Town of Carolina Beach Canal Drive Flooding & Vulnerability Assessment Study

Submitted to:
Town of Carolina Beach

Submitted by:
Aptim Coastal Planning & Engineering of North Carolina, Inc.

Project No. 636236194
February 2019

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Town of Carolina Beach, North Carolina

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EXECUTIVE SUMMARY

In recent years, the Town of Carolina Beach has experienced more frequent and increased flooding of the public and private infrastructure located along Canal Drive and Florida Avenue that borders the Carolina Beach Yacht Basin. Flooding is primarily due to seasonal high tide events (commonly referred to as King Tides), storm related high tides and rainfall events. Faced with existing flooding challenges and recognizing the reality of rising sea levels, the Town commissioned this study to assess the vulnerability of bulkheaded shorelines along Canal Drive and Florida Avenue and the influence that bulkhead condition and elevation plays on flooding of this part of the Town. This report provides a detailed inventory of bulkheads and non-structured shorelines as well as the stormwater system within the project area that may be contributing to flooding. Furthermore, the report provides practical recommendations to reduce the risks of high tide flooding for both public and private properties along Canal Drive and Florida Avenue.

The Town is primarily vulnerable to flooding due to high water events within the Yacht Basin and during significant rain events. High water events in the yacht basin result in the overtopping of existing bulkheaded or flowing through low non-bulkheaded shorelines. Backflow prevention devices installed on stormwater outfalls can be ineffective at preventing flooding if the valves do not seal properly allowing water to backup into the stormwater system and come up through the catch basins or street inlets along the roadways. High water levels in the basin can also reduce or eliminate the hydraulic head necessary to transfer water from the stormwater inlets through the stormwater system and out through the outfalls that drain into the yacht basin. Significant rainfall events also result in flooding, which may be due to a number of factors affecting the stormwater systems effectiveness to drain the road and properties along Canal Drive and Florida Avenue.

The results of the water level analyses performed in this study suggests a range of minimum design elevations when planning for bulkhead improvements on a 30-year planning horizon, from a low range of 4.7 feet NAVD88 to a high range of 5.7 feet NAVD88. Considering the 30-year planning elevation range of 4.7 ft. to 5.7 ft., approximately 72% to 97% of properties along Canal Drive and Florida Avenue are vulnerable to overtopping and require bulkhead raisings or bulkhead installations to help reduce the flooding impacts to Canal Drive and Florida Avenue during high tide events and storm related high tides. Furthermore, this report recommends that the Town should systematically replace the duckbill type backflow prevention devices with the WaStop® check valve type backflow prevention devices (or similar) on all eleven (11) observed outfalls (and possibly 8 unobserved outfalls) and all future outfall pipes.

Without considerable outside funding, it is unrealistic to make all of the recommended improvements to increase bulkhead elevations and ensure proper backflow prevention on all outfalls in the short-term. APTIM recommends that the Town use the spatial data developed in the course of this study to determine priority areas in which improvements will have the greatest reduction in flood impacts. This should be done by seeking real-time public input on flooding events in a way that allows the public to report date, time, and location of flooding within the project area. Furthermore, data collected by the Town's water level and weather monitoring station, installed in late January 2019 in the Carolina Beach Yacht Basin, will provide supplemental data to prioritize public and private investment aimed at mitigating flooding in the study area. These data will also allow engineers to re-assess the water level projections provided in this report, equipping the Town with more accurate numbers for future planning.

These recommendations, which are anticipated to take several years to implement, are intended to allow for an iterative implementation process and will allow the Town to prioritize its resources in those areas that demonstrate the most effective flood risk reduction:

Improvement Implementation Cost Estimates: A comprehensive cost estimate should be developed to include the completion of bulkhead improvements to the minimum design elevation recommended by this study, installation of WaStop® Inline Check Valves backflow prevention devices at the remaining outfall locations along the Carolina Beach Yacht Basin, and re-lining the stormwater pipe network along Canal Drive and Florida Avenue. This estimate should be developed in a timeframe that would allow the Town to have access to the estimates during upcoming budgetary planning for the FY 19/20 budget as well as provide an idea for how long it might take to implement all of the recommended improvements. A comprehensive cost estimate could also be used when submitting applications for grant program funds.

Real-Time Public Flood Data: The Town should use the spatial data developed in the course of this study to determine priority areas in which improvements will have the greatest reduction in flood impacts. This should be done by implementing a system where the public is encouraged to report flooding issues as they occur by simply providing a date, time, location, estimated water depth (if possible) and possibly a photo. The reporting system could be as basic as setting up a general email account (for example: **northendcbflooding@gmail.com**) for residents or visitors to submit their reports and photos. This public input program should be implemented as soon as possible.

6-Month Post-Study Analysis: Following several months of data collection from both the public input program and the water level and weather monitoring station recently installed, an updated analysis should be conducted. This analysis should focus specifically on utilizing the additional data, along with the available data collected as part of this study, to develop a priority list of improvements the Town can implement during FY 19/20 based on the available budget. The scope of the analysis should be developed to ensure completion of data analysis and recommendations are provided in a timely manner to allow the Town to implement priority projects in FY 19/20.

Multi-Year Implementation Cycle: As previously indicated, the recommendations provided herein acknowledge that a one-time implementation of changes to bulkhead elevation and stormwater system improvements within the study area may not be feasible. In order to implement flood risk reduction strategies in an efficient and iterative manner, the Town should re-prioritize remaining improvements needed in both the bulkhead system and stormwater system on an annual basis. This reprioritization should follow a similar method as described under the "6-Month Post-Study Analysis" recommendation. In that regard, the scope of the annual analysis should utilize the most up to date data from the public input program and water level/weather monitoring station. These data, combined with the available data collected as part of this study, and an assessment of the effectiveness of the flood mitigation strategies implemented to date, can be used to set priorities for the corresponding fiscal year.

Upon implementation of the year's priority projects, the cycle would continue with annual inventory of new data, updated analysis, and recommendations for the corresponding fiscal year. This multi-year strategy will allow the Town to appropriate resources based on 1) public input; 2) the effectiveness of past flood risk reduction projects; and 3) the most up to date monitoring data. This cycle can be implemented for whatever period of time sufficient to provide an acceptable level of flood risk reduction and resiliency based on available resources.

Development of Canal Drive/Florida Avenue Stormwater Monitoring and Maintenance Plan: In addition to installation of backflow prevention devices and maintenance of the currently installed devices, it is recommended that the Town continue to monitor the performance of the stormwater networks under higher water levels and with long-term sea level rise. The rise in tidal water levels will also affect local groundwater elevations. It is expected that with the age of the stormwater system along Canal Drive and Florida Avenue, some structural and/or hydraulic decay may have occurred, or will occur in the future. In the event of higher groundwater elevations and decayed pipes, leakage into the pipes may be occurring, which would circumvent efforts of backflow prevention. Re-lining of stormwater pipes in certain areas may be necessary.

It is also recommended that the Town continue to develop standards for maintenance of backflow prevention devices, monitor for structural or hydraulic decay of the stormwater system, and provide guidelines to assist the owners of private stormwater systems along Canal Drive and Florida Avenue to improve and protect those private systems from future flooding events.

The stormwater system observations obtained through this study, revealed opportunities for improvements within the currently installed infrastructure, largely related to maintenance. The following recommendations, listed in order of importance, are made to assist the Town with the initial development of a maintenance plan and will need to be customized for Town implementation:

1. It is recommended that all abandoned stormwater outfalls along the Carolina Beach Yacht Basin that have not been removed be inspected to ensure that they are no longer connected to the system. Abandoned stormwater outfalls that have not been removed, filled, or properly disconnected from the stormwater system could circumvent the Town's effort of backflow prevention.

2. All existing external backflow prevention devices should be inspected and cleaned twice per year for oysters, barnacles, and any other blockages. It is recommended that inspections are scheduled around April and September of each year prior to rainy season, and seasonal high tides. Once the rate of oyster and barnacle growth is known, the cleaning frequency may need to be adjusted.

3. All existing internal backflow prevention devices should be inspected and cleaned twice per year for blockages. Similarly, to the external maintenance, it is recommended that internal inspections are scheduled around April and September of each year prior to rainy season, and seasonal high tides.

Private Stormwater System Improvements: While the Town can endeavor to make improvements to publicly owned systems, improvements on private parcels will also need to be undertaken. In general, it is recommended that the Town perform public outreach and educate residents about the contributing factors to coastal flooding and develop guidelines for improvements to private bulkheads and stormwater systems. The Town may consider providing select data and maps from this study via an online portal for residents to better understand the conditions of their privately owned parcels.

The Town should consider providing guidance to private property owners on how they can contribute to reducing the demand on the public stormwater system during high water and rainfall events thereby reducing the volume of water contributing to flooding along Canal Drive and Florida Avenue. The Town should also consider promoting stormwater initiatives that can be implemented by local residents such as 1) the improvement and/or installation of gutter systems on private homes, 2) the use of permeable pavements for driveway aprons and any areas typically covered by impervious materials to reduce the amount of impervious surfaces and 3) the use of private stormwater storage systems (above or below ground) to retain stormwater on the property during an event that is slowly released following the event.

While these recommendations reduce the risk of high tide flooding, this study was not envisioned to bring recommendations that prevent flooding at all storm return frequencies. As previously stated, it is anticipated to take several years to implement the study's recommendations, which is appropriate considering the low rate of sea level rise, including its observed recent acceleration and the 30-year planning horizon.

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1. INTRODUCTION

The Town of Carolina Beach (Town) has experienced more frequent and increased flooding events of the public and private infrastructure located along Canal Drive and Florida Avenue that border the Carolina Beach Yacht Basin in recent years (Figure 1). These flooding events have been primarily caused by inundation from the Carolina Beach Yacht Basin during elevated water levels and during significant rainfall events. Though it is understood that these two factors are the primary factors contributing to flooding along Canal Drive and Florida Avenue, the amount of influence either factor has on specific flooding events is poorly understood. The Town commissioned this study in order to 1) determine a recommended bulkhead elevation to mitigate overtopping over a 30-year time horizon; 2) evaluate the elevation and conditions of the bulkheads along Canal Drive and Florida Avenue; and 3) to implement a long-term monitoring program aimed at better understanding tidal fluctuations and rainfall totals driving flooding events.

In support of the Town's goals for this study, Aptim Coastal Planning & Engineering of North Carolina, Inc. (APTIM) was retained to review available water level data, climate data, sea level rise modeling performed by NOAA, the USACE, and the Intergovernmental Panel on Climate Change (IPCC), and analyze return periods of extreme events to develop a recommendation for a minimum bulkhead height for the next 30-year horizon. APTIM also conducted field investigations to catalogue existing conditions of bulkheads, stormwater outfalls and inlets, and backflow prevention devices along approximately 1.75 miles of the tidally influenced shoreline along Canal Drive and Florida Avenue within the study area in October/November 2018. APTIM was also hired to coordinate the installation of a remote monitoring station designed to record water levels and weather data affecting the basin shorelines. The extents of this study area are identified by the red line shown in Figure 1.

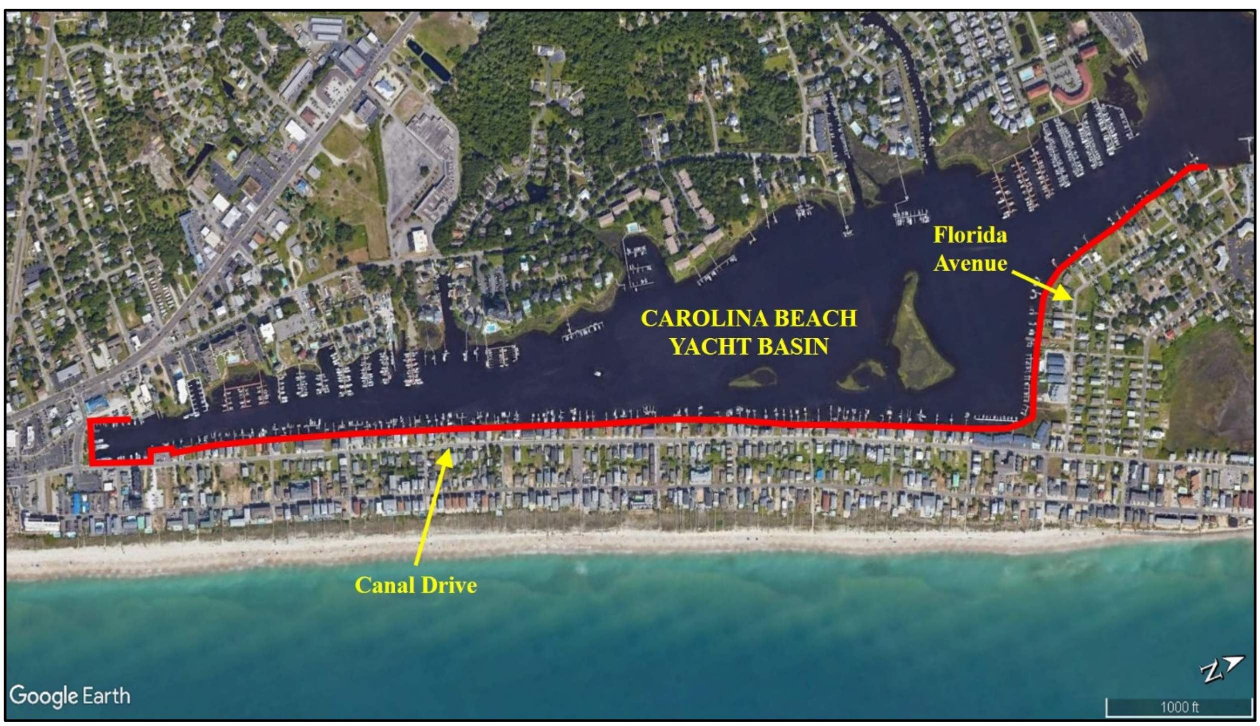

Figure 1. Study Area Map.

The data generated through the conduct of field investigations during the course of this study provide valuable information to Town staff to serve as an inventory of current conditions. These data include condition and elevation of bulkheads along Canal Drive and Florida Avenue, elevations and locations of stormwater outfalls and inlets, inventory of outfall and backflow prevention devices, and maximum water levels for various return period storms. Furthermore, the installation and continuous operation of the water level gauge and rain gauge will provide a robust data set to be used by the Town to refine this initial assessment in the future. APTIM also used an unmanned aerial system (UAS) to collect high-resolution oblique photos and video of the bulkhead as well as ortho-rectified aerial imagery and point cloud data of the project area. These data are included in this report either as tables or in appendices.

In addition to providing recommendations on bulkhead heights, this study also seeks to provide recommendations on retrofitting stormwater outfall systems and planning to assist the Town in developing future Capital Improvement Plans.

2. GEOGRAPHIC SETTING & DATUMS

The Town of Carolina Beach is located in southeastern North Carolina within New Hanover County. The Town encompasses the northern portion of a coastal barrier island known as Pleasure Island. Pleasure Island was once a peninsula before it was separated from the mainland in 1930 by a man-made waterway, known as Snow's Cut, that now borders the northern portion of Carolina Beach. Snow's Cut connects the Cape Fear River to the Intracoastal Waterway (ICW) at the entrance of the Carolina Beach Yacht Basin. Carolina Beach is bounded by the Cape Fear River to the west, the Atlantic Ocean to the east, and the Town of Kure Beach to the south. Figure 2 shows an overview map of Carolina Beach.

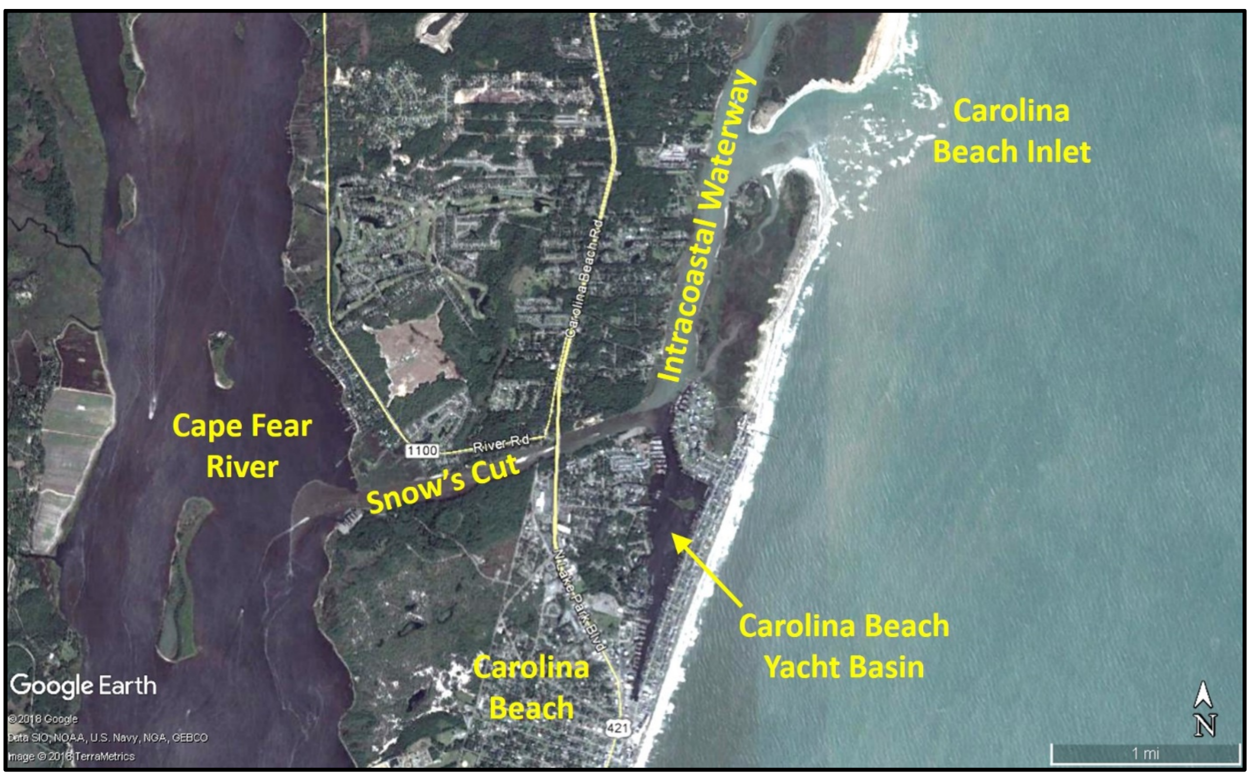

Figure 2. Overview Map.

3. WATER LEVEL PROJECTION

In order to determine recommended bulkhead elevations for future retrofitting and development, this assessment first assessed past, current, and future water levels for a 30-year planning horizon. This section describes analysis of measured water levels, rates of measured sea level rise, future sea level rise projections, and recurrent storm induced water levels.

3.1 Components Influencing Water Levels

The water levels within the Carolina Beach Yacht Basin are influenced by several components including astronomical tides, local winds, stormwater discharge from rain events, ocean storm surge, the Cape Fear River via Snow's Cut, and sea level rise. Each of these components are discussed briefly in the following sections.

3.1.1 Astronomical Tides

The nearest measured water levels are those from the NOAA tide gauges located on the Cape Fear River in Wilmington, NC (Station ID 8658120) and on the Atlantic Ocean at Johnny Mercer's Pier in Wrightsville Beach, NC (Station ID 8658163), shown in Figure 3.

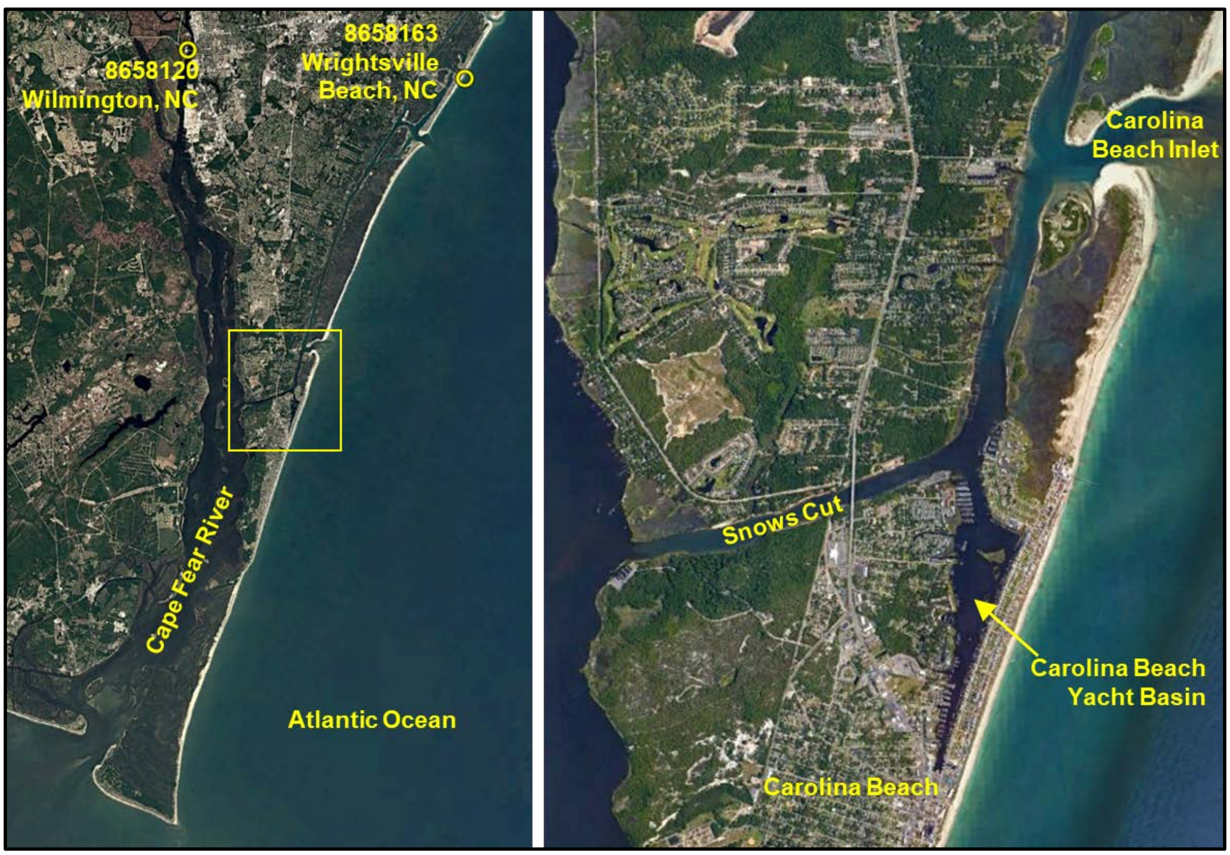

Figure 3. NOAA Tide Gauge Locations.

For purposes of this analysis, all elevations are in feet referenced to North American Vertical Datum 1988 (NAVD), unless specifically noted otherwise. Where source data is in another datum, data were converted to NAVD based on published National Oceanic and Atmospheric Administration (NOAA) tidal benchmarks. The two local tidal benchmarks used: "Gauge 8658120, Wilmington NC" and "Gauge 8658163, Wrightsville Beach NC", report NAVD as 2.60 feet above MLLW and 2.71 feet above MLLW, respectively. The tidal datum associated to NOAA's station 8658120 Wilmington, NC and station 8658163, Wrightsville Beach, NC are given in Table 1.

Table 1. Tidal Datums at 8658120 Wilmington, NC and 8658163 Wrightsville Beach, NC (NOAA).

Tide Station Datum Elevations **Units:** Feet **Epoch:** 1983-2001 **Datum:** NAVD			
Datum	**Description**	**Wilmington, NC**	**Wrightsville Beach, NC**
MHHW	Mean Higher-High Water	2.08	1.77
MHW	Mean High Water	1.83	1.42
NAVD88	North American Vertical Datum of 1988	0.00	0.00
MTL	Mean Tide Level	-0.31	-0.57
MSL	Mean Sea Level	-0.16	-0.56
DTL	Mean Diurnal Tide Level	-0.26	-0.47
MLW	Mean Low Water	-2.44	-2.56
MLLW	Mean Lower-Low Water	-2.60	-2.71

From NOAA's daily tidal predictions for 2017, the expected maximum predicted water levels for the Wilmington gauge were determined to be between approximately +1.5 to +3.0 feet NAVD (Figure 4) and approximately between +0.5 to +3.0 feet NAVD for the Wrightsville Beach gauge except for the months of January and February (Figure 5).

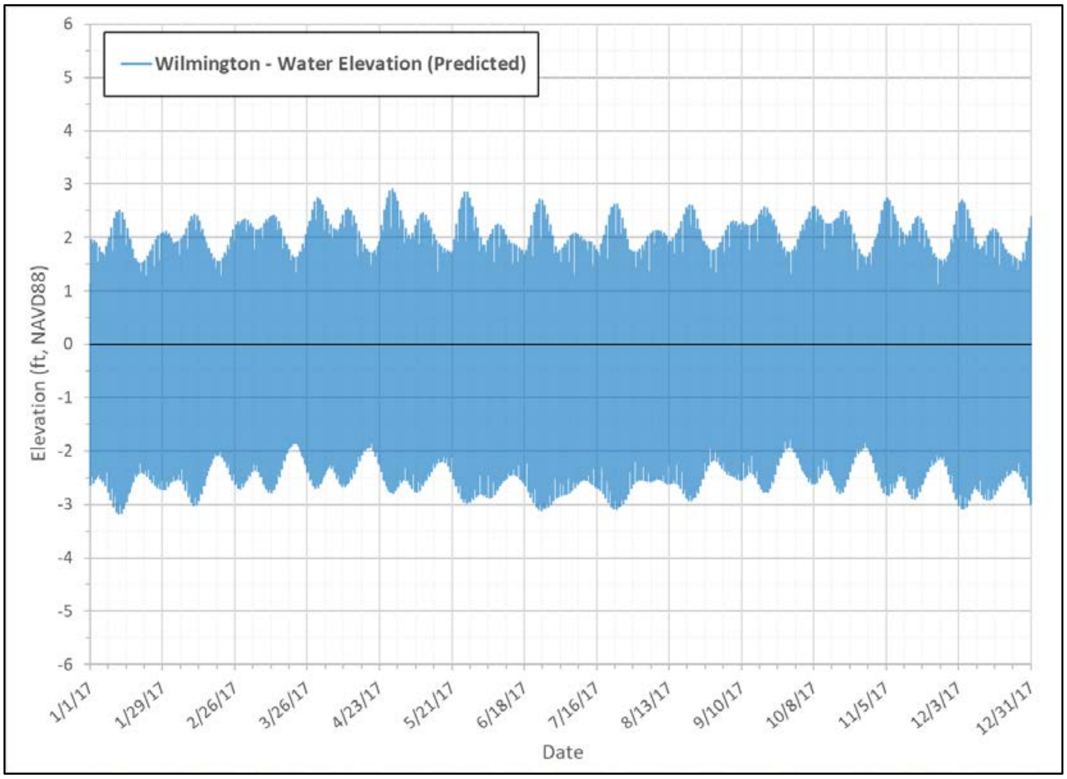

Figure 4. Wilmington, NC (Station ID 8658120) – 2017 Predicted Water Levels by NOAA.

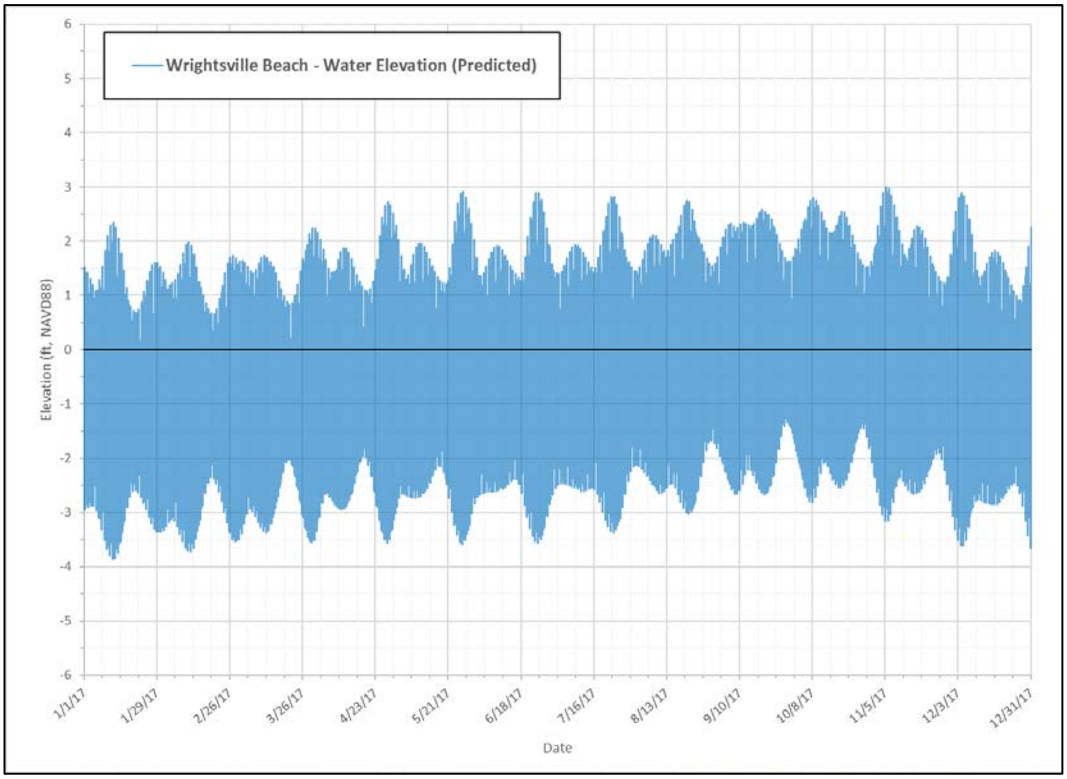

Figure 5. Wrightsville Beach, NC (Station ID 8658163) – 2017 Predicted Water Levels by NOAA.

3.1.2 Ocean Storm Surge

The passage of tropical systems with their associated wind fields and low central pressures can force ocean water to accumulate along the coast of the Atlantic Ocean creating an ocean storm surge. The ocean storm surge can affect the tides and flow of water through Carolina Beach inlet as well as in the Cape Fear River, via Snow's Cut, and impact the water levels in the Carolina Beach Yacht Basin. Strong northeasterly wind and wave events associated with extratropical nor'easter storms, even if distant, can also create a storm surge influencing water levels in the Carolina Beach Yacht Basin. There are also variations in the Gulfstream current and other oceanographic processes that affect the tide in the Atlantic Ocean. These processes can positively or negatively affect the tide and have been categorized for this evaluation as ocean storm surge.

The Carolina Beach Yacht Basin is connected to the Atlantic Ocean through Carolina Beach Inlet and is connected to the Cape Fear River via Snow's Cut (Figure 3). NOAA provides predicted water levels at the Wilmington Gauge (Station ID 8658120) and Wrightsville Beach Gauge (Station ID 8658163) based on astronomical tides and measured water levels. Figure 6 and Figure 7 show both predicted and measured water levels for the Wilmington and Wrightsville Beach gauges, respectively. For 2017, the deviations at the Wilmington Gauge averaged 0.29 feet with the maximum positive deviation occurring on September 12, 2017 attributable to the passing of Hurricane Jose. Likewise, the deviations at the Wrightsville Beach Gauge averaged 0.35 feet with the maximum positive deviation occurring on December 9, 2017.

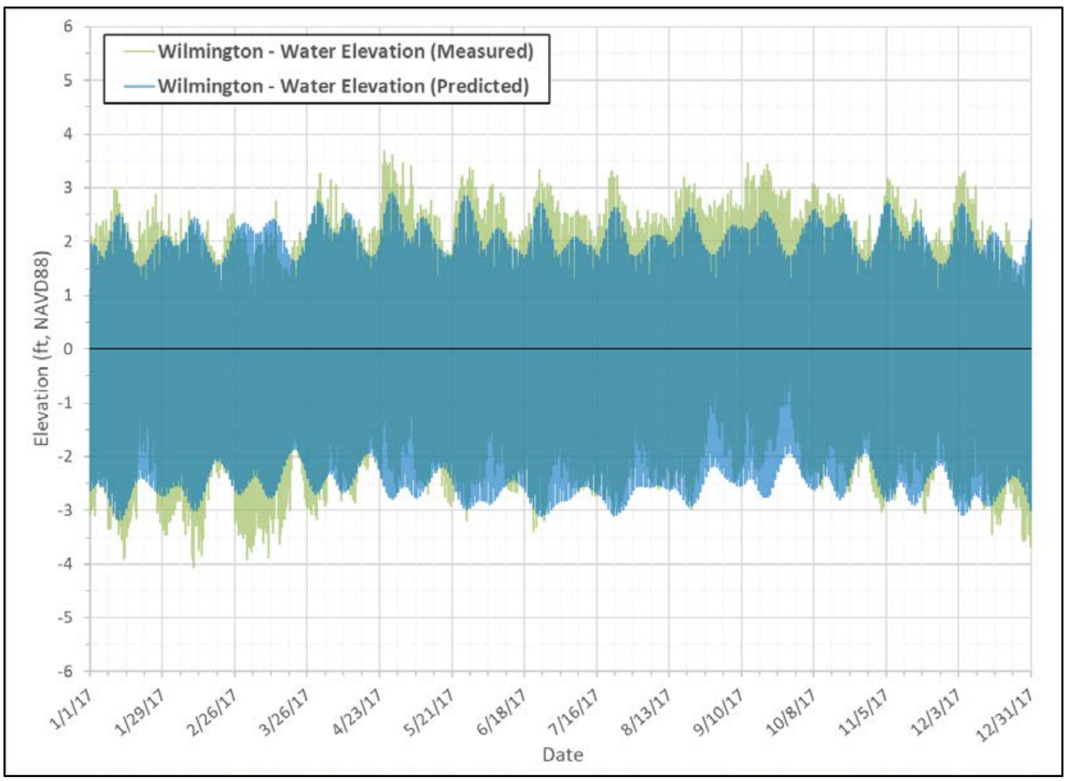

Figure 6. Wilmington, NC (Station ID 8658120) - 2017 Predicted and Measured Water Levels.

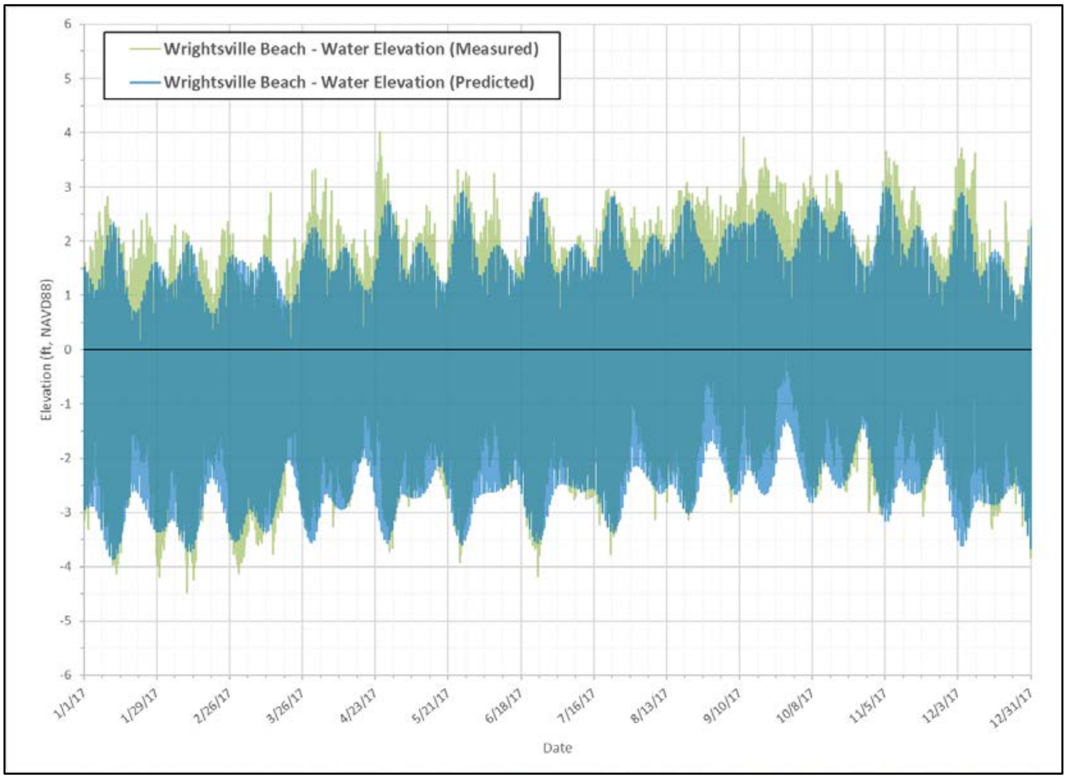

Figure 7. Wrightsville Beach, NC (Station ID 8658163) - 2017 Predicted and Measured Water Levels by NOAA.

3.1.3 Other Components

3.1.3.1 Stormwater Discharge from Inland Rain

Rain that accumulates on the surface and does not infiltrate into the ground is referred to as creating surface water. Within the study area, these surface waters are managed by the public stormwater system. Management of the stormwater is intended to provide flood protection and drainage for public and private lands. As part of this management effort, stormwater within the study site is collected at catch basins located along Canal Drive and Florida Avenue and discharged through outfall pipes to the Carolina Beach Yacht Basin.

3.1.3.2 Local Winds

Atmospheric conditions generate high and low pressures, as well as gradients in both air and sea temperatures. These conditions result in winds at both a regional and local scale that create friction on the water's surface. Depending on the strength, direction, and persistence of these winds, this forcing can cause localized fluctuations in water levels. In particular, northerly and northeasterly winds can force water down the Intracoastal Waterway and affect the water levels within Carolina Beach Yacht Basin.

In order to better understand the effect of wind stress on the water levels within the Carolina Beach Yacht Basin, a quantitative analysis was conducted to assess the effects as part of this study. The assessment, using an assumed average depth of 10 ft. for the entire basin and the length of the basin, determined that a wind speed of 50 mph would result in an approximate 0.3 to 0.4 ft. increase in water level within the basin. The assessment did not account for the shape of the basin that narrows toward the south end or the impacts from elevated water levels generated in the Intracoastal Waterway, which would result in an additional increase in the water level within the basin. The installation of the monitoring station within the basin will provide water level and wind data than can be analyzed to determine the impacts northerly and northeasterly winds have on the water levels within the basin.

3.1.3.3 Sea Level Rise

The Relative Sea Level Trend reported by NOAA for Station 8658120 Wilmington, NC for the period between 1935 and 2017 is 2.30 mm/year (+/-0.34 mm/year). Figure 8 shows the monthly mean sea level with the average seasonal cycle removed as well as the linear relative sea level trend. Relative Sea Level Trends for Station 8658163 Wrightsville Beach, NC are not reported by NOAA. Although the Wrightsville Beach Station is located in the Atlantic Ocean and the Wilmington Station is located 26 miles up the Cape Fear River, in the absence of available data for Wrightsville Beach, this analysis assumes the Relative Sea Level Trend for the Wilmington Station is representative of the Wrightsville Beach Station location. The linear trend reported by NOAA for the Wilmington Station (2.3 mm/year) results in an increase of approximately 0.2 feet from 1992 to 2018 (i.e. the midpoint of the current National Tidal Datum Epoch of 1983-2001 to present).

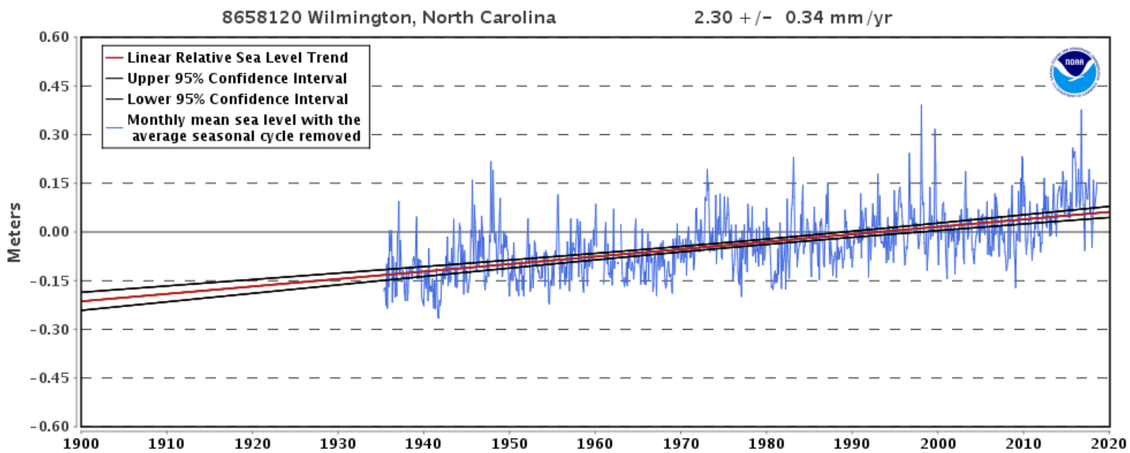

Figure 8. Relative Sea Level Trend; 8658120 Wilmington, NC (NOAA)

Projections of future sea level rise may be based on relative sea level rise derived from the most local, longest term tidal measurements. As shown by Harris (1981), the use of a long record reduces the standard error in linear regression analysis. The longest data record for North Carolina is in Wilmington (NOAA Station ID 8658120) covering a time span of 83 years (1935-2018).

The North Carolina Coastal Resources Commission (CRC) tasked the CRC Science Panel with conducting a comprehensive review of scientific literature and available data for North Carolina that addresses the full range of global, regional, and local sea level change. In 2016, the final report of the Science Panel's assessment of sea level rise in North Carolina was released, updating the initial 2010 NC Sea Level Rise Assessment report. The Science Panel chose to use scenario based global sea level rise projections provided in the most recent Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The IPCC sea level rise scenarios are referred to as Representative Concentration Pathways (RCP) that represent possible trajectories of sea level rise based on projected amounts of greenhouse gases emitted in the future. The sea level rise scenarios provided in the IPCC AR5 report are the RCP 2.6 (lowest greenhouse gas emission), RCP 4.5, RCP 6.0, and RCP 8.5 (highest greenhouse gas emission). A comparison of the published IPCC projections to the monthly mean sea level (MSL) as measured in Wilmington is shown in Figure 9.

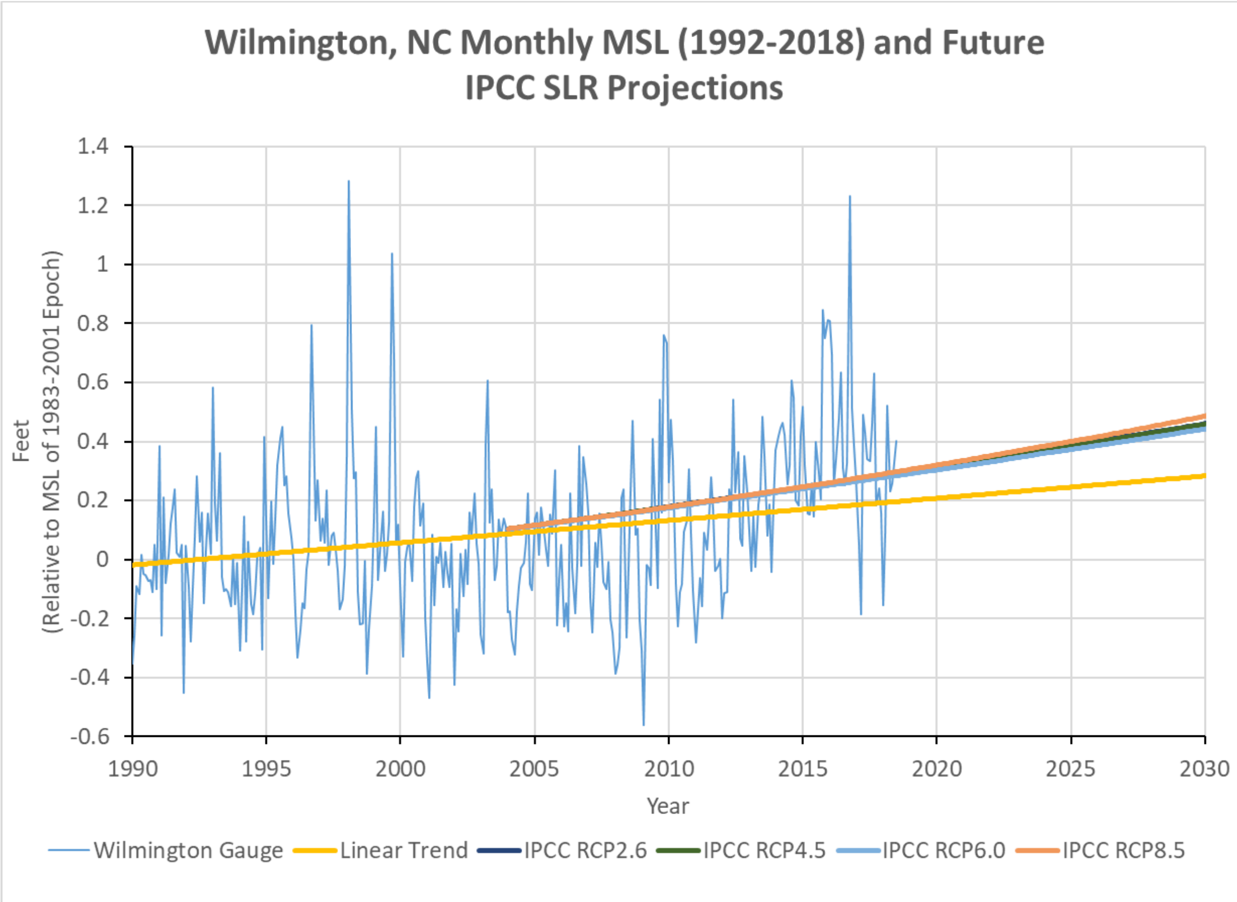

Figure 9. Sea Level Rise Projections overlain on Measured Monthly MSL at Wilmington, NC.

Based on the data comparison illustrated in Figure 9, several preliminary observations can be made:

1. A comparison between the historical linear trend (by NOAA) and the monthly mean sea level changes indicate that the sea level in Wilmington is rising at an increasing rate. Utilization of the historical linear trend does not appear to compare favorably with the measurements since approximately 2013.
2. Based on the linear trend, mean sea level has risen approximately 0.20 feet between 1992 (midpoint of the current National Tidal Datum Epoch) and 2018 in Wilmington.
3. The CRC Science Panel chose the United Nations Intergovernmental Panel on Climate Change (IPCC) AR5-RCP 2.6 (low scenario) and RCP 8.5 (high scenario) projections for use in the NC Sea Level Rise Assessment Report (2015 Update).

The 2015 NC Sea Level Rise Assessment Report focuses on the low and high greenhouse gas scenarios (RCP 2.6 and RCP 8.5) to represent the lower and upper bounds of the potential range of future sea level rise. Table 2 provides the projected mean rise of Global Sea Level in 2018 and 2048 based on a linear interpolation of the IPCC RCP 2.6 and RCP 8.5 sea level rise projections with respect to 1986-2005 at January 1st (modified from Table AII.7.7, IPCC 2013a).

Table 2. Mean Global Sea Level Rise from 2018 to 2048 as Predicted by IPCC Scenarios.

Predicted Amount of Sea Level Rise by Year	Scenario RCP 2.6 (feet)	Scenario RCP 8.5 (feet)
2018	0.24	0.24
2048	0.69	0.78
Change in SLR (2018 to 2048)	0.45	0.54

In order to relate the IPCC projections of the mean Global Sea Level Rise to Wilmington, North Carolina, the NC Sea Level Rise Assessment Report included vertical land movement (VLM) trends based tidal data from Wilmington NOAA tide station. The vertical land movement trend quantified by Zervas (2014) was used as a proxy for local effects. The vertical land movement computed a trend of subsidence at a rate of -0.39 mm/yr for Wilmington, NC (Zervas, 2014), or equivalent to -0.00128 ft./yr. This equates to an estimated vertical land movement of -0.038 ft. over a 30-year period. Table 3 provides the projected mean rise of Relative Sea Level by 2048 in Wilmington based on the IPCC RCP 2.6 and RCP 8.5 scenarios and the vertical land movement for Wilmington, NC.

Table 3. Relative Sea Level Rise by 2048 considering sea level rise predicted by IPCC Scenarios combined with projected vertical land movement for Wilmington, NC.

Relative Sea Level Rise in 30 years	Scenario RCP 2.6 + VLM (feet)	Scenario RCP 8.5 + VLM (feet)
Increase in MSL between 2018 and 2048 + VLM	0.49	0.58

3.2 Storm Effects

Storm surges occur within the Atlantic Ocean and propagate into the Carolina Beach Yacht Basin through tidal inlets, the Cape Fear River, and interior channels. These surges will influence local water levels and can be predicted (statistically) through analysis of historic water levels. An extreme water level analysis was conducted to determine the elevation of expected water levels for a given return period. Data used in the extreme water level analysis included local observations of historical high water marks, short-term USGS tide records measured locally during specific storms, and historical water levels at the Wilmington and Wrightsville Beach NOAA stations. A list of observed high water elevations observed within the Carolina Beach Yacht Basin between 1996 and 2018 is provided in Table 4 where the maximum event was from a local observation of +8.7 feet, NAVD that occurred on September 6, 1996 associated with the passing of Hurricane Fran. Likewise, nine of the top ten water elevation events are associated with the passage of a named tropical system and seven of the top ten water levels were observed within the study area.

Table 4. Observed High Water Elevations within the Carolina Beach Yacht Basin

Event	Water Elev. (ft. NAVD88)	Comment
H. Fran water mark (6 Sep 1996)	8.68	@ 1019 Canal Drive
H. Floyd water mark (16 Sep 1999)	8.18	@ 1019 Canal Drive
H. Bonnie water mark (26 Aug 1998)	6.58	@ 1019 Canal Drive
H. Florence (14 Sep 2018)	5.69	USGS STN Joyner Marina
H. Florence water mark (14 Sep 2018)	5.48	@ 1019 Canal Drive
H. Florence wrack line (14 Sep 2018)	5.37	@ 1001 Canal Drive
H. Matthew (8 Oct 2016)	5.18	USGS STN Joyner Marina
H. Matthew water mark (8 Oct 2016)	5.08	@ 1019 Canal Drive
H. Bertha water mark (July 1996)	4.98	@ 1019 Canal Drive
Lunar High Tide water mark (Sep-Oct 2013)	4.98	@ 1019 Canal Drive
Lunar High Tide water mark (Sep 2008)	4.68	@ 1019 Canal Drive
H. Irene water mark (Oct 1999)	4.63	@ 1019 Canal Drive

As shown in Table 4, elevation data were obtained by the USGS for high water levels that occurred at the Carolina Beach Yacht Basin during Hurricane Matthew and Hurricane Florence. In these two events, high water levels were measured from water level sensors deployed at Joyner Marina prior to the storms. The other high water elevations listed in Table 4 were recorded by a homeowner on the piling of his house located at 1019 Canal Drive after the storms. The water levels measured by the USGS water level sensors during Hurricane Matthew and Hurricane Florence were prioritized over the observations and used in the analysis. However, due to the close agreement between the elevations of the measured water levels by the USGS sensors and the observed high water mark elevations there is a high degree of confidence in the accuracy of the observed high water marks recorded by the homeowner following other storm and tidal events. Local high water observations were made from 1996 to 2018, while tide data associated with the Wilmington NOAA station spans from 1935 to 2018 and data from the Wrightsville Beach NOAA station spans from 2004 to 2018. A comparison between locally observed data and NOAA tide records is provided in Figure 10.

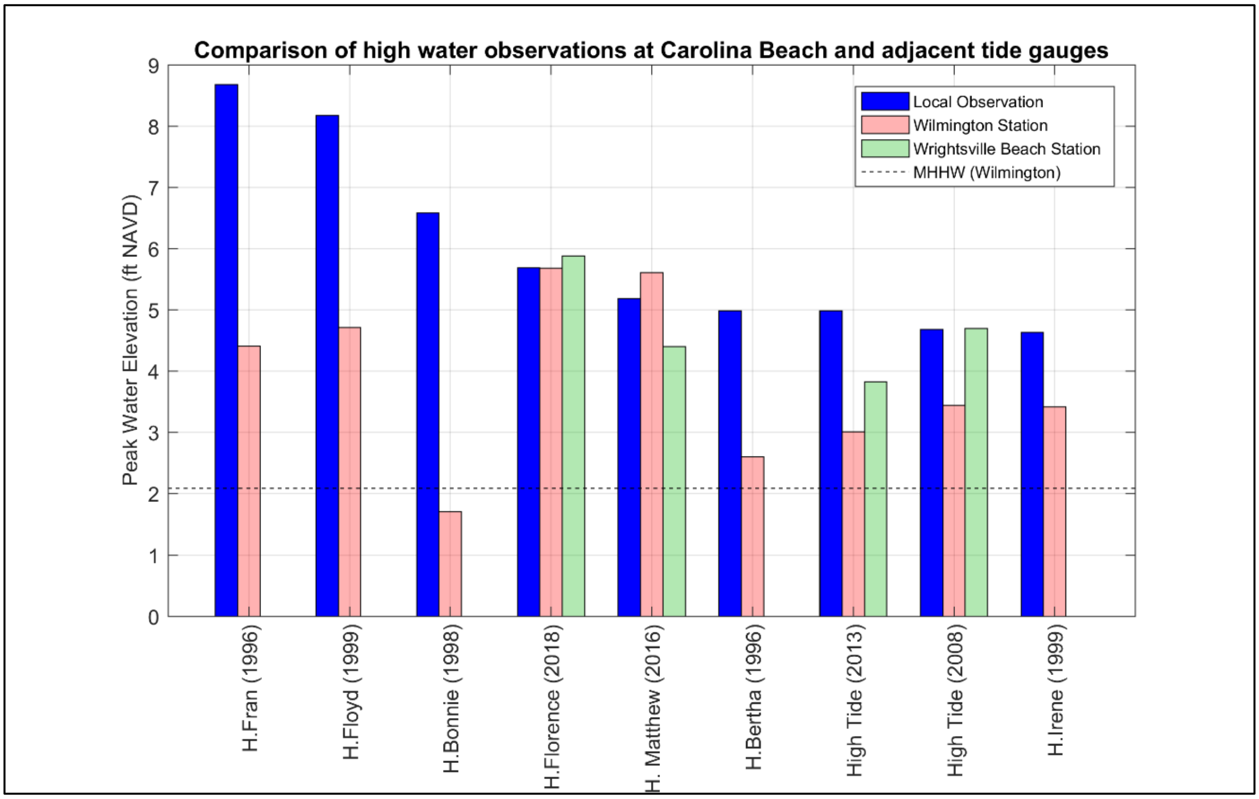

Figure 10. Comparison between local observations and tide records during extreme events.

The three events on local records with the highest recorded water levels occurred between 1996 and 1999. During this period, the Wrightsville Beach NOAA station was still not operational. The associated storm surge levels measured at the Wilmington NOAA station were considerably lower as shown in Figure 10. This discrepancy is attributed to the path of the storms and the prevailing wind speeds/directions. The three storms (Hurricanes Fran, Floyd and Bonnie) moved from the southern to the northern quadrant over or immediately east of the Cape Fear.

Western winds are not critical in terms of storm water levels within the Yacht Basin. Eastern/northeastern winds induce positive storm surges along the coast north of Cape Fear, while south of Cape Fear; surges produced by eastern/northeastern winds are expected to be smaller or even negative due to the change in shoreline orientation. Because the Cape Fear River, and therefore the Wilmington NOAA station, are connected to the coastal region immediately south of the Cape Fear, storm surges associated with eastern/northeastern wind events are less intense. The Carolina Beach Yacht Basin is situated between the eastern coast and the Cape Fear River. During eastern/northeastern wind events, the Yacht Basin is more critically affected by the coastal storm surge propagating through Carolina Beach Inlet rather than the propagation of tides from the Cape Fear River through Snow's Cut.

Divergent elevations between local observations and tidal records were also observed for the less severe events shown in Figure 10. As the local observations are considered accurate/reliable and represent the extreme water level at the study site, the local observed water level data was prioritized in the analysis. Data from the NOAA tidal stations at Wilmington and Wrightsville Beach were used to supplement these locally observed data.

3.3 Return Period Analysis

A return period analysis is a statistical analysis that utilizes historical data to determine the average recurrence interval of a particular event used for assessing risk. For this study, a recurrence interval was defined as the probability of a particular maximum water level being exceeded in any given year. The analysis was performed using a combination of locally observed historical high water marks recorded within the Carolina Beach Yacht Basin during past storm events and lunar high tides, short-term tide records measured at Joyner Marina by the USGS during specific storms, and historical water level data from the Wilmington and Wrightsville Beach NOAA tide stations as shown in Table 4. The data was used to determine the likelihood of exceedance of maximum water levels within the Carolina Beach Yacht Basin for a given return period. The return period analysis utilized available data from the 22.8-year period from 1996 to 2018.

The composite historical water level time series from 1996 to 2018 was normalized by subtracting the observed trend of MSL rise over time (2.3 mm/yr.) from the measured water levels. In doing so, the extreme water levels used in the analysis are all referenced to the same datum (NAVD88). The resulting normalized, or de-trended, water level time series is shown in Figure 11.

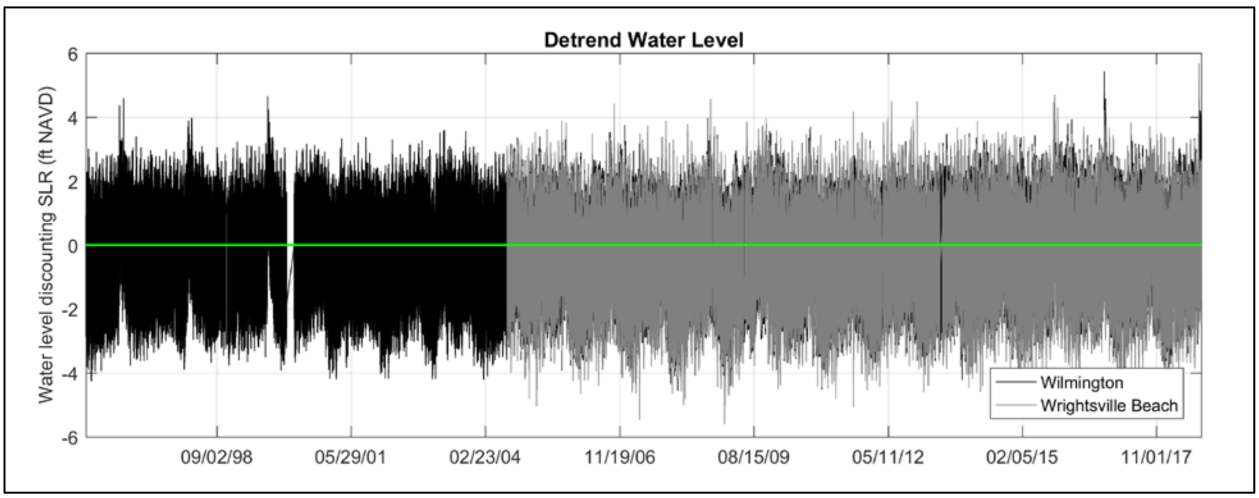

Figure 11. De-Trended Water level time series for NOAA Stations 8658120 Wilmington and 8658163 Wrightsville Beach

From the de-trended time series, a Peaks-Over-Threshold (POT) method was employed to select the individual storm events considered in the probability distribution and curve fitting. An elevation fluctuation threshold was set at +3.9 feet, which resulted in 26 events during the 22.8-year record where the de-trended water levels exceeded the threshold, providing slightly more than one event per year, on average.

To avoid double counting events, a 7-day buffer was applied before and after each peak using the following priority sequence:

1) Local Observations: first priority; peaks from tide stations occurring within 7 days of observed peaks were excluded from analysis;

2) Tide station peaks less than 7 days apart: highest peak recorded, remaining peaks removed.

The data was then fit using the Weibull distribution. The resulting curve is shown in Figure 12. Of interest is the top 10 events, which are listed in Table 5. The top events are mostly related with the passage of significant tropical and extratropical storms.

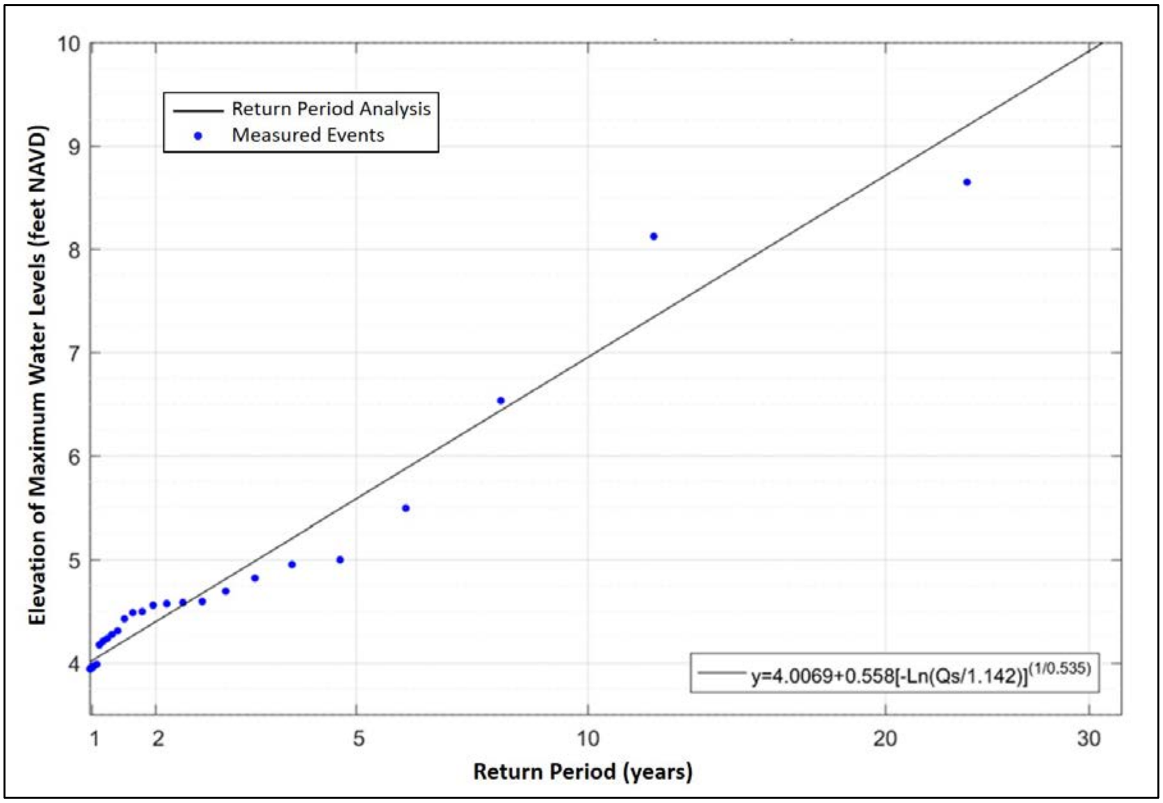

Figure 12. Maximum Water Levels (not adjusted for Sea Level Rise) for Various Return Periods.

Table 5. Top 10 Extreme High Water Events Based on the Analyzed Water Level Data.

Extreme Water Level Events				
Rank	**Date**	**Feet (NAVD)**	**Data Source**	**Event**
#1	9/6/1996	8.68	Local Observations	H. Fran
#2	9/16/1999	8.18	Local Observations	H. Floyd
#3	8/26/1998	6.58	Local Observations	H. Bonnie
#4	9/14/2018	5.69	USGS STN Joyner Marina	H. Florence
#5	10/8/2016	5.18	USGS STN Joyner Marina	H. Matthew
#6	7/12/1996	4.98	Local Observations	H. Bertha
#7	10/9/2013	4.98	Local Observations	Lunar High Tide
#8	10/4/2015	4.87	NOAA Wrightsville Beach Station	H. Joaquin
#9	10/8/1996	4.62	NOAA Wilmington Station	T.S. Josephine
#10	10/17/2016	4.77	NOAA Wilmington Station	H. Nicole

The water levels associated with a given return period are provided in Table 6. The analysis determined that a 1-year return period event (100% chance of exceedance during any given year) had a water level of approximately 4.0 feet NAVD, and a 30-year return period event (3% chance of exceedance during any given year) had a water level fluctuation above the long-term trend of approximately of 9.9 feet NAVD.

Table 6. Extreme Water Elevations – feet above NAVD (not including SLR effects)

Return period (years)	Water elevation (feet NAVD)
1	4.0
2	4.4
5	5.6
10	6.9
20	8.7
30	9.9

Due to the fact that statistical uncertainty increases as the return period exceeds the recorded length of the dataset, it is not recommended to use return period projections beyond twice the length of the measured record. In this study, there was a sufficiently long history of data (23 years) to have statistical confidence for the desired return periods.

In an effort to focus on mitigating the flooding impacts to Canal Drive and Florida Avenue that occur during high tide events the water level elevations associated with the 1-year and 2-year return period events were selected as a basis for the analysis to determine the minimum bulkhead elevation. The 1-year and 2-year return period events are above the maximum measured tide levels in 2017 for both the Wilmington (Figure 6) and the Wrightsville Beach (Figure 7) NOAA stations and are within the range of locally observed high water levels associated with lunar high tide events as shown in Table 4.

3.4 Total Water Level Projections

To determine the water levels to use in long-term planning, a total water level projection was computed by summing together the mean sea level rise (1992 to 2018), the expected sea level rise, the water level associated with the 1-year and 2-year return period events, and a “freeboard” or safety factor. The total water level projection for the Carolina Beach Yacht Basin in 2048 (30-year planning horizon) can be found by summing the following:

Design Elevation = SLR (1992-2018) + SLR (future) + Storm Effects + Structure Freeboard

Where:

- **SLR (1992-2018):** The Sea Level Rise from 1992 to 2018 is equal to 0.20 feet (Section 3.1.3.3).
- **SLR (future):** The expected sea level rise for 30 years based on the IPCC RCP projections + Vertical Land Movement (Table 3).
- **Storm Effects:** The expected water level above the average daily maximum associated with return period events in any given year (Table 6).
- **Structural Freeboard:** An additional vertical distance that represents a safety factor, which can be defined by the Town. It is recommended that a minimum of 0.5 feet be utilized.

The planning elevations in Table 7 represent a range of projected water levels based on the results of the analysis that combine the mean sea level rise (1992 to 2018), the expected sea level rise, expected water levels to occur during a storm event having a 1-year or 2-year return period within the next 30 years and a structural freeboard factor.

Table 7. Summary of Design Planning Water Elevation Projections

	Low Range (1-year Return Period)	Mid Range (1-year Return Period)	Upper Range (2-year Return Period)
SLR 1992-2018 (ft.)	0.20	0.20	0.20
IPCC RCP 2.6 (ft.)	0.49	0.49	-
IPCC RCP 8.5 (ft.)	-	-	0.58
Storm Effects (ft. NAVD)	4.0	4.0	4.4
Structure Freeboard (ft.)	0.0	0.5	0.5
2048 Design Elev. (ft. NAVD)	**4.7**	**5.2**	**5.7**

Therefore, for a 30-year planning horizon, it is recommended that the Town prepare for a minimum design water level elevation of at least 4.7 ft., NAVD (1-year return period event, RCP 2.6 projection, and no structural freeboard). Using the results of this study, the calculation was also completed for a 1-year return period event, RCP 2.6 projection, with the minimum structural freeboard (Mid-Range) and a 2-year return period event, RCP 8.5 projection, with the minimum structural freeboard (High Range) and resulted in water levels of 5.2 ft. and 5.7 ft. NAVD, respectively.

4. EXISTING CONDITIONS SURVEYS

Between October and December 2018, APTIM engineers performed field observations to catalogue the existing conditions of tidally influenced bulkheads, stormwater outfalls and inlets, and backflow prevention devices throughout the study site. The surveys were conducted in accordance with the Minimum Performance Standards for the U.S. Army Corps of Engineers (USACE), Engineering and Design Hydrographic Surveying Manual (EM 1110-2-1003). Methods and results of these field observations are discussed below. For additional information, refer to Appendix A, which includes the series of Bulkhead and Stormwater System Assessment Maps. Furthermore, all data is compiled within a GIS geodatabase that has been provided to the Town along with this report.

4.1 Bulkhead Surveys

Prior to the start of the survey, reconnaissance of known survey monuments were conducted to confirm that survey control was in place and undisturbed. A Real Time Kinematic Global Positioning System (RTK GPS) was used to locate and confirm survey control for this project. The horizontal and vertical accuracy of control data meets the accuracy requirements as set forth in the Engineering and Design Hydrographic Surveying Manual (EM 1110-2-1003). In order to achieve required accuracy, the topographic surveys were controlled using 2nd order monuments, specifically WATERWAY and KURE AZ MK from the National Geodetic Survey (NGS) (Table 8). Horizontal and vertical positioning checks were conducted at the beginning and end of each day using at least two 2nd order monuments in the project area. The RTK GPS utilizes statistical methods to ensure accuracy of RTK GPS data remains within the 95% confidence interval. The control check shots were acquired using the Trimble survey style Topo shot, at a minimum of five (5) epochs, which results in a high accuracy location.

Table 8. Control Monument Information

North Carolina State Plane NAD 83/2011 NAVD 88 US Survey Feet			
Monument Name	**Northing**	**Easting**	**Elevation**
WATERWAY	112223.43	2333343.79	49.59
KURE AZ MK	93936.69	2331623.45	22.72

Upon completion of the control reconnaissance and establishment, operations collecting topographic data for bulkheads, stormwater inlets, and outfalls were initiated. All topographic data in the project area was collected using extended rod RTK GNSS rovers. Topo shots were taken at a minimum of 5 epochs for every position collected on bulkheads, stormwater inlets, and outfalls. All vertical data were collected in the North American Vertical Datum of 1988 (NAVD88) relative to geoid model 12a. All horizontal data were collected in the North Carolina State Plane Coordinate System, North American Datum of 1983/2011 (NAD83/11). All horizontal and vertical data were collected in U.S. survey feet.

For the purposes of this study, a representative elevation was determined for each waterfront parcel's bulkhead, shoreline structure, or vegetation only shoreline along Canal Drive and Florida Avenue. Elevations were taken along the top of each bulkhead or shoreline structure and then averaged to provide a representative elevation. On parcels with no structure, elevations were taken in a straight line across the property, approximately between the bulkheads on the adjacent parcels, and then averaged to provide a representative elevation. Plan view maps showing the average representative elevation of the bulkheads or shoreline surveyed within the study site are provided in Appendix A. All survey data was provided as part of the GIS geodatabase digital deliverable.

Figure 13. APTIM Conducting Survey of the Bulkheads along the Carolina Beach Yacht Basin.

4.2 Stormwater Outfall and Inlet Surveys

In addition to the bulkheads, APTIM located, observed, and surveyed 17 stormwater outfalls and 110 stormwater inlets along Canal Drive and Florida Avenue. The stormwater outfalls flow directly to the Carolina Beach Yacht Basin. Stormwater outfall elevations were collected at the top of the outfall pipe as close to the waterward edge of the pipe as possible. If the outfall had a duckbill, an elevation was taken on the top of the pipe where the pipe met the duckbill as shown in Figure 14. Stormwater inlet elevations were taken at the center of each inlet grate as shown in Figure 14. Plan view maps showing the location and representative elevation of the stormwater outfalls and inlets surveyed within the study site are provided in Appendix A. All survey data was provided as part of the GIS geodatabase digital deliverable.

Figure 14. Surveying an Outfall Pipe Located at 909 Canal Drive (upper). Surveying Stormwater Inlets Along Canal Drive (lower).

In addition to the bulkhead surveys, a video record was collected. The video was captured using a small Un-manned Aerial System (sUAS) or drone to further document the conditions along the study area's shoreline. The video provided a visual record of the study site shoreline and facilitated quality control of the assessment observations. All videos were provided as part of the digital deliverable. An example screenshot is displayed in Figure 15.

Figure 15. Screenshots from the Drone Video showing a portion of the marina bulkhead along Canal Drive and the bulkhead at 1313 Canal Drive.

5. BULKHEAD AND STORMWATER SYSTEM EVALUATION

5.1 Bulkhead Elevations

For the purpose of this study, representative elevations for 144 bulkheads and shorelines (both public and private) within the study area were determined. The average representative elevations for each property (with or without a structure) are presented in a map series provided as Appendix A. Elevations vary throughout the study area due to the timing of development and redevelopment of waterfront properties.

The average elevation for all parcels (with or without structures) assessed during this study was 4.2 ft. NAVD, where the lowest and highest average elevations range from 1.9 ft. NAVD (no bulkhead) to 6.5 ft. NAVD, respectively. On parcels where there was no bulkhead or shoreline structure, the average elevation of the shoreline was 3.4 ft. NAVD, with a range of 1.9 ft. to 4.4 ft., respectively.

Figure 16 presents a summary of the elevations for all the structures surveyed and grouped using 0.5 foot elevation brackets. Considering the 30-year planning elevation ranges, approximately 72% or 104 of the structures have crest elevations below 4.7 ft. (low range), approximately 90% are at or below elevation 5.2 ft. (mid range) and 97% are at or below elevation 5.7 ft. (upper range).

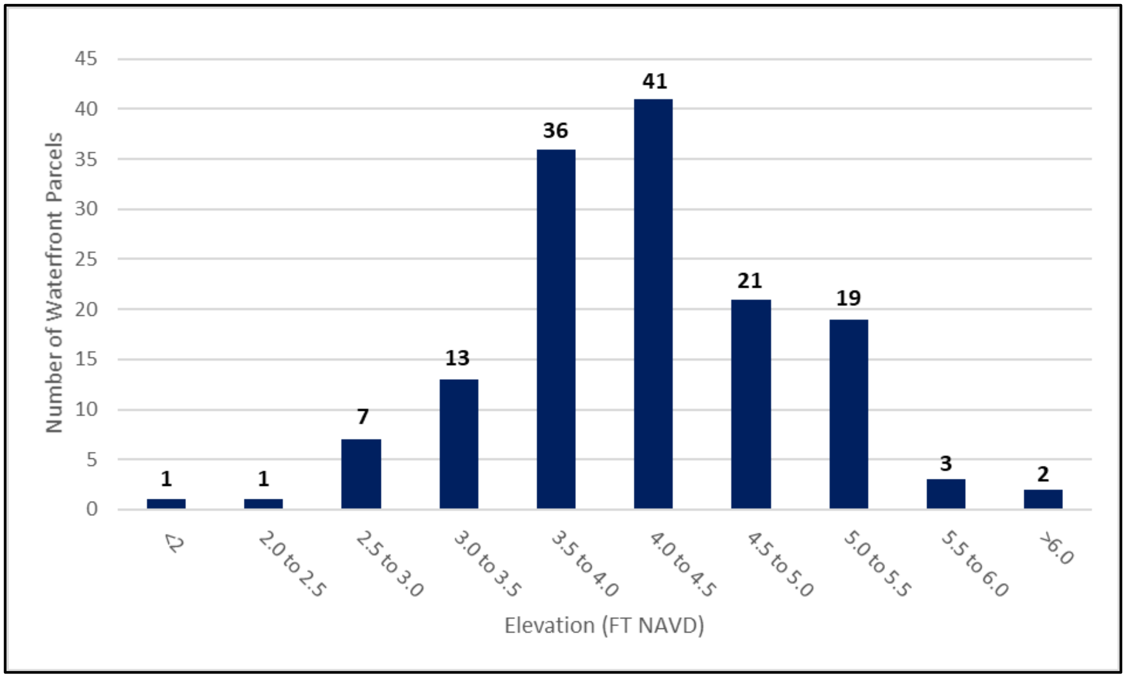

Figure 16. Elevation Summary of All Structures/Shorelines.

Figure 17 displays the distribution of elevations for the 15 public sites inspected during this study. Of the publically owned sites, 73% or 11 of the public sites (6 bulkheads and 5 vegetated shorelines) are below elevation 4.7 ft., approximately 87% are at or below elevation 5.2 ft. (mid range), and 93% are at or below elevation 5.7 ft. (upper range).

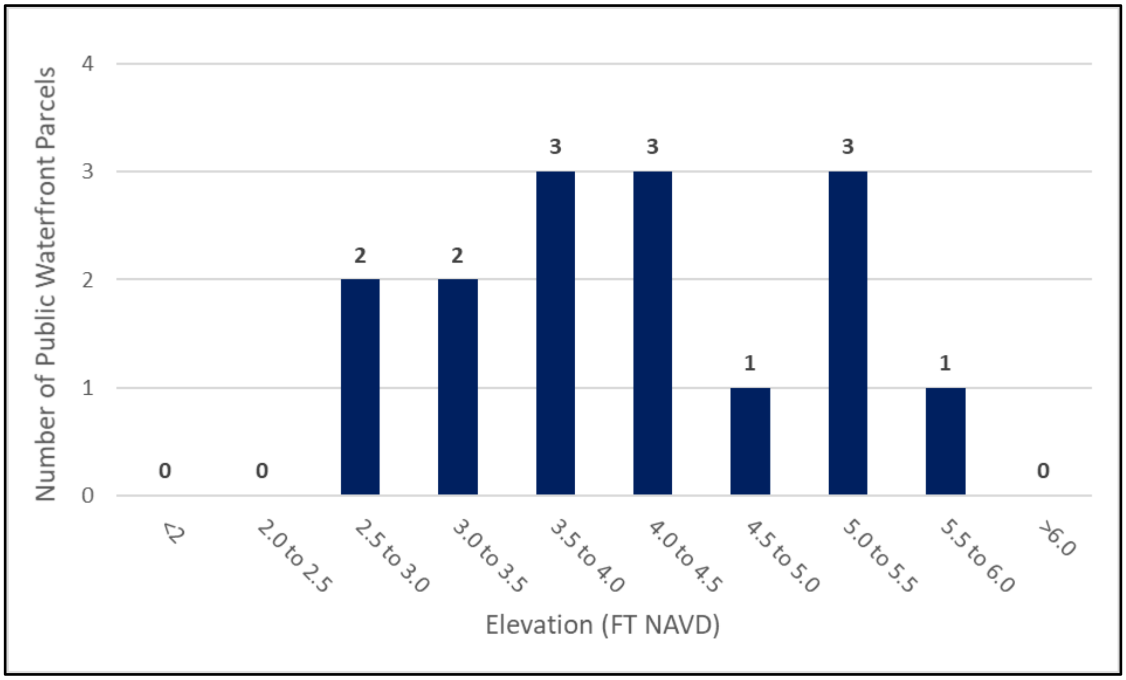

Figure 17. Elevation Summary of Public Structures/Shorelines.

Examples of flooding of Canal Drive directly attributed to overtopping of bulkheads or inundation of low-lying parcels with no bulkhead are shown in Figure 18 and Figure 19. The property at 1007 Canal Drive shown in Figure 18 does not have a bulkhead and has an average elevation of 1.94 ft. NAVD, the lowest elevation along the Canal Drive shoreline. The photographs were taken shortly after high tide on October 9, 2018, water was observed flowing onto Canal Drive from the property as shown in the lower image of Figure 18. The photographs in Figure 19 show a similar situation on the property at 1013 Canal Drive with the exception that the water came around the timber bulkhead (average elevation 4.3 ft. NAVD) and entered from the neighboring property to the north that has an average shoreline elevation of 2.8 ft. NAVD and does not have a bulkhead. The lower image shows the water from the property flowing onto and ponding on Canal Drive.

Figure 18. View of the property at 1007 Canal Drive at high tide (upper); water flooding onto Canal Drive looking south from 1007 Canal Drive (lower).

Figure 19. View of high tide flooding around bulkhead at 1013 Canal Drive (upper) and water flowing from the property onto Canal Drive (lower).

5.2 Bulkhead Conditions

Throughout the study area, an assessment was conducted of private and public parcels to evaluate the current condition of the waterfront structures (if present) fronting each parcel. Observations were conducted by an APTIM engineer and were limited to the exposed visible portions of each bulkhead. Specific attributes of each structure were recorded including the structure type, material, and condition. Structure types included bulkheads (timber, vinyl and metal sheet pile, concrete), rock rubble/concrete fragments, and vegetated shorelines (i.e. no structure). Parcels with multiple shoreline structures were divided into multiple entries. The condition of each structure was evaluated and assigned a rating based on visible deterioration of the structure materials. Deterioration included visible cracking, corrosion, spalling, or rotting. A rating was assigned based on the field observations for each individual structure and the criteria established in the Routine Underwater Condition Assessment Ratings (ASCE, 2001). These criteria are listed and defined in Table 9. The results of the assessment are included within the GIS geodatabase digital deliverable and the ratings were color-coded and are displayed on the assessment maps included in Appendix A.

Table 9. Routine Underwater Condition Assessment Ratings (ASCE, 2001)

Rating		Description
6	Good	No visible damage, or only minor damage is noted. Structural elements may show very minor deterioration, but no overstressing is observed. No repairs are required.
5	Satisfactory	Limited minor to moderate defects or deterioration are observed, but no overstressing is observed. No repairs are required.
4	Fair	All primary structural elements are sound, but minor to moderate defects or deterioration is observed. Localized areas of moderate to advanced deterioration may be present but do not significantly reduce the load-bearing capacity of the structure. Repairs are recommended, but the priority of recommended repairs is low.
3	Poor	Advanced deterioration or overstressing is observed on widespread portions of the structure but does not significantly reduce the load-bearing capacity of the structure. Repairs may be carried out with moderate urgency.
2	Serious	Advanced deterioration , overstressing, or breakage may have significantly affected the load-bearing capacity of primary structural components. Local failures are possible and loading restrictions may be necessary. Repairs may need to be carried out on a high-priority basis with urgency.
1	Critical	Very advanced deterioration, overstressing, or breakage has resulted in localized failure(s) of primary structural components. More widespread failures are possible or likely to occur, and load restrictions should be implemented as necessary. Repairs may need to be carried out on a very high priority basis with strong urgency.

Data and observations of 144 bulkhead structures, including vegetated shorelines, within the 134 public and private waterfront parcels of the study area were collected as part of this study. The data was evaluated to support the Town in assessing its vulnerability to future flooding events and to identify options to protect its infrastructure and citizen's property. To facilitate this evaluation, all of the collected data were incorporated into a GIS geodatabase. The GIS geodatabase is a tool that can be utilized by the Town to analyze the data collected as a part of this study with data collected from the water level and rain gauge monitoring station during future flooding events to assist in identifying and prioritizing the most flood prone areas.

Table 10 presents a summary of the bulkhead conditions throughout the study area by ownership. The data shows that the majority of the bulkheads observed were in the satisfactory to fair classifications. None of the bulkheads observed were in the serious or critical classifications. A total of 9 shorelines (public and privately owned) were not rated either because the structure was unable to be adequately observed or due to the non-structural nature of the shoreline structure (i.e. rock, concrete rubble, and sand bags). Throughout the study area, 16 parcels were identified as having no bulkhead or a portion of the shoreline along the parcel had no structure.

Table 10. Bulkhead Condition Summary

	Good	Satisfactory	Fair	Poor	Serious	Critical	No Structure	Not Rated	All
Public	0	3	5	0	0	0	5	2	15
Private	7	50	50	4	0	0	11	7	129
Total	**7**	**53**	**55**	**4**	**0**	**0**	**16**	**9**	**144**

5.2.1 Private Bulkheads

Privately owned parcels make up approximately 91% of the shoreline frontage along Canal Drive and Florida Avenue; however, results of data collected show that 83% of the private bulkheads were classified in fair to good condition and only 3% were classified to be in poor condition. All of the collected data was incorporated into a GIS geodatabase to allow for additional analysis and provided as a deliverable to the Town.

5.2.2 Public Bulkheads

Publically owned parcels with and without bulkheads were also evaluated to assist the Town in cataloging the existing conditions of the structures, identifying those parcels without structures, and prioritizing installation or improvements of bulkheads on Town owned parcels. A ranking scheme was developed to prioritize which locations were in greatest need of attention. The locations were prioritized by the average elevation (from lowest to highest) with priority given to those locations that do not currently have a structure in place. Table 11 lists the prioritized recommendations for public bulkhead improvements.

Table 11. Recommended Public Bulkhead Improvements

Number	Site name (street name or intersection)	Structure Type	Condition Assessment	Avg. Top Elevation (Ft, NAVD)	Recommendation
1	Maryland Ave / Florida Ave	No Structure	N/A	2.8	Install structure
2	Scotch Bonnet Ln / Canal Dr	Sandbags	N/A	2.8	Install structure
3	Seahorse Ln / Canal Dr	No Structure	N/A	3.6	Install structure
4	Delaware Ave / Florida Ave	No Structure	N/A	3.8	Install structure
5	Clam Shell Ln / Canal Dr	No Structure	N/A	4.1	Install structure
6	Oystershell Ln / Canal Dr	No Structure	N/A	4.4	Install structure
7	Starfish Ln / Canal Dr	Concrete Mass	N/A	3.3	Remove concrete & Install structure
8	Sailfish Ln / Canal Dr	Concrete	Satisfactory	3.4	Raise bulkhead
9	Sandpiper Ln / Canal Dr	Timber Bulkhead	Satisfactory	3.8	Raise bulkhead
10	Dolphin Ln / Canal Dr	Timber Bulkhead	Fair	4.5	Raise bulkhead
11	301 Canal Dr. Marina - South Side	Timber Bulkhead	Fair	4.6	Raise bulkhead
12	Scallop Ln / Canal Dr	Timber Bulkhead	Fair	5.1	Repair leaks in bulkhead
13	Sea Gull Ln / Canal Dr	Timber Bulkhead	Fair	5.9	Observed repair to compensate for broken wailer. Repair leaks in bulkhead.
14	Sand Dollar Ln / Canal Dr	Timber Bulkhead	Satisfactory	5.0	-
15	301 Canal Dr. Marina - East Side	Timber Bulkhead	Fair	5.5	-

While the Town can improve publically owned bulkheads and install new bulkheads to mitigate overtopping and flooding, this effort alone will have limited impact without private owner improvements. For example, consider the structure at Scotch Bonnet Lane and Canal Drive (Figure 20). The existing average elevation of the publically owned sandbagged shoreline is 2.8 feet NAVD. The Town can install a bulkhead to the adopted future design elevation, but flooding will not be prevented until the adjoining bulkheads on either side with existing elevations of 3.6 ft. and 3.7 f.t NAVD are also raised to the adopted future design elevation.

Figure 20. View of the west end of Scotch Bonnet Lane.

5.3 Stormwater System

The Town has installed backflow prevention devices at the stormwater outfalls located along Canal Drive and Florida Avenue to minimize backflow up through the inlets. Backflow prevention devices are a critical component for the stormwater system to work efficiently by preventing water from backing up through the system and into the roadways during high water events. Backflow valves that do not seal properly not only allow water to flood into the stormwater system during high water events, but may also reduce the effectiveness of the flooded system to drain excess surface water that accumulates during rain events.

APTIM conducted observations of the stormwater outfalls, backflow prevention devices and stormwater inlets throughout the study area. During these observations, an APTIM engineer noted the dimensions and material of the outfall and the type of backflow prevention device. A total of 17 stormwater outfalls were observed during the site investigations and 110 stormwater inlets located along Canal Drive and Florida Avenue. All of the stormwater outfalls observed were fitted with backflow prevention devices. Results of these investigations are presented visually on the assessment maps in Appendix A and Appendix C. The information is also included in the GIS geodatabase digital deliverable.

Figure 21. APTIM Conducting Stormwater Outfall Observations.

Currently, there are two types of backflow prevention devices installed throughout the study area including: duckbills (recurved) and WaStop® inline check valves. APTIM inventoried 17 backflow prevention devices. Town GIS records indicate that eight (8) additional outfalls are present, primarily along the marina at the south end of the project area. However, due to the elevations of these outfalls and conditions at the time of the site visit, these outfalls were not observed and it is unknown what type of backflow prevention is installed at those locations. Of the 17 stormwater outfalls observed within the study area, 6 were fitted with the WaStop® inline check valves and the remaining 11 had duckbill type backflow prevention devices installed, both of which are shown in Figure 22.

Figure 22. Examples of Functioning Backflow Prevention Devices Currently Installed. (left: recurved duckbill valve, right: WaStop® Inline Check Valve)

Several of the existing subtidal duckbill backflow prevention devices were observed to be encrusted with oysters and barnacles that inhibit proper sealing of the valves. It has also been observed that debris or trash can get caught in the opening and prevent the duckbill valve from sealing properly. Regular maintenance to remove any obstructions may improve the function of these backflow prevention devices. The WaStop® inline check valves that were observed appeared to be unobstructed with marine growth or debris and functioning properly at the time of the observations. Several residents that live along Canal Drive have reported that inlets along Canal Drive no longer back up with water during high tides in the locations where the duckbill valves were replaced by the WaStop® valves. Table 12 provides a summary of the elevation, pipe material, size and locations where the duckbill valves and WaStop® valves were observed. Included in the table are the approximate locations of that outfalls included in the Town's GIS database, but were not observed during the study.

Table 12. Stormwater Outfall and Backflow Prevention Device Summary

No.	Location	Northing	Easting	Outfall Pipe Elevation (ft, NAVD)	Pipe Material	Size	Backflow Prevention Device
1	Scallop / Canal	2335930.0	107255.9	-0.5	Unknown	24"	Duckbill
2	Seagull / Canal	2336093.9	107742.3	0.4	Corrugated Plastic	16"-18"	Duckbill
3	1407 Canal	2337695.8	112147.2	0.8	Ductile Iron	24"	Duckbill
4	Dolphin / Canal	2335781.4	106734.1	0.9	HDPE	10"	Duckbill
5	Clam Shell / Canal	2337521.9	111755.6	1.4	Ductile Iron	24"	Duckbill
6	403 Canal / 405 Canal	2335838.4	106850.4	1.6	Corrugated Plastic	16"-18"	Duckbill
7	Oystershell / Canal	2336395.0	108743.5	1.7	Corrugated Plastic	16"	Duckbill
8	Starfish / Canal	2337130.6	110742.6	1.8	Unknown	12"	Duckbill
9	Maryland / Florida	2336676.8	113455.1	2.0	Corrugated Plastic	16"	Duckbill
10	513 Canal / 515 Canal	2336053.3	107586.8	2.7	Corrugated Plastic	20"	Duckbill
11	1213 Canal[1]	-	-	-	-	-	Duckbill
12	110 Carl Winner[2]	-	-	-	-	-	Unknown
13	301 Canal A[2]	-	-	-	-	-	Unknown
14	301 Canal B[2]	-	-	-	-	-	Unknown
15	301 Canal C[2]	-	-	-	-	-	Unknown
16	301 Canal D[2]	-	-	-	-	-	Unknown
17	301 Canal E[2]	-	-	-	-	-	Unknown
18	301 Canal F[2]	-	-	-	-	-	Unknown
19	1315 Canal[2]	-	-	-	-	-	Unknown
20	Sailfish / Canal	2336217.1	108248.2	-0.1	Corrugated Plastic	16"	WaStop® Inline Check Valve
21	Sand Dollar / Canal	2337333.7	111272.4	0.0	Ductile Iron	16"-18"	WaStop® Inline Check Valve
22	Sandpiper / Canal	2336568.5	109262.7	0.0	Corrugated Plastic	18"	WaStop® Inline Check Valve
23	909 Canal	2336673.3	109511.0	0.5	Corrugated Plastic	16"	WaStop® Inline Check Valve
24	Seahorse / Canal	2336770.3	109754.6	1.3	Corrugated Plastic	18"	WaStop® Inline Check Valve
25	Scotch Bonnet / Canal	2336944.3	110254.5	1.7	Corrugated Plastic	18"	WaStop® Inline Check Valve

[1] Only the backflow prevention device was observed at 1213 Canal Drive, no measurements were collected due to the conditions at the time of the site visit.
[2] The stormwater outfall was not observed.

During the site investigations, what appeared to be old stormwater outfalls made out of clay or concrete pipes were observed at the Seagull Lane street end, Seahorse Lane street end, and at 909 Canal Drive. The old outfalls were located within several feet of more recently installed stormwater outfalls with backflow prevention devices. Although the old outfalls appeared to be abandoned if not properly sealed or disconnected from the system they could provide a means for water to backflow into the stormwater system. It is not known whether these old outfalls are still connected to the system, this information is only provided to inform the Town of their existence. The photographs in Figure 23 show the relic outfall pipes adjacent to the more recently installed stormwater outfalls.

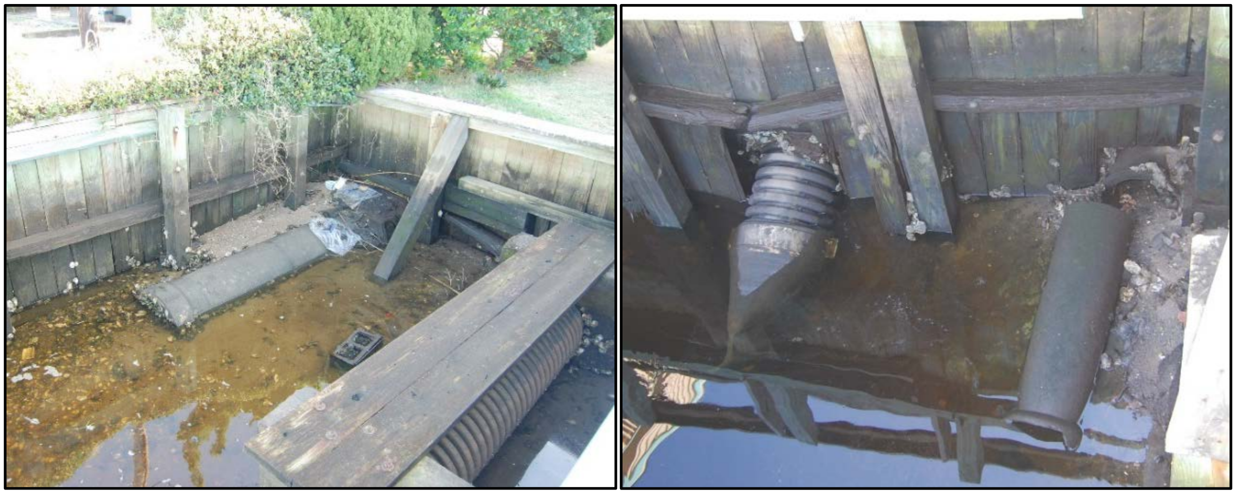

Figure 23. Abandoned Stormwater Outfall Pipes.
(left: 909 Canal Drive, right: Street End at Seagull Lane and Canal Drive)

The photographs in Figure 24 show water coming up through the street inlets in front of 909 and 911 Canal Drive during a high tide on the morning of January 22, 2019. There is a WaStop® backflow prevention device installed on the outfall at this location; however, there is also an abandoned outfall as this location as shown in Figure 23.

Figure 24. Water Coming Up Through Street Inlets During High Tide at 909 and 911 Canal Drive.

6. RECOMMENDATIONS

In response to flooding and high water events that have impacted the Canal Drive and Florida Avenue area, this study aimed to inventory current conditions and develop practical recommendations to reduce the risks of flooding for both public and private properties within the established project area. While these recommendations aim to reduce flooding and improve resiliency over a 30-year planning horizon, the recommendations are not intended to prevent all flooding. In addition, the recommendations are anticipated to take several years to implement, which will allow for adaptive management of the implementation and incremental investment in the most effective flood mitigation strategies.

In order to reduce coastal flooding within the study site and improve the Town's resiliency against rising water levels, the areas along Canal Drive and Florida Avenue with lower elevation bulkheads and shorelines and stormwater systems identified within this study should be addressed. This study primarily assessed the effectiveness of the bulkheads located on the waterfront along Canal Drive and Florida Avenue, and the effectiveness of the stormwater system to prevent water from backing up into the roadways during high water events in the Carolina Beach Yacht Basin.

Observations performed for this study suggest that flood risk reduction can be achieved through the installation of bulkheads at locations currently without a structure, as well as raising top elevations of low structures, repairing leaks, and other structural improvements. Based on the water level projection calculations performed as a part of this study, it is recommended that the Town use elevation of 4.7 feet as a minimum design elevation when planning for bulkhead improvements on a 30-year planning horizon. However, when considering the 30-year planning range of 4.7 ft. to 5.7 ft. approximately 72% to 97% of bulkheads or shoreline elevations in the study area are vulnerable to overtopping and require bulkhead raisings or bulkhead installations to help reduce the flooding impacts to Canal Drive and Florida Avenue during high tide events and storm related high tides.

Of the 17 outfalls located within the project area observed during the study, 11 do not currently have updated check valve backflow prevention devices. Due to conditions at the time of the site visit, 8 outfalls were unable to be observed and it is unknown what type of backflow prevention is installed at those locations. The Town should systematically replace the duckbill type backflow prevention devices with the WaStop® check valve type backflow prevention devices (or similar) on all eleven (11) observed outfalls (and possibly 8 unobserved outfalls) and all future outfall pipes. Given limitations on Town resources, it is unrealistic to make all improvements to increase bulkhead elevations and ensure proper backflow prevention on all outfalls in the short-term.

APTIM recommends that the Town use the spatial data developed in the course of this study to determine priority areas in which improvements will have the greatest reduction in flood impacts. This should be done by seeking real-time public input on flooding events in a way that allows the public to report date, time, and location of flooding within the project area. Furthermore, data collected by the Town's water level and weather monitoring station, installed in late January 2019 in the Carolina Beach Yacht Basin, will provide supplemental data to prioritize public and private investment aimed at mitigating flooding in the study area. These data will also allow engineers to re-assess the water level projections reported in this report, which will give the Town more accurate numbers to use in planning.

As demonstrated throughout this report, the Town is vulnerable to coastal flooding. Although low or unmaintained bulkheads, non-bulkheaded shorelines, and ineffective backflow prevention devices appear to be the primary causes of upland nuisance flooding in the study area they may not be the only causes. The long-term rise in sea level will result in higher water tables within upland areas. If the upland areas are low in elevation relative to the water table, upland flooding may become more frequent. In addition to the bulkhead and stormwater system recommendations provided, it is advised that the Town monitor its public properties for the occurrence of flooding due to rising water table levels over the next decade(s) and incorporate these data into the long-term flood mitigation strategy.

The recommendations provided acknowledge that without outside funding the Town is unlikely to have the financial resources to make all recommended changes to bulkhead elevation and stormwater system improvements in the study area at one time. The following recommendations have been structured in such a way as to allow for an iterative implementation process that takes advantage of new data as it becomes available. This strategy also allows for an adaptive management approach that will prioritize Town resources in those areas that have demonstrated effective flood mitigation:

Improvement Implementation Cost Estimates: A comprehensive cost estimate should be developed to include the completion of bulkhead improvements to the minimum design elevation recommended by this study, installation of WaStop® Inline Check Valves backflow prevention devices at the remaining outfall locations along the Carolina Beach Yacht Basin, and re-lining the stormwater pipe network along Canal Drive and Florida Avenue. This estimate should be developed in a timeframe that would allow the Town to have access to the estimates during upcoming budgetary planning for the FY 19/20 budget as well as provide an idea for how long it might take to implement all of the recommended improvements. A comprehensive cost estimate could also be used when submitting applications for grant program funds.

Real-Time Public Flood Data: The Town should use the spatial data developed in the course of this study to determine priority areas in which improvements will have the greatest reduction in flood impacts. This should be done by implementing a system where the public is encouraged to report flooding issues as they occur by simply providing a date, time, location, estimated water depth (if possible) and possibly a photo. The reporting system could be as basic as setting up a general email account (for example: **northendcbflooding@gmail.com**) for residents or visitors to submit their reports and photos. This public input program should be implemented as soon as possible.

6-Month Post-Study Analysis: Following several months of data collection from both the public input program and the water level and weather monitoring station recently installed, an updated analysis should be conducted. This analysis should focus specifically on utilizing the additional data, along with the available data collected as part of this study, to develop a priority list of improvements the Town can implement during FY 19/20 based on the available budget. The scope of the analysis should be developed to ensure completion of data analysis and recommendations are provided in a timely manner to allow the Town to implement priority projects in FY 19/20.

Multi-Year Implementation Cycle: As previously indicated, the recommendations provided herein acknowledge that a one-time implementation of changes to bulkhead elevation and stormwater system improvements within the study area may not be feasible. In order to implement flood risk reduction strategies in an efficient and iterative manner, the Town should re-prioritize remaining improvements needed in both the bulkhead system and stormwater system on an annual basis. This reprioritization should follow a similar method as described under the "6-month Post-Study Analysis" recommendation. In that regard, the scope of the annual analysis should utilize the most up to date data from the public input program and water level/weather monitoring station. These data, combined with the available data collected as part of this study, and an assessment of the effectiveness of the flood mitigation strategies implemented to date, can be used to set priorities for the corresponding fiscal year.

Upon implementation of the year's priority projects, the cycle would continue with annual inventory of new data, updated analysis, and recommendations for the corresponding fiscal year. This multi-year strategy will allow the Town to appropriate resources based on 1) public input; 2) the effectiveness of past flood risk reduction projects; and 3) the most up to date monitoring data. This cycle can be implemented for whatever period of time sufficient to provide an acceptable level of flood risk reduction and resiliency based on available resources.

Development of Canal Drive/Florida Avenue Stormwater Monitoring and Maintenance Plan: In addition to installation of backflow prevention devices and maintenance of the currently installed devices, it is recommended that the Town continue to monitor the performance of the stormwater networks under higher water levels and with long-term sea level rise. The rise in tidal water levels will also affect local groundwater elevations. It is expected that with the age of the stormwater system along Canal Drive and Florida Avenue, some structural and/or hydraulic decay may have occurred, or will occur in the future. In the event of higher groundwater elevations and decayed pipes, leakage into the pipes may be occurring, which would circumvent efforts of backflow prevention. Re-lining of stormwater pipes in certain areas may be necessary.

It is also recommended that the Town continue to develop standards for maintenance of backflow prevention devices, monitor for structural or hydraulic decay of the stormwater system, and provide guidelines to assist the owners of private stormwater systems along Canal Drive and Florida Avenue to improve and protect those private systems from future flooding events.

The stormwater system observations obtained through this study, revealed opportunities for improvements within the currently installed infrastructure, largely related to maintenance. The following recommendations, listed in order of importance, are made to assist the Town with the initial development of a maintenance plan and will need to be customized for Town implementation:

1. It is recommended that all abandoned stormwater outfalls along the Carolina Beach Yacht Basin that have not been removed be inspected to ensure that they are no longer connected to the system. Abandoned stormwater outfalls that have not been removed, filled, or properly disconnected from the stormwater system could circumvent the Town's effort of backflow prevention.

2. All existing external backflow prevention devices should be inspected and cleaned twice per year for oysters, barnacles, and any other blockages. It is recommended that inspections are scheduled around April and September of each year prior to rainy season, and seasonal high tides. Once the rate of oyster and barnacle growth is known, the cleaning frequency may need to be adjusted.

3. All existing internal backflow prevention devices should be inspected and cleaned twice per year for blockages. Similarly, to the external maintenance, it is recommended that internal inspections are scheduled around April and September of each year prior to rainy season, and seasonal high tides.

Private Stormwater System Improvements: While the Town can endeavor to make improvements to publicly owned systems, improvements on private parcels will also need to be undertaken. In general, it is recommended that the Town perform public outreach and educate residents about the contributing factors to coastal flooding and develop guidelines for improvements to private bulkheads and stormwater systems. The Town may consider providing select data and maps from this study via an online portal for residents to better understand the conditions of their privately owned parcels.

The Town should consider providing guidance to private property owners on how they can contribute to reducing the demand on the public stormwater system during high water and rainfall events thereby reducing the volume of water contributing to flooding along Canal Drive and Florida Avenue. The Town should also consider promoting stormwater initiatives that can be implemented by local residents such as 1) the improvement and/or installation of gutter systems on private homes, 2) the use of permeable pavements for driveway aprons and any areas typically covered by impervious materials to reduce the amount of impervious surfaces and 3) the use of private stormwater storage systems (above or below ground) to retain stormwater on the property during an event that is slowly released following the event.

7. LITERATURE CITED

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APPENDIX A
BULKHEAD AND STORMWATER SYSTEM ASSESSMENT MAPS

APPENDIX B
CANAL DRIVE & FLORIDA AVENUE BULKHEAD ASSESSMENT SUMMARY

Canal Drive & Florida Avenue Bulkhead Assessment Summary				
Ranking Number	**Site name (street name or other landmark)**	**Bulkhead Type**	**Condition Assessment**	**Avg. Top Elevation (Ft, NAVD)**
1	1007 Canal Dr	No Bulkhead	N/A	1.9
2	217 Florida Ave	No Bulkhead	N/A	2.4
3	1305 Canal Dr	Timber Bulkhead	Fair	2.6
4	107 Florida Ave	No Bulkhead	N/A	2.7
5	317 Canal Dr	Rock/Concrete Rubble	Fair	2.7
6	Maryland Ave / Florida Ave	No Bulkhead	N/A	2.8
7	Scotch Bonnet Ln / Canal Dr	Sandbags	N/A	2.8
8	1017 Canal Dr	No Bulkhead	N/A	2.8
9	211 Florida Ave (east side)	No Bulkhead	N/A	2.9
10	1205 Canal Dr (north side)	No Bulkhead	N/A	3.0
11	1005 Canal Dr	Timber Bulkhead	Fair	3.0
12	233 Florida Ave (north side)	No Bulkhead	N/A	3.2
13	905 Canal Dr	No Bulkhead	N/A	3.2
14	1311 Canal Dr	Timber Bulkhead	Fair	3.2
15	Starfish Ln / Canal Dr	Concrete Mass	N/A	3.3
16	619 Canal Dr	Concrete	Satisfactory	3.3
17	227 Florida Ave	Rock/Concrete Rubble	N/A	3.3
18	Sailfish Ln / Canal Dr	Concrete	Satisfactory	3.4
19	233 Florida Ave	Timber Bulkhead	Fair	3.4
20	407 Canal Dr	Timber Bulkhead	Fair	3.4
21	231 Florida Ave	Timber Bulkhead	Fair	3.4
22	1003 Canal Dr	Timber Bulkhead	Fair	3.5
23	207 Florida Ave	Timber Bulkhead	Fair	3.5
24	203 Florida Ave	Concrete/Rock Slope	Fair	3.5
25	1113 Canal Dr	Timber Bulkhead	Fair	3.6
26	1103 Canal Dr	Timber Bulkhead	Satisfactory	3.6
27	Seahorse Ln / Canal Dr	No Bulkhead	N/A	3.6
28	703 Canal Dr	Concrete wall	Fair	3.6
29	1101 Canal Dr	Barrier	Fair	3.6
30	1115 Canal Dr	Vinyl Sheet pile	Satisfactory	3.6
31	1105 Canal Dr	Timber Bulkhead	Fair	3.6
32	1313 Canal Dr	Timber Bulkhead	Fair	3.6
33	215 Florida Ave	Timber Bulkhead	Fair	3.6
34	1117 Canal Dr	Timber Bulkhead	Fair	3.6
35	1119 Canal Dr	Timber Bulkhead	Fair	3.6
36	1019 Canal Dr	Vinyl Sheet pile	Satisfactory	3.7
37	705 Canal Dr	Timber Bulkhead	Satisfactory	3.7
38	1201 Canal Dr	Timber Bulkhead	Fair	3.7
39	413 Canal Dr	Rock/Concrete Rubble	N/A	3.7
40	115 Florida Ave	Timber Bulkhead	Satisfactory	3.7
41	235 Florida Ave	Timber Bulkhead	Fair	3.8
42	205 Florida Ave	Timber Bulkhead	Fair	3.8
43	Sandpiper Ln / Canal Dr	Timber Bulkhead	Satisfactory	3.8
44	507 Canal Dr	Timber Bulkhead	Satisfactory	3.8
45	503 Canal Dr	Timber Bulkhead	Fair	3.8
46	119 Florida Ave	Timber Bulkhead	Fair	3.8
47	Delaware Ave / Florida Ave	No Bulkhead	N/A	3.8
48	1211 Canal Dr	Timber Bulkhead	Fair	3.9
49	235 Florida Ave (Boat House)	Timber Bulkhead	Satisfactory	3.9
50	601 Canal Dr	Timber Bulkhead	Fair	3.9
51	609 Canal Dr	Timber Bulkhead	Fair	3.9

Canal Drive & Florida Avenue Bulkhead Assessment Summary				
Ranking Number	**Site name (street name or other landmark)**	**Bulkhead Type**	**Condition Assessment**	**Avg. Top Elevation (Ft, NAVD)**
52	211 Florida Ave	Timber Bulkhead	Fair	3.9
53	1213 Canal Dr	Timber Bulkhead	Fair	3.9
54	607 Canal Dr	Timber Bulkhead	Fair	3.9
55	605 Canal Dr	Timber Bulkhead	Satisfactory	4.0
56	501 Canal Dr	Timber Bulkhead	Fair	4.0
57	909 Canal Dr	Timber Bulkhead	Fair	4.0
58	907 Canal Dr	Timber Bulkhead	Fair	4.0
59	813 Canal Dr	Rock/Concrete Rubble	N/A	4.0
60	815 Canal Dr	Rock/Concrete Rubble	N/A	4.0
61	817 Canal Dr	No Bulkhead	N/A	4.0
62	405 Canal Dr	Timber Bulkhead	Fair	4.0
63	1205 Canal Dr	Timber Bulkhead	Fair	4.0
64	515 Canal Dr	Timber Bulkhead	Satisfactory	4.0
65	311 Florida Ave	Concrete Block	Poor	4.0
66	Clam Shell Ln / Canal Dr	No Bulkhead	N/A	4.1
67	303 Florida Ave	Timber Bulkhead	Poor	4.1
68	513 Canal Dr	Timber Bulkhead	Fair	4.1
69	311 Florida Ave	Vinyl Sheet pile	Good	4.1
70	915 Canal Dr	Vinyl Sheet pile	Satisfactory	4.1
71	1315 Canal Dr	Vinyl Sheet pile	Good	4.2
72	713 Canal Dr	Timber Bulkhead	Satisfactory	4.2
73	809 Canal Dr	Timber Bulkhead	Satisfactory	4.2
74	811 Canal Dr	Timber Bulkhead	Unknown	4.2
75	707 Canal Dr	Conc / Timber Bulkhead	Satisfactory	4.2
76	903 Canal Dr	Timber Bulkhead	Fair	4.3
77	911 Canal Dr	Timber Bulkhead	Satisfactory	4.3
78	1013 Canal Dr	Timber Bulkhead	Satisfactory	4.3
79	913 Canal Dr	Timber Bulkhead	Fair	4.3
80	115 Florida Ave (east side)	No Bulkhead	N/A	4.3
81	1011 Canal Dr	Timber Bulkhead	Satisfactory	4.3
82	1107 Canal Dr	Timber Bulkhead	Satisfactory	4.3
83	201 Florida Ave	Timber Bulkhead	Poor	4.3
84	807 Canal Dr	Concrete Rubble	N/A	4.4
85	305 Florida Ave	Timber Bulkhead	Poor	4.4
86	711 Canal Dr	Timber Bulkhead	Fair	4.4
87	Oystershell Ln / Canal Dr	No Bulkhead	N/A	4.4
88	615 Canal Dr	Timber Bulkhead	Satisfactory	4.4
89	611 Canal Dr	Timber Bulkhead	Fair	4.4
90	1317 Canal Dr	Timber Bulkhead	Satisfactory	4.4
91	1319 Canal Dr	Timber Bulkhead	Satisfactory	4.4
92	505 Canal Dr	Timber Bulkhead	Satisfactory	4.4
93	301 Florida Ave	No Bulkhead	N/A	4.4
94	517 Canal Dr	Timber Bulkhead	Satisfactory	4.4
95	715 Canal Dr	Timber Bulkhead	Satisfactory	4.4
96	219 Florida Ave	Timber Bulkhead	Satisfactory	4.5
97	321 Canal Dr	Timber Bulkhead	Fair	4.5
98	Dolphin Ln / Canal Dr	Timber Bulkhead	Fair	4.5
99	409 Canal Dr	Timber Bulkhead	Satisfactory	4.5
100	717 Canal Dr	Timber Bulkhead	Satisfactory	4.6
101	209 Florida Ave	Timber Bulkhead	Good	4.6
102	719 Canal Dr	Timber Bulkhead	Satisfactory	4.6

Canal Drive & Florida Avenue Bulkhead Assessment Summary				
Ranking Number	**Site name (street name or other landmark)**	**Bulkhead Type**	**Condition Assessment**	**Avg. Top Elevation (Ft, NAVD)**
103	617 Canal Dr	Timber Bulkhead	Satisfactory	4.6
104	301 Canal Dr Marina - South Side	Timber Bulkhead	Fair	4.6
105	415 Canal Dr	Timber Bulkhead	Fair	4.7
106	1207 Canal Dr	Timber Bulkhead	Satisfactory	4.7
107	613 Canal Dr	Vinyl Sheet pile	Satisfactory	4.7
108	107 Florida Ave (west side)	Timber Bulkhead	Satisfactory	4.7
109	311 Florida Ave	Timber Bulkhead	Fair	4.7
110	1209 Canal Dr	Timber Bulkhead	Satisfactory	4.7
111	411 Canal Dr	Timber Bulkhead	Satisfactory	4.7
112	307 Florida Ave	Timber Bulkhead	Fair	4.8
113	1401 Canal Dr	Timber Bulkhead	Fair	4.8
114	110 Carl Winner Ave Marina - West Side	Vinyl Sheet pile	Good	4.8
115	901 Canal Dr	Metal Sheet pile	Satisfactory	4.9
116	1215 Canal Dr	Timber Bulkhead	Satisfactory	4.9
117	221 Florida Ave	Vinyl Sheet pile	Satisfactory	5.0
118	417 Canal Dr	Vinyl Sheet pile	Satisfactory	5.0
119	419 Canal Dr	Vinyl Sheet pile	Satisfactory	5.0
120	311 Florida Ave	Vinyl Sheet pile	Good	5.0
121	1303 Canal Dr	Timber Bulkhead	Satisfactory	5.0
122	Sand Dollar Ln / Canal Dr	Timber Bulkhead	Satisfactory	5.0
123	1307 Canal Dr	Timber Bulkhead	Satisfactory	5.1
124	1111 Canal Dr	Timber Bulkhead	Satisfactory	5.1
125	111 Florida Ave	Timber Bulkhead	Fair	5.1
126	Scallop Ln / Canal Dr	Timber Bulkhead	Fair	5.1
127	701 Canal Dr	Timber Bulkhead	Satisfactory	5.1
128	1301 Canal Dr	Timber Bulkhead	Good	5.1
129	919 Canal Dr	Timber Bulkhead	Fair	5.2
130	403 Canal Dr	Timber Bulkhead	Fair	5.3
131	1001 Canal Dr	Timber Bulkhead	Satisfactory	5.3
132	319 Canal Dr	Timber Bulkhead	Satisfactory	5.3
133	401 Canal Dr	Timber Bulkhead	Fair	5.4
134	225 Florida Ave	Vinyl Sheet pile	Good	5.4
135	801 Canal Dr	Timber Bulkhead	Fair	5.4
136	213 Florida Ave	Vinyl Sheet pile	Satisfactory	5.5
137	301 Canal Dr Marina - East Side	Timber Bulkhead	Fair	5.5
138	313 Canal Dr	Timber Bulkhead	Fair	5.5
139	819 Canal Dr	Timber Bulkhead	Satisfactory	5.5
140	519 Canal Dr	Timber Bulkhead	Satisfactory	5.7
141	Sea Gull Ln / Canal Dr	Timber Bulkhead	Fair	5.9
142	229 Florida Ave	Concrete Block Wall	N/A	6.0
143	1217 Canal Dr	Timber Bulkhead	Satisfactory	6.1
144	803 Canal Dr	Timber Bulkhead	Fair	6.5

APPENDIX C
STORMWATER OUTFALL AND INLET ASSESSMENT SUMMARY

TOWN OF CAROLINA BEACH
CANAL DRIVE FLOODING & VULNERABILITY STUDY

Row ID	Town ID	Street	APTIM Name	Northing	Easting	Street Inlet Elev (ft, NAVD)	Outfall Pipe Elev (ft, NAVD)	Observed Backflow Prevention
1	SWST-271	CARL WINNER AVE	CATCH_315	2335452.20	106056.80	3.2		
2	SWST-169	CANAL DR	CATCH_314	2335658.96	106037.81	3.7		
3	NO TOWN ID	CANAL DR	CATCH_313	2335686.57	106003.61	3.6		
4	SWST-167	CANAL DR	CATCH_312	2335703.42	106058.99	3.4		
5	SWST-166	CANAL DR	CATCH_310	2335730.48	106199.83	3.0		
6	SWST-163	CANAL DR	CATCH_309	2335744.84	106196.71	2.6		
7	SWST-165	CANAL DR	CATCH_311	2335749.73	106185.44	2.9		
8	SWST-164	CANAL DR	CATCH_308	2335750.17	106213.09	2.8		
9	NO TOWN ID	CANAL DR	CATCH_307	2335755.15	106230.66	2.7		
10	SWST-160	CANAL DR	CATCH_306	2335760.00	106321.00	3.6		
11	SWST-161	CANAL DR	CATCH_305	2335768.29	106318.47	3.2		
12	SWST-162	CANAL DR	CATCH_304	2335780.45	106314.76	3.9		
13	OUTFALL	CANAL DR	Dolphin Ln / Canal Drive	2335781.38	106734.10	-	0.9	Duckbill
14	SWST-159	CANAL DR	CATCH_301	2335783.65	106424.63	3.1		
15	SWST-157	CANAL DR	CATCH_302	2335799.77	106421.16	3.3		
16	SWST-158	CANAL DR	CATCH_303	2335809.90	106414.76	3.0		
17	OUTFALL	CANAL DR	403 Canal Dr / 405 Canal Dr	2335838.39	106850.42	-	1.6	Duckbill
18	SWST-156	CANAL DR	CATCH_408	2335866.26	106706.54	2.8		
19	SWST-154	CANAL DR	CATCH_407	2335896.26	106698.48	2.7		
20	SWST-153	CANAL DR	CATCH_405	2335903.13	106832.24	2.9		
21	SWST-155	CANAL DR	CATCH_406	2335904.26	106719.98	2.8		
22	OUTFALL	CANAL DR	Scallop Ln / Canal Drive	2335929.97	107255.87	-	-0.5	Duckbill
23	SWST-152	CANAL DR	CATCH_404	2335938.30	106848.97	2.8		
24	SWST-149	CANAL DR	CATCH_403	2336028.26	107226.35	3.0		
25	SWST-151	CANAL DR	CATCH_402	2336050.73	107199.38	2.9		
26	OUTFALL	CANAL DR	513 Canal Dr / 515 Canal Dr	2336053.32	107586.81	-	2.7	Duckbill
27	SWST-150	CANAL DR	CATCH_401	2336057.90	107220.71	2.6		
28	OUTFALL	CANAL DR	Seagull Ln / Canal Drive	2336093.93	107742.32	-	0.4	Duckbill
29	SWST-145	CANAL DR	CATCH_505	2336126.90	107559.29	2.4		
30	SWST-146	CANAL DR	CATCH_506	2336157.07	107549.49	2.8		
31	SWST-142	CANAL DR	CATCH_504	2336177.45	107712.80	3.2		
32	NO TOWN ID	CANAL DR	CATCH_501	2336186.07	107739.56	3.1		
33	SWST-140	CANAL DR	CATCH_503	2336204.95	107700.71	2.9		
34	SWST-138	CANAL DR	CATCH_610	2336210.25	107835.02	4.1		
35	SWST-141	CANAL DR	CATCH_502	2336212.41	107724.09	3.3		
36	SWST-138	CANAL DR	CATCH_609	2336215.02	107832.67	3.3		
37	OUTFALL	CANAL DR	Sailfish Ln / Canal Drive	2336217.10	108248.19	-	-0.1	WaStop® Inline Check Valve
38	SWST-137	CANAL DR	CATCH_607	2336223.48	107860.13	3.4		
39	SWST-139	CANAL DR	CATCH_608	2336240.46	107824.12	2.9		
40	SWST-136	CANAL DR	CATCH_606	2336254.35	107957.31	3.2		
41	SWST-135	CANAL DR	CATCH_605	2336269.94	108005.82	2.9		
42	SWST-134	CANAL DR	CATCH_604	2336280.47	108045.30	2.8		
43	SWST-133	CANAL DR	CATCH_603	2336288.84	108069.61	2.8		
44	NO TOWN ID	CANAL DR	CATCH_602	2336325.57	108214.69	2.9		
45	SWST-131	CANAL DR	CATCH_601	2336360.18	108204.33	2.6		
46	SWST-132	CANAL DR	CATCH_705	2336365.95	108224.51	2.6		
47	OUTFALL	CANAL DR	Oystershell Ln / Canal Drive	2336395.01	108743.48	-	1.7	Duckbill
48	SWST-125	CANAL DR	CATCH_704	2336430.94	108550.58	2.9		
49	SWST-124	CANAL DR	CATCH_703	2336484.32	108710.03	2.9		
50	SWST-121	CANAL DR	CATCH_805	2336513.61	108799.13	2.8		
51	SWST-123	CANAL DR	CATCH_702	2336514.34	108705.82	2.7		
52	SWST-122	CANAL DR	CATCH_701	2336519.51	108723.33	2.8		
53	SWST-120	CANAL DR	CATCH_806	2336534.35	108786.22	3.0		
54	OUTFALL	CANAL DR	Sandpiper Ln / Canal Drive	2336568.51	109262.66	-	0.0	WaStop® Inline Check Valve

TOWN OF CAROLINA BEACH
CANAL DRIVE FLOODING & VULNERABILITY STUDY

Row ID	Town ID	Street	APTIM Name	Northing	Easting	Street Inlet Elev (ft, NAVD)	Outfall Pipe Elev (ft, NAVD)	Observed Backflow Prevention
55	SWST-116	CANAL DR	CATCH_804	2336666.85	109228.73	2.6		
56	OUTFALL	CANAL DR	909 Canal Drive	2336673.33	109511.02	-	0.5	WaStop® Inline Check Valve
57	SWST-113	CANAL DR	CATCH_803	2336680.72	109261.25	2.7		
58	SWST-115	CANAL DR	CATCH_802	2336696.99	109222.60	3.6		
59	SWST-114	CANAL DR	CATCH_801	2336705.03	109239.56	2.3		
60	SWST-111	CANAL DR	CATCH_903	2336754.55	109486.65	1.1		
61	SWST-109	CANAL DR	CATCH_902	2336766.17	109504.80	2.3		
62	OUTFALL	CANAL DR	Seahorse Ln / Canal Drive	2336770.34	109754.58	-	1.3	WaStop® Inline Check Valve
63	SWST-108	CANAL DR	CATCH_901	2336779.55	109554.17	1.5		
64	SWST-110	CANAL DR	CATCH_904	2336785.85	109483.50	2.3		
65	SWST-106	CANAL DR	CATCH_1009	2336840.19	109725.65	2.5		
66	SWST-104	CANAL DR	CATCH_1008	2336862.44	109788.55	2.5		
67	SWST-107	CANAL DR	CATCH_1011	2336873.04	109713.87	2.3		
68	SWST-105	CANAL DR	CATCH_1010	2336879.75	109731.55	2.4		
69	SWST-102	CANAL DR	CATCH_1007	2336889.12	109860.74	2.7		
70	SWST-103	CANAL DR	CATCH_1006	2336924.28	109864.90	2.4		
71	SWST-101	CANAL DR	CATCH_1005	2336934.63	109986.15	2.8		
72	OUTFALL	CANAL DR	Scotch Bonnet Ln / Canal Drive	2336944.31	110254.49	-	1.7	WaStop® Inline Check Valve
73	SWST-97	CANAL DR	CATCH_1004	2337017.24	110222.28	2.0		
74	SWST-98	CANAL DR	CATCH_1001	2337027.68	110234.52	7.0		
75	NO TOWN ID	CANAL DR	CATCH_1104	2337045.11	110282.12	2.5		
76	SWST-99	CANAL DR	CATCH_1003	2337047.70	110207.28	2.3		
77	SWST-100	CANAL DR	CATCH_1002	2337052.63	110224.70	2.6		
78	OUTFALL	CANAL DR	Starfish Ln / Canal Drive	2337130.56	110742.57	-	1.8	Duckbill
79	SWST-94	CANAL DR	CATCH_1103	2337199.61	110710.42	2.4		
80	SWST-92	CANAL DR	CATCH_1102	2337220.70	110702.10	2.3		
81	SWST-93	CANAL DR	CATCH_1101	2337229.25	110723.08	2.1		
82	OUTFALL	CANAL DR	Sand Dollar Ln / Canal Drive	2337333.74	111272.43	-	0.0	WaStop® Inline Check Valve
83	OUTFALL	CANAL DR	1213 Canal Drive	-	-	-	-	Duckbill
84	SWST-85	CANAL DR	CATCH_1205	2337339.21	111070.64	2.4		
85	SWST-86	CANAL DR	CATCH_1204	2337368.03	111057.30	2.4		
86	NO TOWN ID	CANAL DR	CATCH_1203	2337380.46	111054.16	2.4		
87	SWST-83	CANAL DR	CATCH_1202	2337417.47	111233.83	2.3		
88	NO TOWN ID	CANAL DR	CATCH_1201	2337440.79	111217.32	2.4		
89	SWST-84	CANAL DR	CATCH_1309	2337448.61	111234.97	2.4		
90	SWST-82	CANAL DR	CATCH_1308	2337508.57	111427.05	2.7		
91	OUTFALL	CANAL DR	Clam Shell Ln / Canal Drive	2337521.91	111755.60	-	1.4	Duckbill
92	SWST-81	CANAL DR	CATCH_1307	2337544.12	111512.62	2.6		
93	SWST-79	CANAL DR	CATCH_1306	2337577.76	111586.98	2.4		
94	SWST-80	CANAL DR	CATCH_1305	2337597.33	111577.58	2.6		
95	SWST-78	CANAL DR	CATCH_1304	2337621.97	111710.78	2.2		
96	NO TOWN ID	CANAL DR	CATCH_1301	2337639.72	111732.82	2.2		
97	SWST-77	CANAL DR	CATCH_1303	2337653.20	111698.73	2.0		
98	SWST-75	CANAL DR	CATCH_1302	2337661.56	111715.69	2.1		
99	OUTFALL	CANAL DR	1407 Canal Drive	2337695.79	112147.18	-	0.8	Duckbill
100	SWST-73	CANAL DR	CATCH_1407	2337732.83	111934.60	2.4		
101	SWST-74	CANAL DR	CATCH_1406	2337755.21	111924.28	2.5		
102	SWST-72	CANAL DR	CATCH_1404	2337778.67	112042.75	2.3		
103	SWST-70	CANAL DR	CATCH_1403	2337803.45	112099.02	2.2		
104	SWST-71	CANAL DR	CATCH_1405	2337803.96	112031.80	2.4		
105	SWST-69	CANAL DR	CATCH_1402	2337841.21	112183.34	2.2		
106	SWST-67	CANAL DR	CATCH_1401	2337873.53	112191.73	2.3		
107	SWST-66	CANAL DR	CATCH_19	2337921.99	112299.83	2.5		

Row ID	Town ID	Street	APTIM Name	Northing	Easting	Street Inlet Elev (ft, NAVD)	Outfall Pipe Elev (ft, NAVD)	Observed Backflow Prevention
108	OUTFALL	FLORIDA AVE	Maryland Ave / Florida Ave	2336676.76	113455.06	-	2.0	Duckbill
109	NO TOWN ID		CATCH_04	2336793.23	113482.70	3.1		
110	SWST-177	FLORIDA AVE	CATCH_05	2336814.18	113395.11	2.7		
111	NO TOWN ID		CATCH_01	2336817.51	113538.78	3.7		
112	SWST-193	MARYLAND AVE	CATCH_02	2336831.22	113508.36	4.1		
113	SWST-193	MARYLAND AVE	CATCH_03	2336831.25	113508.41	4.1		
114	NO TOWN ID		CATCH_06	2336850.02	113399.81	3.1		
115	SWST-181	FLORIDA AVE	CATCH_07	2337067.42	112682.91	3.2		
116	NO TOWN ID		CATCH_08	2337203.31	112622.41	3.1		
117	SWST-182	FLORIDA AVE	CATCH_09	2337248.75	112602.11	3.1		
118	NO TOWN ID		CATCH_12	2337313.74	112515.13	2.8		
119	SWST-184	FLORIDA AVE	CATCH_10	2337334.76	112558.98	3.2		
120	SWST-190	DELAWARE AVE	CATCH_11	2337351.77	112586.33	3.5		
121	NO TOWN ID		CATCH_14	2337446.55	112474.09	3.1		
122	NO TOWN ID		CATCH_13	2337451.49	112511.80	2.9		
123	SWST-187	FLORIDA AVE	CATCH_15	2337550.35	112468.47	3.0		
124	SWST-186	FLORIDA AVE	CATCH_16	2337555.05	112480.23	3.1		
125	SWST-64	FLORIDA AVE	CATCH_18	2337890.40	112304.76	2.7		
126	SWST-65	FLORIDA AVE	CATCH_17	2337899.59	112325.11	2.6		