2023 BEACH MONITORING AND BEACH STABILITY ASSESSMENT
CURRITUCK COUNTY, NORTH CAROLINA

PREPARED FOR
CURRITUCK COUNTY

PREPARED BY
COASTAL PROTECTION ENGINEERING OF NORTH CAROLINA, INC.
ENGINEERING LICENSE CERTIFICATE #: C-2331

NORTH CAROLINA PROFESSIONAL SEAL 048852 ENGINEER ADAM T. PRIEST

ADAM T. PRIEST, PE NO. 048852

11/8/2023
DATE

November 2023

EXECUTIVE SUMMARY

In 2020, Currituck County initiated a Beach Monitoring and Beach Stability Assessment to evaluate long-term and short-term shoreline and volumetric changes occurring along Currituck's oceanfront beaches. The initial study was completed in 2023 following three (3) consecutive years of monitoring. The stated goals of the Assessment were 1) to better understand the changes that are occurring in the beaches and 2) to assist the County in making informed decisions regarding beach management. At the conclusion of the initial Assessment, Currituck County requested that annual monitoring continue to track and assess long-term and short-term shoreline and volumetric changes along its oceanfront beaches.

This 2023 report serves to provide an update to the County in terms of data obtained through June 2023. The report provides an assessment of both long-term and short-term shoreline change trends, an analysis of the impact of projected long-term shoreline change over 10-, 20-, and 30-year horizons, and an assessment of both long-term and short-term volume change trends.

The Currituck County barrier island beaches extend approximately 22.6 miles along the Atlantic Ocean. The beaches extend from the North Carolina/Virginia border south-southeast to the Town of Duck in Dare County, North Carolina. The Currituck County beach is divided up into several segments of privately developed residential and commercial property and publicly owned property. The northernmost 10.9 miles of the Currituck County beach is only accessible via off-road driving. South of the off-road access at N. Beach Access Road and south of the "Horse Gate", the Currituck County beach extends approximately 11.7 miles to the southern County boundary with Dare County. This section of beach is almost entirely developed.

Given the differences in land use, land management, and geomorphology (changes in the dune and beach slope configuration over time), the Assessment Area has been divided into four (4) sections for reporting purposes. The northernmost section is referred to as the Carova Section, which encompasses approximately 4.9 miles of the Assessment Area from the northern County boundary to the northern boundary of the Currituck National Wildlife Refuge. The approximately 6.0-mile section of the Assessment Area that includes the Currituck National Wildlife Refuge, the Currituck Banks Estuarine Reserve, and the developed area along Sandpiper Road and Ocean Pearl Road is referred to as the Reserve/Refuge Section. The largest section, referred to as the Corolla Section, extends approximately 8.2 miles from approximately 250 feet south of the Horse Gate to approximately 500 feet north of Yaupon Lane. The southernmost 3.5 miles of the Assessment Area is referred to as the Pine Island Section.

Projected Shoreline Changes: Publicly available lidar data allowed for a long-term shoreline change analysis to be conducted, which provides insight into overall trends. Shoreline change is calculated by comparing shoreline positions along shore perpendicular transects over time to evaluate the rate in which the shoreline moves landward or seaward. Eight (8) data sets collected between 2009 and 2023 were analyzed to determine shoreline change rates over the past 14 years. These long-term rates were determined using a linear regression method that considers each of the eight data sets available over this 14-year period. The shoreline change rates

computed were then used to project future shoreline changes throughout the Assessment Area over a 10-, 20-, and 30-year time horizon.

The projections show the greatest number of impacts from projected shoreline changes were observed within the Corolla Section of the Assessment Area. In total, 154 houses were shown to be impacted over the 30-year horizon throughout the Corolla Section. The majority of these houses are located between the Horse Gate and Albacore St. (C-084). Of the 154 houses shown to be impacted over the 30-year horizon, 43 of the houses were shown to be impacted over the 20-year horizon and 2 were shown to be impacted over the 10-year horizon. The oceanfront houses along the Corolla Section are concentrated along three general areas. The northernmost area spans from the Horse Gate to Corolla Village Road (station C-059 to C-066). Along this approximately 1.4-mile stretch of beach, nearly every oceanfront house was shown to be impacted over the 30-year horizon. Approximately 42% of the oceanfront houses along this section were shown to be impacted over the 20-year horizon and 2 of the houses in this section were shown to be impacted over the 10-year horizon along this stretch of beach. Furthermore, portions of the road along Atlantic Avenue were shown as impacted over the 30-year horizon.

The second concentrated section of oceanfront structures shown to be impacted over the various time horizons are located along the 2.9 miles of beach fronting Lighthouse Drive. Along the northern 1.3 miles of Lighthouse Drive (north of station C-075), approximately 45% of the oceanfront structures were shown to be impacted over the 30-year horizon, and no houses were shown to be impacted over the 20-year or 10-year horizons. Along the southern 1.1 miles of Lighthouse Drive, approximately 83% of the oceanfront structures were shown to be impacted over the 30-year horizon and approximately 25% were shown to be impacted over the 20-year horizon.

South of Albacore Street, the northernmost house in the Crown Point community was shown as impacted over the 30-year horizon. Approximately 2,000 feet south of that house, 8 houses along the Tide Arch community (station C-087 to station C-088) were shown to be impacted over the 30-year horizon. No houses along the 2.6-mile stretch of beach between the south end of the Tide Arch community (station C-088) and the north end of the Spindrift community (station C-101) were indicated as impacted over the 30-year horizon.

Along the oceanfront section of the Spindrift community, all 9 houses located along the beach were shown to be impacted over the 30-year horizon. Out of the 9 houses along Spindrift shown to be impacted over the 30-year horizon, 4 were shown to be impacted over the 20-year horizon.

Volume Changes:

A complete volumteric analyses was completed as part of the 2023 Assessment through a comparison of May 2020, May 2022, and June 2023 data. Volume change rates measured between 2020 and 2023 indicate an overall accretional trend during the 3.1-year period. The average volumetric change rate along the entire Assessment Area was +6.3 cy/ft./yr. between 2020 and 2023; this equates to a net volume gain of approximately 1,188,500 cy. South of the Horse Gate was the only area analyzed in this 2023 report. A positive volumetric change of

approximately 739,900 cy was measured along the Corolla Section during this time period. Similarly, a positive volumetric change of approximately 448,600 cy was measured in the Pine Island Section.

The finding of overall a net volumetric gain along the Assessment Area was unexpected given the fact that various studies and beach monitoring programs established both north and south of the Currituck County shoreline have documented erosional trends over various periods of time Furthermore, these studies and monitoring programs north and south of Currituck County have prompted Sandbridge, Virginia to the north and the Towns of Duck, Southern Shores, Kitty Hawk, Kill Devil Hills, and Nags Head to the south to implement beach nourishment programs.

A number of various analyses were conducted to better understand volumetric changes in terms of which portions of the beach (both along-shore and across-shore) experienced gains and losses. As mentioned previously, the Corolla and Pine Island Sections experienced positive volume changes between May 2020 and June 2023. The only net negative volume change was observed in the Corolla Section in the portion of the beach between the backside of the primary frontal dune and the +10 ft. NAVD88 contour. However, significant positive volumetric changes were measured in the Inner Nearshore portion of the beach, which was defined as the portion of the beach profile between the -6.0 ft. NAVD88 contour seaward to the -19.0 ft. NAVD88 contour. This significant positive volumetric change resulted in a net positive volumetric change along the Assessment Area between May 2020 and June 2023.

The -19.0 ft. NAVD88 contour was established as the depth of closure for this study. The concept of depth of closure is used in coastal engineering application to define a theoretical depth along a beach profile where sediment transport is very small or non-existent, dependent on wave characteristics and sediment grain size. The increase in volume measured between the -6.0 ft. NAVD88 contour seaward to the -19.0 ft. NAVD88 contour, which is referred to in this report as the Inner Nearshore portion of the beach, is nearly ten times greater than the positive volume changes measured landward of the -6.0 ft. contour. This suggests that the volume gains measured within the Assessment Area may be migrating from deeper water seaward of the depth of closure.

As previously stated, the depth of closure typically refers to a theoretical depth along a beach profile where sediment transport is very small or non-existent, depending on wave characteristics and sediment grain size. Given this definition, one would not expect to find considerable volumetric changes occurring seaward of an established depth of closure. However, seaward of the previously established -19.0 ft. NAVD88 depth of closure, positive volumetric changes were also measured between May 2020 and June 2023. More specifically, south of the Horse Gate in the Corolla and Pine Island Sections, a net positive volumetric change of approximately 1,179,500 cy was measured between May 2020 and June 2023 between the -19.0 ft. NAVD88 contour and the -25.0 ft. contour.

Numerous monitoring programs throughout the east coast and gulf coast of the US, established to monitor the performance of beach nourishment projects, have documented a phenomenon in which a large storm or a period of time with multiple large storms, resulted in the movement of

sediment from the active beach seaward of the typical depth of closure. Furthermore, these studies have also demonstrated that a multi-year recovery period may follow these storm events, during which sand that had previously migrated into deeper water, migrates landward into the active beach profile.

A general review of wave data reflective of conditions offshore Currituck County was conducted to evaluate whether the offshore wave climate prior to the study period (January 2017 to January 2020) differed significantly from the wave climate during the study period (May 2020 to June 2023). These wave data indicate that the pre-monitoring period (January 2017 to January 2020) was significantly more active in terms of wave events that produced significant wave events. Specifically, there were three storm events during this three year period where significant wave heights exceeded 20 ft.

The comparison of these wave data, coupled with the observations along beaches north and south of Currituck County, which also experienced positive volumetric changes during portions of the 2020 to 2023 monitoring period, suggests that the positive volumetric changes experienced during the May 2020 to June 2023 monitoring period along the Currituck County beaches may be explained as continued recovery following storm induced migration of sand into deeper depths offshore. Furthermore, if this explanation holds true, negative volume change trends may follow this temporary period of recovery.

Recommendations: Based on the various beach assessments described in this report and conclusions drawn from those assessments, CPE provides the following recommendations for the County's consideration as they seek to make informed decisions regarding beach management:

1. **Continue Monitoring of the Beach Profiles:** The completion of the initial 3-year Beach Monitoring and Beach Stability Assessment (2020 through 2022) established a baseline of shoreline change and volumetric change rates. Given the results of the shoreline and volume change analysis, the distribution of potential impacts from the shoreline projections over 10 to 30 years and the distribution of houses identified through the vulnerability analysis, a recommendation was made to the County to continue to monitor on an annual basis (CPE, 2023). This recommendation suggested that the Corolla and Pine Island Sections should be monitored on an annual basis based on several factors.

   The first was that the majority of the houses indicated as vulnerable through both the SBEACH analysis and the projected shoreline change rates, were located south of the Horse Gate. Secondly it was stated that given the possibility that the positive volumetric changes observed between 2020 and 2022 may be due to a temporary recovery of the beach following a period where sand had been pulled offshore due to storms, annual monitoring was important to track whether the beach is still in a state of recovery or whether it reverts to a trend of volume loss. The third reason given to monitor the area south of the Horse Gate on an annual basis was due to the Pine Island Section being the only one of the four

(4) Sections to have shown a negative volumetric change over the monitoring period between May 2020 and May 2022. Furthermore, the monitoring would allow for the tracking of the anomalous volumetric loss measured along profile C-117 in Pine Island.

North of the Horse Gate, in the Carova and Reserve Refuge Area, it was recommended that monitoring could be conducted every other year. This recommendation was based on the fact that only a small number of houses located north of the Horse Gate were indicated as vulnerable coupled with the amount of undeveloped beach north of the Horse Gate.

The County contracted with CPE to continue monitoring as recommended through 2025. Based on the results of the 2023 monitoring, it is still recommended that this annual monitoring continue through at least 2025 to include the Corolla and Pine Island Sections annually and the Carova and Reserve/Refuge Section every other year for the same reasons as stated previously. It appears as though the positive volumetric changes that have continued to be observed between 2020 and 2023, which may be due to a temporary recovery of the beach following a period where sand had been pulled offshore due to storms, has not yet reverted to a trend of volume loss as suggested may happen. However, given the elevated sea conditions experienced at the end of the summer and into early fall 2023, it is still possible for the trend of positive volumetric changes to reverse.

The same profiles established at the beginning of the County-wide assessment in 2020 should be collected at a similar time of year to reduce the impacts of seasonal changes on conditions of the profile, particularly the portion of the profile above Mean High Water (MHW).

2. <u>Develop a Beach Management Plan:</u> A Beach Management Plan is a document that first requires the establishment of tangible goals for how a local government desires to manage the beach. Beaches serve a variety of purposes from storm damage reduction, to flood mitigation, to recreational opportunity that draws in tourist dollars, to impacts to transportation or evacuation corridors, to environmental habitat that supports such resources as sea turtles and shore birds. A properly established beach management plan first establishes the local government's goals and then once the goals have been established, a feasibility analysis is conducted to look at multiple options for achieving the desired goals of the plan.

   CPE renews its previous recommendation that the County develop a Beach Management Plan. The development of this Beach Management Plan would allow the County to first establish goals for managing the beaches. The development of the beach management plan would then involve the development of various management concepts, which may include beach nourishment, sand fencing/dune vegetation, beach bulldozing (dune push), targeted buyouts, etc. Once various management concepts have been developed, those

various concepts would be evaluated in terms of effectiveness, cost, and other aspects used to determine feasibility. Through the evaluation of these various concepts, the County would determine the most feasible options that would both meet the pre-established goals of the plan and be economically feasible to implement. The management plan would ultimately provide thresholds for implementing actions established in the management plan, cost estimates, and schedules for implementing such actions. The County issued a Public Notice on September 5, 2023 requesting statements of qualifications for firms that could assist with the development of a Beach Management Plan.

3. Coordinate with Dare County on Regional Sand Resource Investigation: In 2023 Dare County commissioned a two-year regional sand investigation study to locate sand for future beach nourishment projects. The reconnaissance phase of this investigation was conducted in the summer of 2023 and the County and its consultants are assessing data acquired. The geographic extent of the Study Area includes portions of southern Currituck County including portions offshore of the Corolla and Pine Island Sections as defined in this report. State and federal rules do not limit offshore sand resources to be used only by the adjacent local community. These resources are typically considered state and or federal resources for which permits can be applied for by neighboring municipalities to use these sediments for beach nourishment projects. If Currituck County anticipates the future development of a Beach Management Plan, CPE recommends that County staff coordinate with Dare County on this regional sand resource investigation.

2023 BEACH MONITORING AND BEACH STABILITY ASSESSMENT CURRITUCK COUNTY, NORTH CAROLINA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

1 INTRODUCTION

In 2020, Currituck County initiated a Beach Monitoring and Beach Stability Assessment to evaluate long-term and short-term shoreline and volumetric changes occurring along the County's oceanfront beaches. The initial study was completed in 2023 following three (3) consecutive years of monitoring (2020, 2021, and 2022). Based on recommendations from that initial Assessment (CPE, 2023), Currituck County chose to continue the annual monitoring of the beaches in 2023 to track and assess long-term and short-term shoreline and volumetric changes along the beach.

Again, based on recommendations from the 2023 Assessment, annual monitoring is focused on the Corolla and Pine Island sections, south of the Horse Gate. This recommendation was based on the fact that the majority of vulnerable houses were located south of the Horse Gate and that Pine Island was the only section that saw negative volumetric changes over the initial monitoring period from 2020 to 2022 (CPE, 2023). With regards to the beaches located north of the Horse Gate, the Assessment recommended biennial monitoring. The next survey of the beaches north of the Horse Gate is scheduled for spring 2024. The Assessment also noted that positive volumetric changes may be attributed to a temporary recovery of the beach that may have occurred between 2020 and 2022 when the initial monitoring data was collected. Regular monitoring would therefore be important to identify whether the beach is still in recovery or if it has reverted to a trend of volume loss.

The State of North Carolina's Division of Coastal Management 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 represent 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 required 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 Currituck County oceanfront, this report has compiled and utilized a variety of data sources collected by CPE, the US Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), McKim & Creed, and others.

1.1 Project Location

Currituck County is located on the Outer Banks of North Carolina just south of the Virginia border. The County encompasses approximately 527 square miles, which is divided by the Currituck Sound. This geographical division creates two distinct regions namely, the Currituck Mainland, and the Currituck Barrier Island Beaches. The Currituck Barrier Island Beaches extend approximately 22.6 miles along the Atlantic Ocean. The beaches extend from the North

Carolina/Virginia border south-southeast to the Town of Duck in Dare County, North Carolina. A location map is provided in Figure 1.

The Currituck County beaches are divided up into several segments of privately developed residential and commercial property and publicly owned property. The Assessment Area has been divided into four sections referred to throughout the report, with consideration given to differences in land use, land management, and geomorphology (changes in the dune and beach slope configuration over time). The northernmost section is referred to as the Carova Section, which encompasses approximately 4.9 miles of the Assessment Area from the northern County boundary to the northern boundary of the Currituck National Wildlife Refuge. The approximately 6.0-mile section of the Assessment Area that includes the Currituck National Wildlife Refuge, the Currituck Banks Estuarine Reserve, and the developed area along Sandpiper Road and Ocean Pearl Road is referred to as the Reserve/Refuge Section. The largest section, referred to as the Corolla Section, extends approximately 8.2 miles from approximately 250 feet south of the Horse Gate to approximately 500 feet north of Yaupon Lane. The southernmost 3.5 miles of the Assessment Area is referred to as the Pine Island Section. The sections are shown in Figure 1, and the length, geographical limits, and baseline stations for each section are provided in Table 1.

Several papers have described historic inlets that had existed along the Currituck County beaches (Mallinson et al., 2011 and Moran et al., 2015). Like many modern day, unmanaged inlets, these features were likely not stationary, but rather migrated throughout their history. Though the exact locations of these inlets are unknown, the southernmost inlet, known as Caffey's Inlet, is believed to have existed in the area between the Hampton Inn (station C-110) and the southern County boundary (station C-120). Caffey's Inlet is believed to have been open between 1770 and 1811. Though little is known of the specifics of the inlet, it has been theorized that the extensive back barrier marsh west of this portion of the barrier beach is built upon the relic flood tide delta system of Caffey's Inlet. Research conducted by Moran et al., (2015) suggested that Caffey's Inlet "accommodated a significant tidal prism", meaning that it was a significant inlet for the region.

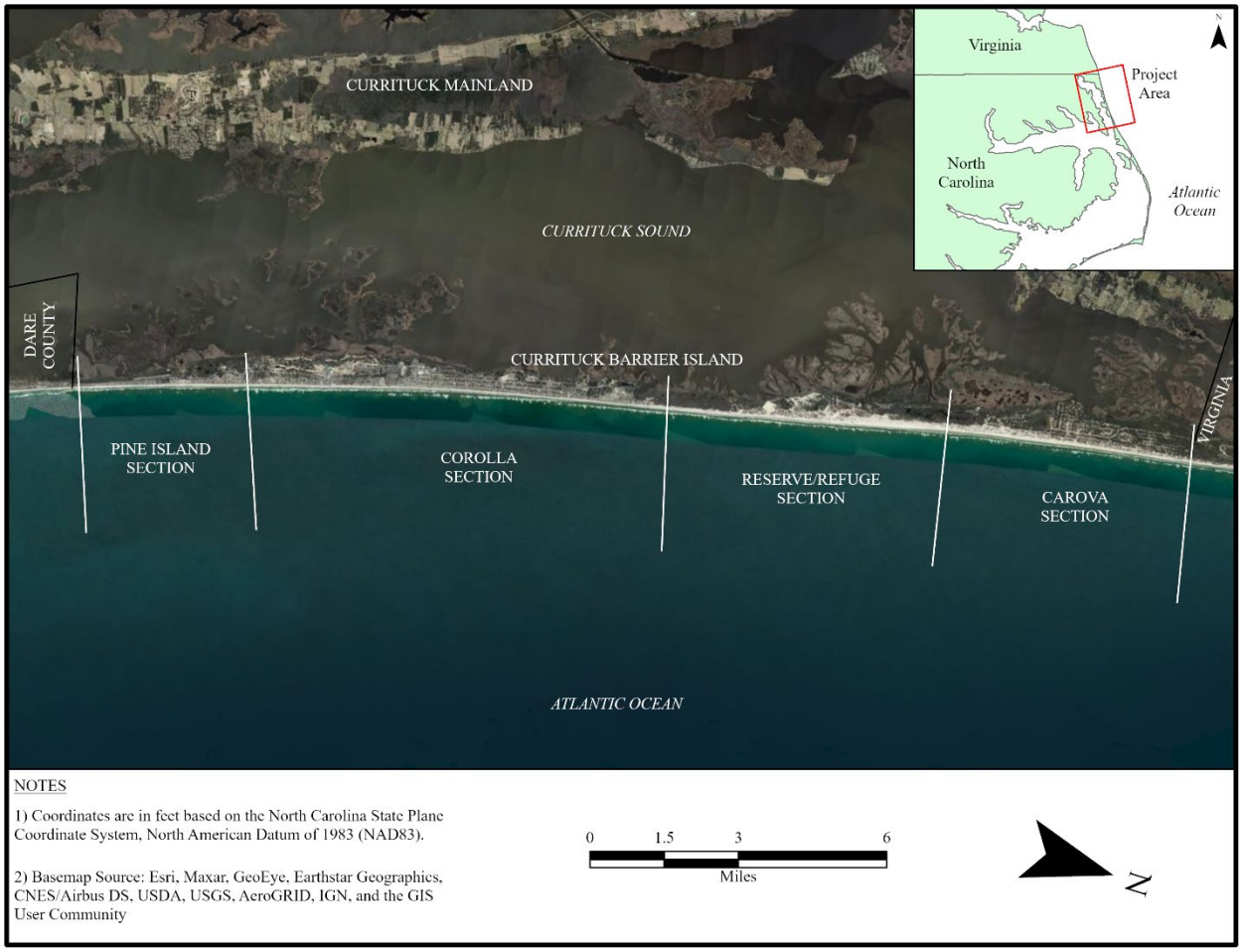

Figure 1. Currituck Project Location Map

Table 1. Section Descriptions

Section Name	Approximate Length	Geographic Extent	Baseline Stations
Carova	4.9 Miles	Northern County Boundary to Currituck Wildlife Refuge	C-001 to C-027
Reserve/Refuge	6.0 Miles	Northern boundary of Currituck Wildlife Refuge to 250 feet south of Horse Gate	C-027 to C-059
Corolla	8.2 Miles	250 feet south of Horse Gate to 500 feet north of Yaupon Lane	C-059 to C-102
Pine Island	3.5 Miles	500 feet north of Yaupon Lane to southern County boundary	C-102 to C-120

2 DATA COLLECTION

Data used in this study included eleven (11) different data sets including the most recent beach profile data acquired by CPE in 2023. See Table 2 below for dates and description of the datasets that were used.

Table 2. Dataset Descriptions

Agency/Firm	Survey Type	Date Range	Stations
USACE	Lidar	6/18/2009-6/25/2009	C-001 to C-120
CSE	Profile Survey	09/2015	C-097 to C-120
USACE	Lidar	6/9/2017-9/16/2017	C-001 to C-120
CSE	Profile Survey	10/2017	C-097 to C-120
USACE	Lidar	8/24/2018-8/28/2018	C-001 to C-120
USACE	Lidar	6/18/2019-6/25/2019	C-001 to C-120
CPE	Profile Survey/Offshore Bathymetry	4/24/2020-5/15/2020	C-001 to C-120
CPE	Profile Survey	6/1/2021-6/9/2021	C-001 to C-120
CPE	Profile Survey	5/14/2022-5/22/2022	C-001 to C-120
CPE	Offshore Bathymetry	5/21/2022-6/15/2022	C-001 to C-120
CPE	Profile Survey	6/06/2023-6/10/2023	C-059 to C-120

The data sets used include:

- Lidar data collected by US Army Corps of Engineers (USACE) in 2009, 2017, 2018, and 2019 along the entire oceanfront of Currituck County (station C-001 to station C-120);
- Beach profile data collected by Coastal Science & Engineering (CSE) in 2015 and 2017 along the southern 3.4 mi. of Currituck County beach (station C-097 to station C-120);
- Beach profile data collected by Coastal Protection Engineering of North Carolina (CPE) in May 2020, June 2021, and May 2022 along the entire oceanfront of Currituck County (station C-001 to station C-120).
- Beach profile data collected by CPE in June 2023 along the two southernmost sections of Currituck County, south of the Horse Gate (station C-059 to station C-120).

Throughout this report, elevations provided are referenced to the North American Vertical Datum (NAVD88). Table 3 provides tidal datums used in this study. The beach profiles are shown visually along the oceanfront in Figure 2 through Figure 6.

Table 3. Tidal Datums

Datum	Elevation (ft., NAVD88)
Mean High Water (MHW)	+1.24
Mean Tide Level (MTL)	-0.41
Mean Low Water (MLW)	-2.05

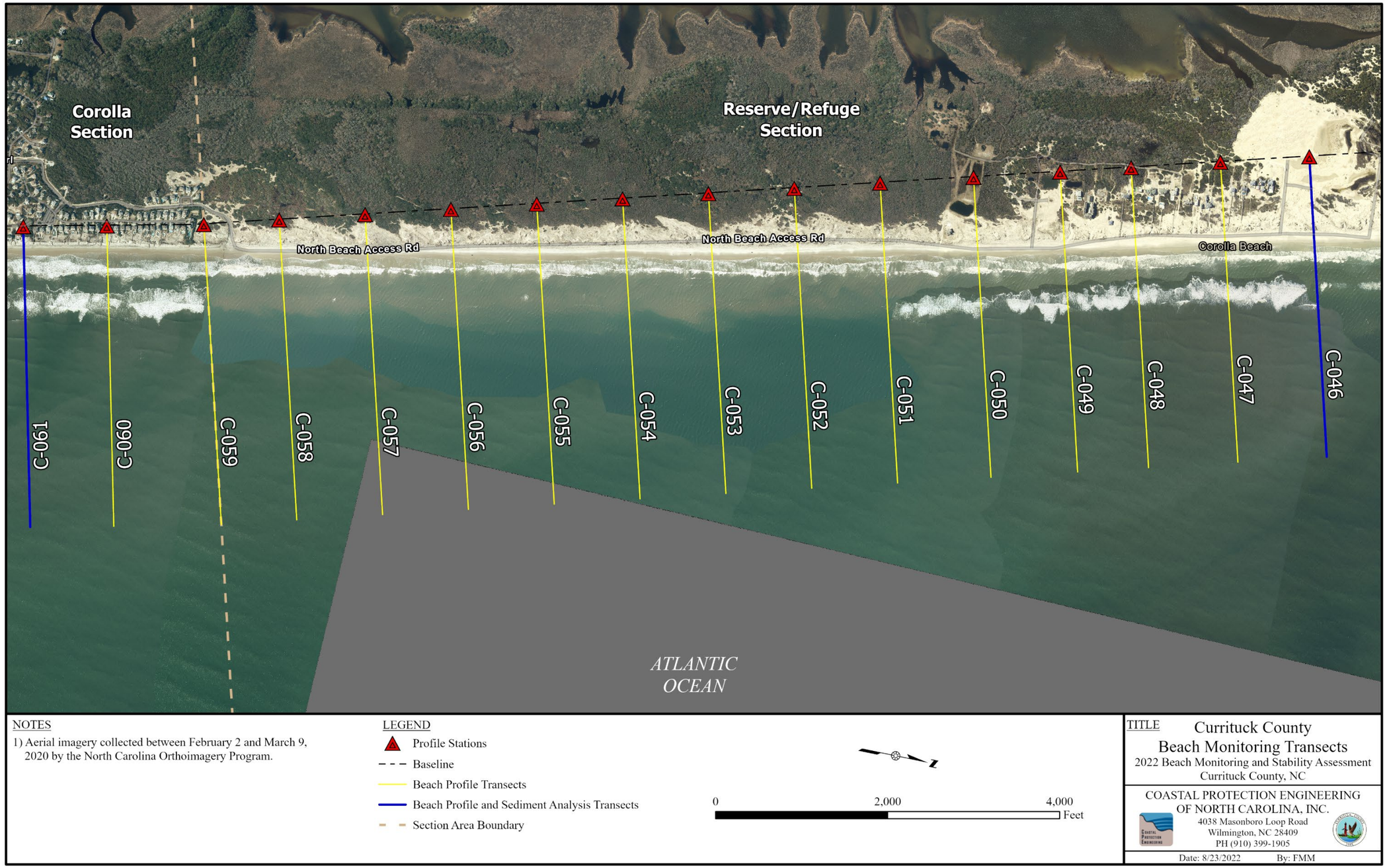

Figure 2. Monitoring Transects Map Station C-046 to C-061

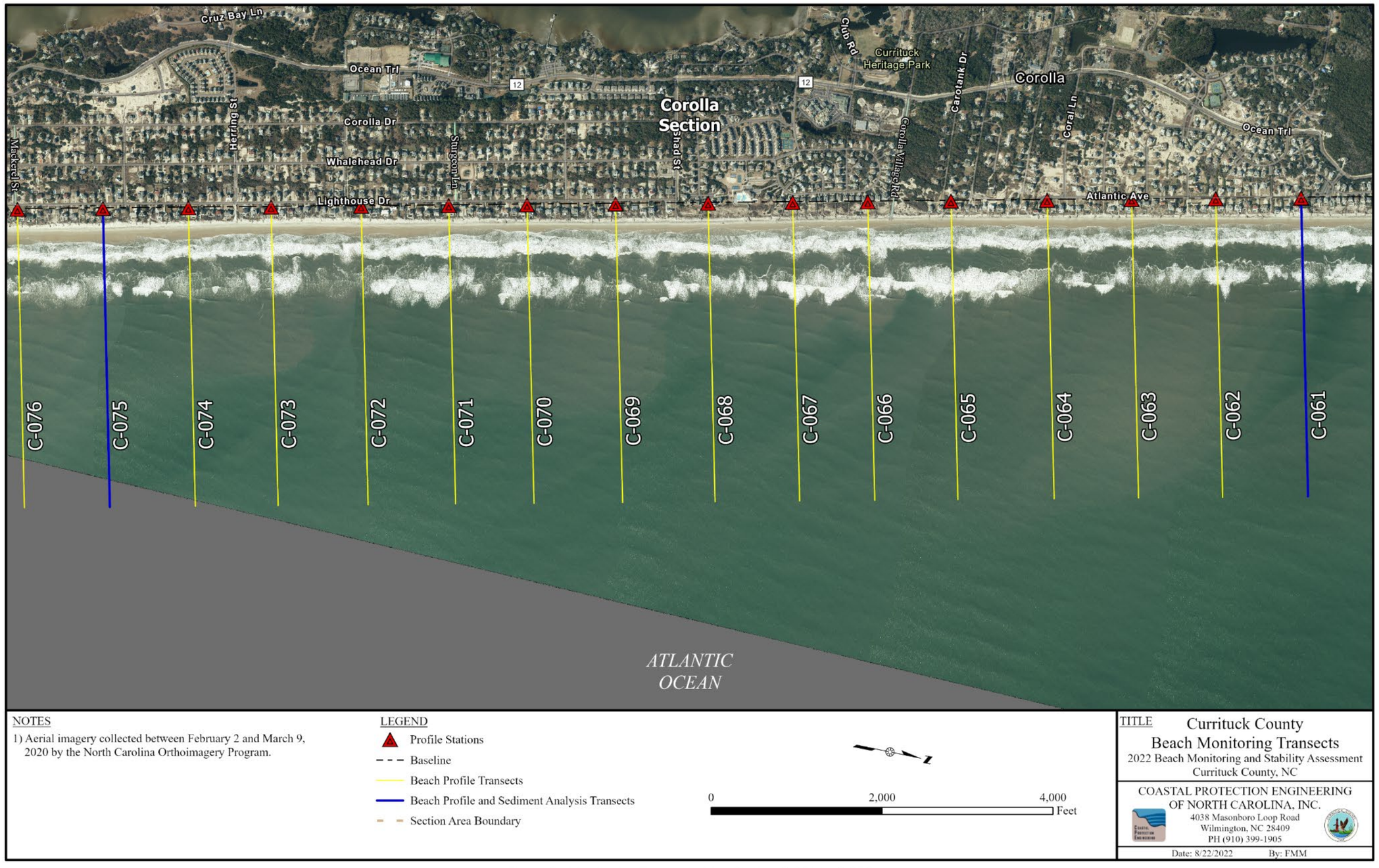

Figure 3. Monitoring Transects Map Station C-061 to C-076

Figure 4. Monitoring Transects Map Station C-076 to C-091

Figure 5. Monitoring Transects Map Station C-091 to C-106

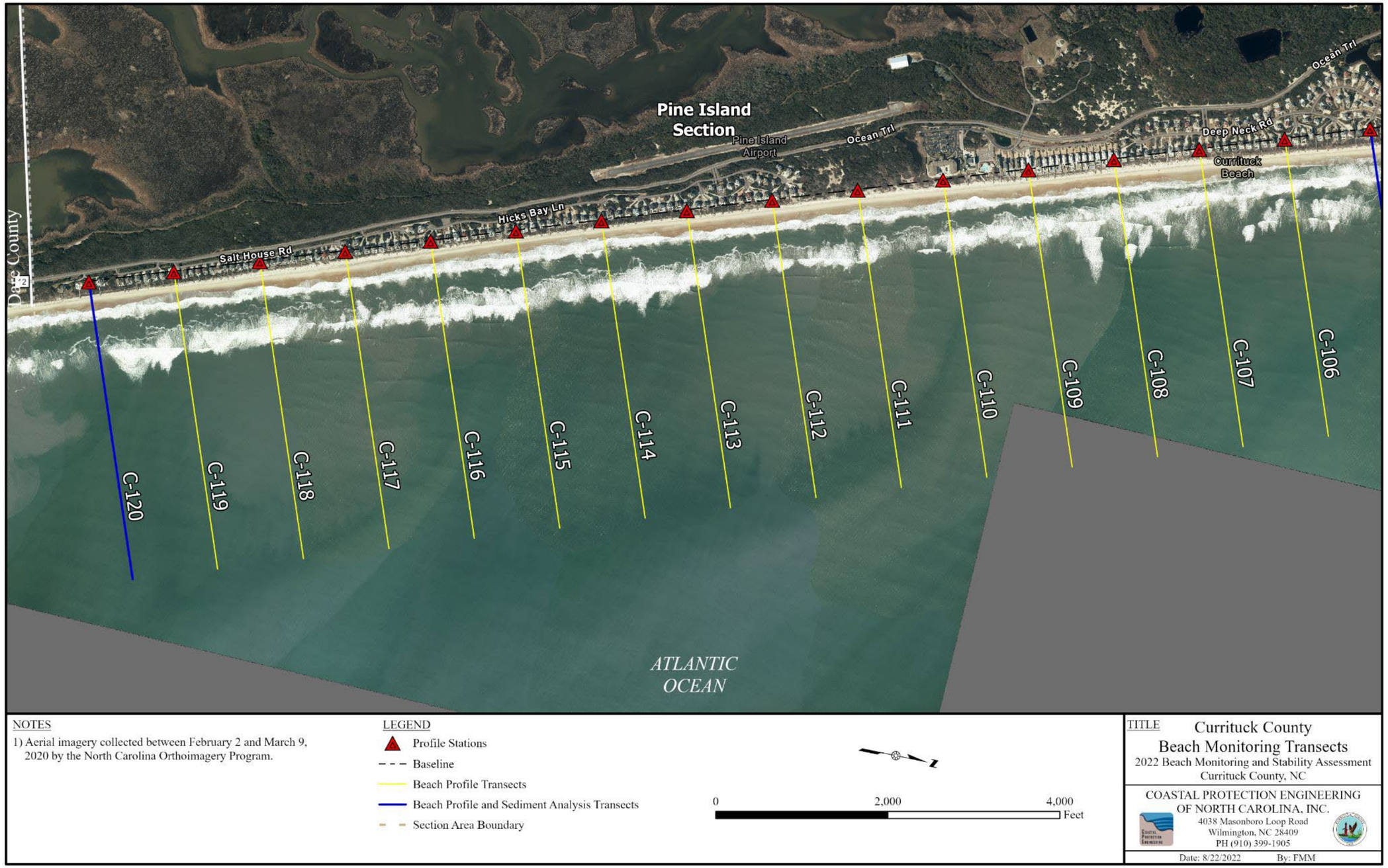

Figure 6. Monitoring Transects Map Station C-106 to C-120

2.1 NC DCM Long-Term Average Annual Shoreline Change Rates

As described on the North Carolina Division of Coastal Management's (NC DCM) website, 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. The change rates acquired from the North Carolina 2019 Oceanfront Setback Factors & Long-Term Average Annual Erosion Rate Update Survey report created by the NC DCM are compared to the shoreline change rates computed as part of this monitoring report (See Section 3).

2.2 USACE Lidar Data

Light Detection and Ranging (Lidar) is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth (NOAA, 2012). These light pulses, combined with other data recorded by the airborne system, generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.

A Lidar instrument principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes are used for acquiring lidar data over broad areas. There are two types of Lidar, topographic and bathymetric. Topographic Lidar typically uses a near-infrared laser to map the land, while bathymetric Lidar uses water-penetrating green light to also measure seafloor and riverbed elevations.

Lidar systems allow scientists and mapping professionals to examine both natural and manmade environments with accuracy, precision, and flexibility. NOAA and USACE scientists are using lidar to produce more accurate shoreline maps, make digital elevation models for use in geographic information systems, assist in emergency response operations, and in many other applications. Lidar data from August 2009 was determined to be the earliest reliable topographic data and was selected for the long-term analysis.

2.3 CSE Beach Profile Data

Beach profile survey data were collected by CSE in September 2015 and October 2017 as part of the Pine Island, Currituck County, Beach Condition Monitoring (CSE, 2018). The monitoring study initiated by the Pine Island Property Owners Association (PIPOA) included beach profile surveys encompassing approximately 5.3 miles of the beach, 1 mile north and south of the Pine Island community. These profiles were spaced every 500 feet alongshore extending from the foredune to a depth greater than 30 ft. CSE profiles 0+00 through 230+00 were used by CPE for the County study. Table 4 shows a comparison between the CSE referenced stations and the names of the stations used in the County Study (C-097 through C-120).

Table 4. CPE and CSE Monitoring Station Comparison

CPE Station	CSE Station
C-097	000+00
C-098	010+00
C-099	020+00
C-100	030+00
C-101	040+00
C-102	050+00
C-103	060+00
C-104	070+00
C-105	080+00
C-106	090+00
C-107	100+00
C-108	110+00
C-109	120+00
C-110	130+00
C-111	140+00
C-112	150+00
C-113	160+00
C-114	170+00
C-115	180+00
C-116	190+00
C-117	200+00
C-118	210+00
C-119	220+00
C-120	230+00

2.4 CPE Beach Profile Data

CPE conducted beach profile surveys for Currituck County in May 2020, June 2021, May 2022, and June 2023. The 2020 through 2022 surveys included 120 profiles (station C-001 to station C-120) along the beachfront of Currituck County. However, the June 2023 survey was limited to the 61 profiles (station C-059 to station C-120) along the beachfront of Currituck County south of the Horse Gate. The 2023 CPE survey conducted in conjunction with McKim & Creed, Inc., includes a topographic survey of the dune, berm, and foreshore section of the beach and a bathymetric survey of the offshore portion of the profile. See Appendix A for 2023 Currituck County Data Acquisition Survey Report. The data acquisition reports for 2020, 2021, and 2022 are included as appendices to the 2020, 2021, and 2022 beach assessment reports (CPE, 2020, CPE, 2021a, and CPE, 2022).

Beach profiles extended landward from the beach toward the monitoring 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 each profile to a range of 2,500 feet beyond the shoreline or to the -30-ft. NAVD88 contour, whichever was more landward.

Land-based or "upland" data collection included 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 was 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 nearshore portion of the profile data collection commenced from a point overlapping the upland data by 50 feet to ensure seamless transitions and extended seaward to a point overlapping the offshore data collected by the survey vessel by a minimum of fifty (50) feet. The nearshore portion of the profiles were surveyed by two (2) surveyors with an Extended Rod Trimble RTK GNSS rovers who entered the water wearing personal floatation devices. This system allowed for the collection of RTK GNSS data in the nearshore region while maintaining data accuracy and personal safety.

The offshore hydrographic survey was conducted using Teledyne Odom Hydrographic's ECHOTRAC E-20 (or equivalent) on a survey vessel with a centrally located hull-mounted transducer. Offshore data points were collected with a maximum spacing of 25 feet. A Trimble RTK GNSS and an Applanix POS MV Inertia Navigation system were used onboard the survey vessel to provide instantaneous tide corrections as well as heave corrections. Tide corrections were obtained redundantly using RTK GNSS and a local tide gauge verified to meet the requirements for the specific work. In order to maintain the vessel's track along the profile lines, HYPACK navigation software was used for real time navigation and data acquisition.

The sounder was calibrated with a sound velocity probe and conventional bar-check at the beginning and end of each survey day. The AML CTD Base X sound velocity probe provides a fast and accurate sounder calibration. Bar-checks were performed as a redundant calibration from a depth of five (5) feet to a minimum depth of twenty-five (25) feet.

Offshore profiles extended seaward, beyond the projected depth of closure. Depth of closure (DOC) is a theoretical depth along a beach profile where sediment transport is typically negligible. For more information pertaining to the determination of the depth of closure for this project, please refer to the 2020 Beach Monitoring and Beach Stability Assessment (CPE, 2020). The offshore data collection landward limit was based on a safe approach distance for the survey vessel based on conditions. All offshore data had a minimum overlap of fifty (50) feet with the nearshore beach profile.

3 SHORELINE ANALYSES

Shoreline change is calculated by comparing shoreline positions along shore perpendicular transects over time. This linear change in the position of the shoreline moving either landward or seaward, is often easier for the general public to visualize; however, shoreline changes are not always synonymous with volumetric changes. Figure 7 shows a typical comparison plot of two beach profile surveys conducted approximately 10.6 years apart along station C-001, illustrating graphically how the shoreline change is measured.

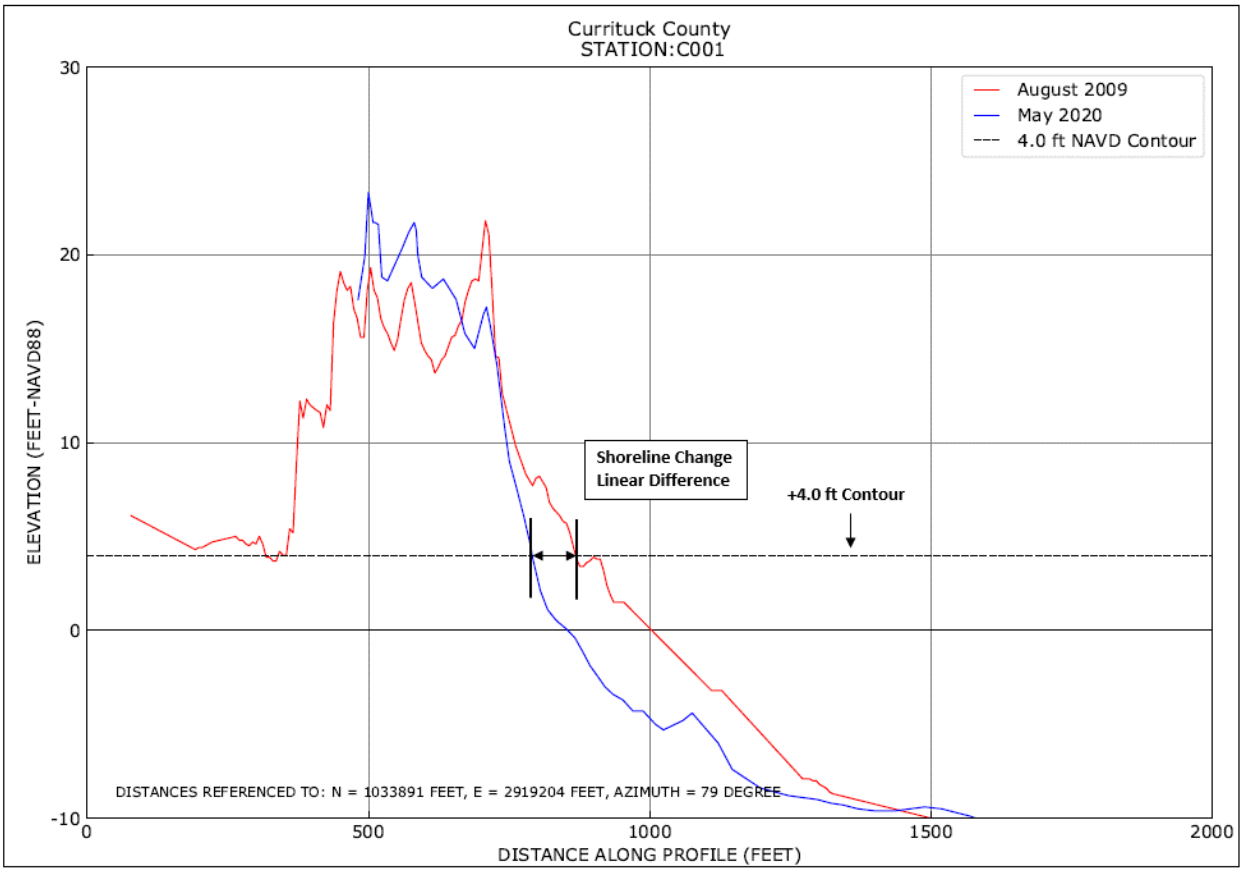

Figure 7. Beach Profile Cross Section Illustrating Shoreline Change.

As previously mentioned, the State of North Carolina maintains long-term shoreline change rates for the State's shoreline with the sole purpose of establishing construction setbacks. Figure 8 shows an example of the State long-term average shoreline change rates.

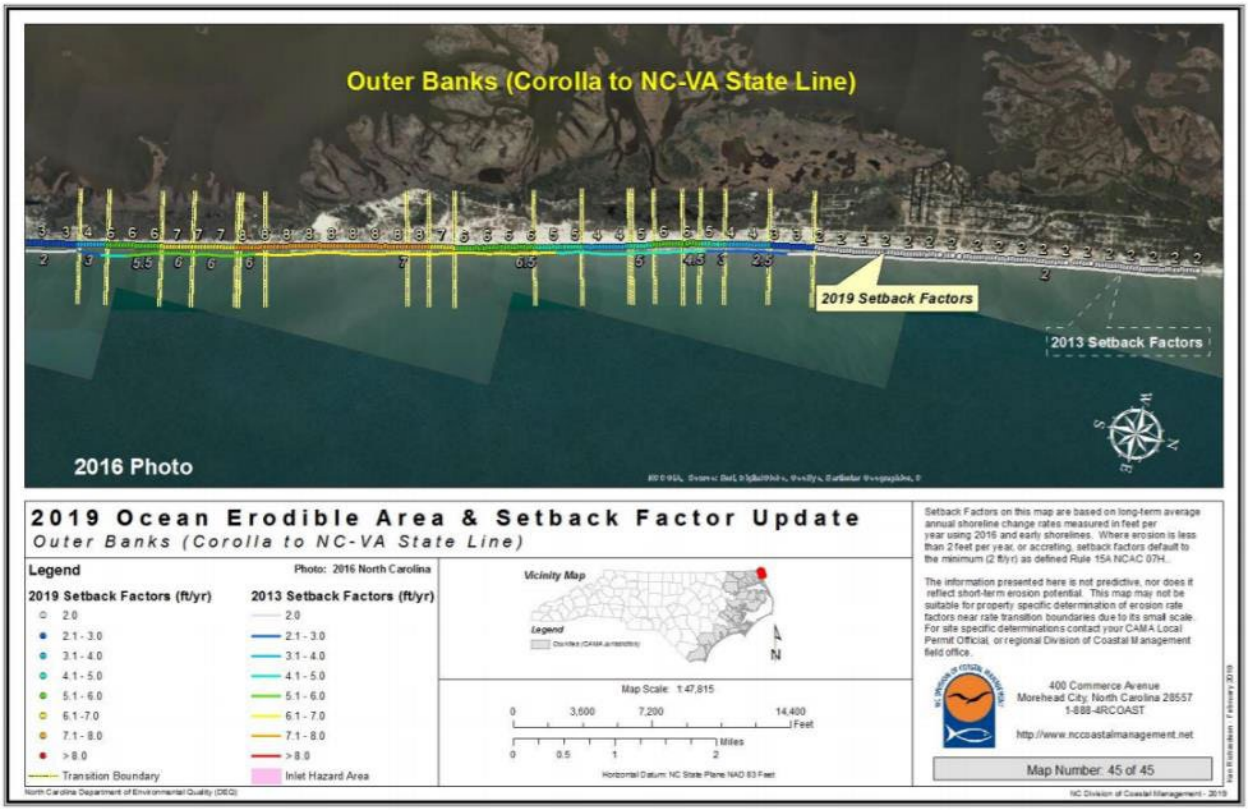

Figure 8. Map showing the SBF for Reserve/Refuge and Carova Sections of Currituck County

The average, maximum, and minimum Set Back Factor's (SBF's) for each of the 4 sections of the Assessment Area are provided in Table 5. As shown in the table, the average SBF for the Carova, Corolla, and Pine Island Sections are between 2 and 3 ft./yr., whereas the average SBF for the Reserve/Refuge area is over 6 ft./yr. The SBF published by the State for the Pine Island Section (station C-102 located near Spindrift Trail to station C-120 located near Station 1 Lane) is 2 ft./yr. However, the State does not publish a SBF of less than 2.0 ft./yr. and therefore, this value may indicate shoreline change of less than 2 ft. per year, or accreting. This default SBF is defined by Rule 15 NCAC 07H. 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).

Table 5. NC DCM 2019 Setback Factors

Section	Average Setback Factor (ft./yr.)	Maximum Setback Factor (ft./yr.)	Minimum Setback Factor (ft./yr.)
Carova (C-001 to C-027)	2.49	6.00	2.00
Reserve/Refuge (C-027 to C-059)	6.57	8.00	4.00
Corolla (C-059 to C-102)	2.28	6.00	2.00
Pine Island (C-102 to C-120)	2.00	2.00	2.00
Total Assessment Area (C-001 to C-120)	3.37	8.00	2.00

Setback factors infer a recession rate or movement of the shoreline landward

Rates computed for this 2023 Assessment were calculated using a linear regression method. The rate is calculated by determining the slope of the linear trendline for a certain shoreline position (+4 ft. NAVD88) for all available survey events. Figure 9 illustrates the approach showing shoreline positions (black dots) and the trendline for station C-059. These rates are described in terms of positive (+) for advance (shoreline moving seaward) and negative (-) for recession (shoreline moving landward).

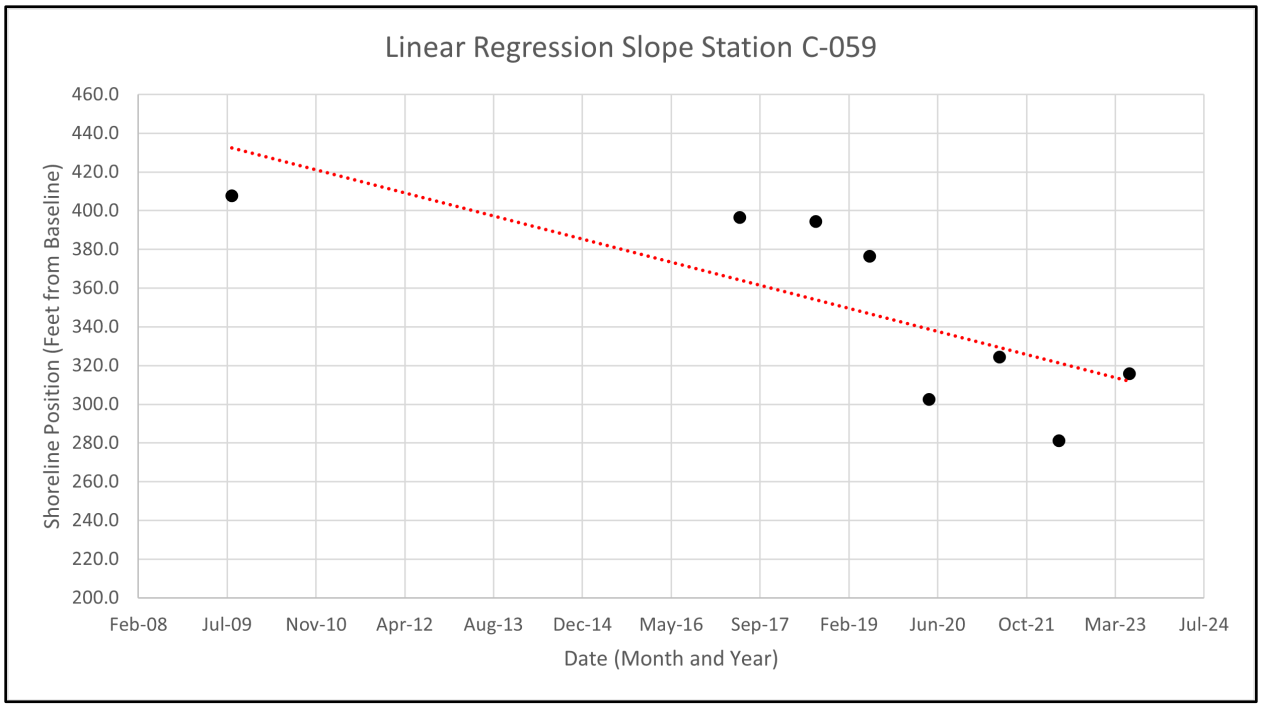

Figure 9. Example of Linear Regression Slope

Using available beach profile and Lidar data, a shoreline change analysis was conducted to assess shoreline advance and recession along the Assessment Area. As it relates to shoreline change, the "shoreline" is typically defined as a specified elevation contour. Often times the Mean High Water (MHW) contour is chosen as the representative contour. For this study, the shoreline was defined as the +4 ft. NAVD88 contour for two primary reasons. The first is that the older Lidar data sets used, such as the 2009 data, do not reliably capture the MHW contour on every profile. The +4 ft. NAVD88 contour appears to be consistently and reliably captured along the Assessment Area. The second reason the +4 ft. NAVD88 contour was used is that this contour more closely aligns with the shoreline position that is used by the State of North Carolina in their long-term shoreline change rates.

It is important for the reader to note that although shoreline change can be an indicator of loss or gain of beach width, the nature of sand movement in response to wave and water level conditions makes shoreline position highly variable temporally. The response to a beach due to storm conditions typically results in a steepening of the beach slope near the water line and the movement of sand in the seaward direction forming offshore sand bars. During calmer wave periods, the beach often recovers as sand moves landward. Along the Outer Banks, the beach

exhibits a steeper slope and narrower dry sand beach in the winter; whereas the beach slope is less steep in the summer and the dry beach is generally wider.

3.1 Long-Term Time Period (August 2009 to June 2023)

Data collected throughout the Assessment Area between August 2009 and June 2023 were examined to compare the positions of the +4 ft. NAVD88 contour and determine shoreline change rates. Shoreline change rates were determined using a linear regression method given the various data sets available between August 2009 and June 2023. The averages were determined by computing a weighted average based on distance. A summary of the recent and long-term average annualized shoreline change rates computed for the +4 ft. NAVD88 contour for each section of the Assessment Area, as well as an overall project average, are provided in Table 6.

Table 6. Summary of Average Long-Term and Recent Shoreline Change Rates by Monitoring Section

Section	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2023)	Recent Rate (ft./yr.) (May 2020 to June 2023)
Corolla (C-059 to C-102)	-5.6	-1.3
Pine Island (C-102 to C-120)	-1.3	-2.0
Total Assessment Area (C-059 to C-120)	**-4.3**	**-1.5**

Long-term and recent shoreline change rates at each station along the Assessment Area are provided in Table 7. Long-term shoreline change rates are shown graphically in Figure 10. The recent shoreline change rates represent changes observed between 2020 and 2023.

Table 7. Summary of Currituck County Recent and Long-Term Shoreline Change Rates

Station	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2023)	Recent Rate (ft./yr.) (May 2020 to June 2023)	Station	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2023)	Recent Rate (ft./yr.) (May 2020 to June 2023)
C-059	-8.7	0.1	C-090	-5.7	-3.9
C-060	-10.0	-1.6	C-091	-4.2	-3.3
C-061	-9.6	-2.5	C-092	-5.1	-7.6
C-062	-8.6	-1.8	C-093	-4.9	-7.9
C-063	-8.0	-5.6	C-094	-2.6	-4.7
C-064	-4.6	-0.4	C-095	-5.4	-8.9
C-065	-7.4	-4.0	C-096	-1.8	-3.4
C-066	-5.4	3.7	C-097	-4.6	-9.0
C-067	-4.4	3.8	C-098	-2.4	-1.1
C-068	-6.5	-2.5	C-099	-8.0	-0.2
C-069	-5.5	0.2	C-100	-3.3	0.3
C-070	-2.6	3.6	C-101	-4.5	2.4
C-071	-5.2	-5.5	C-102	-4.7	0.5
C-072	-6.2	-5.5	C-103	-4.1	-5.7
C-073	-4.9	4.0	C-104	-1.4	0.4
C-074	-5.9	-3.4	C-105	-0.7	-6.2
C-075	-5.6	-0.9	C-106	-2.4	-5.7
C-076	-5.8	0.9	C-107	1.4	-3.0
C-077	-3.4	5.0	C-108	-1.7	-5.7
C-078	-5.0	1.1	C-109	0.2	3.6
C-079	-6.2	-3.1	C-110	0.3	0.9
C-080	-9.9	2.6	C-111	-3.4	0.1
C-081	-6.4	0.5	C-112	-1.5	-4.2
C-082	-6.3	-0.6	C-113	-1.3	-8.0
C-083	-5.7	3.9	C-114	-1.5	-1.8
C-084	-4.8	4.2	C-115	-2.7	-5.2
C-085	-6.5	-1.2	C-116	-3.1	-2.5
C-086	-4.9	-3.5	C-117	-1.3	4.5
C-087	-6.2	-1.8	C-118	2.7	-4.0
C-088	-6.6	0.7	C-119	0.8	5.2
C-089	-3.9	1.7	C-120	-2.4	2.8

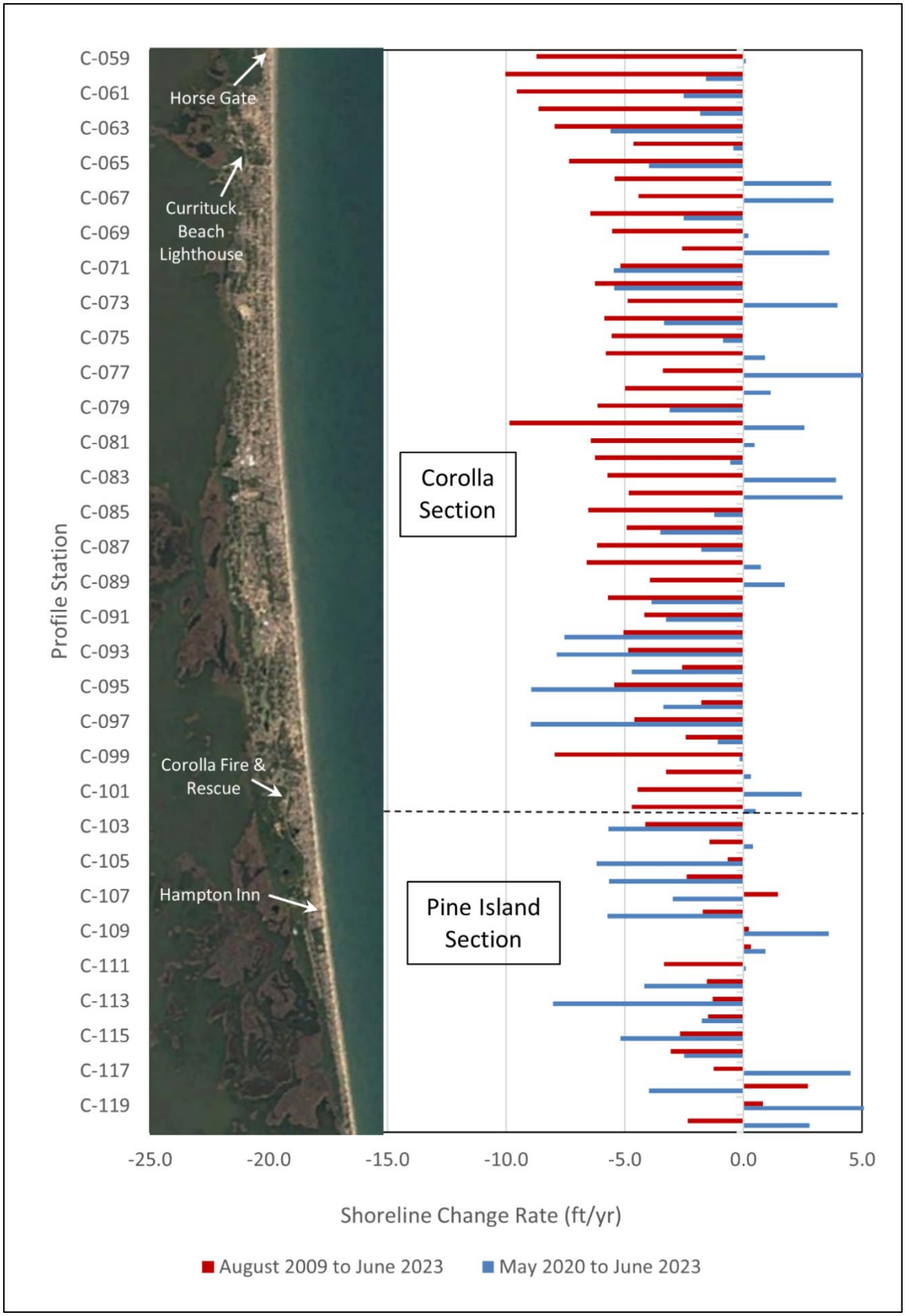

Figure 10. Shoreline Change Rate (+4 ft. NAVD88) South of the Horse Gate (C-059 to C-120)

Corolla Section: The average long-term shoreline change rate calculated for the Corolla Section was -5.6 ft./yr. This is an increase in the long term erosion rate measured between 2009 and 2022 which was -5.1 ft./yr. The State determined an average SBF of 2.28 ft./yr. in the Corolla Section (note SBF's infer a recession rate or movement of the shoreline landward). A negative shoreline change rate was measured at each profile along the Corolla Section of the Assessment Area, ranging from -10.0 ft./yr. at station C-060 to -1.8 ft./yr. at station C-096.

Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the Horse Gate, and just north of Carotank Drive (station C-059 to station C-065), the average long-term shoreline change rate was -8.1 ft./yr. From just north of Carotank Drive to a point located on the north side of 889 Lighthouse Dr. (station C-065 to station C-079), the average shoreline change rate was -5.2 ft./yr. From station C-079 south to station C-088, located along Wave Arch off Seabird Way, the average shoreline change rate was -6.4 ft./yr. Along the southern portion of the Corolla Section, between stations C-088 (Wave Arch) and C-102, located approximately 500 feet north of Yaupon Lane, the average shoreline change rate was -4.4 ft./yr.

Pine Island Section: The average long-term shoreline change rate between August 2009 and June 2023, in the Pine Island Section was relatively stable, measuring -1.3 ft./yr. This is an increase in the long-term erosion rate measured between 2009 and 2022 which was -0.3 ft./yr. The State determined an average SBF of 2.0 ft./yr. in the Pine Island Section (station C-102 to station C-120) (note SBF's infer a recession rate or movement of the shoreline landward). Shoreline change rates varied along the Pine Island Section from -4.7 ft./yr. at station C-102 (located approximately 500 feet north of Yaupon Lane) to +2.7 ft./yr. at station C-118 (located along the middle of Salt House Rd).

3.2 Recent Rate (May 2020 to June 2023)

The average recent shoreline change rate between May 2020 and June 2023 along the entire Assessment Area (station C-059 to station C-120) was -1.5 ft./yr. Recent shoreline change rates at each station along the Assessment Area are provided in Table 7. A summary of the recent and long-term average annualized shoreline change rates computed for the +4 ft. NAVD88 contour for each section of the Assessment Area, as well as an overall project average, are provided in Table 6. Short-term shoreline change rates are shown graphically in Figure 10.

Corolla Section: The average shoreline change rate calculated for the Corolla Section between May 2020 and June 2023 was -1.3 ft./yr. A profile-by-profile comparison shows shoreline change rates in this section ranging from -9.0 ft./yr. at station C-097 to +5.0 ft./yr. at station C-077. Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the Horse Gate, and approximately 800 ft north of Sea Oats Ct. (station C-059 to station C-091), the average shoreline change rate was negligible measuring -0.4 ft./yr. However, the shoreline changes in this section varied considerably. Of the 33 beach profiles along this section, negative shoreline change rates were measured along 55 percent while positive rates were measured along the other 45 percent of the profiles. Between station C-091 (approximately 800 ft north of Sea Oats Ct.) and station C-098, located on the north end of Breakers Arch, the average shoreline

change rate was -6.2 ft./yr. Along the southern portion of the Corolla Section, between stations C-098 (north end of Breakers Arch) and C-102, located approximately 500 feet north of Yaupon Lane, the average shoreline change rate was also relatively stable, measuring +0.6 ft./yr.

Pine Island Section: The average shoreline change rate calculated for the Pine Island Section between May 2020 and June 2023 was -2.0 ft./yr. Shoreline change rates varied along the Pine Island Section from -8.0 ft./yr. at station C-113 (located approximately 200 feet south of Ballast Point) to +5.2 ft./yr. at station C-119 (located near south end of Cottage Cove Rd.).

3.3 Shoreline Projections

As part of this study, the shoreline change model previously developed to project shoreline change over a 10-, 20-, and 30- year period was updated to incorporate the June 2023 survey data. The June 2023 shoreline location of the +4 ft. NAVD88 contour was projected into the future for periods of 10-, 20-, and 30-years based on the long-term shoreline change rates calculated between August 2009 and June 2023.

A three-point average was applied to the individual shoreline change rates that were measured at each station in order to smooth the data along the Assessment Area, while maintaining the observed trends. This is consistent with the method used for shoreline projections presented in the 2020 (CPE, 2020), 2021 (CPE, 2021a), and 2022 (CPE, 2023) reports. For the stations on the north end of the Assessment Area (station C-059) and south end of the Assessment Area (station C-120), the actual measured shoreline change rate was used to determine projected shorelines. For those profiles on which the three-point average shoreline change rate was positive, indicating a seaward trend in the shoreline movement, no shoreline projection is shown. Maps showing the results of the projected shoreline change are included in Appendix B.

This analysis identified a house as "impacted" if any part of the footprint of the structure, as shown in the Currituck County GIS, was seaward of the 10-, 20-, or 30-year projected shorelines. Table 8 shows the number of houses in each of the two project sections shown to be impacted over the 10-, 20-, and 30-Year time horizons. The analysis does not include specific evaluations of damages to individual houses due to direct flooding, wave impacts, or wind impacts, nor will it quantify the economic impacts resulting from the damage or loss of such structures. If the County requires this type of economic impact, additional analyses will be required.

Table 8. Number of houses shown to be impacted over the 10-, 20-, and 30-year time horizons

Section	10-Year	20-Year	30-Year
Corolla (C-059 to C-102)	2	43*	154*
Pine Island (C-102 to C-120)	0	2	4
Total Assessment Area (C-001 to C-120)	**2**	**45**	**158**

*One of the structures indicated as impacted was located on the border between Corolla and Pine Island. That structure was included in the totals for the Corolla Section and not in the Pine Island section.

In the Corolla Section of the Assessment Area, the projected shoreline change shown in Table 8 indicates extensive numbers of oceanfront houses may be impacted over a 30-year time horizon. Along the northern portion of the Corolla Section from the Horse Gate (station C-059) to south of Corolla Village Rd (or station C-066) to, a total of 66 houses were shown to be impacted over the 30-year horizon. Out of those 66 houses, 28 were impacted over the 20-year horizon and 2 were impacted over the 10-year horizon. Along the portion of the Corolla Section between Shad St. (station C-068) to Mackeral St. (station C-076), a total of 31 houses were shown to be impacted over the 30-year horizon. No houses were shown to be impacted over the 20-year horizon along this portion. Along the central portion of the Corolla Section between 901 Lighthouse Dr. and Albacore St. (station C-078 to station C-084), a total of 43 oceanfront houses were shown to be impacted over the 30-year horizon. Out of those 43 houses, 13 were shown to be impacted over the 20-year horizon. Along the Crown Point community in the Corolla section (station C-085 to station C-086), 1 house was shown to be impacted over the 30-year horizon. Along the Tide Arch community (station C-087 to station C-088), 8 houses were shown to be impacted over the 30-year horizon.

Along the oceanfront section of the Spindrift community, all 9 houses located along the oceanfront were shown to be impacted over the 30-year horizon. This area straddles the beach profile at station C-102, which is the boundary between the Corolla Section and the Pine Island Section. Four of the houses are located in the Corolla Section, 4 are located in the Pine Island Section, and 1 house is located along station C-102. The house that falls along station C-102 was included in the totals for the Corolla Section in Table 8. Out of the 9 houses along Spindrift shown to be impacted over the 30-year horizon, 4 were impacted over the 20-year horizon. Two of the houses are located in the Corolla Section and 2 are located in the Pine Island Section. No houses were shown to be impacted in Pine Island, south of the Spindrift Community, over the 30-year horizon.

To summarize, the northern two thirds within the Corolla Section (station C-059 to station C-088) included 149 oceanfront houses that were shown to be impacted over the 30-year horizon. The gap between impacted houses in the area did not exceed 3,000 feet. In total, 158 houses were shown to be impacted over the 30-year horizon from the Horse Gate to Yaupon Lane (station C-059 to C-103). Out of these 158 houses, 45 were shown to be impacted over the 20-year horizon and 2 houses were shown to be impacted over the 10-year horizon just south of the Horse Gate between station C-062 and station C-065. All but one of the oceanfront houses north of station C-065 (north of Carotank Dr.) in the Corolla Section were shown to be impacted by the 30-year horizon.

4 VOLUME ANALYSES

As discussed in the previous section, changes in the shoreline position represented by a single elevation contour can vary considerably based on sea conditions leading up to the time in which the surveys were conducted. Sand on the beach is distributed by wind and wave action over the entire active profile. 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 active profile is an important parameter to track to gauge the health of the beach. As provided in previous monitoring reports, volumetric change was calculated between the dune and the depth of closure (-19 ft. NAVD88), this represents the landward and seaward limits of the active profile as defined for this particular assessment. Additional information on the determination of this depth can be found in the 2020 report (CPE, 2020). A complete volumteric analyses was completed as part of the 2023 Assessment through a comparison of May 2020, May 2022, and June 2023 data. A long-term rate was calculated between May 2020 and June 2023 and a short-term rate was calculated between May 2022 and June 2023. The results of this volumetric analysis are detailed in Section 4.1. After reviewing the available data collected between May 2020 and May 2022, an additional method for evaluating volumetric changes was conducted. This additional method splits the active profile into 4 parts or "Lenses" in the cross-shore direction. Results of volumetric changes measured within each lens are provided in Section 4.2 and discussed further in Section 5.0.

4.1 Volumetric Change (-19 Ft. NAVD88 Depth of Closure)

As discussed above, volumetric change was computed using the 2023 data out to the -19 ft. NAVD88 depth contour, which was established as the "Depth of Closure" in the previous Beach Assessment reports (CPE, 2020, CPE, 2021a, and CPE, 2023). Figure 11 shows the same profile shown in Figure 7 with areas between the profiles shaded to show areas of volume gains (green-accretion) and volumes losses (red-erosion) along the profile. The net difference between these gains and losses is referred to as the volume change.

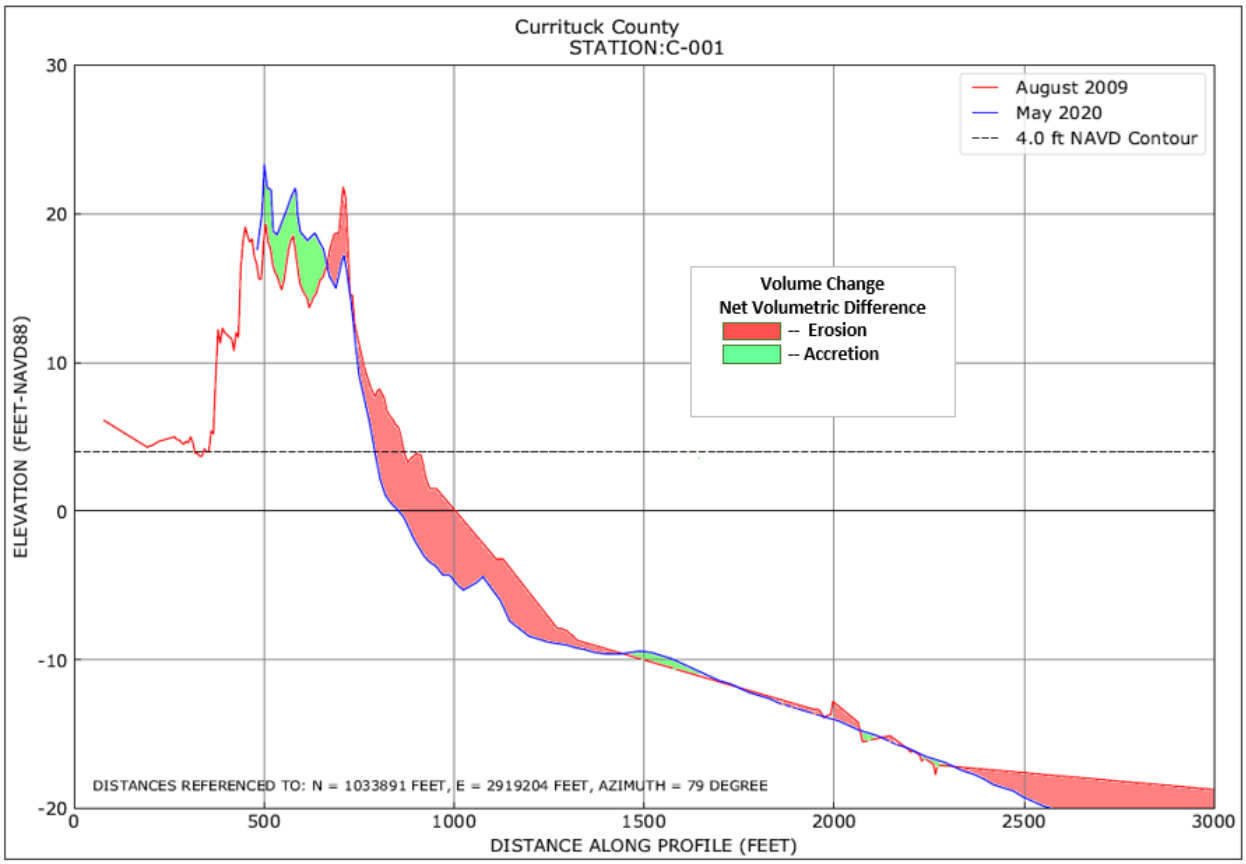

Figure 11. Beach Profile Cross Section Illustrating Volume Change

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

With the collection of the June 2023 beach profile data along the southern half of the Currituck County beach south of the horse gate, long-term and short-term volumetric changes were computed between May 2020 and June 2023 (long-term) and May 2022 and June 2023 (short-term). The average density change rate and total volumetric change for the Corolla and Pine Island Sections and the overall 2023 Assessment Area are provided in Table 9.

Table 9. Summary of Average Volumetric Change Rates and Total Volume Changes Measured to -19 ft. NAVD88.

Section	Long-term and Recent Average Density Change Rate (cy/ft./yr.)		Long-term and Recent Total Volume Change (cy)	
	May 2020 to June 2023	May 2022 to June 2023	May 2020 to June 2023	May 2022 to June 2023
Corolla	5.6	8.4	739,900	376,000
Pine Island	8.0	33.8	448,600	675,000
Total Assessment Area	**6.3**	**16.0**	**1,188,500**	**1,051,000**

4.1.1 Long-term Period May 2020 to June 2023

The average long-term volumetric change rate of the overall Assessment Area measured between May 2020 and June 2023 was +6.3 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 1,188,500 cubic yards (Table 9). Both the Corolla and Pine Island Sections experienced a positive volumetric change during this period. Table 10 lists the individual volumetric change rates computed for each profile (C-059 to C-120) between May 2020 and June 2023. Figure 12 shows the 2020 to 2023 change rates graphically.

Table 10. Volumetric Change Rates May 2020 to June 2023 and May 2022 to June 2023.

Station	Long-term Rate (cy/ft./yr.) (May 2020 to June 2023)	Recent Rate (cy/ft./yr.) (May 2022 to June 2023)	Station	Long-term Rate (cy/ft./yr.) (May 2020 to June 2023)	Recent Rate (cy/ft./yr.) (May 2022 to June 2023)
C-059	11.7	24.9	C-090	5.3	-3.4
C-060	3.3	-6.2	C-091	3.1	2.2
C-061	9.6	44.8	C-092	-5.7	-0.2
C-062	9.6	14.1	C-093	-9.5	0.2
C-063	9.4	5.9	C-094	-3.9	-0.3
C-064	2.2	-0.7	C-095	-8.3	-1.5
C-065	15.7	20.4	C-096	1.1	7.2
C-066	2.9	19.9	C-097	-0.5	20.4
C-067	6.9	7.0	C-098	3.0	1.1
C-068	-2.8	-10.9	C-099	3.7	13.1
C-069	14.9	17.8	C-100	7.7	9.7
C-070	3.5	-2.2	C-101	13.5	28.6
C-071	8.9	13.2	C-102	7.7	17.4
C-072	1.7	-7.4	C-103	2.9	28.8
C-073	12.3	7.1	C-104	3.0	41.9
C-074	3.3	7.8	C-105	8.3	28.2
C-075	8.1	12.1	C-106	3.4	17.2
C-076	9.1	2.2	C-107	-0.7	22.8
C-077	19.5	23.2	C-108	11.9	23.9
C-078	13.0	3.8	C-109	8.0	17.3
C-079	9.7	-3.7	C-110	15.3	34.5
C-080	7.0	7.5	C-111	12.2	20.6
C-081	10.9	16.5	C-112	13.6	30.3
C-082	0.1	-7.4	C-113	7.6	10.7
C-083	12.4	25.2	C-114	15.2	32.6
C-084	8.2	22.5	C-115	-1.0	35.0
C-085	2.8	8.4	C-116	11.0	71.1
C-086	3.1	-11.8	C-117	1.6	115.0
C-087	0.8	20.7	C-118	9.4	30.2
C-088	6.4	-9.0	C-119	17.5	44.4
C-089	6.5	8.2	C-120	4.6	19.6

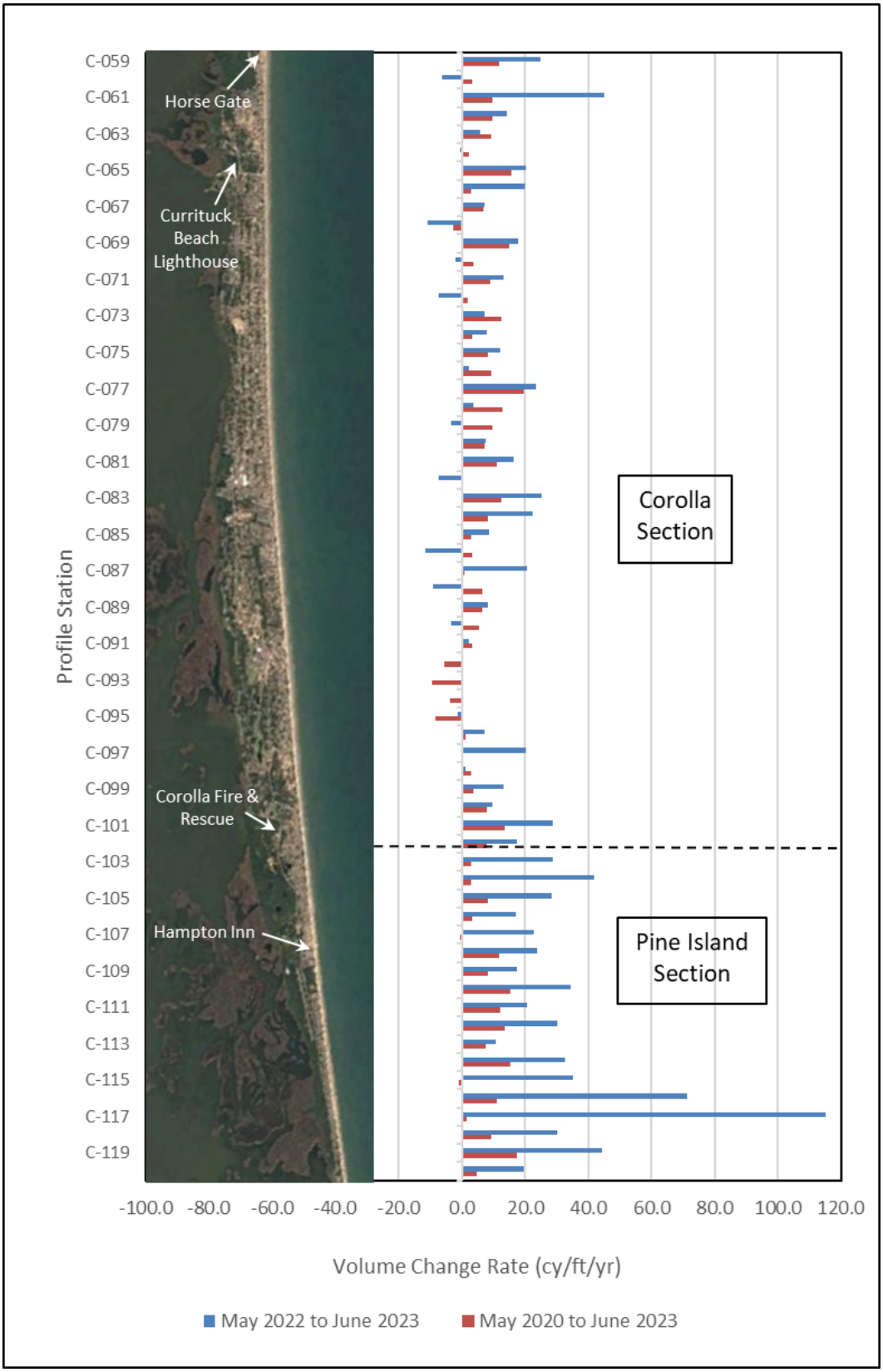

Figure 12. Volume Change Rate Above -19 ft. NAVD88 - South of the Horse Gate May 2020 to June 2023 and May 2022 to June 2023

Corolla Section: The average long-term volumetric change rate in the Corolla Section was +5.6 cy/ft./yr., which equates to a net volume gain of 739,900 cy. Negative volumetric change rates were measured on 6 profiles in this section (Table 10 and Figure 12). A profile-by-profile comparison shows volumetric change rates in this section ranging from -9.5 cy/ft./yr. at station C-093 to +19.5 cy/ft./yr. at station C-077. The Corolla Section was analyzed further for observable trends within the section. Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the Horse Gate, and approximately 200 feet south of Tern Arch (station C-059 to station C-090), the average volumetric change rate was +7.4 cy/ft./yr. From approximately 200 feet south of Tern Arch to north end of Breakers Arch (station C-090 to station C-098), the average volumetric change rate was a -1.7 cy/ft./yr. From station C-098 south to station C-102, north of end Breakers Arch, approximately 500 feet north of Yaupon Lane, the average volumetric change rate was +7.1 cy/ft./yr.

Pine Island Section: The average long-term volumetric change rate in the Pine Island Section was +8.0 cy/ft./yr. This equates to a net volume gain of approximately 448,600 cy. This is a reversal from the long-term rate measured in 2022 (CPE, 2023) where the average volumetric change rate in this section was -5.9 cy/ft./yr. Negative volumetric change rates were only measured at two profiles: Sta. C-107 and Sta. C-115 along this Section (Table 10 and Figure 12). A profile-by-profile comparison shows volumetric change rates in this section ranging from -1.0 cy/ft./yr. at station C-115 to +17.5 cy/ft./yr. at station C-119. The Pine Island Section was analyzed further for observable trends within the section. Between the northern boundary of the Pine Island Section, which is located approximately 500 feet north of Yaupon Lane, and north end of Lindsey Lane (station C-102 to station C-108), the average volumetric change rate was +5.2 cy/ft./yr. From north end of Lindsey Lane to located approximately at 101 Station 1 Lane, (station C-108 to station C-120), the average volumetric change rate was +9.8 cy/ft./yr.

4.1.2 Recent Period May 2022 to June 2023

The average volumetric change rate measured along the entire Assessment Area, between May 2022 to June 2023 was +16.0 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 1,051,000 cubic yards. Table 10 lists the individual volumetric rates computed for each profile in the Corolla and Pine Island Sections between May 2022 and June 2023. Figure 12 shows the May 2022 to June 2023 volume change rates graphically.

Corolla Section: The average volumetric change rate in the Corolla Section was +8.4 cy/ft./yr. This equates to a net volume gain of approximately 376,000 cy over the 13-month period from May 2022 to June 2023. This average change rate is three times larger than what was measured between June 2021 to May 2022, which measured +2.7 cy/ft./yr. A profile-by-profile comparison shows volumetric change rates in this section ranging from -11.8 cy/ft./yr. at station C-086 to +44.8 cy/ft./yr. at station C-061 (Table 10 and Figure 12). The Corolla Section was analyzed further for observable trends within the section. Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the Horse Gate, and 550 feet north of Tuna Street (station C-059 to station C-069), the average volumetric change rate was +12.5 cy/ft./yr. From approximately 550 feet north of Tuna Street to Mackerel Beach Access (station C-069 to station

C-076), the average volumetric change rate was +6.3 cy/ft./yr. From station C-076 south to station C-087, Mackerel Beach Access, to south end of Mainsail Arch, the average volumetric change rate was +8.9 cy/ft./yr. From the south end of Mainsail Arch to Sandhill Lane (station C-087 to station C-096), the average volumetric change rate was relatively stable at +2.4 cy/ft./yr. Along the southern portion of the Corolla Section, between station C-096 (Sandhill Lane) and station C-102 (located approximately 500 feet north of Yaupon Lane), the average volumetric change rate was +13.9 cy/ft./yr.

Pine Island Section: The average volumetric change rate in the Pine Island Section over the 13-month period from May 2022 to June 2023 was +33.8 cy/ft./yr. This rate is more than three times greater than the rate measured along the Corolla Section over the same time period and equates to a net volume gain of approximately 675,000 cy. The large positive change rate for this recent period is a reversal from the negative average change rate measured between June 2021 and May 2022 (-28.6 cy/ft./yr.). Positive volume changes were measured along all of the profiles along the Pine Island Section between May 2022 and June 2023. This large positive volumetric change is partially attributed to the infilling of a nearshore trough that was present along Pine Island in May 2022. A profile-by-profile comparison shows volumetric change rates in this section ranging from +10.7 cy/ft./yr. at station C-113 to +115.0 cy/ft./yr. at station C-117. The Pine Island Section was analyzed further for observable trends within the section. Between the northern boundary of the Pine Island Section, which is located approximately 500 feet north of Yaupon Lane, and 120 ft. north of Ogein Dr. (station C-102 to station C-115), the average volumetric change rate was +25.8 cy/ft./yr. Along the southern portion of the Pine Island Section, between station C-115 (120 ft. north of Ogein Dr.) and station C-120, located approximately at 101 Station 1 Lane, the average volumetric change rate was +52.5 cy/ft./yr. This average rate was heavily influenced by the large gain measured on the profile at station C-117 (north end of Salthouse Road) of +115.0 cy/ft./yr. associated with a large nearshore trough which was present in May 2022 filling in.

4.2 Volumetric Change (Lens Calculations)

As previously stated, a second volumetric analysis was incorporated into the annual monitoring assessment beginning in 2022 to further resolve volumetric changes occurring in various lenses of the beach from the dune out to depths beyond the established depth of closure (-19 ft. NAVD99). While the volumetric analysis reported on in Section 4.1 provides a basis for measuring long-term and recent volumetric changes as is typically done out to a specific depth of closure, this additional method provides insight into cross-shore variability in volumetric change. This method splits the profiles into various lenses based on depth contours. For this analysis, the beach was divided into four discreet lenses, which include the Dune, Visible Beach, the Inner Nearshore, and the Outer Nearshore portions of the profile. Figure 13 provides an illustration of the limits of each lens. The elevation contours used as the limits of the lenses were determined by profile inspection and reviewing results of the initial volume change analysis. As part of that profile inspection and initial review of volume changes, cross-shore changes were observed beyond the established -19 ft. NAVD88 contour. However, the offshore limit of these changes appeared to vary along the original Assessment Area, which includes the entire Currituck County oceanfront. North of the Horse Gate, the average depth of closure between May 2020 and May 2022 was determined to be

approximately -22 ft. NAVD88; whereas, south of the Horse Gate, the average depth of closure was determined to be approximately -25 ft NAVD88. Guidance on the determination of elevation limits for the lenses also comes from the "2017 Beach Condition Monitoring Pine Island, Currituck County, North Carolina" (CSE, 2018). In this report, since only the Sections south of the Horse Gate are included, the offshore limit used for the Outer Nearshore Lens is -25 ft. NAVD88.

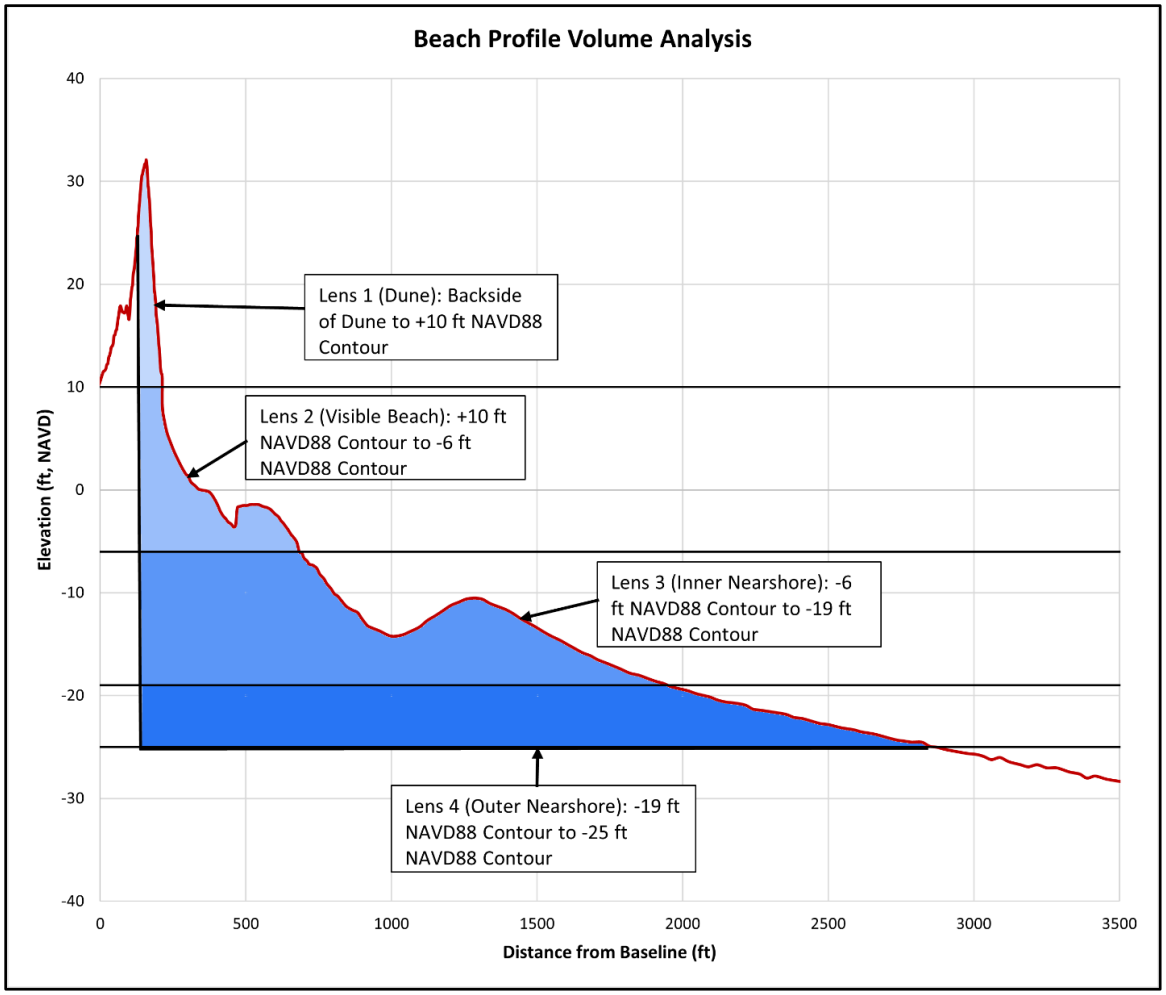

Figure 13. Beach Profile Cross Section Illustrating Lenses

- **Lens 1 (Dune):** Volume from Backside of the dune to +10 ft. NAVD88 — The volume between the backside of the primary frontal dune and the +10 ft. NAVD88 contour is a measure of the sand quantity in the dunes. The +10 ft. NAVD88 contour typically is representative of the toe of the dune though this elevation can change seasonally and spatially. This lens of sand would also be landward of runup experienced during minor storms.
- **Lens 2 (Visible Beach):** Usable Beach (+10 ft. to −6 ft. NAVD88) — This lens includes the dry-sand beach ("berm") and wet-sand beach (sloping wave swash zone) to low-tide wading depth at −6 ft. NAVD88. This is the primary recreational portion of the beach.

- **Lens 3 (Inner Nearshore):** Outer Surf Zone (−6 ft. to −19 ft. NAVD88) — This lens represents the underwater part of the beach extending seaward of the bar to the previously established depth of closure.
- **Lens 4 (Outer Nearshore):** Outer limits of the Active Beach Profile (-19 ft. to -25 ft. NAVD88) — This lens represents the underwater part of the beach profile in and around the various observed depths of closure during this study.

4.2.1 Long-term Period May 2020 to June 2023

Lens 1 (Dune): The average volumetric change rate measured between May 2020 and June 2023 in the Dune Lens was +0.1 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 31,600 cubic yards along the Assessment Area. A volumetric change of greater than -0.1 cy/ft./yr. was measured between May 2020 and June 2023 along the Corolla Section whereas, a positive volumetric change rate of +0.6 cy/ft./yr. was measured along the Pine Island Section over the same period. The average rates of volumetric change and total volumetric change calculated for the Dune Lens along the Assessment Area and each of the two (2) Sections are provided in Table 11. The rates of volumetric change for each station are provided in Table 12 and are shown graphically in Figure 14.

A profile-by-profile comparison shows volumetric change rates computed for the Dune Lens range from -3.9 cy/ft./yr. at station C-061 (North end of Atlantic Avenue) to +2.2 cy/ft./yr. at station C-098 (north end of Breakers Arch). A graphical representation of the volumetric changes in the Dune and Visible Beach Lenses is provided in Figure 14. In general, volumetric changes were positive along the Assessment Area. As shown in Figure 14, negative volumetric changes were measured in the dune lens along all of the beach profiles from station C-059 (250 feet south of Horse Gate) to station C-067 (located approximately 1,200 feet south of Corolla Village Road). These negative volumetric changes are believed to be driven by volume loss that occurred between June 2021 and May 2022. This volume loss is exhibited as dune scarping which can be seen in Figure 15.

Table 11. Summary of Average Volumetric Change Rates and Total Volume Changes

Sections	May 2020 to June 2023 Density Change Rate (cy/ft./yr.)			
	Lens 1 Dune	Lens 2 Visible Beach	Lens 3 Inner Nearshore	Lens 4 Outer Nearshore
Corolla	> -0.1	0.1	5.6	6.8
Pine Island	0.6	1.2	6.1	5.1
Total	0.1	0.4	5.8	6.2
May 2020 to June 2023 Volume (cy)				
Corolla	-2,100	5,400	736,600	900,600
Pine Island	33,700	71,400	343,500	278,900
Total	31,600	76,800	1,080,100	1,179,500

Lens 2 (Visible Beach): The average volumetric change rate measured between May 2020 and June 2023 within the Visible Beach Lens was +0.4 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 76,800 cubic yards. As shown in Table 11, the average rate of change and total volumetric change was positive in both the Corolla (+0.1 cy/ft./yr.) and Pine Island (+1.2 cy/ft./yr.) Sections.

While the total average volumetric change and the average rates of volume change within both the Corolla and Pine Island Sections were relatively low, several portions of the Assessment Areas saw more significant changes as shown in Figure 14. Between station C-076 (located between Perch and Bonito Street along Lighthouse Dr.) and station C-084 (located approximately 170 feet south of Albacore Street) the average volumetric change rate of the visible beach was +3.6 cy/ft./yr. Between station C-090 (located approximately 200 feet south of the access at Tern Arch) and station C-098 (located at the north end of Breakers Arch) the average volumetric change rate of the visible beach was -3.5 cy/ft./yr. Between station C-105 (located near Sprig Point) and station C-112 (located at the north end of Longfellow Court) the average volumetric change rate of the visible beach was +2.5 cy/ft./yr.

Table 12. Lens Volumetric Change Rates (May 2020 to June 2023) (cy/ft./yr.)

Station	Lens 1 Dune	Lens 2 Visible Beach	Lens 3 Inner Nearshore	Lens 4 Outer Nearshore[(1)]
C-059	-2.6	1.4	12.9	3.8
C-060	-0.2	-2.5	6.0	5.6
C-061	-3.9	-0.8	14.3	5.7
C-062	-1.4	-0.6	11.5	3.6
C-063	-0.5	-0.7	10.6	5.8
C-064	-0.5	-0.2	2.9	4.7
C-065	-0.5	3.5	12.7	7.0
C-066	-1.5	-1.1	5.6	5.0
C-067	-1.5	1.7	6.7	6.5
C-068	0.2	-3.6	0.6	4.0
C-069	0.0	1.9	13.0	6.5
C-070	0.2	-0.4	3.6	5.5
C-071	-0.1	-0.7	9.7	8.1
C-072	0.0	-3.5	5.2	5.8
C-073	0.6	0.9	10.8	8.6
C-074	-0.9	-1.3	5.5	7.0
C-075	0.2	0.0	7.9	7.7
C-076	-0.2	3.3	6.0	5.7
C-077	0.4	5.1	14.0	10.0
C-078	0.7	5.5	6.8	9.3
C-079	0.3	0.5	8.9	11.0
C-080	0.2	4.7	2.2	9.4
C-081	0.1	3.3	7.6	12.0
C-082	-1.0	-0.4	1.5	9.4
C-083	0.8	4.3	7.2	11.4
C-084	0.4	5.9	1.9	9.4
C-085	-0.6	-2.4	5.8	9.3
C-086	-0.1	0.2	3.1	8.3
C-087	0.2	-1.4	2.0	5.9
C-088	0.7	1.3	4.4	7.2
C-089	0.8	2.2	3.5	5.6
C-090	0.7	-2.0	6.5	6.3
C-091	1.5	2.3	-0.7	4.9
C-092	0.3	-4.5	-1.4	6.4
C-093	-0.3	-6.1	-3.2	4.9
C-094	0.9	-5.6	0.8	4.8
C-095	0.0	-5.7	-2.5	2.1
C-096	1.5	-3.3	2.9	5.6
C-097	0.4	-3.4	2.5	5.3
C-098	2.2	-3.4	4.2	4.6
C-099	0.1	0.8	2.8	4.0
C-100	0.2	1.1	6.4	7.4
C-101	-0.1	6.0	7.6	7.9
C-102	0.4	-0.2	7.5	8.6
C-103	-0.7	1.4	2.2	4.7
C-104	0.5	-1.0	3.5	5.7
C-105	0.3	3.6	4.4	4.4
C-106	0.4	-0.9	3.8	4.1
C-107	1.6	-0.4	-1.9	2.4
C-108	1.8	3.2	6.9	7.6
C-109	1.1	4.1	2.8	5.7
C-110	0.9	5.1	9.3	6.1
C-111	1.1	2.6	8.5	5.2
C-112	0.6	3.0	10.1	6.8
C-113	0.0	1.0	6.6	3.4
C-114	-0.2	1.4	13.9	7.2
C-115	-0.1	-1.1	0.2	2.4
C-116	-0.1	-1.0	12.2	7.0
C-117	0.7	-6.1	7.0	0.9
C-118	1.2	2.7	5.5	10.2
C-119	1.3	5.2	11.0	0.1
C-120	0.6	0.9	3.1	4.8

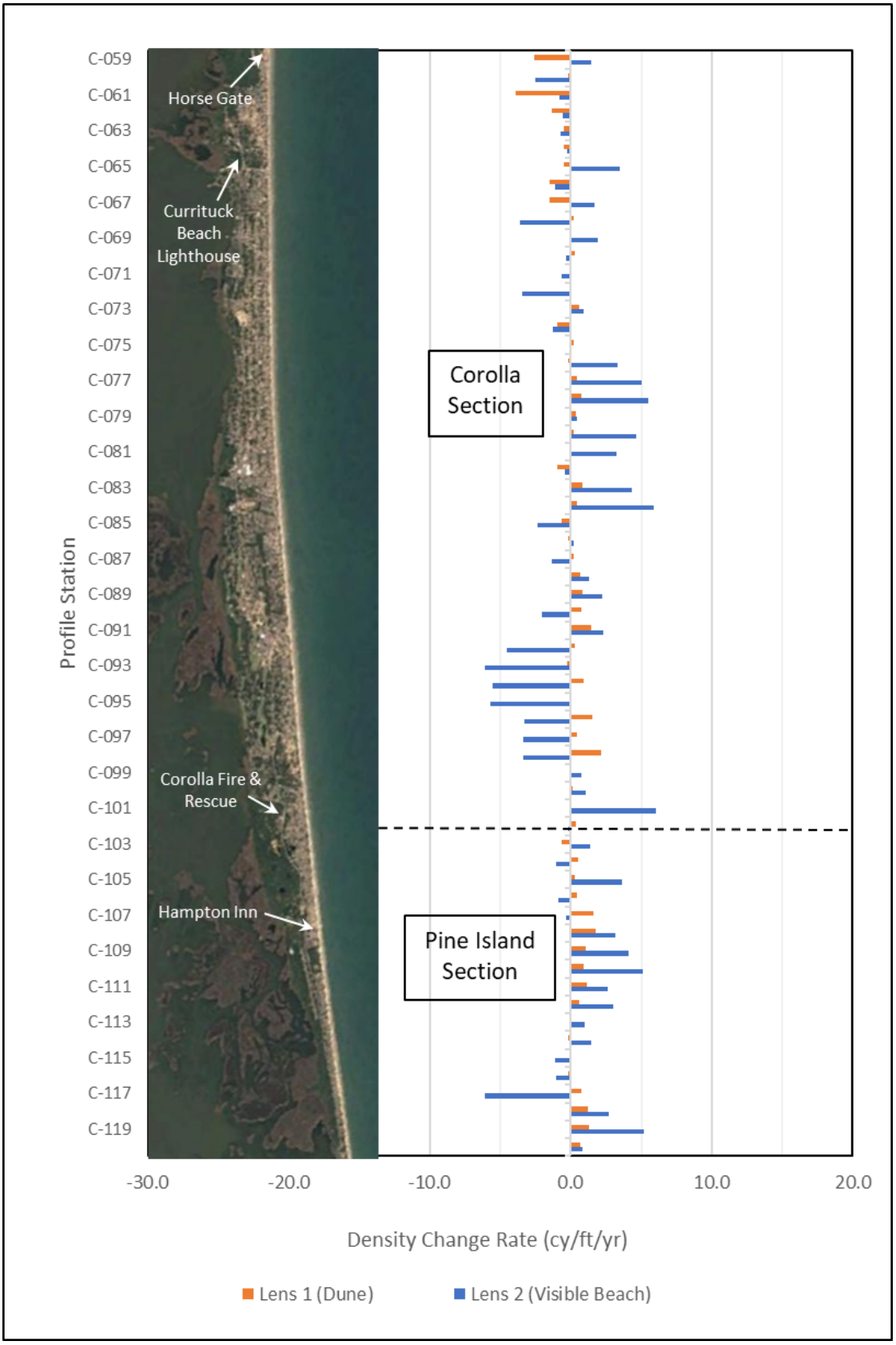

Figure 14. Volume Change Rate Lens 1 and Lens 2 - May 2020 to June 2023

Figure 15. View of Dune Scarping approximately 500 feet north of Sta. C-060. (Photo date 5/15/22).

Lens 3 (Inner Nearshore): The average volumetric change rate measured between May 2020 and June 2023 within the Inner Nearshore Lens was +5.8 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 1,080,100 cubic yards. As shown in Table 11, the average rate of change and total volumetric change was positive in both the Corolla and Pine Island Sections. The average volumetric change rates within the Inner Nearshore Lens in the Carolla and Pine Island Sections were +5.6 cy/ft./yr. and +6.1 cy/ft./yr., respectively.

While the positive volumetric trend within the Inner Nearshore Lens was relatively consistent throughout the Assessment Area, several portions of the Assessment Areas saw variations in these trends as shown in Figure 16. Between station C-059 (located 250 feet south of the Horse Gate) and station C-079 (located approximately 800 feet north of Sailfish Street) the average volumetric change rate of the Inner Nearshore Lens was +8.3 cy/ft./yr. The only portion of the Assessment Area where a negative volumetric change trend was observed other than the profile at station C-107, which is near Pine Gate Road in Pine Island, was between station C-091 (located approximately 800 feet north of Sea Oats Ct) and station C-098 (located at the north end of Breakers Arch). Along this portion of the beach, the average volumetric change rate of the Inner Nearshore Lens was -1.4 cy/ft./yr. Between station C-110 (located at the Hampton Inn & Suites) and station C-119 (located near the south end of Cottage Cove Rd) the average volumetric change rate of the Inner Nearshore Lens was +8.4 cy/ft./yr.

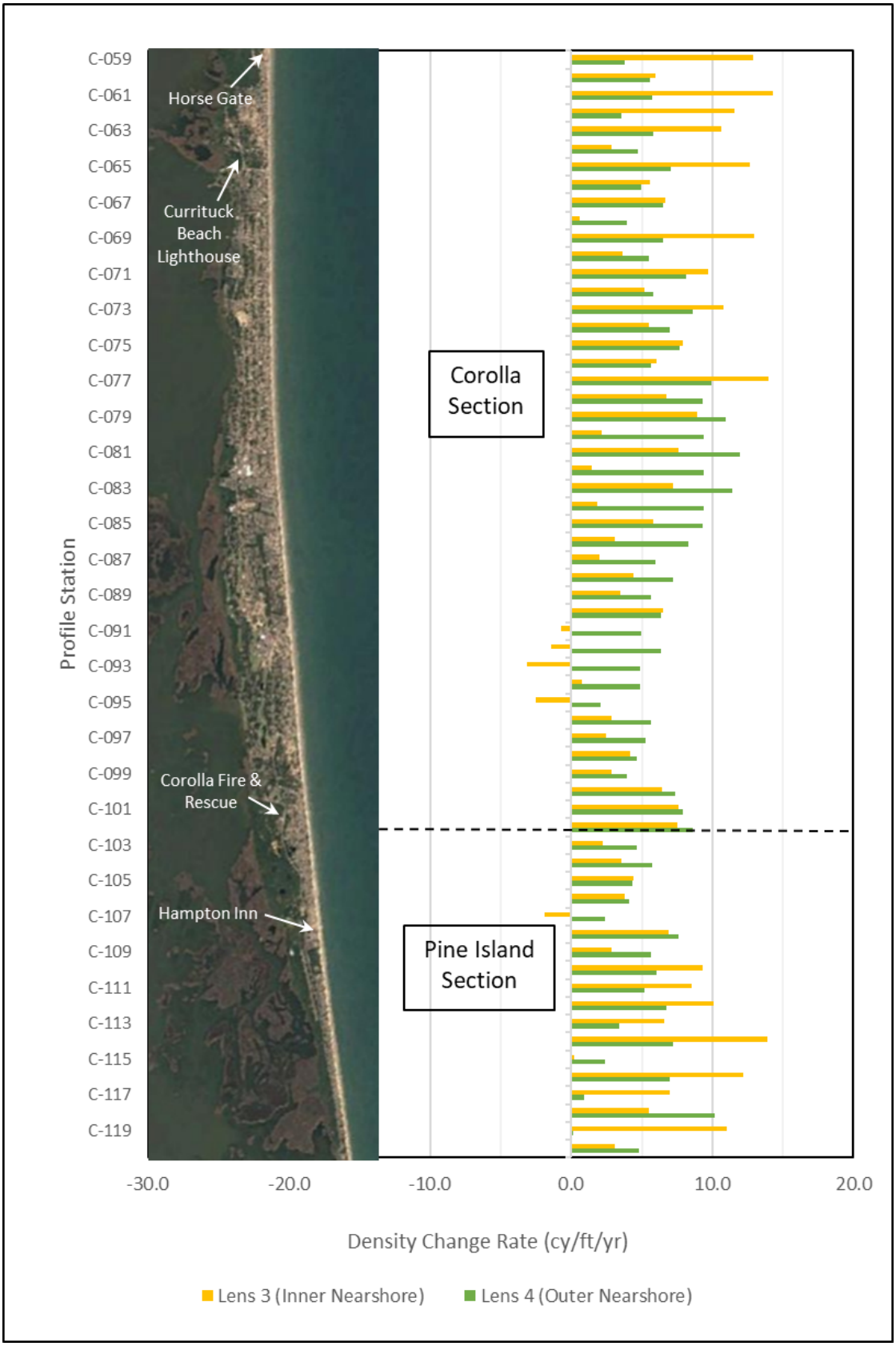

Figure 16. Volume Change Rate Lens 3 and Lens 4 - May 2020 to June 2023

Lens 4 (Outer Nearshore): The average volumetric change rate measured between May 2020 and June 2023 within the Outer Nearshore Lens was +6.2 cy/ft./yr. Positive volumetric changes in the Outer Nearshore Lens were calculated in both the Corolla and Pine Island Sections. The average volumetric change rates measured along the Corolla and Pine Island Sections were +6.8 cy/ft./yr. and +5.1 cy/ft./yr., respectively. Figure 16 illustrates that a positive volumetric change rate was measured along every profile in the Assessment Area between May 2020 and June 2023. The rates are generally consistent throughout. The average rate between stations C-071 (located 100 feet south of Sturgin St.) and C-085 (located at the south end of Voyager Road) was 8.9 cy/ft./yr., which is 2.7 cy/ft./yr. higher than the overall average along the Assessment Area.

4.3 Pine Island Section Volumetric Change Rates

As previously stated, two beach profile surveys were conducted along the Pine Island Section of the Assessment Area in September 2015 and October 2017 (CSE, 2018). CSE reported a volumetric change rate along Pine Island from Yaupon Dr. to the southern boundary of Currituck County of +2.6 cy/ft./yr., which equated to a net volume gain of approximately 46,000 cy. This analysis employed a similar method as was described in Section 4.2 in which volumetric changes were examined within discreet lenses. The analysis showed that although volumetric losses were measured from the dune crest to the -6 ft. NAVD88 contour, the overall volumetric change was positive due to additional gains in the offshore portion of the profile (-6 ft. NAVD88 to -19 ft. NAVD88).

Volumetric change rates were computed between September 2015 (CSE) and June 2023 (CPE) to provide additional long-term volumetric change trends where data exists. The average volumetric change rate between September 2015 and June 2023 along the Pine Island Section was relatively stable at +0.4 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 85,800 cubic yards. Table 13 lists the individual volumetric change rates computed for each profile out to the -19 ft. NAVD88 contour between September 2015 and June 2023.

Table 13. Pine Island Long-term Volume Change Rate 2015 to 2023

Stations	September 2015 to June 2023 (cy/ft./yr.)
C-102	-5.1
C-103	-2.5
C-104	-2.0
C-105	1.5
C-106	-5.6
C-107	0.3
C-108	3.0
C-109	1.9
C-110	3.7
C-111	2.3
C-112	2.0
C-113	1.9
C-114	1.8
C-115	-2.1
C-116	1.7
C-117	-1.6
C-118	2.7
C-119	5.6
C-120	-2.4
Average	0.4
Max	5.6
Min	-5.6

Figure 17 shows a graphical comparison of the 2015 to 2023 rates. Negative volumetric changes were measured along seven (7) of the nineteen (19) profiles along the Pine Island section.

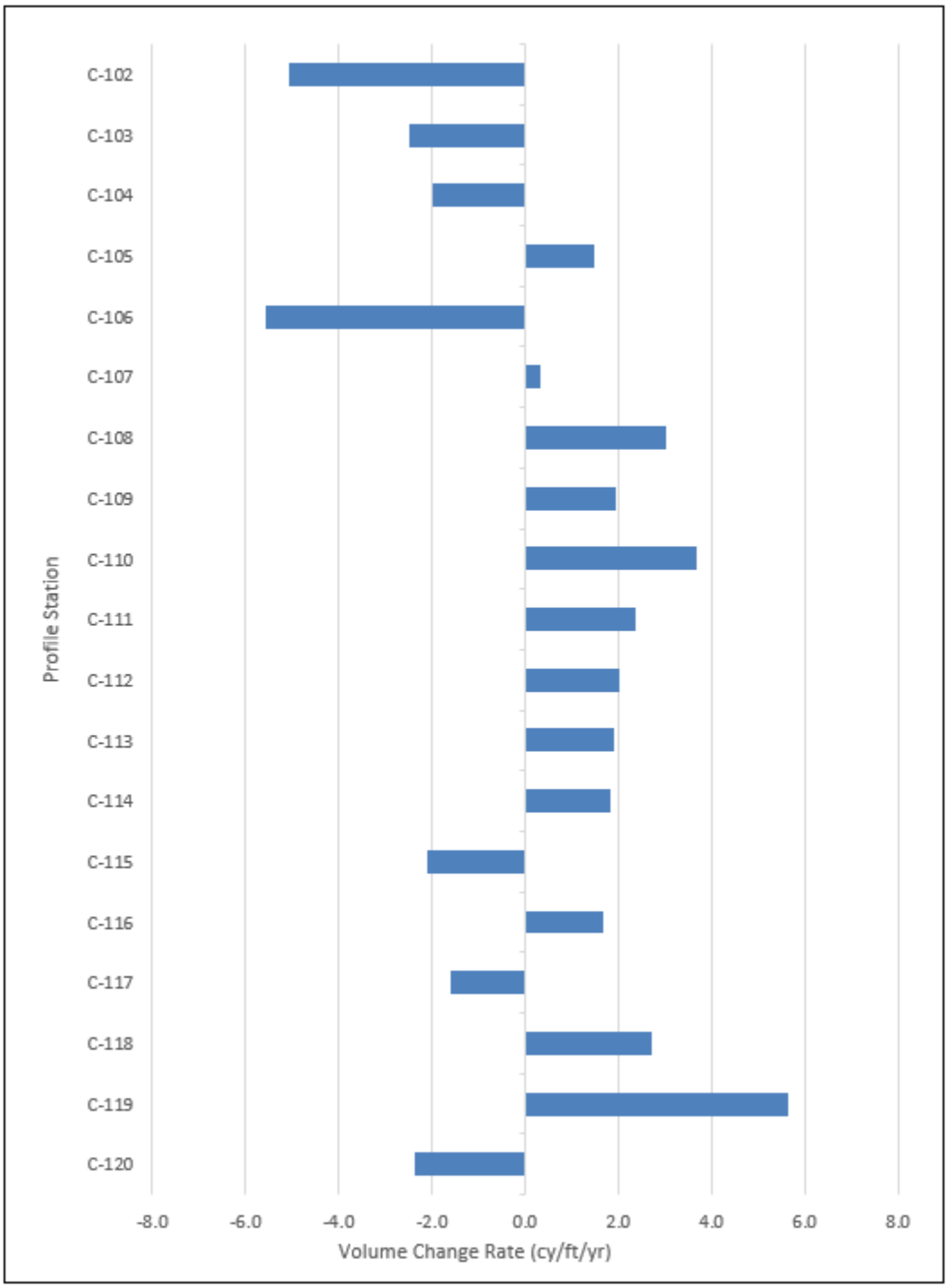

Figure 17. Pine Island (C-102 to C-120) Volume Change Rates Above -19.0 ft. NAVD88 – Sept. 2015 to June 2023

5 CONCLUSIONS

This 2023 Beach Monitoring and Beach Stability Assessment evaluated long-term and short-term shoreline and volumetric changes occurring along the County's beaches. The County initiated an annual monitoring program in 2020 with the initial goals of better understanding the changes occurring to the beaches and to assist the County in making informed decisions regarding beach management. The continued annual monitoring of the oceanfront beaches allows managers to track long-term and short-term trend and provides specific quantified data to facilitate informed management decisions. The conclusions provided in this section were drawn from the results of the various analyses described in this report.

5.1 Shoreline Change and Projected Shorelines

Shoreline change rates measured between 2009 and 2023 were computed using a linear regression method that considers various shoreline position data available between 2009 and 2023 including shoreline positions measured during each of the four surveys conducted as part of this study (May 2020, June 2021, May 2022, and June 2023). The average long-term shoreline change rate measured along the Corolla Section (250 feet south of the Horse Gate to 500 feet north of Yaupon Lane) was -5.6 ft./yr. The average long-term shoreline change rate measured along the Pine Island Section (500 feet north of Yaupon Lane to Southern County boundary) was -1.3 ft./yr.

Shoreline change rates measured along the Assessment Area between 2009 and 2023 were used to project future shoreline positions throughout the Assessment Area over a 10-, 20-, and 30-year time horizon. These projected shorelines are shown in the maps in Appendix B. The projected shorelines were then compared to the footprint of oceanfront houses and roads to evaluate potential impacts over the various time horizons.

In total, 158 houses were shown to be impacted over the 30-year horizon throughout the Assessment Area. All of these houses were located north of Yaupon Lane with most of them being in the Corolla Section located north of Albacore Street. Of the 158 houses shown to be impacted over the 30-year horizon, 45 of the houses were shown to be impacted over the 20-year horizon and 2 were shown to be impacted over the 10-year horizon. While the same number of houses were shown to be impacted over the 30-year horizon as reported in the 2022 Beach Assessment (CPE, 2023), the number of houses shown as impacted over the 20-year horizon and 10-year horizon dropped from 66 to 45 and 11 to 2, respectively.

The oceanfront houses indicated as impacted along the Assessment Area are concentrated along several general areas. The northernmost area spans from the Horse Gate, south to Corolla Village Road. Along this approximately 1.3-mile stretch of beach, nearly every oceanfront house was shown to be impacted over the 30-year horizon. Approximately 42% of the oceanfront houses along this section were shown to be impacted over the 20-year horizon and the only two (2) houses within the Assessment Area shown to be impacted over the 10-year horizon are along this

stretch of beach. Furthermore, portions of the road along Atlantic Avenue were shown as impacted over the 30-year horizon.

Moving south, the second concentrated section of oceanfront houses shown to be impacted over the various time horizons are located along the 2.9 miles of beach fronting Lighthouse Drive. Along the northern 1.3 miles of Lighthouse Drive (north of station C-075), approximately 45% of the oceanfront houses were shown to be impacted over the 30-year horizon. None of these houses were shown to be impacted over the 20-year horizon. Along the southern 1.1 miles of Lighthouse Drive (south of station C-078), approximately 83% of the oceanfront houses were shown to be impacted over the 30-year horizon and approximately 25% were shown to be impacted over the 20-year horizon.

South of Albacore Street, the northernmost house in the Crown Point community was shown as impacted over the 30-year horizon. Approximately 2,000 feet south of that house, 8 houses along the Tide Arch community (station C-087 to station C-088) were shown to be impacted over the 30-year horizon. No houses along the 2.6-mile stretch of beach between the south end of the Tide Arch community (station C-088) and the north end of the Spindrift community (station C-101) were indicated as impacted over the 30-year horizon. Along the oceanfront section of the Spindrift community, all 9 houses located along the beach were shown to be impacted over the 30-year horizon. Out of the 9 houses along Spindrift shown to be impacted over the 30-year horizon, 4 were shown to be impacted over the 20-year horizon.

While long-term shoreline change projections provide useful information to evaluate trends and determine future potential impacts, oceanographic conditions that influence shoreline change are not constant (water levels, storm frequency, dominate wind direction). This variability can result in short-term trends that differ from long-term trends observed. The evaluation of recent shoreline changes that occurred between May 2020 and June 2023 also indicated negative average shoreline change rates along both the Corolla and Pine Island Sections.

5.2 Volume Change

On average, the data collected in 2020, 2021, 2022, and 2023 indicate positive volumetric changes along the Assessment Area. The average volumetric change rate along the entire Assessment Area was +6.3 cy/ft./yr. between 2020 and 2023; this equates to a net volume gain of 1,188,500 cy. A positive volumetric change of approximately 739,900 cy was measured along the Corolla Section during this period; similarly, along the Pine Island Section, a positive volumetric change of approximately 448,600 cy was measured.

The positive volumetric changes measured over the monitoring period in the Corolla and Pine Island Sections were primarily driven by changes that occurred between the -6.0 ft. NAVD88 contour and the -19.0 ft. NAVD88 contour. Furthermore, large volumetric gains were measured during the recent period between May 2022 and June 2023. A net volume gain of approximately 376,000 cy was measured along the Corolla Section between May 2022 and June 2023. Similarly, a net volume gain of approximately 675,000 cy was measured along the Pine Island Section

between May 2022 and June 2023. Also of note regarding volumetric changes in the Pine Island Section is the anomalous positive volumetric change rate of 115.0 cy/ft./yr., measured at station C-117 (north end of Salthouse Road). The volumetric change measured along this profile was more than twice as great as the volume measured along any other profile along the entire Assessment Area and is associated with the filling in of a large nearshore trough, which was present in May 2022.

Coastal communities both north and south of the Currituck County shoreline have constructed beach nourishment projects as a result of long-term erosional trends and vulnerability of oceanfront structure to storms. North of the Assessment Area, in Sandbridge, Virginia, a beach nourishment project was constructed in 1998. This project was re-nourished in 2003, 2007, and 2013. South of the Assessment Area, erosional trends and storm vulnerability prompted the Northern Dare County Towns of Duck, Southern Shores, Kitty Hawk, Kill Devil Hills, and Nags Head to implement beach nourishment programs. Initial construction of the beach nourishment project at Nags Head was constructed in 2011, while the projects at Duck, Kitty Hawk, and Kill Devil Hills were initially constructed in 2017. The Nags Head project has since been re-nourished twice, while the Kitty Hawk and Kill Devil Hills projects were re-nourished in 2022 at the same time as the initial construction of the project in the Town of Southern Shores. The Duck project was re-nourished in 2023. Despite the need for renourishment projects north and south of Currituck County, the data collected between 2020 and 2023 along the Currituck County oceanfront suggests an accretional volumetric change trend (positive).

The volumetric analysis described in Section 5.2, in which volumetric changes were evaluated in terms of discrete cross shore lenses, was conducted to better understand volumetric changes in terms of which portions of the beach were seeing the majority of gains and losses. The discrete cross-shore lenses evaluated included the Dune, the Visible Beach, the Inner Nearshore, and the Outer Nearshore. Between May 2020 and June 2023, the Dune portion of the beach, which extends from the landward side of the dune crest to the seaward +10.0 ft. NAVD88 contour, gained on average +0.1 cy/ft./yr. south of the horse gate. The only losses reported of the four different lenses evaluated were measured in the Dune Lense along the Corolla Section at an average rate greater than -0.1 cy/ft./yr. While the average rate of volumetric gain was +0.6 cy/ft./yr. in the Dune Lense of the Pine Island Section.

When combined, the net positive volume change observed in the Dunes and the positive volume change observed within the Visible Beach resulted in a net positive volume change of approximately 108,400 cy along the entire Assessment Area. However, the majority of the positive volumetric changes were measured in the Inner Nearshore Lense, which resulted in a significant net positive volumetric change along the Assessment Area between May 2020 and June 2023. The Inner Nearshore portion was defined as the portion of the beach from the -6.0 ft. NAVD88 contour seaward to the -19.0 ft. NAVD88 contour, which is the established depth of closure used in this study. The concept of depth of closure is used in coastal engineering application to define a theoretical depth along a beach profile where sediment transport is very small or non-existent, dependent on wave characteristics and sediment grain size. On average, the volumetric change rate measured between May 2020 and June 2023 along the Inner Nearshore portion of the beach

was +5.8 cy/ft./yr., which equates to 1,080,100 cy. This significant increase in volume in the Inner Nearshore portion of the beach, which is nearly ten (10) times greater than the positive volume changes measured landward of the -6.0 ft. contour, suggests that the volume gains measured within the Assessment Area may be migrating from deeper water seaward of the depth of closure.

As stated above, the depth of closure typically refers to a theoretical depth along a beach profile where sediment transport is very small or non-existent. Kraus (1998) states that the "depth of closure for a given or characteristic time interval is the most landward depth seaward of which there is no significant change in bottom elevation and no significant net sediment transport between the nearshore and the offshore." Given this definition, one would not expect to find considerable volumetric changes occurring seaward of an established depth of closure. However, a fourth lens, seaward of the previously established -19.0 ft. NAVD88 depth of closure was also examined in terms of volumetric change and within that lens, positive volumetric changes were also measured between May 2020 and June 2023. In the Corolla and Pine Island Sections, a net positive volumetric change of approximately 1,179,400 cy was measured between May 2020 and June 2023 between the -19.0 ft. NAVD88 contour and the -25.0 ft. contour.

Numerous monitoring programs throughout the east coast and gulf coast of the US, established to monitor the performance of beach nourishment projects, have documented a phenomenon in which a large storm or a period of time with multiple large storms, resulted in the movement of sediment from the active beach seaward of the typical depth of closure. Furthermore, these studies have also demonstrated that a multi-year recovery period may follow these storm events, during which sand that had previously migrated into deeper water, migrates landward into the active beach profile. This principle was documented in a white paper published by Keehn and Pierro (2003) which demonstrated similar storm response and multi-year recovery that occurred along beach nourishment projects in Fire Island, New York, and Panama City Beach, Florida in the 1990's and early 2000's. One contributing factor described in the white paper that both locations had in common, was the presence of large sand bar systems. More recently, this phenomenon was described with regards to two beach nourishment projects constructed in the Town of Southampton, New York following the impacts of Super Storm Sandy (Kaczkowski, 2020). In this case, the post-construction monitoring of the beach nourishment projects indicated that the project maintained over 100% of the volume placed 6 years into the beach nourishment project. The author concluded that the additional sand gained in the Assessment Area migrated landward from deposits of sand that were moved into relatively deep water during Super Storm Sandy.

A general review of wave data reflective of conditions offshore Currituck County was conducted to evaluate whether the offshore wave climate prior to the study period (Jan. 2017 to Jan. 2020) differed significantly from the wave climate during the study period (May 2020 to June 2023). Figure 18 shows the measured significant wave heights from a waverider buoy located in approximately 26 m of water offshore of the Duck Field Research Facility pier.

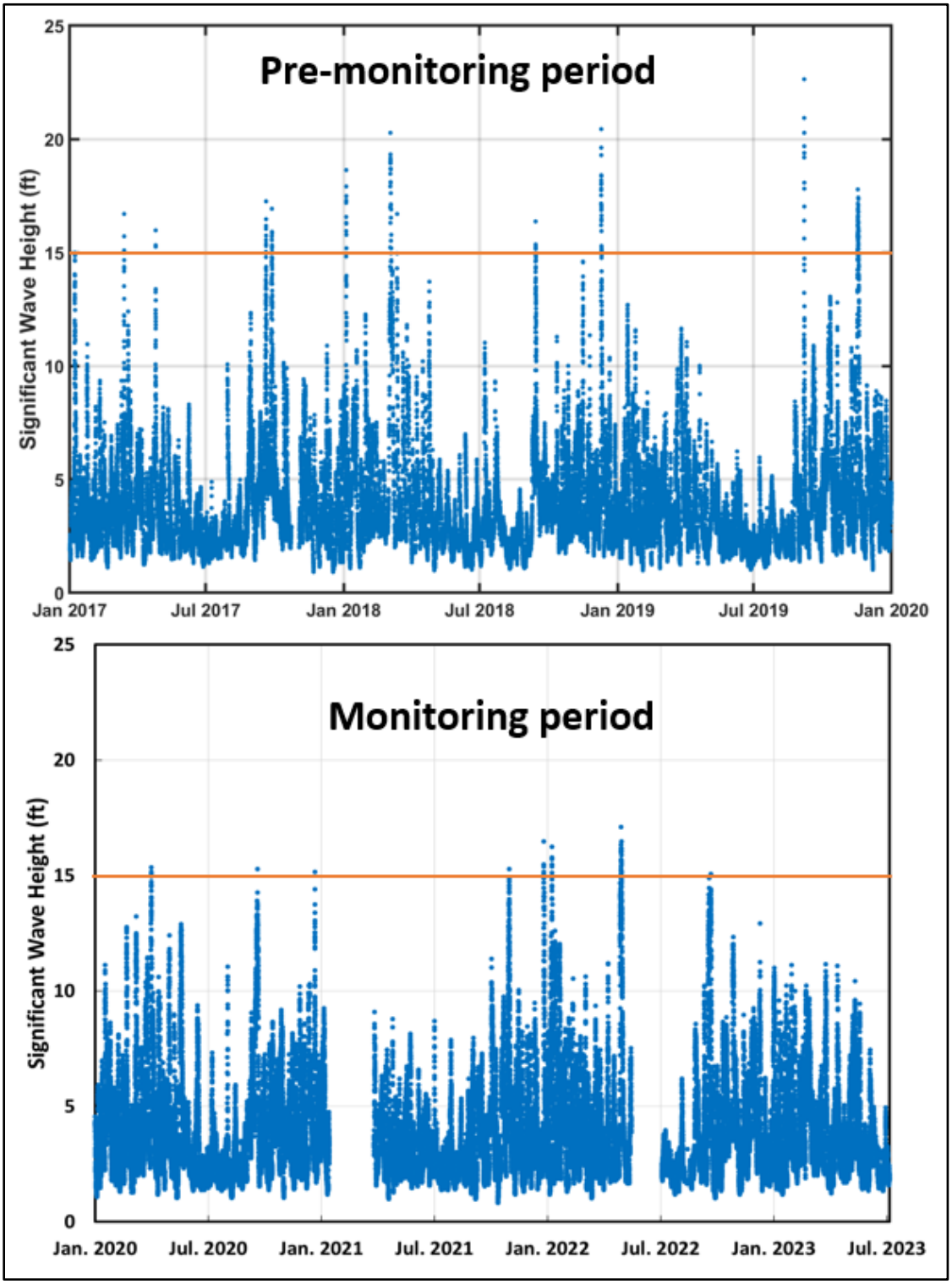

Figure 18. Significant Wave Height data for waverider buoy located in 26 m of water offshore Duck, NC (Station 44100) prior to and during the monitoring period.

The upper panel shows the wave data for the three-year period prior to the commencement of the Currituck County Beach Monitoring and Beach Stability Assessment (January 2017 to January

2020). The lower panel shows the wave data for the three-year period from January 2020 to June 2023, which includes the monitoring conducted as part of this Assessment. These wave data indicate that the pre-monitoring period (January 2017 to January 2020) was more active in terms of wave events that produced significant wave heights of > 15 ft. Specifically, there were three storm events during this three-year period where significant wave heights exceeded 20 ft. The first was a nor'easter in March 2018. This event was an extratropical cold front that brought strong winds, heavy snow, and tremendous coastal flooding to communities from the Mid-Atlantic to northern Maine. A second event with significant wave heights in excess of 20 ft. occurred in December 2018. The third event with significant wave heights in excess of 20 ft. was Hurricane Dorian, which occurred in September 2019. Hurricane Dorian was the first major hurricane of the 2019 Atlantic hurricane season and caused severe flooding and hurricane-force winds over parts of the coastal Carolinas. After stalling over the Bahamas for three days as a Category 5 hurricane, Dorian proceeded generally to the northwest, before making landfall near Buxton, North Carolina, on September 6. This storm caused significant impacts to the beach fill projects at Duck, Kill Devil Hills, Nags Head, and Buxton. Approximately two (2) months following the impacts of Hurricane Dorian, a major Nor'easter impacted the Outer Banks in mid-November of 2019 that produced significant wave heights at the same buoy of nearly 18 ft. A significant storm surge was also experienced during this event.

An examination of the wave data shown in the lower panel of Figure 18, indicates that generally, the monitoring period (May 2020 to June 2023) included no wave events in which significant waves heights exceeded 20 ft., less wave events in which significant wave heights exceeded 15 ft., and generally experienced an overall wave climate that was calmer than the preceding three years (January 2017 to January 2020).

The comparison of these wave data, coupled with the observations along beaches north and south of Currituck County, which experienced positive volumetric changes during this same period that varied from the typical negative volumetric changes observed, suggests that the positive volumetric changes experienced during the May 2020 to June 2023 monitoring period may be explained as a recovery following storm induced migration of sand into deeper depths offshore of the Assessment Area. Furthermore, if this explanation holds true, then negative volume change trends may follow this temporary period of recovery.

6 RECOMMENDATIONS

Based on the various beach assessments described in this report and conclusions drawn from those assessments, CPE provides the following recommendations for the County's consideration as they seek to make informed decisions regarding beach management:

1. <u>Continue Monitoring of the Beach Profiles:</u> The completion of the initial 3-year Beach Monitoring and Beach Stability Assessment (2020 through 2022) established a baseline of shoreline change and volumetric change rates. Given the results of the shoreline and volume change analysis, the distribution of potential impacts from the shoreline

projections over 10 to 30 years and the distribution of houses identified through the vulnerability analysis, a recommendation was made to the County to continue to monitor on an annual basis (CPE, 2023). This recommendation suggested that the Corolla and Pine Island Sections should be monitored on an annual basis based on several factors.

The first was that the majority of the houses indicated as vulnerable through both the SBEACH analysis and the projected shoreline change rates, were located south of the Horse Gate. Secondly it was stated that given the possibility that the positive volumetric changes observed between 2020 and 2022 may be due to a temporary recovery of the beach following a period where sand had been pulled offshore due to storms, annual monitoring was important to track whether the beach is still in a state of recovery or whether it reverts to a trend of volume loss. The third reason given to monitor the area south of the Horse Gate on an annual basis was due to the Pine Island Section being the only one of the four (4) Sections to have shown a negative volumetric change over the monitoring period between May 2020 and May 2022. Furthermore, the monitoring would allow for the tracking of the anomalous volumetric loss measured along profile C-117 in Pine Island.

North of the Horse Gate, in the Carova and Reserve Refuge Area, it was recommended that monitoring could be conducted every other year. This recommendation was based on the fact that only a small number of houses located north of the Horse Gate were indicated as vulnerable coupled with the amount of undeveloped beach north of the Horse Gate.

The County contracted with CPE to continue monitoring as recommended through 2025. Based on the results of the 2023 monitoring, it is still recommended that this annual monitoring continue through at least 2025 to include the Corolla and Pine Island Sections annually and the Carova and Reserve/Refuge Section every other year for the same reasons as stated previously. It appears as though the positive volumetric changes that have continued to be observed between 2020 and 2023, which may be due to a temporary recovery of the beach following a period where sand had been pulled offshore due to storms, has not yet reverted to a trend of volume loss as suggested may happen. However, given the elevated sea conditions experienced at the end of the summer and into early fall 2023, it is still possible for the trend of positive volumetric changes to reverse.

The same profiles established at the beginning of the County-wide assessment in 2020 should be collected at a similar time of year to reduce the impacts of seasonal changes on conditions of the profile, particularly the portion of the profile above Mean High Water (MHW).

2. <u>Develop a Beach Management Plan:</u> A Beach Management Plan is a document that first requires the establishment of tangible goals for how a local government desires to manage the beach. Beaches serve a variety of purposes from storm damage reduction, to flood

mitigation, to recreational opportunity that draws in tourist dollars, to impacts to transportation or evacuation corridors, to environmental habitat that supports such resources as sea turtles and shore birds. A properly established beach management plan first establishes the local government's goals and then once the goals have been established, a feasibility analysis is conducted to look at multiple options for achieving the desired goals of the plan.

CPE renews its previous recommendation that the County develop a Beach Management Plan. The development of this Beach Management Plan would allow the County to first establish goals for managing the beaches. The development of the beach management plan would then involve the development of various management concepts, which may include beach nourishment, sand fencing/dune vegetation, beach bulldozing (dune push), targeted buyouts, etc. Once various management concepts have been developed, those various concepts would be evaluated in terms of effectiveness, cost, and other aspects used to determine feasibility. Through the evaluation of these various concepts, the County would determine the most feasible options that would both meet the pre-established goals of the plan and be economically feasible to implement. The management plan would ultimately provide thresholds for implementing actions established in the management plan, cost estimates, and schedules for implementing such actions. The County issued a Public Notice on September 5, 2023 requesting statements of qualifications for firms that could assist with the development of a Beach Management Plan.

3. Coordinate with Dare County on Regional Sand Resource Investigation: In 2023 Dare County commissioned a two-year regional sand investigation study to locate sand for future beach nourishment projects. The reconnaissance phase of this investigation was conducted in the summer of 2023 and the County and its consultants are assessing data acquired. The geographic extent of the Study Area includes portions of southern Currituck County including portions offshore of the Corolla and Pine Island Sections as defined in this report. State and federal rules do not limit offshore sand resources to be used only by the adjacent local community. These resources are typically considered state and or federal resources for which permits can be applied for by neighboring municipalities to use these sediments for beach nourishment projects. If Currituck County anticipates the future development of a Beach Management Plan, CPE recommends that County staff coordinate with Dare County on this regional sand resource investigation.

7 REFERENCES

APTIM, 2018. APTIM Coastal Planning & Engineering of North Carolina Inc., 2018. Town of Southern Shores, North Carolina – Vulnerability Assessment & Beach Management Plan. Prepared for the Town of Southern Shores, North Carolina. December 2018, 41 pgs.

APTIM, 2019a. APTIM Coastal Planning & Engineering of North Carolina, Inc. Town of Kitty Hawk and Kill Devil Hills 2019 Shoreline & Volume Change Monitoring Report. Prepared for the Towns of Kitty Hawk and Kill Devil Hills, North Carolina by APTIM Coastal Planning & Engineering of North Carolina, Inc. Wilmington, NC. December 2019, 34 pgs.

APTIM, 2019b. APTIM Coastal Planning & Engineering of North Carolina, Inc. Town of Kitty Hawk and Kill Devil Hills 2018 Shoreline & Volume Change Monitoring Report. Prepared for the Towns of Kitty Hawk and Kill Devil Hills, North Carolina by APTIM Coastal Planning & Engineering of North Carolina, Inc. Wilmington, NC. February 2019, 31 pgs.

Bonanata, R., Medina, R., Silveira, L. and Benedet, L., 2010. Metología para la Caracterización del Clima Marítimo en un Punto Cerca de la Costa a Partir de Una Seria de Datos en Aguas Profundas. [Methodology for the Characterization of the Maritime Climate in a Point Near the Coast Based on a Series of Data in Deep Waters]. VI Argentine Congress of Port Engineering.

Coastal Science & Engineering (CSE), 2018. 2017 Beach Condition Monitoring Pine Island, Currituck County, North Carolina. Prepared by Coastal Science & Engineering, March 2018, 86 pgs.

CPE, 2020. Coastal Protection Engineering of North Carolina, Inc., Currituck County North Carolina, 2020 Beach Monitoring and Beach Stability Assessment. Prepared for Currituck County. Wilmington, NC. November 2020, 56 pgs.

CPE, 2021a. Coastal Protection Engineering of North Carolina, Inc., Currituck County North Carolina, 2021 Beach Monitoring and Beach Stability Assessment. Prepared for Currituck County. Wilmington, NC. December 2021, 50 pgs.

CPE, 2021b. Coastal Protection Engineering of North Carolina, Inc., Town of Duck, North Carolina Erosion & Shoreline Management Design Report. Prepared for the Town of Duck, North Carolina. October 2021, 68 pgs.

CPE, 2021c. Coastal Protection Engineering of North Carolina, Inc., Town of Kitty Hawk, North Carolina Erosion & Shoreline Management Design Report. Prepared for the Town Kitty Hawk, North Carolina. November 2021, 88 pgs.

CPE, 2021d. Coastal Protection Engineering of North Carolina, Inc., Town of Southern Shores, North Carolina Erosion & Shoreline Management Design Report. Prepared for the Town of Southern Shores, North Carolina. December 2021, 83 pgs.

CPE, 2023. Coastal Protection Engineering of North Carolina, Inc., Currituck County North Carolina, 2022 Beach Monitoring and Beach Stability Assessment. Prepared for Currituck County. Wilmington, NC. January 2023, 82 pgs.

CPE-NC, 2013. Coastal Planning & Engineering of North Carolina, Inc., Erosion and Shoreline Management Feasibility Study. Prepared for the Town of Duck, North Carolina. May 2013, 48 pgs.

CPE-NC, 2015. Coastal Planning & Engineering of North Carolina, Inc., Town of Duck North Carolina Erosion & Shoreline Management Design Report. Prepared for the Town of Duck, North Carolina. July 2015, 96 pgs.

Federal Emergency Management Agency (FEMA), 2016. Flood Frequency and Extreme Value Analysis.

Federal Emergency Management Agency (FEMA), 2018. Guidance for Flood Risk Analysis and Mapping – Coastal Wave Runup and Overtopping.

Federal Emergency Management Agency (FEMA), 2020. Public Assistance Program and Policy Guide (4), 137-138.

Kaczkowski, H.L., 2022. When a Project Performed Better than Expected, Beach Nourishment at Sagaponack and Bridghampton, Town of Southampton, Long Island, New York. Oral Presentation presented at Florida Shore and Beach Preservation Association (FSBPA) Conference, February 2022, St. Augustine, FL.

Keehn, S. and Pierro, T., 2003. Temporal Variations of Offshore Sand Bars in Response to Extreme Events. White Paper developed internally by Coastal Planning & Engineering, Inc. Boca Raton, Florida.

Kraus, N.C., Larson, M., and Wise, R.A., 1998. Depth of Closure in Beach-Fill Design. Technical Note. U.S. Army Corps of Engineers, Vicksburg, MS.

Larson, M. and Kraus, N.C., 1989. SBEACH: Numerical Model for Simulating Storm-Induced Beach Change. Technical Reports, CERC-89-9, U.S. Army Corps of Engineers, Vicksburg, MS.

Larson, M. and Kraus, N.C., 1998. SBEACH: Numerical Model for Simulating Storm Induced Beach Changes, Report 1, Empirical Formulation and Model Development, U.S. Army Corps of Engineers, Vicksburg, MS.

Mallinson, D.; Culver, S.; Riggs, S.; Walsh, J.P.; Ames, D.; Smith, C., 2008. Past, Present and Future Inlets of the Outer Banks Barrier Islands, North Carolina. White Paper published by the Department of Geological Sciences, East Carolina University, 22 pgs.

Moran, K.; Mallinson, D.; Culver, S.; Leorri, E.; and Mulligan, R., 2015. Late Holocene Evolution of Currituck Sound, North Carolina, USA: Environmental Change Driven by Sea-Level Rise, Storms, and Barrier Island Morphology. Journal of Coastal Research, 31 – 4, pgs. 827 – 841.

National Oceanic and Atmospheric Administration, 2012. What is Lidar?. Prepared by National Ocean Service, October 2012: https://oceanservice.noaa.gov/facts/lidar.html

North Carolina Division of Coastal Management, 2019. North Carolina 2019 Oceanfront Setback Factors & Long-Term Average Annual Erosion Rate Update Study Methods Report. Prepared by North Carolina Division of Coastal Management, January 2019, 190 pgs.

Stockdon, H.F., Holman, R.A., Howd, P.A., Sallenger, A.H., 2006. Empirical parameterization of setup, swash, and run-up. Coast. Eng. 53 (7), 573–588.