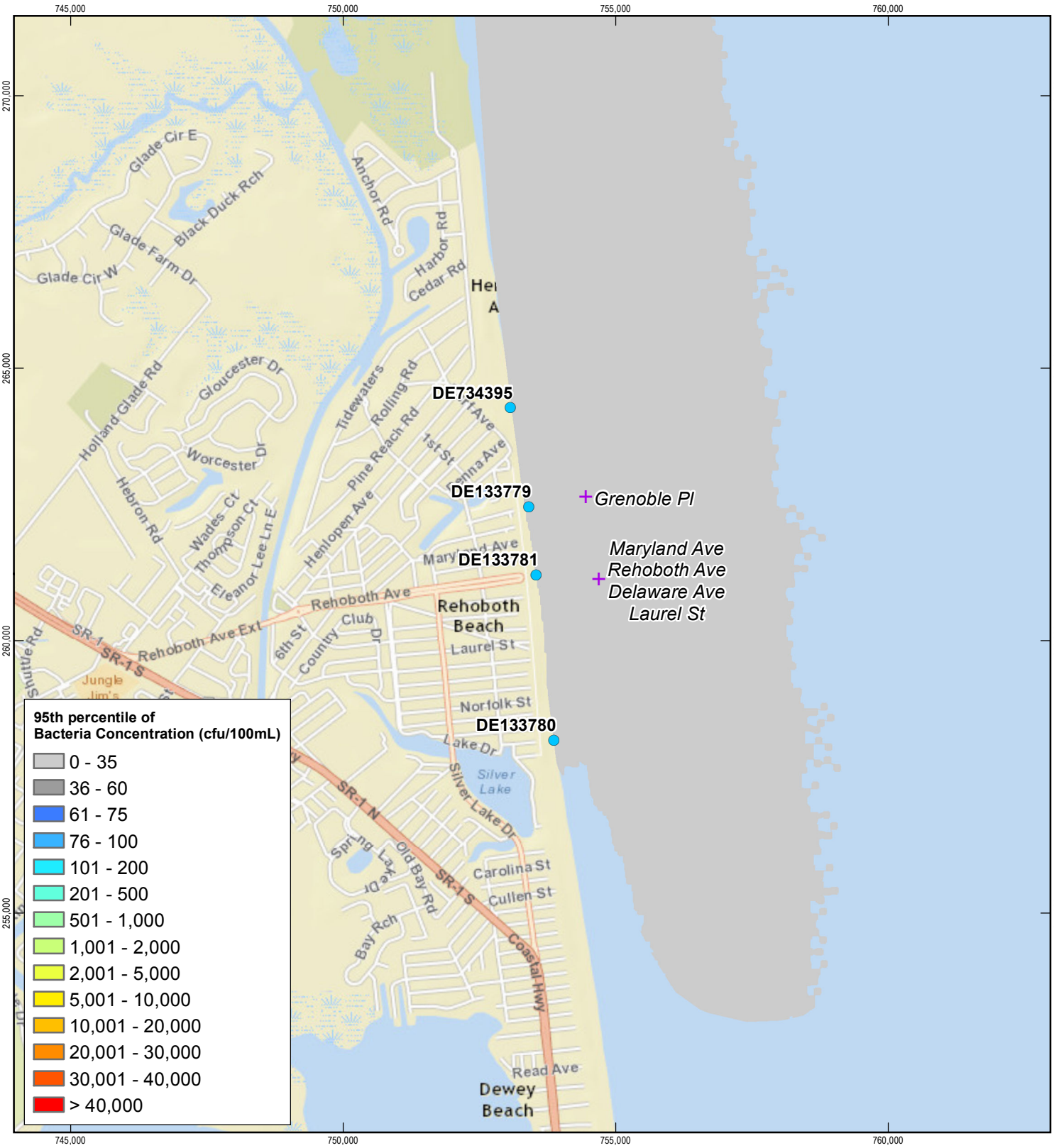

LEGEND

+ Proposed Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 09 June 00:00 to 09 June 06:00 AM
PER 30 - Two Outfalls: G&R1,shifted 300 m offshore
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

City of Rehoboth Beach
Stormwater PER

Job Number	86-18689
Revision	A
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Figure A14

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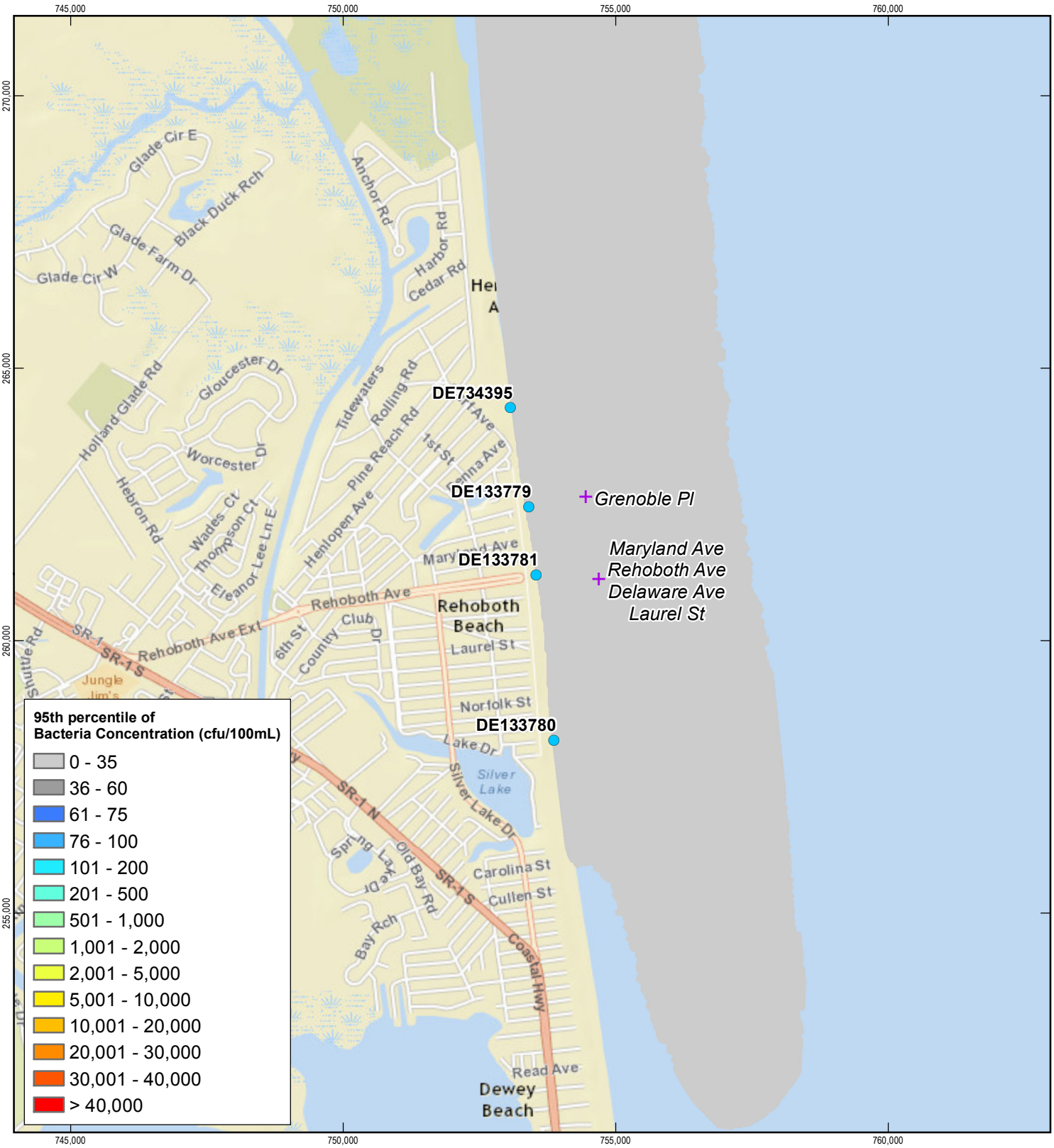

LEGEND

+ Proposed Outfall

● Bacterial Data Collection Point

95th percentile of Bacteria Concentration
for 10 June 00:00 to 10 June 06:00 AM
PER 30 - Two Outfalls: G&R1,shifted 300 m offshore
Baseline Condition

Paper Size ANSI A
1:30,000
0 1,550 3,100
Feet
Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Delaware FIPS 0700 Feet

N

City of Rehoboth Beach
Stormwater PER

Job Number	86-18689
Revision	A
Date	Dec 23, 2015

Figure A15

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GHD

145 Ann Street Brisbane QLD 4000
GPO Box 668 Brisbane QLD 4001
T: (07) 3316 3000 F: (07) 3316 3333 E: bnemail@ghd.com

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	IBB / JW	R Fryar		R Fryar		Nov 13th 2015
1	TG/DB	R Fryar		R Fryar		Dec 23rd 2015
2	JR/TG	R Fryar		R Fryar		May 18th 2016

www.ghd.com

GHD Inc.

16701 Melford Boulevard
Suite 330
Bowie MD 20715

T: 1 240 206 6810 F: 1 240 206 6811 E: bowmail@ghd.com

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		Name	Signature	Name	Signature	Date
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1	J. Riling	J. Sturdevant	On File	J. Sturdevant	On File	5/18/2016

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