TOWN OF SOUTHERN SHORES NORTH CAROLINA
BEACH ASSESSMENT REPORT

SUBMITTED TO:

TOWN OF SOUTHERN SHORES

SUBMITTED BY:

APTIM COASTAL PLANNING & ENGINEERING OF NORTH CAROLINA, INC.

March 2018

EXECUTIVE SUMMARY

The Town of Southern Shores undertook this study to determine long-term and short-term shoreline and volumetric changes that have occurred along its oceanfront beaches. The study is a first step toward assessing long term needs to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. In order to more accurately resolve the erosional and accretional trends occurring along the Southern Shores oceanfront, this report has compiled and utilized a variety of data sources collected by the US Army Corps of Engineers (USACE) Field Research Facility (FRF), Aptim Coastal Planning & Engineering of North Carolina, Inc. (APTIM) and others. This study provides valuable information to the Town regarding the current conditions of the beach and erosional and accretional trends, which will assist them in determining future coastal management needs.

The data collection process entailed the acquisition of several different existing data sets as well as conducting beach profile surveys to acquire updated beach profile data along the entire Southern Shores oceanfront beach. The data sets used include:

- The North Carolina Division of Coastal Management (NC DCM) long-term (approximately 50 years) average annual shoreline change rates;
- Beach profile data collected by the USACE Field Research Facility (FRF) along the southern 15,000 ft. of the Town of Southern Shores in 2004, 2005 and 2006;
- Beach profile data collected by APTIM in 2013 and 2015 along the southern 2,000 ft. and northern 2,000 ft. of the Town of Southern Shores;
- Beach profile data collected by Great Lakes Dredge and Dock Company in 2017 (pre-construction, before dredging (BD) and after dredging (AD) surveys) along the Town of Kitty Hawk and the southern 3,500 ft. of the Town of Southern Shores;
- Beach profile data collected by APTIM in December 2017 (post-construction) along the entire oceanfront of the Town of Southern Shores.

Based on an assessment of the various data sets available, this report examined shoreline change and volume change between the following time periods and along the following portions of the Town:

- October 2004 to October 2006 (Station -150+00 located near 3rd Ave. to Station 0+00 located at the southern Town Boundary);
- October 2006 to May 2015 (Fill Area Only: Station -20+00 located approximately 150 feet south of Skyline Road to Station 0+00 located at the southern Town Boundary);
- May 2015 to June 2017 (Fill Area Only: Station -20+00 located approximately 150 feet south of Skyline Road to Station 0+00 located at the southern Town Boundary);
- October 2006 to December 2017 (Station -150+00 located near 3rd Ave. to Station 0+00 located at the southern Town Boundary);
- September 2013 to December 2017 (Station -197+12 located at the northern Town Boundary to Station -177+13 located approximately 200 ft. south of 9th Ave.); and
- June 2017 to December 2017 (Fill Area Only: Station -20+00 located approximately 150 feet south of Skyline Road to Station 0+00 located at the southern Town Boundary).

Shoreline Change Analysis

The shoreline change analysis examined the change in the MHW line (+1.2 ft. NAVD contour). The portion of shoreline from Station -150+00 to Station 0+00 experienced an average shoreline change rate of +4.9 ft./yr. in the two-year period between October 2004 and October 2006; however extensive variability was measured from station to station. This variability may be due to the recovery of the shoreline following Hurricane Isabel, which impacted the Outer Banks region in September 2003. The average MHW shoreline change rate measured along this same portion of the shoreline during the approximately 11-year period between October 2006 and December 2017 was -0.4 ft./yr., indicating an essentially stable shoreline.

The "Fill" area (southern 2,000 ft. of the Town) experienced an average shoreline change rate of 13.3 ft./yr. between October 2004 and October 2006. This average rate was highly influenced by the MHW shoreline change measured along Station -20+00, which moved seaward 55 ft. over the two (2) year period. This relatively large variation may be due to shoreline adjustments taking place after the impact of Hurricane Isabel to the region in 2003. Over the approximately 8.6-year period from October 2006 to May 2015 the MHW shoreline rate along Station -20+00 was -7.3 ft./yr. (recession); whereas the MHW shoreline change rate along Stations -10+00 and 0+00 were 4.1 ft./yr. and 1.5 ft./yr. (advance), respectively. Between May 2015 and June 2017, the fill area, specifically profiles -10+00 and 0+00 experienced severe shoreline retreat, which prompted the Town to pursue the beach fill project. Surveys conducted in May 2015 and June 2017 show that over the 25-month period, Stations -10+00 and 0+00 experienced shoreline change of -67.6 ft. and -59.5 ft., respectively.

A comparison of the December 2017 data with data collected in September 2013 as part of an assessment completed for the Town of Duck, provided insight into shoreline change along the northern 2000 ft. of the Town's oceanfront. An average MHW shoreline change rate of 1.3 ft./yr. was measured between Stations -197+12 (northern Town Limit) and -177+13 (approximately 200 feet south of 9th Ave.). This suggests the shoreline in this area was fairly stable between September 2013 and December 2017.

Volume Change Analysis

The volume change analysis examined the changes in the volume measured along profiles above the -24 ft. NAVD88 contour. The depth of -24 ft. NAVD88 was used as the depth of closure in the design of the beach nourishment projects constructed as part of the multi-town project in 2017. Similarly to what was found in the shoreline change analysis, between October 2004 and October 2006, there was a considerable amount of variability in the volume change rates measured between Stations -150+00 and 0+00. Although the average volume change rate through this portion of the Town over the 2-year period was only -0.4 cy/ft./yr., the individual volume change rates along the profiles varied from -19.4 cy/ft./yr. to +22.6 cy/ft./yr. The overall variability in volume change may be due to the response of the beach following Hurricane Isabel, which impacted the Outer Banks region in September 2003. In comparison, the average volume change rate measured along this same portion of the shoreline (Stations -150+00 to 0+00) during the approximately 11-year period between October 2006 and December 2017 was 3.2 ft./yr. (accretion). Far less variability in the volume change rates were observed from station to station over the approximately 11-year

period. The volume change along each of the 16 profiles exhibited an accretional trend during this period.

Between October 2004 and October 2006, the "Fill" area experienced a positive volume change of approximately 23,000 cy. Stations -20+00 and 0+00 exhibit positive volume change rates; whereas Station -10+00 experience an erosional rate of -7.5 cy/ft./yr. Over the approximately 8.6-year period from October 2006 to May 2015, profiles at Stations -20+00 and -10+00 experienced negative volume change rates of -3.3 and -4.1 cy/ft., respectively; whereas the profile at Station 0+00 saw a significant increase in volume, with a calculated volume change rate of 10.8 cy/ft./yr. Between May 2015 and June 2017, a net negative volume change of approximately 93,000 cubic yards was measured in the fill area. This was largely driven by the losses between Stations -10+00 and 0+00 of approximately 88,000 cy over a 1,000 ft. length of beach. These dramatic changes prompted the Town to initiate the 2017 beach fill project. Based on the data analyzed in this study and discussions with Town officials, the dramatic erosion that took place between May 2015 and June 2017 was unprecedented. The reason for the accelerated erosion rates may be associated with variations in the offshore bathymetry that resulted in the variations of wave approaches to shore. Such variations can have dramatic effects on long shore transport of sand and result in locally high erosion or hot spot areas.

A comparison of the December 2017 data and data collected in September 2013 as part of an assessment completed for the Town of Duck showed an average volume change rate of -0.4 cy/ft./yr. was measured between Stations -197+12 (northern Town Limit) and -177+13 (approximately 200 feet south of 9th Ave.). This area exhibited relatively stable volume change over the approximately 4.25-year period.

Executive Summary Table 1 lists the average volumetric change rates above the -24 ft. contour for 1) all profiles from Stations -150+00 to 0+00; 2) profiles from Stations -20+00 to 0+00 (Fill Section); and 3) profiles from Stations -197+12 to -177+13 (North Section).

Executive Summary Table 1. Average volume change rates above the -24 ft. contour.

	Stations -150+00 to 0+00 16 Profiles	**Fill Section (Stations -20+00 to 0+00)** 3 Profiles	**North Section (Stations -197+12 to -177+13)** 3 Profiles
Volume Change Rate (CY/Ft./Yr.)			
October 2004 to October 2006	-0.4 cy/ft/yr.	10.1 cy/ft/yr.	
October 2006 to May 2015		1.1 cy/ft/yr.	
May 2015 to June 2017		-31.7 cy/ft/yr.	
October 2006 to December 2017	3.2 cy/ft/yr.	2.7 cy/ft/yr. *	
September 2013 to December 2017			-0.4 cy/ft/yr.

* Rate includes the impact of the beach fill project constructed in August 2017

In order to evaluate the profiles for which no historical data existed, the total volume measured along each profile above the -24 ft. NAVD88 contour and seaward of the +20 ft. contour on the landward side of the dune, was calculated. This area of the profile is referred to in this report as the volume envelope. Comparing the volume measured in the volume envelope along the Town's oceanfront allows for the relative comparison of each profile.

The average volume within the envelope measured along all 22 profiles in December 2017 was 830 cy/ft. The area from Station -150+00 (located near 3rd Ave.) to Station -70+00 (located approximately 500 ft. south of where Ocean Blvd. and Duck Rd. meet), is relatively less than the portions of Southern Shores to the north and south of this section. The average volume within the envelope measured along the nine (9) profiles from Stations -150+00 to -70+00 is 793 cy/ft. The average volume within the volume envelope measured along the six (6) profiles to the north from Stations -197+12 to -157+41 was 873 cy/ft. and the volume measured along the seven (7) profiles to the south from Stations -60+00 to 0+00 is 840.9 cy/ft.

Although the volume of sand present within the envelope provides for a way of making relative comparisons between one profile and another, this volume is not necessarily indicative of the vulnerability of structures in a given vicinity. In this regard, the greater the distance a given structure is set back from the dune the higher the level of storm damage reduction. A qualitative assessment of the distance structures are set back from the vegetation line was made using publicly available satellite imagery from Google Earth. A visual examination of imagery from March 2017 shows that houses are generally situated closest to the vegetation line between Stations -140+00 and -100+00 and along the very southern part of the Town between Stations -10+00 and 0+00. Houses located between Stations -157+00 and -140+00 and Stations -100+00 to -70+00 generally appear to have a relatively moderate setback. The area north of Station -157+00 and between Stations -40+00 and -20+00 appear to have the greatest setback from the edge of vegetation.

Recommendations

Based on the analysis and conclusions discussed in this report, APTIM makes the following recommendations:

1. **Conduct a vulnerability assessment of the oceanfront structures:** The vulnerability assessment employs a profile-based storm simulation model called SBEACH. A similar assessment was conducted during the design phase of the Duck and Kill Devil Hills Beach Projects. The vulnerability assessment can both identify structures that may be vulnerable to a specific design storm and determine the design requirements to avoid impacts to a design storm.
2. **Continue Monitoring of the Beach Profiles:** In order to monitor the shoreline and volume change trends along the Town's oceanfront shoreline, Southern Shores should implement an annual beach profile monitoring program starting in spring 2019. Coordinating with monitoring that is occurring along the Towns of Duck and Kitty Hawk may provide cost savings to the Town in data acquisition.

3. **Determine a Minimum Cross Section Volume:** Based on the results of the vulnerability analysis and the beach fill design for the Towns of Duck and Kill Devil Hills, the Town should determine the ideal minimum cross section volume it should maintain in order to provide an acceptable level of storm damage reduction.

Through the implementation of these recommendations, the Town of Southern Shores can determine what level of storm damage mitigation is currently in place, where vulnerability exists, and project if, and when, beach nourishment may be required. With this information, the Town can then determine the financial needs necessary to maintain an acceptable level of storm damage mitigation.

Given the active programs established in Dare County for beach nourishment, the Town of Southern Shores is well positioned to develop a long-term management program that leverages cost saving opportunities realized through multi-town cooperation as was seen during the 2017 beach fill project. Furthermore, by developing a management plan before the beach reaches a critically eroded state, the Town may be able to maintain a greater level of storm damage reduction.

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INTRODUCTION

The Town of Southern Shores undertook this study to determine long-term and short-term shoreline and volumetric changes that have occurred along its oceanfront beaches. The study is a first step toward assessing long term needs to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. Infrastructure protection, storm damage mitigation and rapid recovery from storm events are important considerations for any oceanfront community. This study consisted of two phases referred to as (1) data collection and (2) beach analysis. The results of the study establish long-term and short-term trends in shoreline movement and volume change.

The State of North Carolina's Division of Environmental Quality publishes long-term average annual shoreline change rates for the entire coast of North Carolina, for the sole purpose of establishing oceanfront construction setback factors. The change rates, which utilize the endpoint method, typically represents the rate change as measured from aerial photos over 50 years. While these general trends may be sufficient for establishing construction setback guidance, more detailed shoreline and volume change analyses are typically used to determine higher resolution erosional and accretional trends both spatially and temporally.

In order to more accurately resolve the erosional and accretional trends occurring along the Southern Shores oceanfront, this report has compiled and utilized a variety of data sources collected by the US Army Corps of Engineers (USACE) Field Research Facility (FRF), Aptim Coastal Planning & Engineering of North Carolina, Inc. (APTIM), and others.

PROJECT LOCATION

The Town of Southern Shores is located on the Outer Banks of North Carolina approximately 29 miles south-southeast of the North Carolina and Virginia border. The Town encompasses approximately 9.9 square miles extending along 3.7 miles of Atlantic Ocean shoreline from the Town of Duck south-southeast to the Town of Kitty Hawk. A location map is provided in Figure 1.

During initial public discussions regarding this beach assessment study, an erosion hot spot spanning approximately 1,500 ft. along the southern most portion of the Town of Southern Shores was identified. In the spring of 2016, three other beach towns in Dare County (Kill Devil Hills, Kitty Hawk, and Duck) obtained permits and authorizations to construct a multi-town beach nourishment project, proposed to be constructed in 2017. To address the immediate erosion hot spot identified along the Town's southern boundary, the Town of Southern Shores coordinated with Dare County, the Town of Kitty Hawk and APTIM, and sought and obtained permits and authorizations to provide a one-time beach nourishment project that would include sand placement along the most critically eroded portion of the Town's shoreline. Figure 1 shows the location of the Southern Shores project in relation to the other three (3) beach projects in northern Dare County. The Southern Shores portion of this project was constructed in cooperation with Dare County and the Towns of Duck, Kitty Hawk, and Kill Devil Hills in early August 2017.

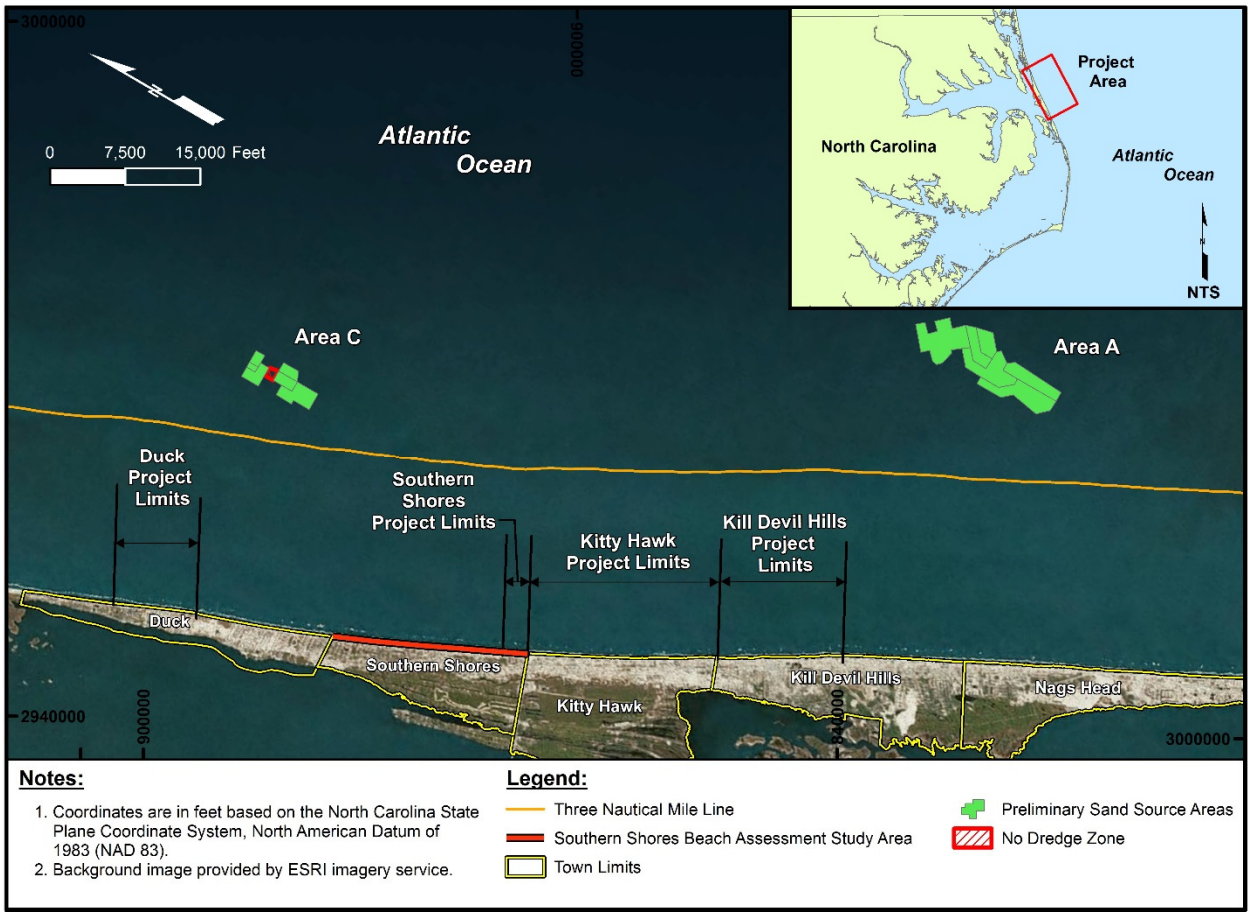

Figure 1. Project Location Map.

DATA COLLECTION

The data collection process entailed the acquisition of several different existing data sets as well as conducting beach profile surveys to acquire updated beach profile data along the entire Southern Shores oceanfront beach. Figure 2 shows the locations of the beach profile stations along the oceanfront shoreline of Southern Shores. The data sets used include:

- The North Carolina Division of Coastal Management (NC DCM) long-term (approximately 50 years) average annual shoreline change rates;
- Beach profile data collected by the USACE Field Research Facility (FRF) along the southern 15,000 ft. of the Town of Southern Shores (Stations -150+00 to 0+00) in 2004, 2005 and 2006;
- Beach profile data collected by APTIM in 2013 and 2015 along the southern 2,000 ft. (Stations -20+00 to 0+00) and northern 2,000 ft. of the Town of Southern Shores (Stations -197+12 to -177+13);
- Beach profile data collected by Great Lakes Dredge and Dock Company in 2017 (pre-construction, before dredging (BD) and after dredging (AD) surveys) along the Town of

Kitty Hawk and the southern 2,000 ft. of the Town of Southern Shores (Stations -20+00 to 0+00);

- Beach profile data collected by APTIM in December 2017 (post-construction) along the entire oceanfront of the Town of Southern Shores (Stations -197+12 to 0+00).

Though numerous historical data sets were used to evaluate shoreline and volume change rates, the beach profile surveys conducted by APTIM in December 2017 represent the first Town-wide beach profile survey and will serve as a baseline for future monitoring and analysis. The December 2017 surveys consist of a total of 22 profiles with a spacing of roughly 1,000 feet (Stations -197+12 to 0+00). Concurrently with this survey, APTIM conducted beach profile surveys for the Towns of Duck and Kitty Hawk, which provided data to assess the shorelines in proximity to the northern and southern Town boundaries. Survey data along the Town of Southern Shores were collected along the transects listed in Table 1. Coordinates shown in Table 1 are referenced to the North Carolina State Plane coordinate system in feet NAD83 and the profile azimuth refers to degrees referenced to true north. Transects listed in Table 1 are shown graphically in Figure 2. The complete survey report, which includes detailed plan view maps and comparative profile cross sections, is included as Appendix A.

G:\Enterprise\Dare\636216500\Mxd\Profile Map.mxd

Notes:

1. Coordinates are in feet based on the North Carolina State Plane Coordinate System, North American Datum of 1983 (NAD 83).
2. 2016 background imagery is provided by NC OneMap.

Legend:

- Profiles
- Municipal Boundaries

Feet
0 800 1,600

1 inch = 1,600 feet

TITLE:

Profile Map
Dare County, NC

Aptim
Coastal Planning & Engineering of North Carolina, Inc.
4038 MASONBORO LOOP ROAD
WILMINGTON, NC 28409
PH. (910) 791-9494

Date: 12/18/17	By: HMV	Comm No. : 636216500	Figure No.:2

Table 1. Profile Survey Baseline and Azimuth

Profile[(1)]	Easting	Northing	Azimuth
-197+12	2962840	889616.1	70
-187+14	2963230	888697.7	70
-177+13	2963619	887775.8	70
-170+56	2963880	887172.9	66.6
-163+99	2964142	886569.9	66.6
-157+41	2964403	885966.9	66.6
-150+00	2964665	885364.0	65.3
-140+00	2965116	884444.0	65.3
-130+00	2965239	883452.0	65.3
-120+00	2965920	882604.0	65.3
-110+00	2966366	881697.0	62.6
-100+00	2966790	880778.0	62.6
-90+00	2967110	879895.0	62.6
-80+00	2967533	878988.0	62.6
-70+00	2967951	878106.0	62.6
-60+00	2968381	877175.0	62.6
-50+00	2968838	876228.0	62.6
-40+00	2969249	875440.0	62.6
-30+00	2969732	874496.1	62.6
-20+00	2970190	873607.2	62.6
-10+00	2970653	872721.0	62.6
0+00	2971224	871890.8	62.6

[(1)]Southern Shores transects (XX+XX) based on USACE baseline

NC DCM Long-Term Average Annual Shoreline Change Rates

As described on the North Carolina Division of Environmental Quality's website (https://deq.nc.gov/about/divisions/coastal-management/coastal-management-oceanfront-shorelines/oceanfront-construction-setback-erosion-rate) long-term average annual shoreline change rates are computed for the sole purpose of establishing oceanfront construction setback factors. The change rates are calculated using the endpoint method, which uses the earliest and most current shoreline data points where they intersect a given shore-perpendicular transect. The distance between the shoreline position of the two data sets is computed and divided by the time between the data sets. Typically, the State rates represent a 50-year rate. The shoreline position change rate information provided by the State is admittedly not predictive, nor does it reflect the short-term erosion that can occur during storms.

USACE FRF Beach Profile Data

The 2004, 2005 and 2006 beach profile survey data was collected as part of the Dare County Beaches, Shore Protection Project. The physical monitoring program initiated by the USACE as part of the Dare County Beaches project included beach profile surveys from approximately 3rd Ave. in Southern Shores south to Oregon Inlet. Although the Dare County Beaches federal storm damage reduction project was authorized by Congress in 2000, sufficient construction funds were never appropriated and the project was never constructed. However, the data collected by the USACE FRF in 2004, 2005 and 2006 provided useful data for this assessment.

The USACE FRF utilized a combination of data acquisition techniques during the beach profile surveys. A Lighter Amphibious Resupply Cargo vessel or LARC equipped with Real Time Kinematic (RTK) GPS, a Knudsen 320BP dual frequency fathometer and a VT TSS Ltd. DMS Series 3-25 heave, roll, and pitch sensor was used to collect data from the toe of the dune out to a depth of approximately 30 ft. Topographic or beach portions of the profiles were obtained with a backpack mounted Trimble 4700 RTK system. Points along the profile were surveyed approximately every 10 ft. On each profile the topographic surveys overlapped the LARC surveys for quality control purposes. Additional information on the USACE FRF data collection methodology can be found in USACE, 2004.

Great Lakes Dredge and Dock 2017 Construction Data

As part of the 2017 construction project, Great Lakes Dredge and Dock Company conducted three sets of surveys along the Town of Kitty Hawk and along the southern 2,500 ft. of Southern Shores. A pre-construction survey was conducted at 500 ft. intervals in early June 2017, which includes the dune, berm, shoreface and nearshore zone out to a depth of between -20.0 and -25.0 ft. NAVD88. The profiles located along the Southern Shores oceanfront included in the pre-con survey were Stations 0+00, -5+00, -10+00, -15+00, -20+00, and -25+00. A before dredge (BD) and an after dredge (AD) survey was also conducted along each 100 ft. station along the Southern Shores project area between Stations 0+00 and -25+08; however the BD and AD surveys were not used in this analysis as the data only extends out to a depth of approximately -12.0 ft. NAVD88.

The standards used for the pre-construction surveys conducted by Great Lakes required that a sufficient number of points be surveyed along each profile line to ensure adequate description of all topographic features, and major breaks in slope, including dunes, beach berms, foreshore, and bar trough systems, with a maximum elevation difference of approximately 1 foot between adjacent points and a maximum horizontal distance of 25 feet between adjacent points. All surveys within the pay template were performed with RTK technology. Vertical accuracy met or exceeded 0.3 feet and horizontal accuracy met a maximum of 3.0 feet tolerance. Surveys extended a minimum distance of 250 ft. seaward of the construction toe of fill.

APTIM Beach Profile Data

In 2015, APTIM conducted beach profile surveys for the Towns of Duck and Kitty Hawk in preparation for the development of the plans for the 2017 beach nourishment projects. The survey conducted in May 2015 included profiles within the northern and southern 2,000 ft. of the Town

of Southern Shores. Furthermore, during the design of the two projects, APTIM conducted a survey in September 2013 and April 2014 for the Towns of Duck and Kitty Hawk, respectively. These surveys also included the northern and southern 2,000 ft. of the Southern Shores oceanfront. Finally, in December 2017, following the construction of the multi-town beach nourishment projects in northern Dare County, APTIM conducted a beach profile survey along the entire Southern Shores Oceanfront as well as the Towns of Duck and Kitty Hawk. All of the APTIM surveys include a topographic survey of the dune, berm, and foreshore section of the beach and a bathymetric survey of the offshore portion of the profile.

Beach profiles extended landward from the beach toward the baseline until a structure was encountered or a range of 25 feet beyond the dune was reached, whichever was more seaward. Elevation measurements were also taken seaward along the profile to a range of 2,500 feet beyond the shoreline or to the -30 NAVD88 contour, whichever was more landward.

Land-based or "upland" data collection includes all grade breaks and changes in topography to provide a representative description of the conditions at the time of the work. The maximum spacing between data points along individual profiles is 25 feet. The upland work extended into wading depths sufficiently to provide a minimum 50-foot overlap with the offshore data. This overlap between the topographic and bathymetric surveys provides quality control and quality assurance of the survey.

The hydrographic survey work or "offshore" portions of the beach profiles was conducted with an Odom Hydrotrac depth sounder at 200 kHz and RTK GPS systems. Tide corrections were obtained redundantly through the use of RTK GPS and the tide station located at the USACE FRF in Duck, North Carolina. Offshore data points were collected with a maximum spacing of 25 feet.

Horizontal and vertical positioning checks were conducted to verify the accuracy was within a horizontal limit of 3 feet and a vertical limit of 0.5 ft. for all electronic equipment. Vertical positioning checks for depth measuring equipment were conducted at 5 ft. increments between the minimum and maximum depths expected. These specifications meet the Minimum Performance Standards for the U.S. Army Corps of Engineers (USACE) (EM 1110-2-1003).

Based on an assessment of the various data sets available, this report examined shoreline and volume change between the following periods and along the following portions of the Town:

- October 2004 to October 2006 (Station -150+00 located near 3rd Ave. to Station 0+00 located at the southern Town Boundary);
- October 2006 to May 2015 (Fill Area Only: Station -20+00 located approximately 150 feet south of Skyline Road to Station 0+00 located at the southern Town Boundary);
- May 2015 to June 2017 (Fill Area Only: Station -20+00 located approximately 150 feet south of Skyline Road to Station 0+00 located at the southern Town Boundary);
- October 2006 to December 2017 (Station -150+00 located near 3rd Ave. to Station 0+00 located at the southern Town Boundary);
- September 2013 to December 2017 (Station -197+12 located at the northern Town Boundary to Station -177+13 located approximately 200 ft. south of 9th Ave.); and
- June 2017 to December 2017 (Fill Area Only: Station -20+00 located approximately 150 feet south of Skyline Road to Station 0+00 located at the southern Town Boundary)

SHORELINE CHANGE ANALYSIS

As previously mentioned, the State of North Carolina maintains long-term shoreline change rates for the States shoreline for the sole purpose of establishing construction setbacks. Figure 3 shows a map from the NC DEQ website depicting the long-term oceanfront setback factors (SBF) for the Town of Southern Shores. The SBF for the entire Town is 2.0 ft., which means that the calculated long-term shoreline change rate is 2 feet or less per year over the long term as measured by the State. However, as noted by the State in their disclaimer, the shoreline position change rates are not predictive and do not reflect short-term erosion that can occur over shorter periods of time (i.e. decadal, seasonally or during storm events).

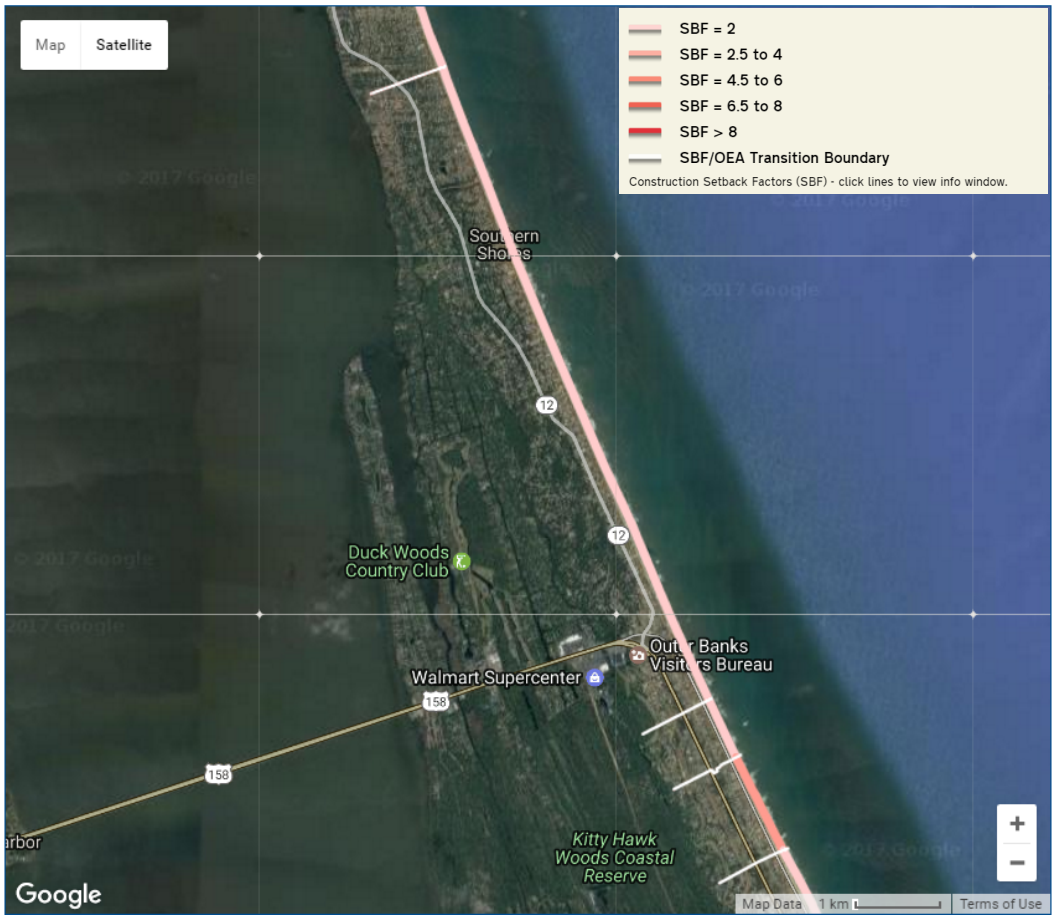

Figure 3. Map showing the SBF for the Town of Southern Shores from (https://deq.nc.gov/about/divisions/coastal-management/coastal-management-oceanfront-shorelines/oceanfront-construction-setback-erosion-rate)

Using available beach profile data, a shoreline change analysis was conducted to assess shoreline advance and recession where data were available along the study area between 2004 and 2017. As it relates to shoreline change, the "shoreline" is typically defined as a specified elevation contour. For this study, the shoreline was defined as the Mean High Water (MHW) contour, which represents the +1.2 feet NAVD elevation. Shoreline change is calculated by comparing shoreline

position along shore perpendicular transects. Figure 4 shows a typical comparison plot of two beach profile surveys conducted approximately 2 years apart along Station -10+00, illustrating graphically how the shoreline change is measured. Shoreline change is provided in terms of the actual linear change measured between surveys and as a rate in an annualized form. The rate is calculated by dividing the measured distance of shoreline change by the time period (number of years) between survey events (i.e. feet per year). These rates are described in terms of positive ("+") or advance (shoreline moving seaward) and negative ("-") or recession (shoreline moving landward).

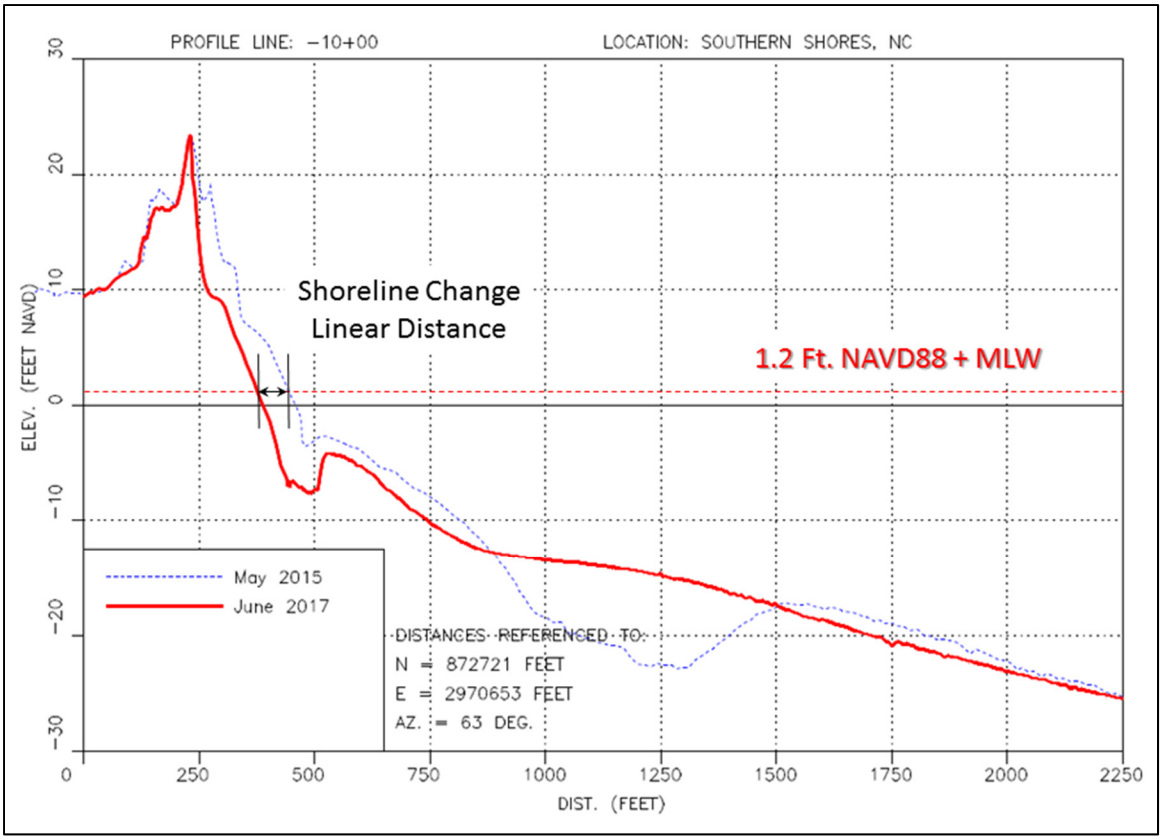

Figure 4. Beach profile cross section illustrating shoreline change.

October 2004 to October 2006:

Data collected along approximately 1,000 ft. spaced profiles from approximately 3rd Ave. (Station -150+00) south to the southern Town limit of Southern Shores in October 2004 and October 2006 was examined to compare the MHW (+1.2 Ft. NAVD) location and determine shoreline change rates. Both of these data sets were collected by the USACE FRF.

The average MHW shoreline change rate measured between October 2004 and October 2006 between Stations -150+00 and 0+00 was +4.9 ft./yr. (shoreline advanced seaward). Although the average shoreline change was positive, a profile by profile comparison shows variation ranging

from -13.3 ft./yr. at Station -50+00 (approximately 450 ft. south of Chicahauk Tr.) to +27.9 ft./yr. at Station -20+00 (approximately 130 ft. south of Skyline Rd.). The MHW shoreline change rates measured between October 2004 and October 2006 for each profile between Stations -150+00 and 0+00 are shown in Figure 5. Figure 5 also includes shoreline change rates measured between October 2006 and December 2017, which are described later in this report.

The average MHW shoreline change rate was also calculated within the area in which fill was placed as part of the 2017 beach nourishment project (Stations -20+00 to 0+00). The beach fill placed during the 2017 project in the Town of Southern Shores was placed between Stations -25+00 and 0+00 and therefore, we refer to the analyses in this report that compares data from Stations -20+00 to 0+00 as the "fill area". The average MHW shoreline change rate measured between October 2004 and October 2006 in the fill area was +13.3 ft./yr. (shoreline advanced seaward). All three profiles evaluated within the fill area between October 2004 and October 2006 showed a seaward movement of the MHW line.

October 2006 to May 2015:

In May 2015, APTIM surveyed the Town of Kitty Hawk as part of the final design development for their beach nourishment project. That survey included the three profiles between Skyline Dr. and the southern town limit of Southern Shores (Stations -20+00, -10+00 and 0+00), referred to as the "fill area".

The position of the MHW shoreline in the fill area at the time of the October 2006 survey was compared to the position measured during the May 2015 survey. An average MHW shoreline change of -5.2 ft. was measured over the approximately 8.6-year period. This equates to an average MHW shoreline change rate of -0.6 ft./yr. Although the average shoreline change and shoreline change rate are relatively low, a profile by profile comparison shows a wide range of changes in the MHW position between the two surveys. The measured MHW shoreline change at Station -20+00 from October 2006 to May 2015 was -63.1 feet; whereas, the change measured along Stations -10+00 and 0+00 over the same time period was +35.0 ft. and +12.6 ft., respectively.

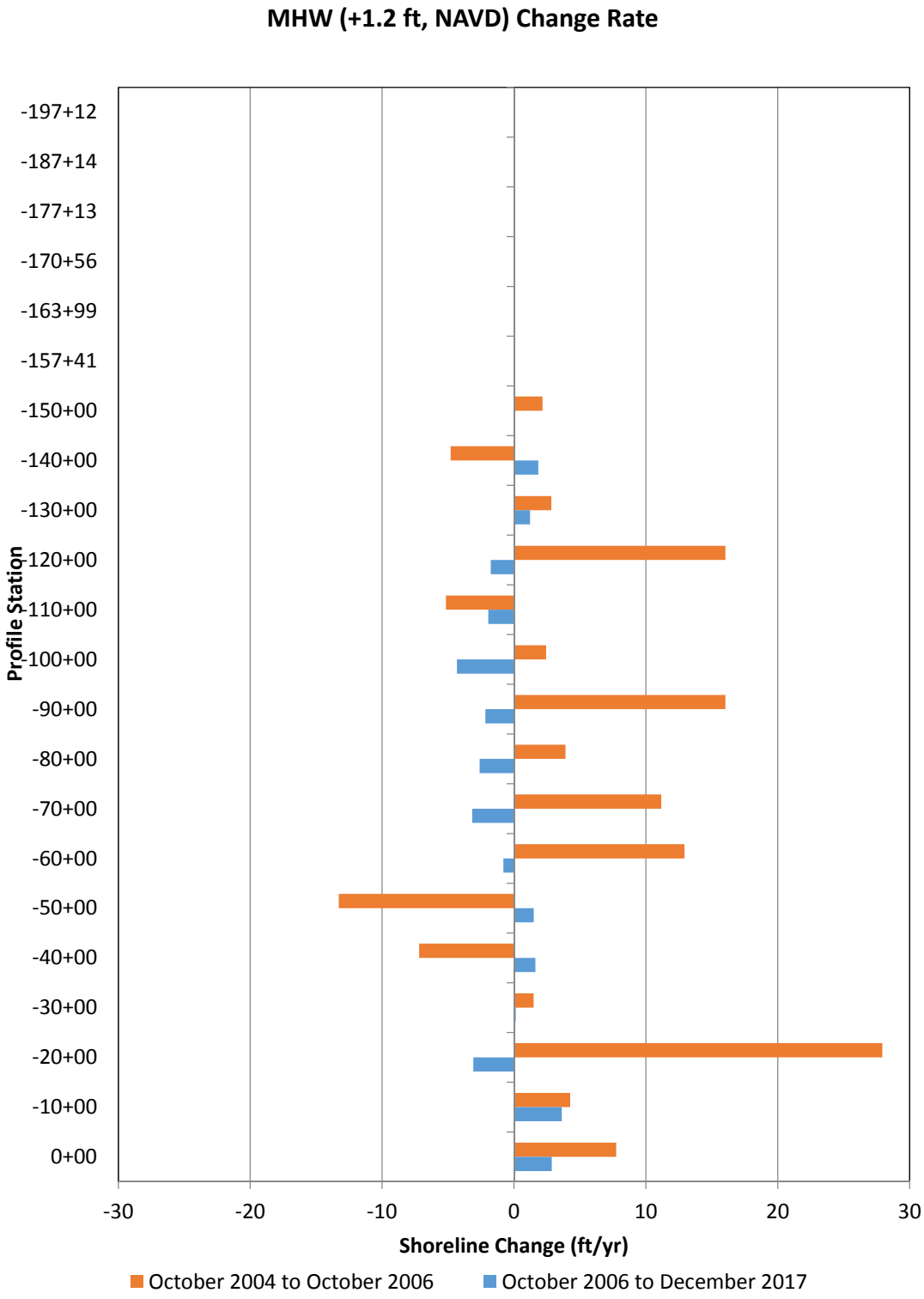

Figure 5. Shoreline change rate measured between October 2004 and October 2006, and October 2006 and December 2017 between Stations -150+00 and 0+00.

May 2015 to June 2017:

In June 2017, Great Lakes Dredge and Dock Company conducted a pre-construction survey of the fill area (Stations -20+00 to 0+00), as part of the 2017 construction project. The position of the MHW shoreline in the fill area at the time of the May 2015 survey was compared to the position measured during the June 2017 pre-construction survey. An average MHW shoreline change of -42.2 ft. was measured over the 25-month period. This equates to an average MHW shoreline change rate of -20.3 ft./yr. This is a significant increase in the rate from that which was measured in the same area between October 2006 and May 2015, which was -0.6 ft./yr. The rate measured along the profile at Station -20+00 was essentially unchanged (0.2 ft./yr.); whereas the rate measured along Stations -10+00 and 0+00 were -32.4 ft./yr. and -28.6 ft./yr., respectively.

Figure 6 shows the comparison of the MHW shoreline change rate for each profile in the fill area measured between October 2004 and October 2006; October 2006 and May 2015; and May 2015 and June 2017.

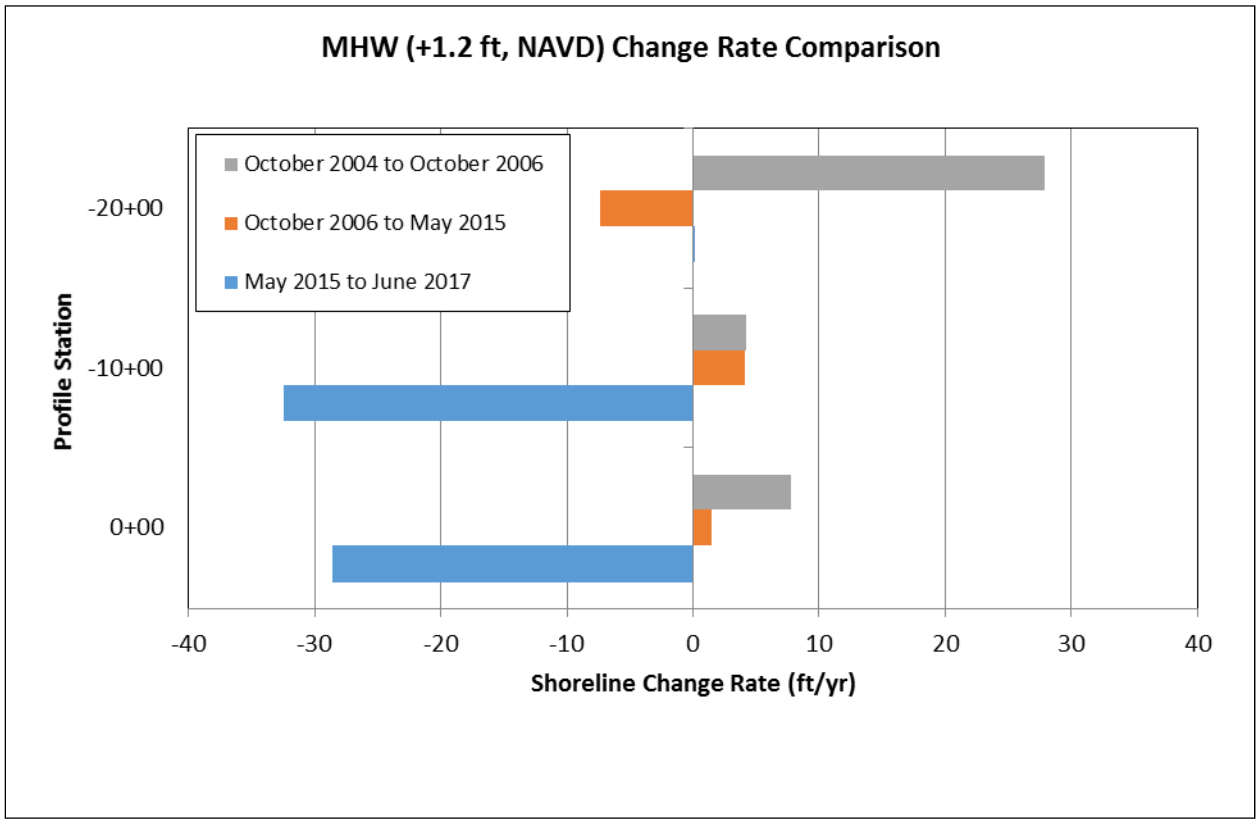

Figure 6. Shoreline change rates measured in the "Fill Area" between Oct. 2004 and Oct. 2006 (gray), Oct. 2006 and May 2015 (orange), and May 2015 and June 2017 (blue).

October 2006 to December 2017:

In December 2017, APTIM conducted beach profile surveys along the entire oceanfront of Southern Shores. All 22 beach profiles from Station -197+12 at the northern town boundary to Station 0+00 at the southern town boundary were surveyed. The position of the MHW shoreline along the portion of beach from Stations -150+00 to 0+00, was compared to the position of the MHW shoreline measured during the 2006 survey conducted by the USACE FRF. An average MHW shoreline change of -4.9 ft. was measured over the approximately 11-year period. This equates to an average MHW shoreline change rate of -0.4 ft./yr. This rate of less than 1 ft. per year of change, suggests that on average, this portion of the shoreline is relatively stable. A profile by profile comparison shows relatively minimal variation throughout the area with rates ranging from -4.3 ft./yr. at Station -100+00 (Dolphin Run) to 3.6 ft./yr. at Station -10+00 (approximately 490 ft. south of Ocean View Loop). It should be noted that the gains seen at Station -10+00 are in large part due to the beach fill placed between Stations 0+00 and -25+00 in August 2017. Figure 7 shows a photo of the beach fill project under construction in August 2017. The effective average shoreline change rate along the portion of the shoreline from Stations -150+00 to -30+00 (eliminating the fill area) is -0.8 ft./yr. Although the average rate is negative (shoreline retreat) the rate is still relatively small, suggesting a relatively stable shoreline. The MHW shoreline change rates measured between October 2006 and December 2017 for each profile between Stations -150+00 and 0+00 are shown in Figure 5.

Figure 7. Aerial photo looking north along the Southern Shores Beach Nourishment project on August 4th, 2017.

September 2013 to December 2017:

APTIM is not aware of any historical beach profile survey data available north of Station -150+00 in Southern Shores, with the exception of three (3) profiles that were surveyed in 2013 and 2015 as part of a monitoring initiative conducted by the Town of Duck. Comparisons of the MHW shoreline position as measured during the September 2013 and December 2017 surveys along Stations -197+12 (northern Town Limit), -187+14 (11th Ave.) and -177+13 (approximately 200 feet south of 9th Ave.) were evaluated. An average MHW shoreline change of 5.4 ft. (seaward movement) was measured over the approximately 4.25-year period. This equates to an average MHW shoreline change rate of 1.3 ft./yr. The greatest change rate of 2.5 ft./yr. was measured along Station -197+12. The lowest rate of change of 0.3 ft./yr. was measured at Station -177+13. Figure 8 shows the MHW shoreline change rate for each of the three northern profiles measured between September 2013 and December 2017.

June 2017 to December 2017:

A comparison of MHW shoreline position was also made between the June 2017 pre-construction survey and the December 2017 town-wide survey to examine the effect of the beach fill project constructed in August 2017. Because the June 2017 survey only covered the fill area (Stations 0+00 to -20+00) the comparison is limited to this portion of Town. An average MHW shoreline change of 60.0 ft. was measured over the approximately 6-month period. This seaward advance is a direct result of the beach fill project constructed in August 2017. The change measured along Stations -10+00 and 0+00 were 73.1 ft. and 78.8 ft. respectively. The change measured at Station -20+00 was 28.2 ft. This trend follows the relative fill density placed during the project in that Station 0+00 received the highest fill density and Station -20+00 was in the taper area.

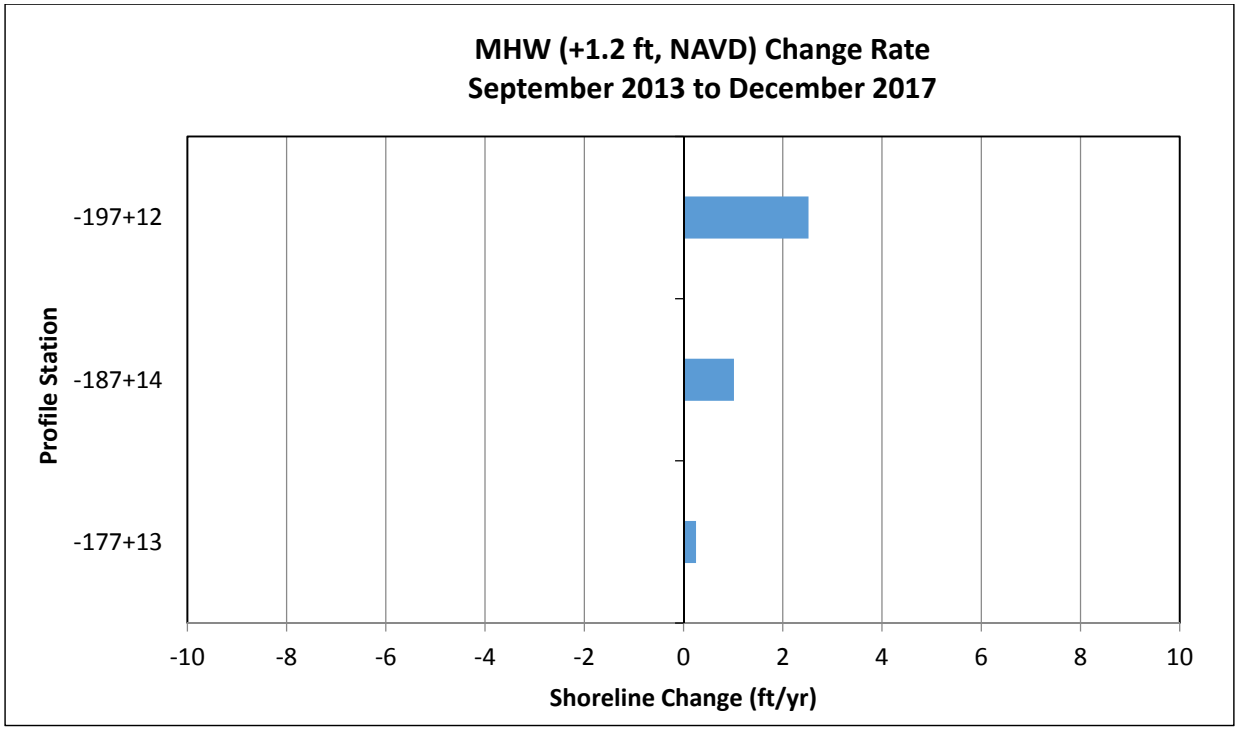

Figure 8. Shoreline change rates measured along the northern portion of the Town between September 2013 and December 2017.

Figure 9 shows the comparison of the MHW shoreline position along the southern 5,000 ft. of the Town of Southern Shores as measured in October 2004, October 2006, May 2015, June 2017 (Pre-Construction) and December 2017 (Post-Construction). The comparison of the shoreline positions show a seaward shift in the MHW shoreline south of Station -30+00 between October 2004 and October 2006 and a landward shift in the MHW shoreline position north of Station -30+00. From October 2004 to May 2015, the MHW shoreline position continued to move seaward. From May 2015 to June 2017, the MHW shoreline retreated considerably to its most landward location of the five (5) surveys. As a result of the beach fill project constructed in August 2017, the MHW shoreline position in December 2017 was shifted approximately 75 ft. seaward at Stations 0+00 and -10+00 and approximately 28 ft. seaward at Station -20+00.

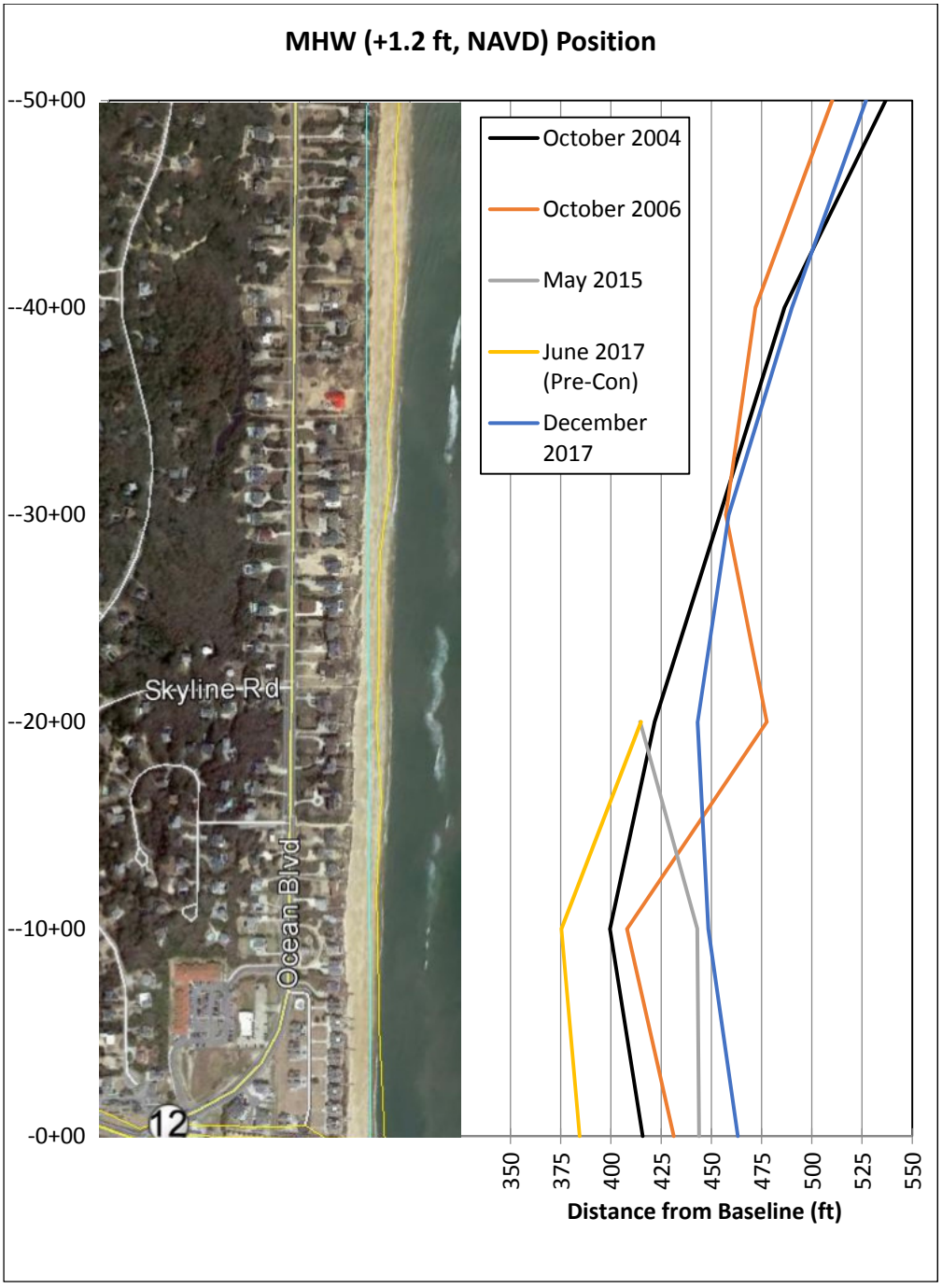

Figure 9. MHW shoreline position as measured along monitoring profiles between October 2004 and December 2017.

VOLUME CHANGE ANALYSIS

Changes in the shoreline position represented by the MHW contour can vary considerably based on sea conditions leading up to the time in which the surveys were conducted. This difference is often due to differences in the slope of the foreshore at a particular station. The trends observed through shoreline change analysis of a particular contour (i.e. MHW line) may give a sense of how the beach is performing, but it can also differ from the volume change trends.

Sand on the beach is distributed by wind and wave action over the entire active profile (from the dunes/vegetation out to the depth of closure). The dry beach often observed above the water represents only a fraction of the active beach profile. Therefore, the volume of sand measured on the entire profile is an important parameter to track and to gauge the health of the beach and performance of beach fill projects. The volume of sand in place is the metric that defines the three-dimensional beach, which provides storm protection. Figure 10 shows the same two profiles shown in Figure 4 with areas between the profiles color coded to show gains (green-accretion) and losses (red-erosion) in volume along the profile. The net difference between these gains and losses is referred to as the volume change.

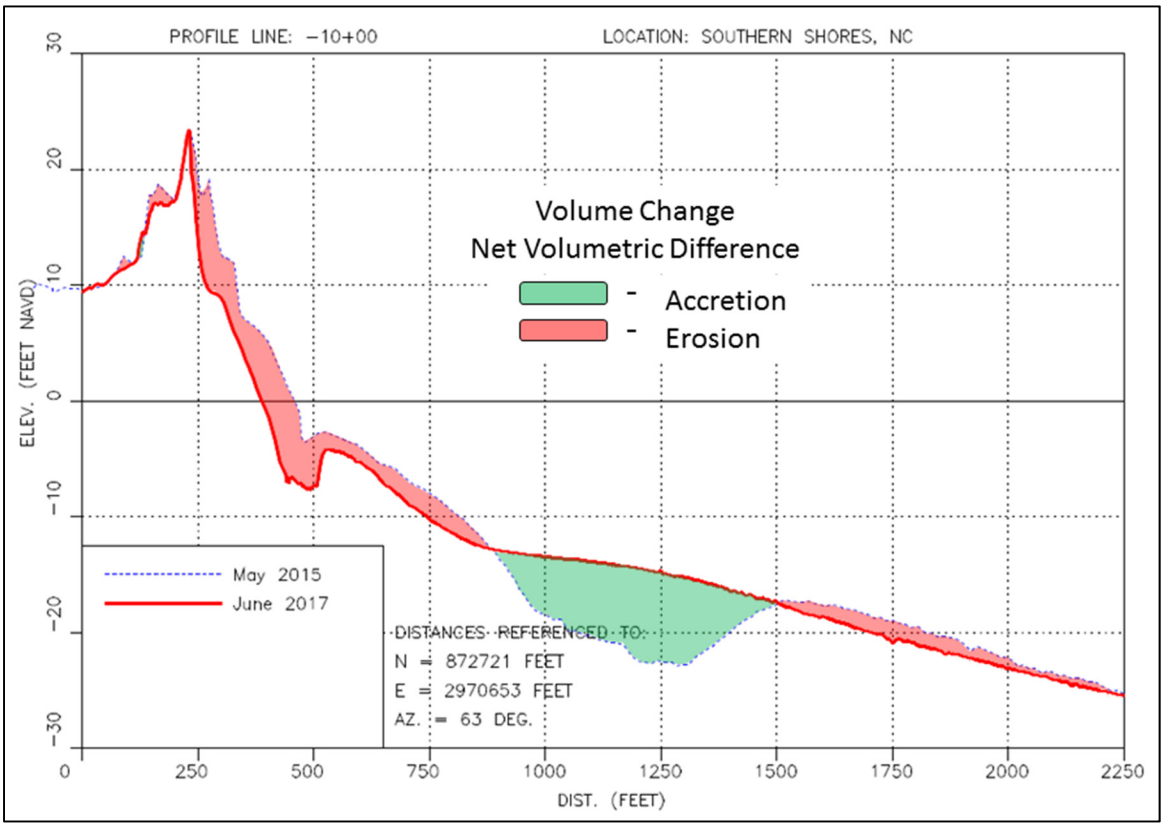

Figure 10. Beach profile cross section illustrating volume change.

Volumetric changes discussed in this report represent the change in the quantity of sediment measured through comparison of the available data sets collected between 2004 and 2017.

All volumetric changes along a profile or averaged over multiple profiles are given in cubic yards per linear foot. At times, this report also provides total volume in cubic yards measured between certain profiles. These volumes are based on the average end area method; whereby the average volume change between adjacent profiles is multiplied by the distance between stations. Volumetric change rates are given in cubic yards per linear feet of shoreline per year. The volumetric changes are calculated along the entirety of the profile from the depth of closure, which in this case is the -24 ft. contour, to the landward most point at which overlapping data exists.

October 2004 to October 2006:

Data collected along approximately 1,000-foot spaced profiles from approximately 3rd Ave. (Station -150+00) south to the southern Town limit of Southern Shores in October 2004 and October 2006 were examined to compare volumetric changes along that portion of the Town. This data was collected by the USACE FRF.

The average volumetric change rate measured along the profiles from Station -150+00 to Station 0+00 above the -24 ft. contour was -0.4 cy/ft./yr. Although the average volume change rate is less than 1 cy/ft./yr., considerable variability in the volume change rate was measured from profile to profile. The measured rates of volume change along this stretch of beach varied from a gain 22.6 cy/ft./yr. at Station 0+00 (Southern Shores/Kitty Hawk Town boundary) to a loss of -19.4 cy/ft./yr. at Station -50+00 (approximately 450 ft. south of Chicahauk Tr.). A profile by profile comparison of the volume change rate is provided in Figure 11. Figure 11 also includes volume change rates measured between October 2006 and December 2017, which are described later in this report.

As previously discussed in the Shoreline Change section, the beach fill placed during the 2017 project in the Town of Southern Shores was placed between Stations -25+00 and 0+00 and therefore, we have referred to the analyses in this report that compares data from Stations -20+00 to 0+00 as the "fill area". The average volumetric change rate in the fill area between October 2004 and October 2006 was +10.1 cy/ft./yr. This high rate of accretion was primarily driven by positive volume change along Stations -20+00 (22.6 cy/ft./yr.) and 0+00 (15.1 cy/ft./yr.); however, profile -10+00 showed a negative volume change rate of -7.5 cy/ft./yr.

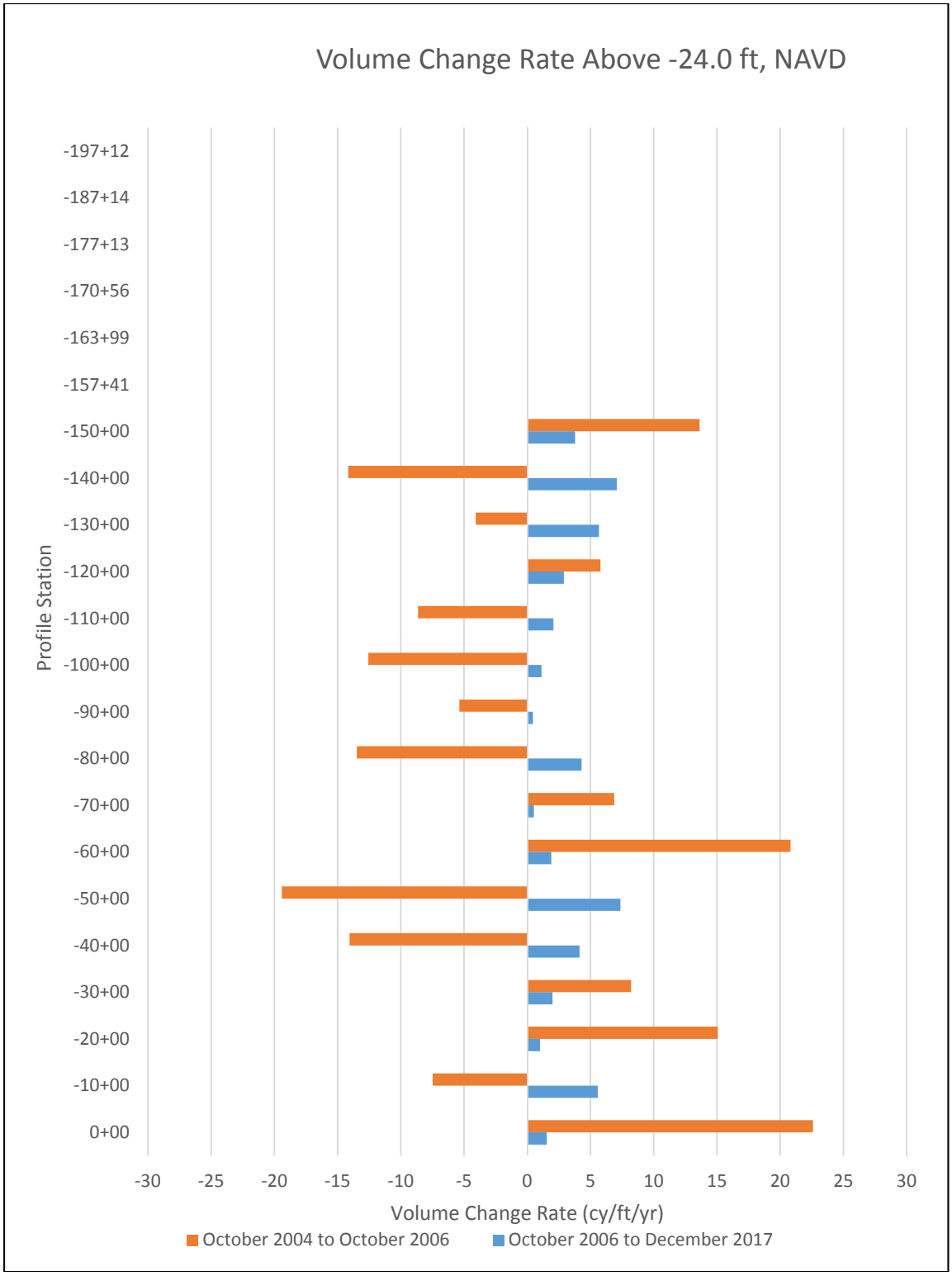

Figure 11. Annual Volumetric Change Rate above -24 FT NAVD (CY/FT/YR) between October 2004 and October 2006, and between October 2006 and December 2017.

October 2006 to May 2015:

Data collected by APTIM in May 2015 as part of the design survey for the Kitty Hawk Beach project was compared to the October 2006 data collected by the USACE to determine volume changes from 2006 to 2015 in the fill area. The average volumetric change rate measured along the profiles from Station -20+00 to Station 0+00 above the -24 ft. contour was +1.1 cy/ft./yr. Recall that from October 2004 to October 2006, the average volume change rate in the fill area was 10.1 cy/ft./yr. The relative stability in the fill area suggested by the average rate of +1.1 cy/ft./yr. was a combination of erosion rates of -3.3 cy/ft./yr. and -4.1 cy/ft./yr. along profiles -20+00 and -10+00, respectively and accretion of +10.8 cy/ft./yr. at Station 0+00.

Figure 12 shows a comparison of the volume change rates measured in the fill area between October 2004 and October 2006, October 2006 and May 2015, and May 2015 and June 2017.

The average end area method was used to compute the change in the volume of sand between Stations -20+00 and 0+00. Between October 2006 and May 2015, a net volume change of approximately -3,100 cy was computed along this portion of the beach above the -24.0 ft. NAVD88 contour. Annualizing this loss over the nearly 8.5-year period would result in a volume change rate of approximately -364 cy/yr. in the fill area.

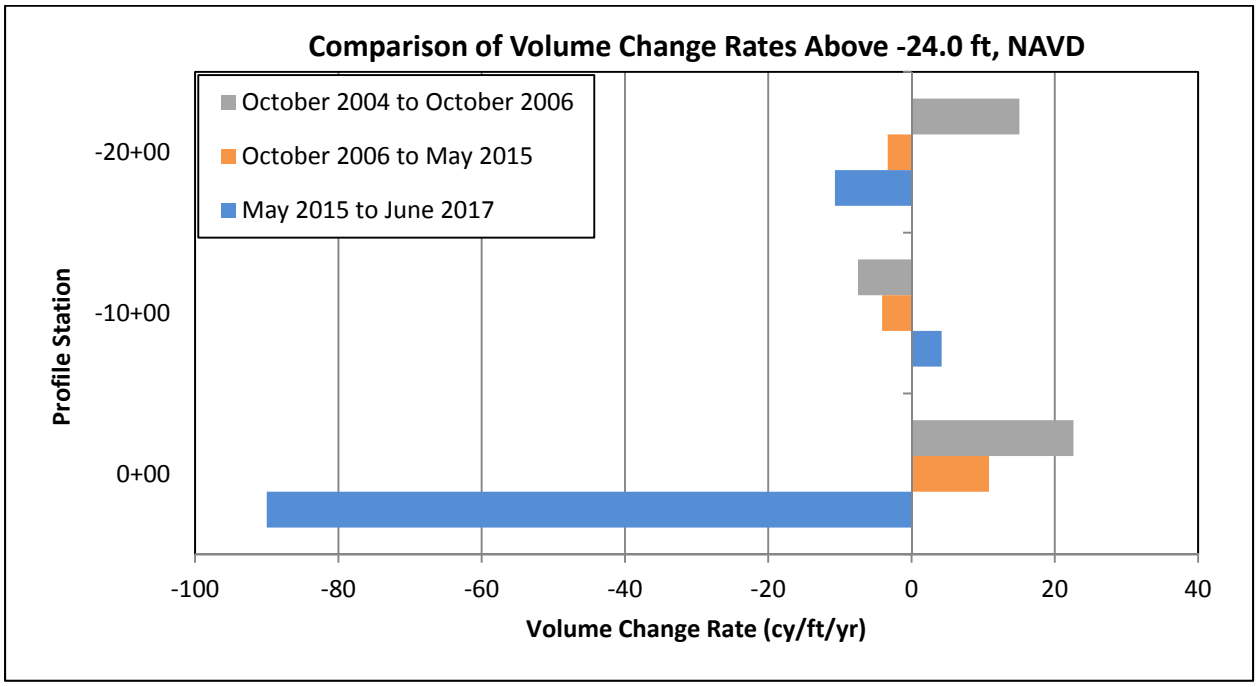

Figure 12. Volume change rates measured in the "Fill Area" between Oct. 2004 and Oct. 2006 (gray), Oct. 2006 and May 2015 (orange), and May 2015 and June 2017 (blue).

May 2015 to June 2017:

Great Lakes Dredge and Dock Company conducted a pre-construction survey of the fill area (Stations -20+00 to 0+00) as part of the 2017 construction project in June 2017. Using this survey and the APTIM survey conducted in May 2015, volume change was measured in the fill area between May 2015 and June 2017 (25 months). The average volumetric change rate measured along the profiles from Station -20+00 to Station 0+00 above the -24 ft. contour was -31.7 cy/ft./yr. Recall that the volume change trend in the fill area from October 2004 to October 2006 was accretional and the trend from October 2006 to May 2015 was essentially stable. The high rate of negative volume change was primarily driven by a measured loss of approximately 187 cy/ft. along Station 0+00 from May 2015 to June 2017. Figure 12 shows a comparison of the volume change rates measured in the fill area between October 2004 and October 2006, October 2006 and May 2015, and May 2015 and June 2017.

The average end area method was used to compute the change in the volume of sand between Stations -20+00 and 0+00. Between May 2015 and June 2017, a net volume change of approximately -93,200 cy was computed along this portion of the beach above the -24.0 ft. NAVD88 contour. As a point of comparison, this area only saw a net loss of 3,100 cy of sand over the approximately 8.5-year period from October 2006 to May 2015.

October 2006 to December 2017:

In December 2017, APTIM conducted beach profile surveys along the entire oceanfront of Southern Shores. All 22 beach profiles from Station -197+12 at the northern town boundary to Station 0+00 at the southern town boundary were surveyed. Using this survey and the USACE FRF October 2006 survey data, volume change was measured along the portion of beach from Stations -150+00 to 0+00. The average volumetric change rate measured over the approximately 11-year period along the profiles from Station -150+00 to Station 0+00 above the -24 ft. contour was 3.2 cy/ft./yr. Recall that the volume change rate along this same area from October 2004 to October 2006 was -0.4 cy/ft./yr., or essentially stable.

A profile by profile comparison of the volume change rate is provided in Figure 11. The comparison of the October 2006 and December 2017 profile data show that all 16 profiles experienced positive volume changes over the approximate 11 years ranging from a gain of 0.4 cy/ft./yr. at Station -90+00 (between Porpoise Run and Trout Run) to a gain of 7.4 cy/ft./yr. at Station -50+00 (approximately 450' south of Chicahauk Trl.).

September 2013 to December 2017:

As mentioned previously, APTIM is not aware of any historical beach profile survey data available north of Station -150+00 in Southern Shores, with the exception of three (3) profiles that were surveyed in 2013 and 2015 as part of a monitoring initiative conducted by the Town of Duck. Volume change between September 2013 and December 2017 was computed along Stations -197+12 (northern Town Limit), -187+14 (11th Ave.) and -177+13 (approximately 200 feet south of 9th Ave.). An average volume change of -1.6 cy/ft. (erosion) was measured over the

approximately 4.25-year period. This equates to an average volume change rate of -0.4 cy/ft./yr. An erosional rate of -2.5 cy/ft./yr. was measured along Station -187+14; whereas, an accretional rate of 0.5 cy/ft./yr. and 0.8 cy/ft./yr. was measured along Stations -197+12 and -177+13, respectively. Figure 13 shows the volume change rates for each of the three northern profiles measured between September 2013 and December 2017.

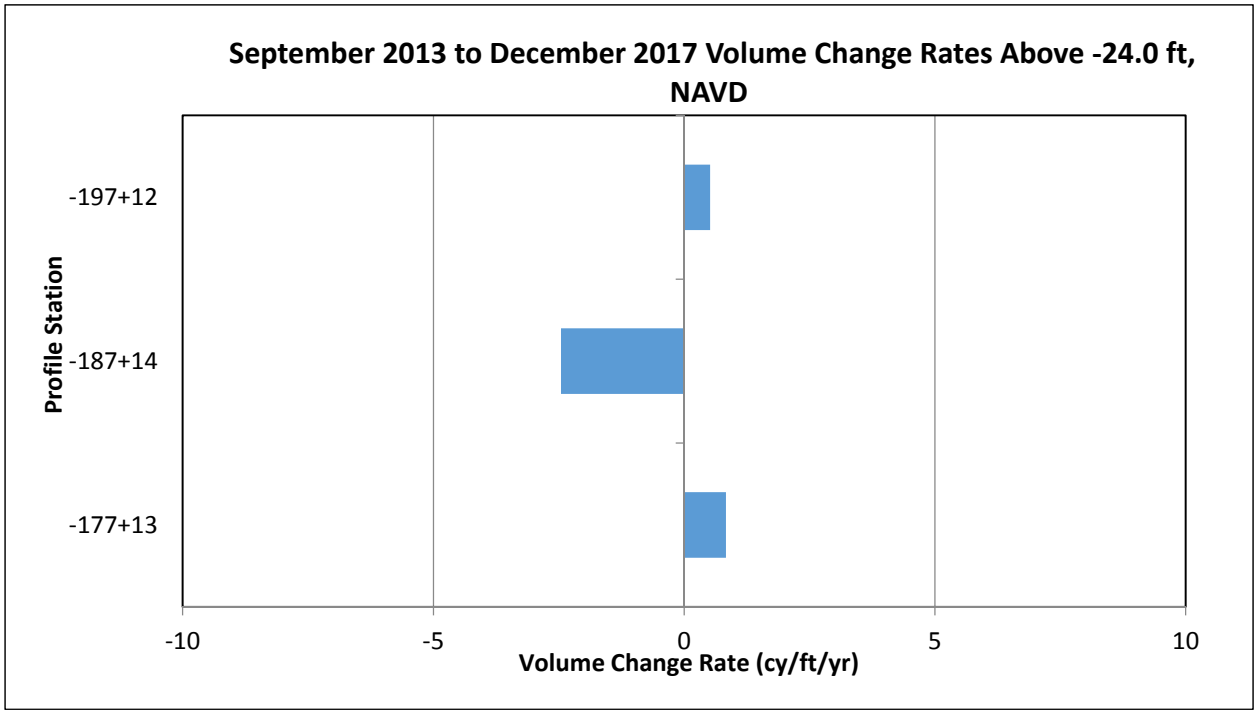

Figure 13. Volume change rates measured along the northern portion of the Town between September 2013 and December 2017.

June 2017 to December 2017:

A calculation of the volume change between the June 2017 pre-construction survey and the December 2017 town-wide survey was also made to examine the effect of the beach fill project constructed in August 2017. Because the June 2017 survey only covered the fill area (Stations 0+00 to -20+00) the comparison is limited to this portion of Town. An average volume change of 87.6 cy/ft. was measured over the approximately 6-month period. This increase in volume is a direct result of the beach fill project constructed in August 2017. The change measured along Stations -10+00 and 0+00 were 86.0 cy/ft. and 114.7 cy/ft., respectively. The change measured at Station -20+00 was 62.2 cy/ft. This trend follows the relative fill density placed during the project in that Station 0+00 received the highest fill density and Station -20+00 was in the taper area.

CONCLUSIONS

The Town of Southern Shores undertook this study to determine long-term and short-term shoreline and volumetric changes that have occurred along its oceanfront beaches. This report compiled and utilized a variety of data sources collected by the USACE FRF, APTIM and others to evaluate the shoreline change and volume changes that have occurred between 2004 and 2017.

The historic data sets used for this analysis did not provide continuous coverage throughout the Town. The December 2017 survey conducted by APTIM as part of this study is the first known survey to have covered the entire Town. Given the discontinuous nature of the historic data, this assessment focused on trends in three (3) primary areas where multiple data sets were available for comparison. Data collected by the USACE FRF in 2004 and 2006 covered the area from Station -150+00 located near 3rd Ave. to Station 0+00 located at the southern Town Boundary. Several surveys conducted between 2015 and 2017 included three (3) profiles along the southern 2,000 feet of the Town from approximately 150 feet south of Skyline Road to the southern Town Boundary. This is also the area in which the beach fill project was constructed in August 2017 and is therefore referred to as "The Fill Area". Surveys conducted in 2013 and 2015 by the Town of Duck, similarly covered the 2000 ft. of shoreline on the north end of Southern Shores from Station -197+12 located at the northern Town Boundary to Station -177+13 located approximately 200 ft. south of 9th Ave.

Shoreline Change Analysis: The shoreline change analysis examined the change in the MHW line (+1.2 ft. NAVD contour). The portion of shoreline from Station -150+00 to Station 0+00 experienced an average shoreline change rate of +4.9 ft./yr. in the two-year period between October 2004 and October 2006; however, the profile by profile comparison shows considerable variability from station to station. Variation during this time period ranged from -13.3 ft./yr. to +27.9 ft./yr. This variability may be due to the recovery of the shoreline following Hurricane Isabel, which impacted the Outer Banks region in September 2003. The average MHW shoreline change rate measured along this same portion of the shoreline during the approximately 11-year period between October 2006 and December 2017 was -0.4 ft./yr. The rate indicates an essentially stable shoreline. Figure 5 shows a comparison of the October 2004 to October 2006 rates and the October 2006 to December 2017 rates. Figure 5 shows that all the profiles from Station -120+00 (approximately 600 ft. north of Dogwood Trail) to -60+00 (approximately 600 ft. north of Chicahauk Tr.) experienced a long-term recession trend, which averaged -2.4 ft./yr.

The "Fill" area (southern 2,000 ft. of the Town) experienced an average shoreline change rate of 13.3 ft./yr. between October 2004 and October 2006. This average rate was highly influenced by the MHW shoreline change measured along Station -20+00, which moved seaward 55 ft. over the two (2) year period; whereas the shoreline change measured along Stations -10+00 and 0+00 during the same two (2) year period were 8.5 ft. and 15.5 ft., respectively. As stated previously, this relatively large variation may be due to shoreline adjustments taking place after the impact of Hurricane Isabel to the region in 2003. Over the approximately 8.6-year period from October 2006 to May 2015 the MHW shoreline rate along Station -20+00 was -7.3 ft./yr. (recession); whereas the MHW shoreline change rates along Stations -10+00 and 0+00 were 4.1 ft./yr. and 1.5 ft./yr. (advance), respectively. Between May 2015 and June 2017, the fill area, specifically profiles -10+00 and 0+00 experienced severe shoreline retreat, which is what prompted the Town to pursue

the beach fill project. Surveys conducted in May 2015 and June 2017 show that over the 25-month period, Stations -10+00 and 0+00 experienced shoreline change of -67.6 ft. and -59.5 ft., respectively. This equates to a shoreline change rate of -32.4 ft./yr. and -28.6 ft./yr., respectively. Figure 6 provides a comparison of the different shoreline change rates measured in the fill area between October 2004 and June 2017.

A comparison of the June 2017 pre-construction survey and the December 2017 post-construction survey of the beach fill project constructed in August 2017 indicate that the MHW shoreline advanced seaward approximately 60 ft. in the fill area as a result of the project. The shoreline change resulting from the fill project along Stations -10+00 and -0+00 was 78.8 ft. and 73.1 ft., respectively and the shoreline change along Station -20+00 was 28.2 ft. As shown in Figure 9 the beach fill project resulted in a shoreline seaward of where the shoreline existed in October 2004 and May 2015.

A comparison of the December 2017 data with data collected in September 2013 as part of an assessment completed for the Town of Duck, provided insight into shoreline change along the northern 2000 ft. of the Town's oceanfront. An average MHW shoreline change rate of 1.3 ft./yr. was measured between Stations -197+12 (northern Town Limit) and -177+13 (approximately 200 feet south of 9th Ave.). As shown in Figure 8, all three (3) profiles showed rates less than 3 ft./yr. over the approximately 4.25-year period. This suggests the shoreline in this area was fairly stable between September 2013 and December 2017.

Volume Change Analysis: The volume change analysis examined the changes in the volume measured along profiles above the -24 ft. NAVD88 contour. The depth of -24 ft. NAVD88 was used as the depth of closure in the design of the beach nourishment projects constructed as part of the multi-town project in 2017. Similarly to what was found in the shoreline change analysis between October 2004 and October 2006, there was a considerable amount of variability in the volume change rates measured between Stations -150+00 and 0+00. Although the average volume change rate through this portion of the Town over the 2-year period was only -0.4 cy/ft./yr., the individual volume change rates along the profiles varied from -19.4 cy/ft./yr. at Station 50+00 to +22.6 cy/ft./yr. at Station 0+00. The net volume change measured along this approximately 15,000 ft. portion of the Town's oceanfront over the 2-year period was approximately -42,000 cy. However, the area between Stations -150+00 and -80+00 exhibited a larger net volume loss of approximately -82,000 cy. The overall variability in volume change may be due to the response of the beach following Hurricane Isabel, which impacted the Outer Banks region in September 2003. In comparison, the average volume change rate measured along this same portion of the shoreline (Stations -150+00 to 0+00) during the approximately 11-year period between October 2006 and December 2017 was 3.2 ft./yr. (accretion). Figure 11 shows a comparison of the October 2004 to October 2006 rates and the October 2006 to December 2017 rates. All of the profiles from Stations -150+00 to 0+00 exhibited an accretional trend over the approximately 11-year period.

Between October 2004 and October 2006, the "Fill" area experienced a positive volume change of approximately 23,000 cy. Figure 12 shows the variability by profile in the fill area where Stations -20+00 and 0+00 exhibit positive volume change rates; whereas Station -10+00

experienced an erosional rate of -7.5 cy/ft./yr. Over the approximately 8.6-year period from October 2006 to May 2015, profiles at Stations -20+00 and -10+00 experienced negative volume change rates of -3.3 and -4.1 cy/ft./yr., respectively; whereas the profile at Station 0+00 saw a significant increase in volume, with a calculated volume change rate of 10.8 cy/ft./yr. Between May 2015 and June 2017, a net negative volume change of approximately 93,000 cubic yards was measured in the fill area. This was largely driven by the losses between Stations -10+00 and 0+00 of approximately 88,000 cy over a 1,000 ft. length of beach. These dramatic changes can be seen in the photos in Figure 14. Based on the data analyzed in this study and discussions with Town officials, the dramatic erosion that took place between May 2015 and June 2017 was unprecedented. The reason for the accelerated erosion rates may be associated with variations in the offshore bathymetry that resulted in the variations of wave approaches to shore. Such variations can have dramatic effects on long shore transport of sand and result in locally high erosion or hot spot areas.

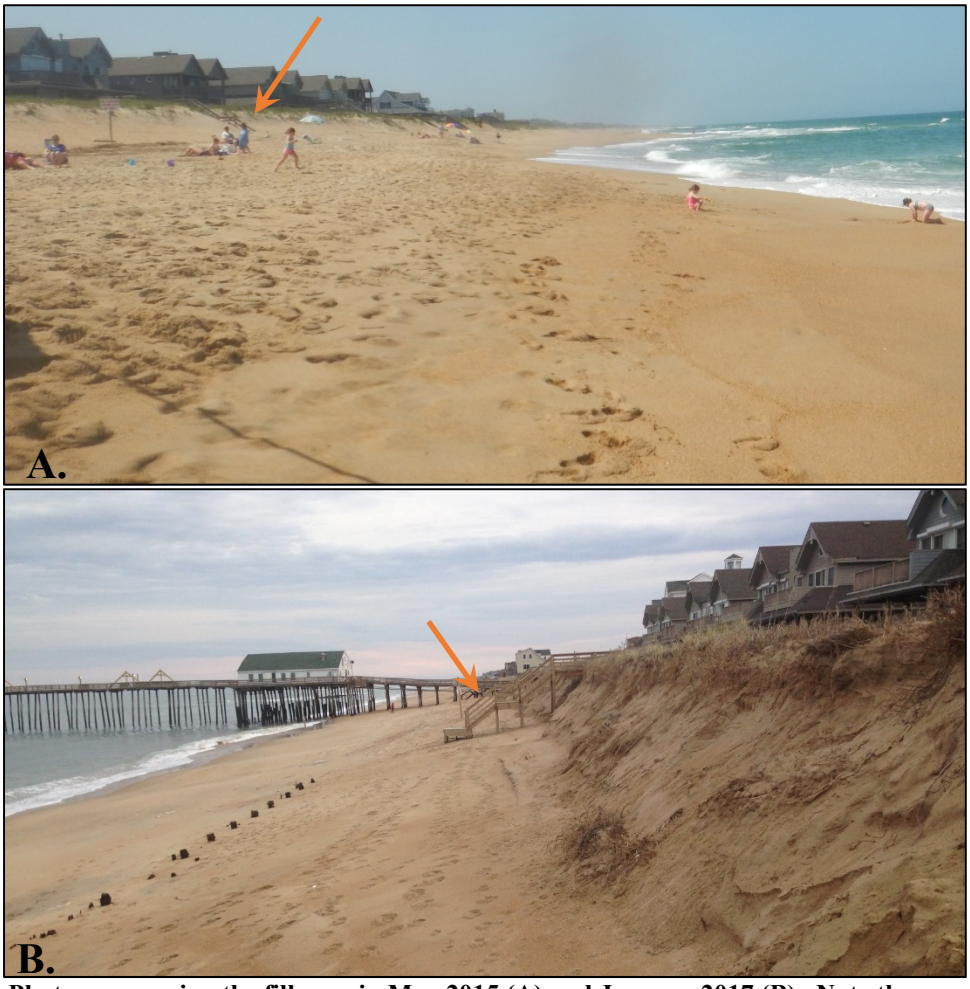

Figure 14. Photos comparing the fill area in May 2015 (A) and January 2017 (B). Note the orange arrows which indicate the location of the same set of stairs in both pictures.

A comparison of the June 2017 pre-construction survey and the December 2017 post-construction survey of the beach fill project constructed in August 2017, indicate that the fill area experienced a net increase in volume of approximately 174,000 cy. Surveys conducted during the beach fill project in August 2017 measured a direct placement of approximately 85,000 cy of beach fill in the fill template along the southern 1,500 ft. of the Town. The additional volume measured based on the comparison of the June 2017 and December 2017 may be a combination of some shoreline recovery that occurred between June 2017 and the time the beach fill project was constructed in August and the spreading of material off of the larger Kitty Hawk project following the construction of the northern portion of the Kitty Hawk project in August and September.

A comparison of the December 2017 data with data collected in September 2013 as part of an assessment completed for the Town of Duck provided insight into volume change along the northern 2000 ft. of the Town's oceanfront. An average volume change rate of -0.4 cy/ft./yr. was measured between Stations -197+12 (northern Town Limit) and -177+13 (approximately 200 feet south of 9th Ave.). Figure 7 depicts the individual rates for each of the three (3) profiles in this area. This area exhibited relatively stable volume change over the approximately 4.25-year period.

Table 2 lists the average volumetric change rates above the -24 ft. contour for 1) all profiles from Stations -150+00 to 0+00; 2) profiles from Stations -20+00 to 0+00 (Fill Section); and 3) profiles from Stations -197+12 to -177+13 (North Section).

Table 2. Average volume change rates above the -24 ft. contour.

	Stations -150+00 to 0+00 16 Profiles	**Fill Section (Stations -20+00 to 0+00)** 3 Profiles	**North Section (Stations -197+12 to -177+13)** 3 Profiles
Volume Change Rate (CY/Ft./Yr.)			
October 2004 to October 2006	-0.4 cy/ft./yr.	10.1 cy/ft./yr.	
October 2006 to May 2015		1.1 cy/ft./yr.	
May 2015 to June 2017		-31.7 cy/ft./yr.	
October 2006 to December 2017	3.2 cy/ft./yr.	2.7 cy/ft./yr. *	
September 2013 to December 2017			-0.4 cy/ft./yr.

* Rate includes the impact of the beach fill project constructed in August 2017

In order to evaluate the profiles for which no historical data existed, the total volume measured along each profile above the -24 ft. NAVD88 contour and seaward of the +20 ft. contour on the landward side of the dune, was calculated. This area of the profile is referred to in this report as the volume envelope. Figure 15 shows a cross section of profile -10+00, which graphically depicts the volume envelope. Comparing the volume measured in the volume envelope along the Town's oceanfront allows for the relative comparison of each profile.

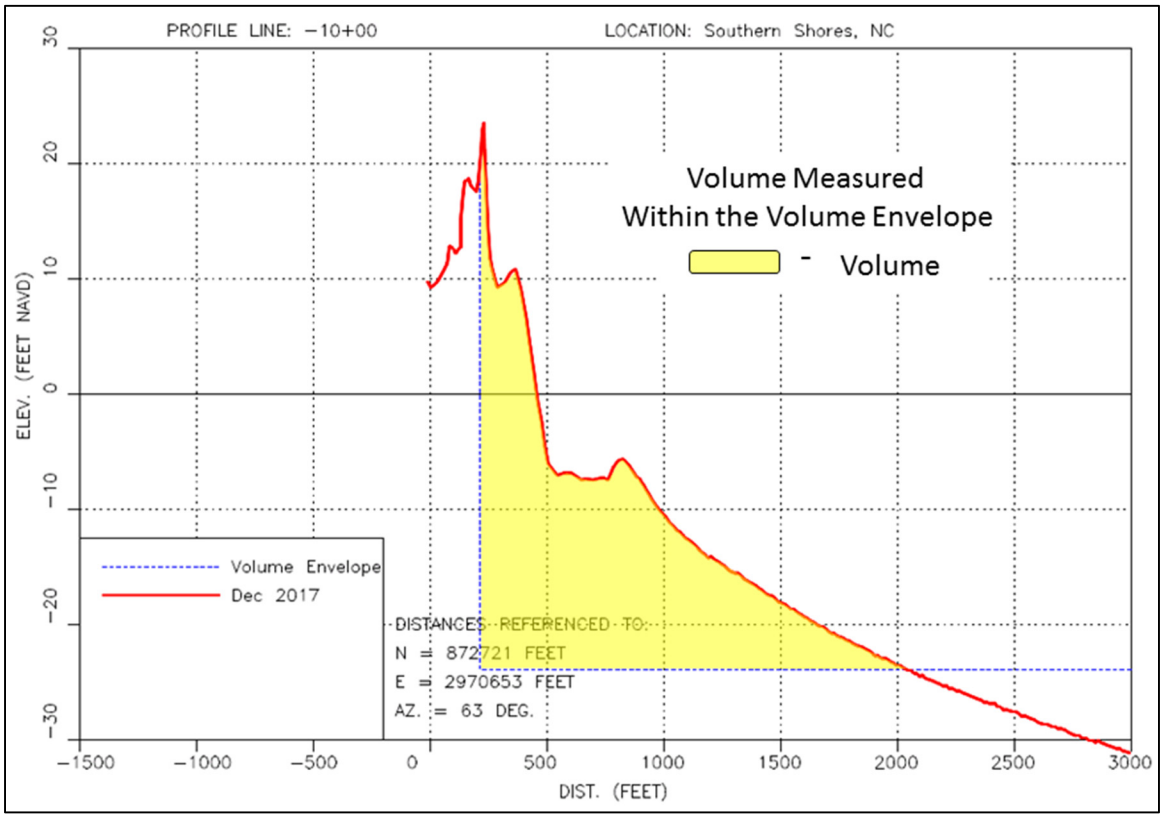

Figure 15. Beach profile cross section illustrating the volume envelope.

Figure 16 shows the volume measured within the volume envelope along each of the 22 Southern Shores profiles surveyed in December 2017. The average volume within the envelope measured along all 22 profiles in December 2017 was 830 cy/ft. The data represented in Figure 16 suggests that the area from Station -150+00 (located near 3rd Ave.) to Station -70+00 (located approximately 500 ft. south of where Ocean Blvd. and Duck Rd. meet), is relatively less than the portions of Southern Shores to the north and south of this section. The average volume within the envelope measured along the nine (9) profiles from Stations -150+00 to -70+00 is 793 cy/ft. The average volume within the volume envelope measured along the six (6) profiles to the north from Stations -197+12 to -157+41 was 873 cy/ft. and the volume measured along the seven (7) profiles to the south from Stations -60+00 to 0+00 is 841 cy/ft.

Figure 16 also shows the volume measured within the volume envelope along profiles surveyed by the USACE FRF in 2006 and along profiles surveyed by Great Lakes Dredge and Dock in June 2017. As previously mentioned, comparison of the volume present in October 2006 and the volume present in December 2017 shows all profiles had more volume within the volume envelope in December 2017 than were present at the time of the October 2006 survey. However, a comparison of the volume within the envelope in the Fill Area in June 2017 prior to the beach fill project, shows each of these three profiles had less volume than was present at the time of the October 2006 survey.

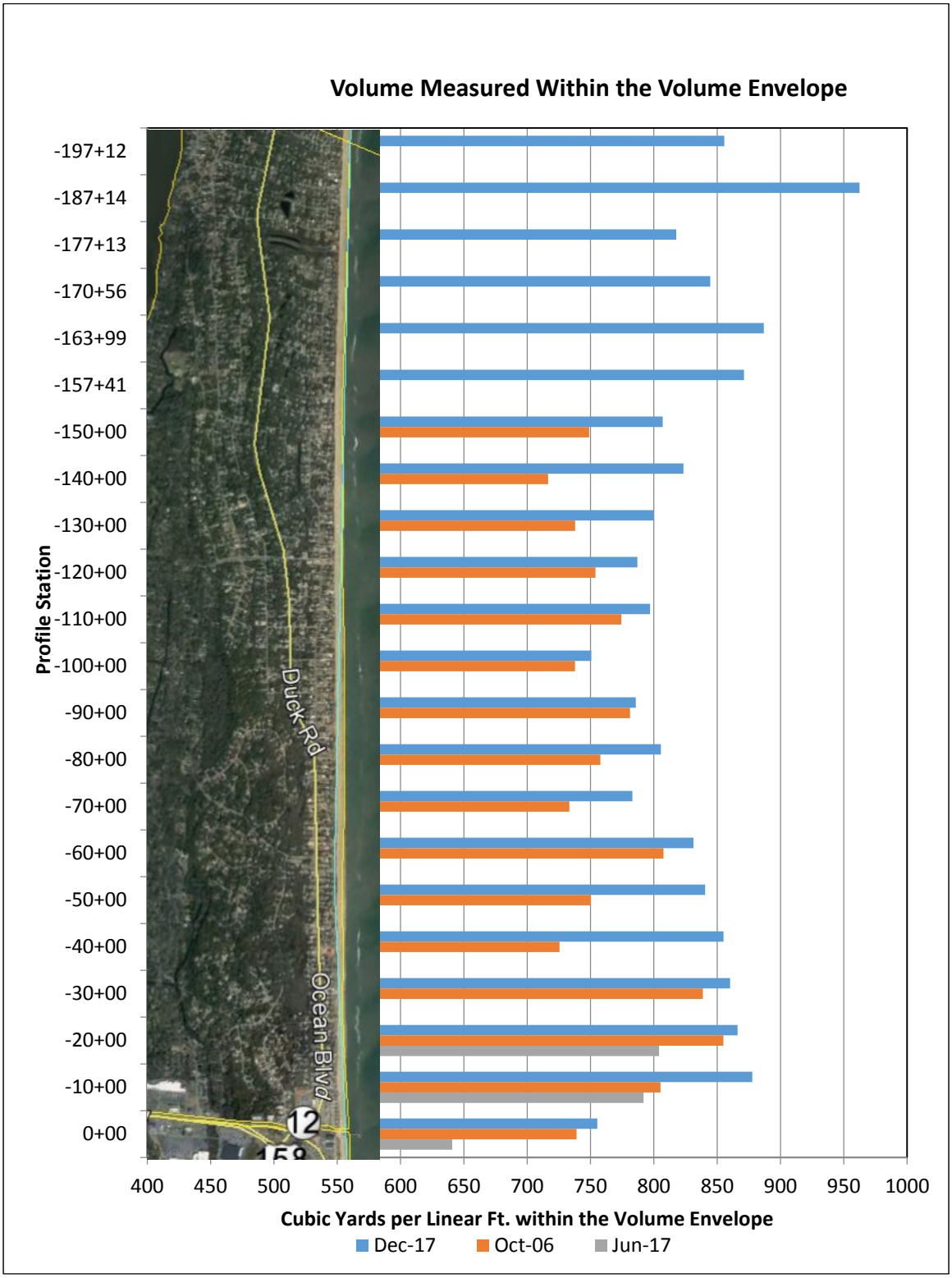

Figure 16. Beach profile cross section illustrating the volume envelope.

Although the volume of sand present within the envelope provides for a way of making relative comparisons of the available level of storm damage reduction between one profile and another, this volume is not necessarily the only indication of a structures vulnerability to potential storm damage. In this regard, the greater the distance a given structure is set back from the dune the higher the level of potential storm damage reduction.

A qualitative assessment of the distance structures are set back from the vegetation line was made using publicly available satellite imagery from Google Earth. A visual examination of imagery from March 2017 shows that houses are generally situated closest to the vegetation line between Stations -140+00 and -100+00 and along the very southern part of the Town between Stations -10+00 and 0+00. Houses located between Stations -157+00 and -140+00 and Stations -100+00 to -70+00 generally appear to have a relatively moderate setback. The area north of Station -157+00 and between Stations -40+00 and -20+00 appear to have the greatest setback from the edge of vegetation. Figure 17 shows examples of the comparison of the relatively minimal setback of structures between Stations -110+00 and -100+00 and the relatively greater setback of structures between Stations -170+56 and -163+99.

Figure 17. Google Earth Images from March 2017 showing the relatively minimal setback of structures from the vegetation between Stations -110+00 and -100+00 (A.) and the relatively greater setback of structures from the vegetation between Stations -170+56 and -163+99.

RECOMMENDATIONS

Based on the analysis and conclusions discussed in this report, APTIM is recommending the following:

1. **Conduct a vulnerability assessment of the oceanfront structures:** The vulnerability assessment employees a profile-based storm simulation model called SBEACH. A similar assessment was conducted during the design phase of the Duck and Kill Devil Hills Beach Projects. The vulnerability assessment can both identify structures that may be vulnerable to a specific design storm and determine the design requirements to avoid impacts to a design storm.
2. **Continue Monitoring of the Beach Profiles:** In order to monitor the shoreline and volume change trends along the Town's oceanfront shoreline, Southern Shores should implement an annual beach profile monitoring program starting in spring 2019. Coordinating with monitoring that is occurring along the Towns of Duck and Kitty Hawk may provide cost savings to the Town in data acquisition.
3. **Determine a Minimum Cross Section Volume:** Based on the results of the vulnerability analysis and the beach fill design for the Towns of Duck and Kill Devil Hills, the Town should determine the ideal minimum cross section volume to maintain to provide an acceptable level of storm damage reduction.

Through the implementation of these recommendations, the Town of Southern Shores can determine what level of storm damage mitigation is currently in place, where vulnerability exist, and project if and when beach nourishment may be required. With this information, the Town can then determine the financial needs necessary to maintain an acceptable level of storm damage mitigation.

Given the active programs established in Dare County for beach nourishment, the Town of Southern Shores is well positioned to develop a long term management program that leverages cost saving opportunities realized through multi-town cooperation as was seen during the 2017 beach fill project. Furthermore, by developing a management plan before the beach reaches a critically eroded state, the Town may be able to maintain a greater level of storm damage reduction.

REFERENCES

U.S. Army Corps of Engineers, 2004. Dare County Beaches, Shore Protection Project Physical Monitoring Program Profile Survey and Sediment Sampling Report 2004. Prepared by USACE-ERDC-CHL Field Research Facility, 16 pgs.