2022 BEACH MONITORING AND BEACH STABILITY ASSESSMENT

CURRITUCK COUNTY, NORTH CAROLINA

PREPARED FOR
CURRITUCK COUNTY

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

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EXECUTIVE SUMMARY

Currituck County has commissioned a three-year Beach Monitoring and Beach Stability Assessment to evaluate long-term and short-term shoreline and volumetric changes occurring along Currituck's oceanfront beaches. The scope includes annual beach monitoring in Year-1, Year-2, and Year-3, an initial beach stability assessment to be completed following Year-1 surveys, and annual reports to be provided in Year-2 and Year-3 updating the County on shoreline and volume change trends. This Year-3 Beach Stability Assessment includes an assessment of volume change trends, an update of shoreline change trends, an update to the projected shoreline changes into the future over a 10-, 20-, and 30-year period, and a final vulnerability analysis.

The stated goals of the Assessment are 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. The three-year study aims to assess trends and provide a foundation for future coastal management in the County through data collection and beach analyses.

This 2022 (Year-3) report serves to provide an update to the County on the 3-year study in terms of data obtained through Year 3. 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 a final vulnerability analysis. The conclusions provided in this Year-3 report are based on data collected in Year-1, Year-2, and Year-3 of a 3-year study.

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 Beaches are 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 Beaches are 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 Beaches extend 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.

The data collection and analysis methodology are described in Sections 2.0 of the main report. Section 3.0 presents a summary of grain size analysis conducted in Year-1 of the study (2020) and a large clast analysis conducted in Year-3 of the study (2022). Section 4.0 provides the results of the shoreline change analysis and the projections of shoreline change rates over a 10-, 20-, and 30-year time horizon. Section 5.0 provides the results of the volumetric change analysis. Section 6.0 provides results of the analysis of the nearshore bathymetric data collected in 2020 and 2022 including the analysis of offshore features that may be impacting sediment transport along the project. Section 7.0 provides an update to the beach vulnerability analysis conducted in Year-1 (2020). This analysis employed the numerical model SBEACH to simulate storm impacts to the Assessment Area based on 2022 conditions. Sections 8.0 and 9.0 provide conclusions drawn from the results of the study and recommendations.

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. Seven (7) data sets collected between 2009 and 2022 were analyzed to determine shoreline change rates over the past 13 years. These long-term rates were determined using a linear regression method that considers each of the seven data sets available over this 13-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 no impacts based on projected shoreline change rates over a 30-year horizon in the Carova Section nor the Pine Island Section. Five (5) oceanfront houses within the Reserve/Refuge Section were shown to be impacted over the 30-year horizon. Four (4) of the houses are located seaward of Sandfiddler Road along an approximately 4,000-foot portion of the oceanfront south of Canary Ln. (between stations C-040 and C-044) and the fifth is located just north of the Currituck Banks Estuarine Reserve between stations C-050 and C-051. The four houses located between station C-040 and C-044 were all shown to be impacted over the 20-year horizon. The two (2) houses between stations C-041 and C-042 were shown to be impacted over the 10-year projection. While the number of houses shown to be impacted in this section may not be significant, the retreat of the shoreline may create pinch points for traffic transiting north and south through these areas as the homes end up out on the dry sand beach.

The greatest number of impacts from projected shoreline changes were observed within the Corolla Section of the Project Area. In total, 158 houses were shown to be impacted over the 30-year horizon throughout the Corolla Section. These houses are all located between the Horse Gate and Wave Arch in the Ocean Lake community (C-080). Of the 158 houses shown to be impacted over the 30-year horizon, 66 of the houses were shown to be impacted over the 20-year horizon and 11 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. Along this approximately 1.3 mile stretch of beach, nearly every ocean front house was shown to be impacted over the 30-year horizon. Approximately 40% of the oceanfront houses along this section were shown to be impacted over the 20-year horizon and all 11 of the houses in the Corolla Section shown to be impacted over the 10-year horizon are along this stretch of beach. Furthermore, portions of the road along both Atlantic Avenue and Sandcastle Drive are 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 1.9 miles of Lighthouse Drive, approximately 30% of the oceanfront structures were shown to be impacted over the 30-year horizon, and only one of those was shown to be impacted over the 20-year horizon. Along the southern 1.0 mile of Lighthouse Drive, over 95% of the oceanfront structures were shown to be impacted over the 30-year horizon and approximately 55% were shown to be impacted over the 20-year horizon. The southernmost cluster of oceanfront houses within the Corolla Section shown to be impacted over the various time horizons, are located in the Crown Point community (between station C-085 and C-086) and the Ocean Lake community (between station C-087 and C-088). Four (4) of the oceanfront houses in the Crown Point community were shown to be impacted over the 30-year time horizon, while all eight (8) of the oceanfront houses along Tide Arch within the Ocean Lake community were also shown to be impacted over the 30-year time horizon.

Volume Changes:

A complete volumteric analyses was completed as part of the Year-3 Assessment through a comparison of Year-1 (May 2020), Year-2 (June 2021), and Year-3 (May 2022) data. Volume change rates measured between 2020 and 2022 indicates an overall accretional trend during the 2-year period. The average volumetric change rate along the entire Assessment Area was +5.5 cy/ft./yr. between 2020 and 2022; this equates to a net volume gain of 1,314,600 cy. The majority of the volumetric gains were measured north of the Horse Gate along the Carova and Reserve/Refuge Sections. In those two sections a net positive volume change of approximately 1,176,000 cy was measured between May 2020 and May 2022. South of the Horse Gate, a net positive change of approximately 138,700 cy was measured between 2020 and 2022. A positive volumetric change of approximately 363,500 cy was measured along the Corolla Section during this time period; whereas along the Pine Island Section, a negative volumetric change of approximately 224,800 cy was measured.

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 Carova, Reserve/Refuge, and Corolla Sections experienced positive volume changes while the Pine Island Section experience negative volumetric change. A net negative volume change was observed in the portion of the beach that includes the primary frontal dune, the dry sand beach, and the subaerial beach out to a depth of -6 ft. NAVD88. 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 May 2022. 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 five (times) greater than the negative 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 May 2022. More specifically, south of the Horse Gate in the Corolla and Pine Island Sections, a net positive volumetric change of approximately 1,138,300 cy was measured between May 2020 and May 2022 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 (May 2020 to May 2022) differed significantly from the wave climate during the study period. 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 2022 monitoring period, suggests that the positive volumetric changes experienced during the May 2020 to May 2022 monitoring period along the Currituck County beaches may be explained as a 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.

Beach Vulnerability:

The Vulnerability Analysis conducted through the use of the SBEACH model, coupled with the results of the shoreline projections provides useful information to determine future vulnerability of public and private development along the County's oceanfront beach. In total, 43 oceanfront homes were determined to be vulnerable from a storm similar in characteristics to Hurricane Isabel, which impacted the County in 2003. These houses were spread throughout the Project Area, and primarily located in areas where shoreline change projections also indicated potential impacts.

No houses were identified as impacted by the SBEACH vulnerability analysis or the projected shorelines over the 30-year horizon in the Carova Section of the Project Area. In the Reserve/Refuge Section, four (4) houses located seaward of Sandfiddler Road along an approximately 4,000-foot portion of the oceanfront south of Canary Lane (stations C-040 to C-044) were identified as vulnerable through both the SBEACH analysis and projection of shoreline change rates. A fifth house, which is the southernmost oceanfront house located north of the Currituck Banks Estuarine Reserve (between station C-050 and C-051), was shown to be impacted by the shoreline change projections over the 30-year horizon; however, was not identified as vulnerable through the SBEACH analysis. These houses could impact traffic through this section of beach should a storm or continued shoreline recession result in the homes being situated on the dry or wet sand beach.

Thirty-nine (39) homes were identified as impacted by the SBEACH Vulnerability analysis south of the Horse Gate in the Corolla and Pine Island Sections of the Project Area. The majority (34) are located within the Corolla Section. The largest stretch of impacted homes is located along an approximate 1.0-mile portion of the Corolla Section between the northern end of Atlantic Avenue and Corolla Village Road. Twenty-nine (29) oceanfront houses identified as vulnerable and several other oceanfront pools are located within this portion of the Project Area. This is generally the same stretch of beach in which projected shoreline recession impacts were indicated at both the 10- and 20- year horizon between the Horse Gate and Corolla Village Road.

The vulnerability analysis conducted as part of the Year-1 (2020) assessment indicated several houses within the Whalehead Beach community were vulnerable. The updated analysis conducted using 2022 conditions and the updated wave data do not indicate any of the oceanfront houses along the Whalehead Beach Community along Lighthouse Drive as vulnerable based on the established criteria. That said, a significant number of oceanfront homes were shown to have been impacted over the 20-year and 30-year horizons. Furthermore, the proximity of the impact line to the oceanfront pools along this portion of the Assessment Area suggest that several pools may be vulnerable based on the established storm vulnerability criteria.

All nine (9) oceanfront homes located along the Spindrift community were determined to be vulnerable based on the established criteria. The Spindrift Community was split between the Pine

Island and Corolla Section. While none of these 9 homes were shown to be impacted by projected shoreline recession between the 10- and 30-year horizons, the lack of suggested impact due to shoreline retreat is primarily a factor of the location of the +4.0 ft. NAVD88 contour in May 2022.

Although no projected shoreline recession impacts were identified along the Pine Island Section south of Yaupon Lane, one oceanfront home was identified as vulnerable through the SBEACH analysis. That home is located near the north end of Salt House Road (station C-117). The volumetric change measured at C-117 was more than twice as high as the volume change measured along any other profile in the Project Area. The significant volumetric loss appears to be due to the formation of a deep trough.

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 3-year Beach Monitoring and Beach Assessment (2020 through 2022) has 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, CPE recommends the County continue to monitor on an annual basis.

   The Corolla and Pine Island Sections of the Assessment Area should be monitored on an annual basis. This recommendation is based on several factors. The first is that the majority of the houses indicated as vulnerable through both the SBEACH analysis and the projected shoreline change rates, are located south of the Horse Gate. Secondly, 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 is important to track whether the beach is still in a state of recovery or whether it reverts to a trend of volume loss. A third reason to monitor the area south of the Horse Gate on an annual basis is 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 will 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, monitoring could be conducted every other year. This recommendation is 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.

   If the County decides to continue with a monitoring program, the same profiles established through this assessment 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 governments 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 recommends 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.

3. <u>Coordinate with Dare County on Regional Sand Resource Investigation:</u> Dare County recently commissioned a two-year regional sand investigation study to locate sand for future beach nourishment projects. The investigation is slated to occur over a two year period in 2023 and 2024. 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 should coordinate with Dare County on this regional sand resource investigation.

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CURRITUCK COUNTY, NORTH CAROLINA

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1 INTRODUCTION

Coastal Protection Engineering of North Carolina, Inc. (CPE) was contracted by Currituck County to perform three years of beach monitoring and vulnerability assessments (2020-2022) to investigate long-term and short-term shoreline and volumetric changes occurring along Currituck's oceanfront beaches. The scope of work was developed through coordination with County staff and includes services to be provided over the course of a three-year study period. In that regard, the scope includes annual beach monitoring in Year-1, Year-2, and Year-3, an initial beach stability assessment to be completed following Year-1 surveys, and annual reports to be provided in Year-2 and Year-3 updating the County on shoreline and volume change trends. This Year-3 Beach Stability Assessment is the culmination of the analysis completed by CPE since initiating the study in 2020. This report includes an update of volume change and shoreline change trends, updated projections of shoreline changes into the future over a 10-, 20-, and 30-year period and an updated vulnerability analysis. Furthermore, this report summarizes sediment analyses conducted by CPE as part of the 3-year study including grain size analysis conducted in 2020 (CPE, 2020) and large sediment clast analysis conducted in 2022.

The goals of the beach monitoring and beach stability assessment are 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. The three-year study aimed to assess trends and provide a foundation for future coastal management in the County through data collection and beach analyses.

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), APTIM Environmental & Infrastructure (APTIM E&I), 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. As described in the Year-1 report, 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.

Two historic inlets, namely Old Currituck and New Currituck, are believed to have been opened in the vicinity of Carova. Old Currituck Inlet is believed to have been opened in 1585 and closed in 1731 (Mallinson et al., 2008). The Old Currituck Inlet is believed to have been located between stations C-010 and C-017. This inlet has opened a couple of times in recent history due to several large storms. The two most recent openings happened in a September 1933 hurricane and the 1962 "Ash Wednesday" storm. The New Currituck Inlet is believed to have been opened in 1713 due to a violent storm and closed in 1731. The New Currituck Inlet is believed to have been located between stations C-032 and C-040. A third historic inlet, referred to as Musketo Inlet, is believed to have existed in the 17th century and closed around 1682. This Inlet is thought to have been closer to where the present Horse Gate is located somewhere between stations C-040 and C-053.

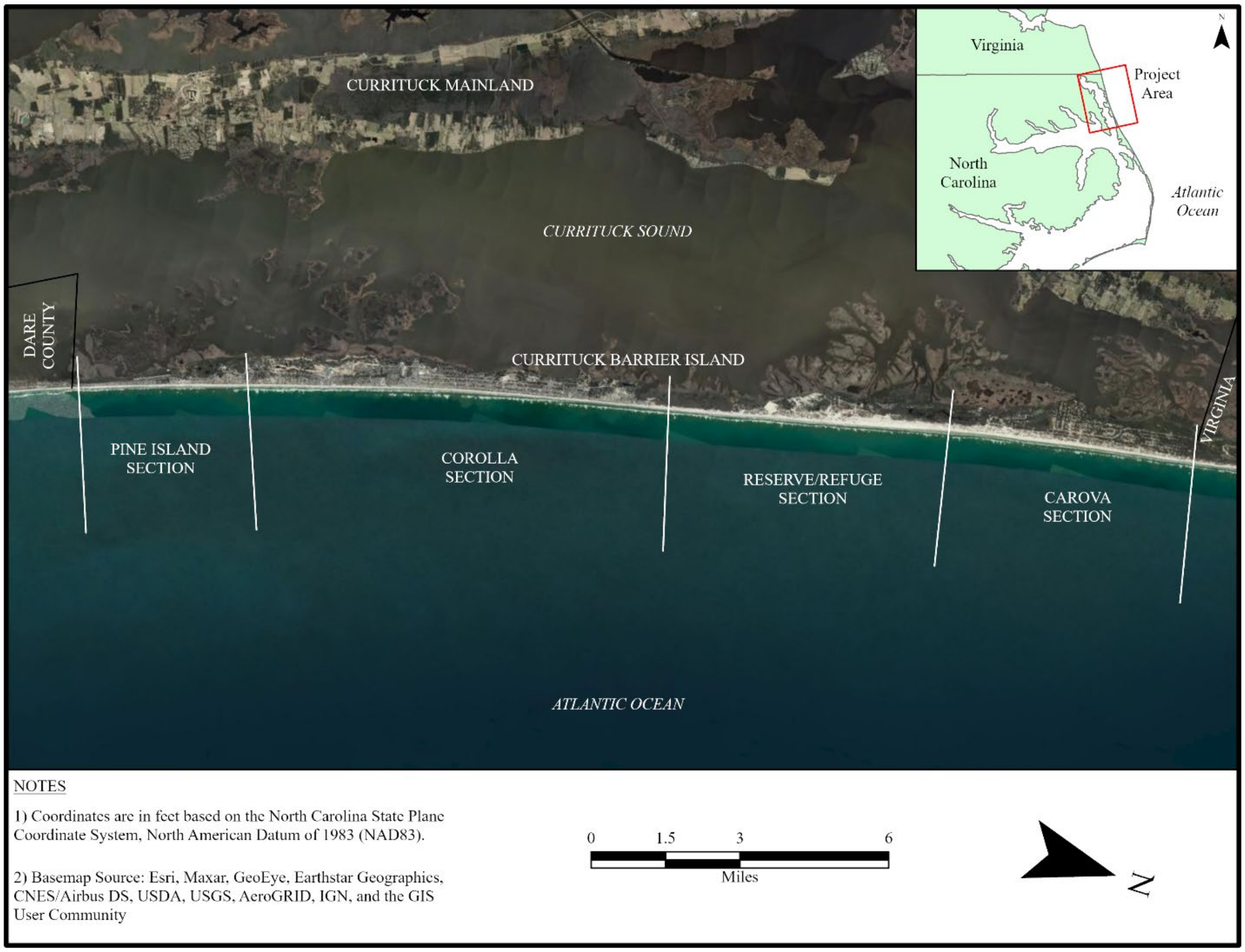

Figure 1. Currituck Project Location Map

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 several different existing data sets as well as beach profile data acquired by CPE as part of the County's beach monitoring study. See Table 2 below for dates and description of the datasets that were used.

Table 2. Dataset Descriptions

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

The data sets used include:

- The North Carolina Division of Coastal Management (NC DCM) long-term (approximately 50 years) average annual shoreline change rates;
- 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).

Throughout this report, elevations provided are referenced to the North American Vertical Datum (NAVD88). Table 3 provides tidal datums used in this study. Table 4 and Table 5 are referenced to the North Carolina State Plane coordinate system in feet NAD83 and the profile azimuth refers to degrees referenced to true north. The beach profiles are shown visually along the oceanfront in Figure 2 through Figure 9.

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

Table 4. Currituck County Transects List

Station	Easting (ft)	Northing (ft)	Azimuth (°)	Station	Easting (ft)	Northing (ft)	Azimuth (°)
C-001	2919204.1	1033891.1	79	C-031	2924973.6	1004209.6	79
C-002	2919457.8	1032585.8	79	C-032	2925164.4	1003228.0	79
C-003	2919630.9	1031695.2	79	C-033	2925456.8	1002271.7	75
C-004	2919858.4	1030524.9	79	C-034	2925749.1	1001315.4	75
C-005	2920012.6	1029731.9	79	C-035	2926041.5	1000359.0	75
C-006	2920203.4	1028750.3	79	C-036	2926333.9	999402.8	75
C-007	2920394.2	1027768.7	79	C-037	2926606.5	998511.0	75
C-008	2920540.9	1027013.7	79	C-038	2926918.6	997490.1	75
C-009	2920827.6	1025538.9	79	C-039	2927216.6	996515.5	75
C-010	2920953.7	1024890.2	79	C-040	2927541.4	995453.2	75
C-011	2921175.8	1023747.7	79	C-041	2927795.7	994621.2	75
C-012	2921368.9	1022753.9	79	C-042	2928088.1	993664.9	75
C-013	2921520.9	1021972.4	79	C-043	2928395.9	992658.1	75
C-014	2921746.1	1020813.5	79	C-044	2928699.6	991664.7	75
C-015	2921927.1	1019882.2	79	C-045	2928965.2	990796.0	75
C-016	2922111.5	1018934.0	79	C-046	2929257.6	989839.7	75
C-017	2922307.4	1017926.0	79	C-047	2929560.3	988849.5	75
C-018	2922493.1	1016970.8	79	C-048	2929864.5	987854.5	75
C-019	2922668.1	1016070.2	79	C-049	2930106.2	987063.9	75
C-020	2922878.7	1014986.7	79	C-050	2930401.3	986098.7	75
C-021	2923056.5	1014072.0	79	C-051	2930719.5	985058.2	75
C-022	2923256.3	1013044.2	79	C-052	2931011.8	984101.9	75
C-023	2923449.6	1012049.7	79	C-053	2931304.2	983145.6	75
C-024	2923637.9	1011081.0	79	C-054	2931596.6	982189.3	75
C-025	2923809.4	1010199.0	79	C-055	2931888.9	981233.0	75
C-026	2924019.6	1009117.7	79	C-056	2932181.3	980276.7	75
C-027	2924210.4	1008136.1	79	C-057	2932473.7	979320.3	75
C-028	2924401.2	1007154.5	79	C-058	2932766.1	978364.0	75
C-029	2924592.0	1006172.9	79	C-059	2933022.9	977523.9	75
C-030	2924782.8	1005191.2	79	C-060	2933302.1	976430.5	77

Table 5. Currituck County Transects List (continued)

Station	Easting (ft)	Northing (ft)	Azimuth (°)	Station	Easting (ft)	Northing (ft)	Azimuth (°)
C-061	2933537.1	975487.8	77	C-091	2941405.3	946526.2	73
C-062	2933778.9	974518.0	77	C-092	2941697.7	945569.9	73
C-063	2934017.0	973563.3	77	C-093	2941985.2	944629.4	73
C-064	2934256.0	972604.6	77	C-094	2942282.4	943657.3	73
C-065	2934528.4	971512.0	77	C-095	2942574.8	942700.9	73
C-066	2934763.9	970567.6	77	C-096	2942854.8	941785.1	73
C-067	2934976.5	969714.8	77	C-097	2943159.6	940788.3	70
C-068	2935215.9	968754.5	77	C-098	2943506.6	939850.5	70
C-069	2935477.7	967704.8	77	C-099	2943853.5	938912.6	70
C-070	2935728.5	966698.8	77	C-100	2944200.5	937974.7	70
C-071	2935950.4	965808.9	77	C-101	2944547.5	937036.8	70
C-072	2936198.2	964814.8	77	C-102	2944894.5	936098.9	70
C-073	2936453.0	963793.0	77	C-103	2945241.5	935161.0	70
C-074	2936687.3	962853.3	77	C-104	2945588.5	934223.2	70
C-075	2936929.2	961883.0	77	C-105	2945935.5	933285.3	70
C-076	2937171.1	960912.7	77	C-106	2946282.5	932347.4	70
C-077	2937389.8	960035.7	77	C-107	2946629.5	931409.5	70
C-078	2937660.1	958951.4	77	C-108	2946976.5	930471.6	70
C-079	2937909.0	957962.1	77	C-109	2947323.5	929533.7	70
C-080	2938195.4	957025.3	73	C-110	2947670.5	928595.9	70
C-081	2938490.1	956061.5	73	C-111	2948017.4	927658.0	70
C-082	2938785.1	955096.6	73	C-112	2948364.4	926720.1	70
C-083	2939058.6	954201.9	73	C-113	2948711.4	925782.2	70
C-084	2939342.6	953273.0	73	C-114	2949058.4	924844.3	70
C-085	2939651.1	952264.0	73	C-115	2949405.4	923906.5	70
C-086	2939953.0	951276.5	73	C-116	2949752.4	922968.6	70
C-087	2940235.8	950351.4	73	C-117	2950099.4	922030.7	70
C-088	2940530.9	949386.4	73	C-118	2950446.4	921092.8	70
C-089	2940820.6	948438.8	73	C-119	2950795.5	920149.2	70
C-090	2941113.0	947482.5	73	C-120	2951140.4	919217.0	70

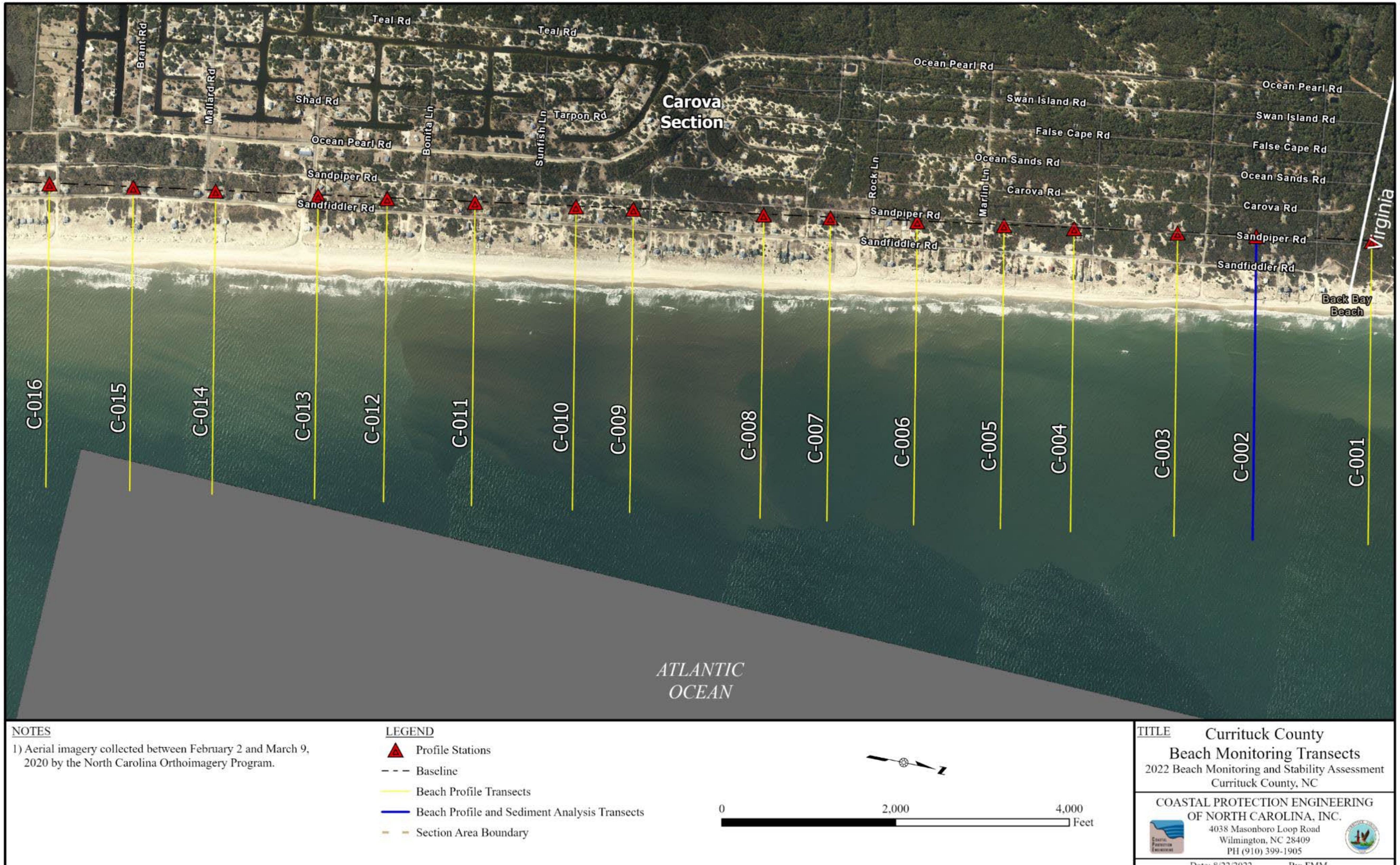

Figure 2. Monitoring Transects Map Station C-001 to C-016

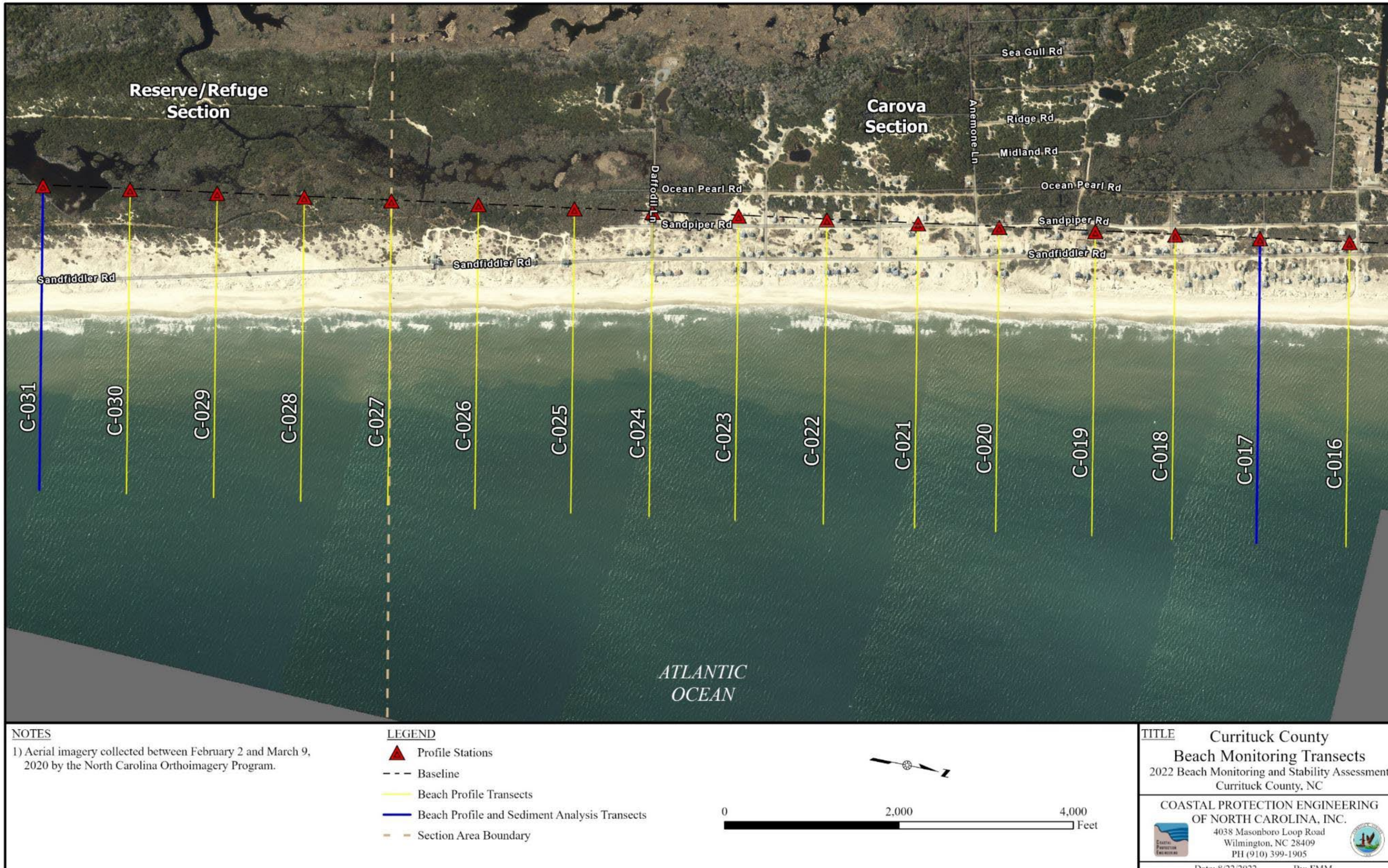

Figure 3. Monitoring Transects Map Station C-016 to C-031

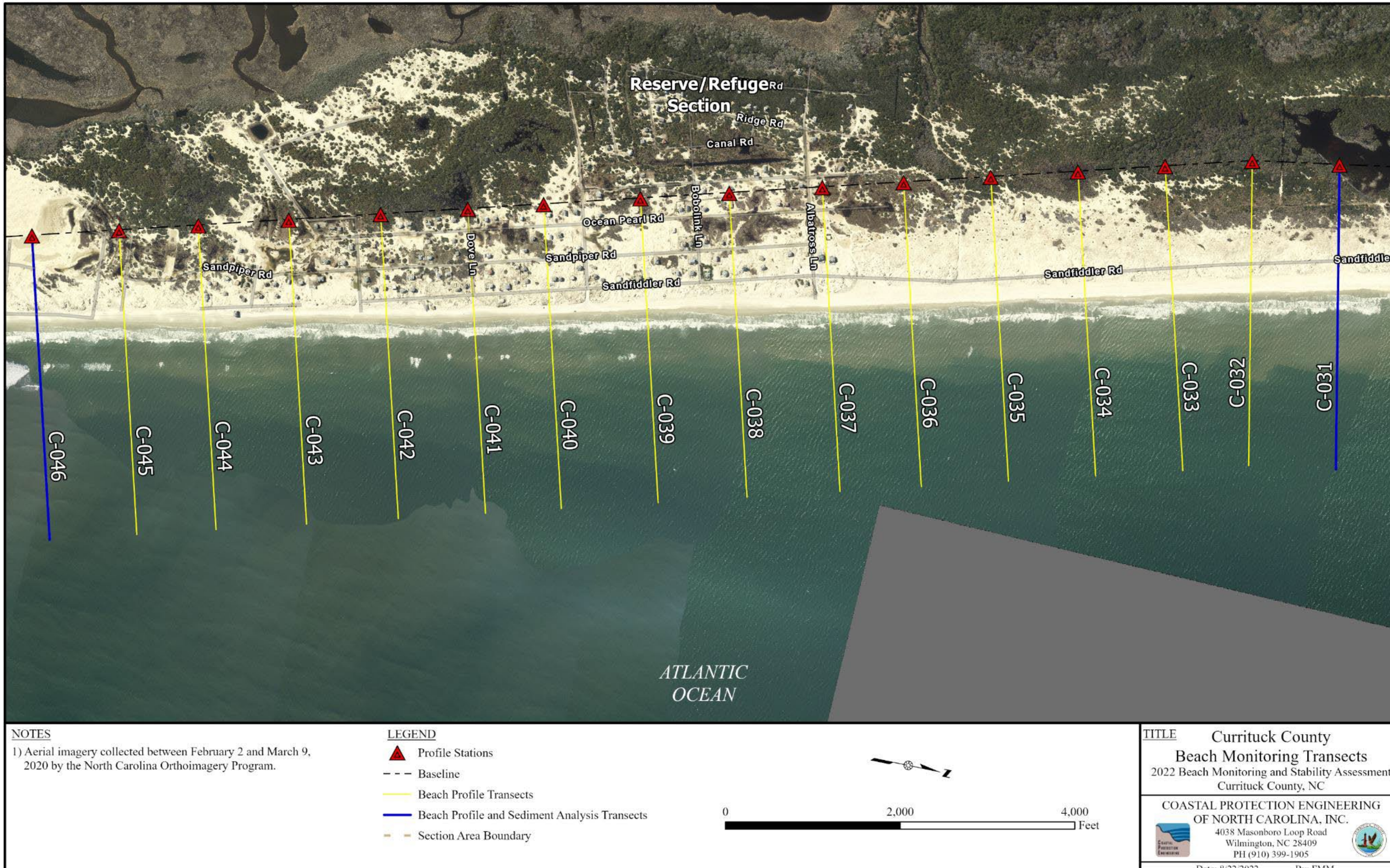

Figure 4. Monitoring Transects Map Station C-031 to C-046

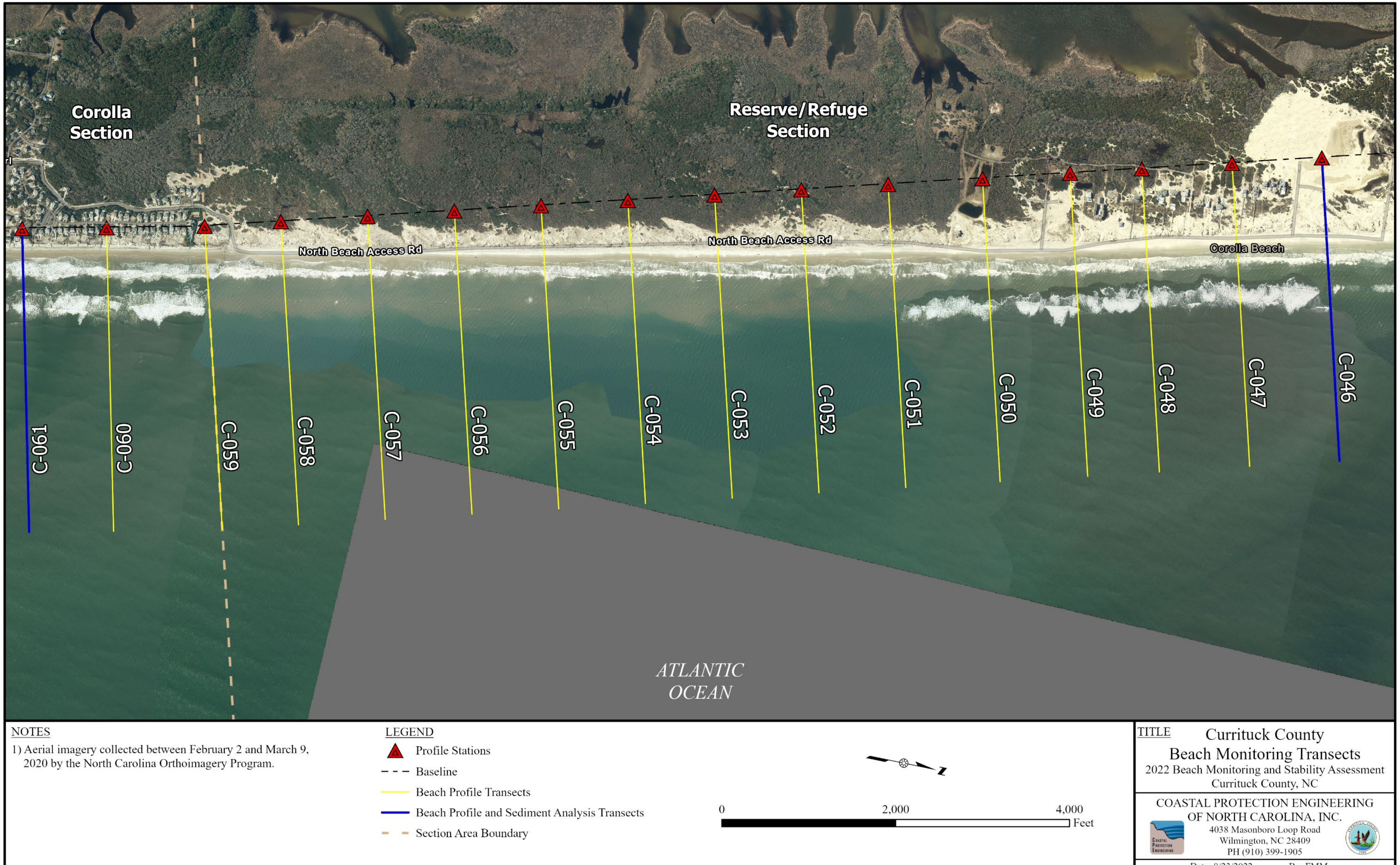

Figure 5. Monitoring Transects Map Station C-046 to C-061

Figure 6. Monitoring Transects Map Station C-061 to C-076

Figure 7. Monitoring Transects Map Station C-076 to C-091

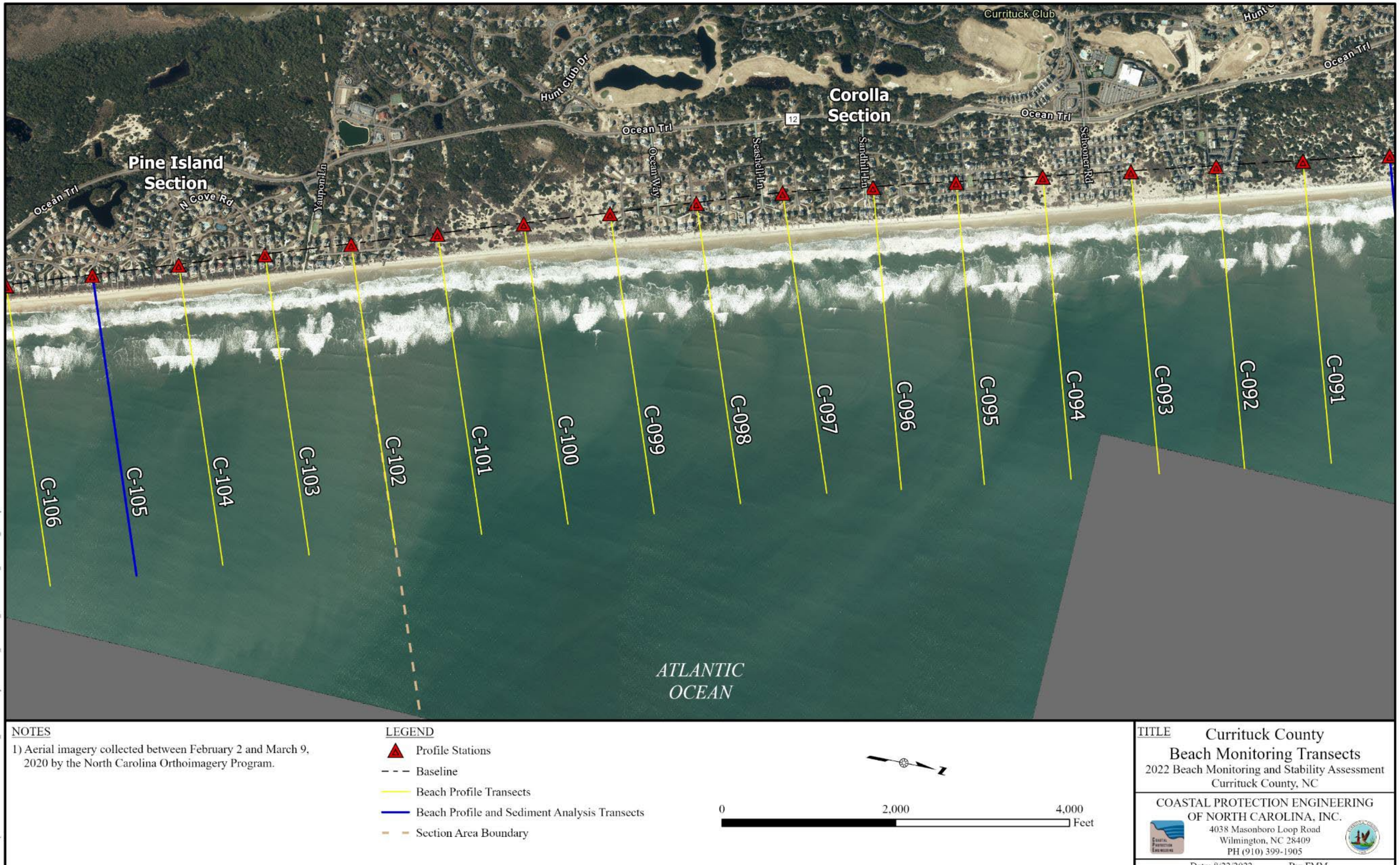

Figure 8. Monitoring Transects Map Station C-091 to C-106

Figure 9. 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 were used as a reference to the values that CPE computed.

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. 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 6 shows a comparison between the CSE referenced stations and the names of the stations used in the County Study (C-097 through C-120). Additional information pertaining to the CSE survey methodology is available in the 2020 Beach Monitoring and Beach Stability Assessment (CPE, 2020).

Table 6. CPE and CSE Transects 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, and May 2022. These surveys included 120 profiles (station C-001 to station C-120) along the beachfront of Currituck County. The CPE survey 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 Data Acquisition Report: 2022 Currituck County Beach Monitoring and Beach Stability Study. The acquisition reports for 2020 and 2021 are included as appendices to the 2020 and 2021 beach assessment reports (CPE, 2020 and CPE, 2021a).

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 SBG Ekinox-A motion sensor 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 Odom DigiBar PRO sound velocity probe provides a fast and accurate sounder calibration as compared to the traditional bar-check. 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.

2.5 CPE Shore-Parallel Bathymetric Data

The standard method used to monitor a beach is to conduct repeated beach profile surveys and track the changes in volume of sand along the beach and the shoreline position. The beach profile data are used to calculate volume changes using the average end area method which assumes that bathymetric contours running parallel to shore between the profiles are relatively parallel to the shoreline. While this is a safe assumption along many beaches, a number of studies conducted offshore of the Outer Banks over the past 20 years have identified deep depressions or troughs and shore oblique sandbars. Detailed analyses conducted along the Dare County Towns of Kitty Hawk and Kill Devil Hills, have indicated that some of the apparent loss of material measured along the beaches was due to the inability of the 1,000-foot spacing between profile lines to capture volume changes due to the proximity of the survey lines to the mobile nearshore depressions (APTIM, 2019a and APTIM, 2019b). Based on detailed analyses comparing beach profile surveys and more-dense shore-parallel offshore bathymetric surveys, it was concluded that using a combination of these methods provided a more accurate volume change calculation.

A study commissioned by The Pine Island Property Owner's Association (PIPOA) included beach profile surveys at 500-foot spacing, in 2015 and 2017, along the extent of their community (CSE, 2018). During that study, evidence was presented that similar features may be present offshore of the southern portion of their community.

As part of the Year-3 data acquisition, a shore-parallel bathymetric survey was conducted along the entire Project Area. The total length of the survey area was approximately 119,500 ft. (approximately 22.6 miles). Survey data were collected from approximately the -12 ft. contour out to approximately 3,000 ft. offshore. Survey lines were laid out to run parallel to shore and spaced approximately 200 ft. apart. Data were post processed and used to generate a series of bathymetric charts that are included in Appendix A - Data Acquisition Report: 2022 Currituck County Beach Monitoring and Beach Stability Study. This same survey was performed as a part of the Year-1 data acquisition and bathymetric charts associated with that survey are included in Appendix A of the Data Acquisition Report: 2020 Currituck County Beach Monitoring and Beach Stability Study (CPE, 2020). An analysis of the bathymetric surfaces developed from the Year-1 and Year-3 survey data can be found in Section 6.0 Nearshore Bathymetric Analysis.

3 BEACH SEDIMENT ANALYSES

3.1 2020 Sediment Analysis

The stability of a beach is a factor of many different variables including wave climate, sediment input into the littoral system, proximity to tidal inlets, presence/absence of coastal structures, and the grain size characteristics of the beach sediments. Grain size distribution, mean grain size, and mineral composition can all contribute to the slope of the beach, and the way in which a beach responds to storm conditions. It is also well established that when beach nourishment is required, the suitability of a sand source for beach nourishment is directly linked to the characteristics of the recipient beach.

As part of this analysis, CPE collected representative sediment samples in May 2020 along nine (9) evenly spaced lines throughout the Assessment Area to determine grain size distribution, mean grain size, mineralogy, and color. The sediment characteristic data were used both in the setup of the storm vulnerability model described in Section 7.0 and to evaluate factors that may contribute to variable beach slopes throughout the Project Area. The results of the grain size analysis have also been archived in this report, as this type of data will be necessary to determine sediment compatibility if the County were to implement a program of sand placement on the County beaches. The transects along which sediment samples were collected are shown in Figure 2 through Figure 9.

The State of North Carolina has established the importance of accurately characterizing recipient beach sediments prior to any beach nourishment activities. The quality of material that can be placed on North Carolina's beaches is governed by Rule 15A NCAC 07H .0312. As such, CPE designed the sampling regiment for each profile to adhere to this Rule. It is necessary to note however, that although data collected as part of this study adheres to the State Rule, supplemental data between sampling transects may be required in the future if the County were to pursue beach nourishment. Furthermore, carbonate testing of the beach sediments may also be necessary in the future.

CPE collected thirteen (13) samples in May 2020 from specifically defined locations along each of the nine (9) beach profiles indicated by the dark blue transect lines in Figure 2 through Figure 9, for a total of 117 samples. One surface sediment sample was taken from each of the following morphodynamic zones where present: frontal dune, frontal dune toe, mid berm, mean high water (MHW), mid tide (MT), mean low water (MLW), trough, bar crest, and at even depth increments from the bar crest out to the 20-foot depth contour. Samples were collected at 12-foot, 14-foot, 16-foot, 18-foot, and 20-foot contours. Figure 10 shows a cross section diagram illustrating the locations along each profile where samples were collected.

The sediment samples collected along each profile were individually analyzed to determine color and grain size distribution. During sieve analysis, the wet, dry, and washed Munsell colors were noted. Sieve analysis of the sediment samples was performed in accordance with the American Society for Testing and Materials (ASTM) Standard Methods Designation D 422-63 for particle size analysis of soils. This method covers the quantitative determination of the distribution of sand size particles. For sediment finer than the No. 230 sieve (4.0 phi) the ASTM Standard Test Method, Designation D1140-00 was followed. Mechanical sieving was accomplished using calibrated sieves with a gradation of half phi intervals. Table 7 shows those sieves used in the analysis. Additional sieves representing key ASTM sediment classification boundaries were included to meet North Carolina technical standards for beach fill projects (15A NCAC 07H .0312 (d)). Weights retained on each sieve were recorded cumulatively. Grain size results were entered into the gINT® software program, which computes the mean and median grain size, sorting, silt/clay percentages for each sample using the moment method. Upon completion of individual sediment analysis, composite sediment characteristics were calculated for each profile. Granularmetric reports, grain size distribution curves, and composite tables were compiled for each sample and are included in Appendix B. The summary of the results are shown in Table 8.

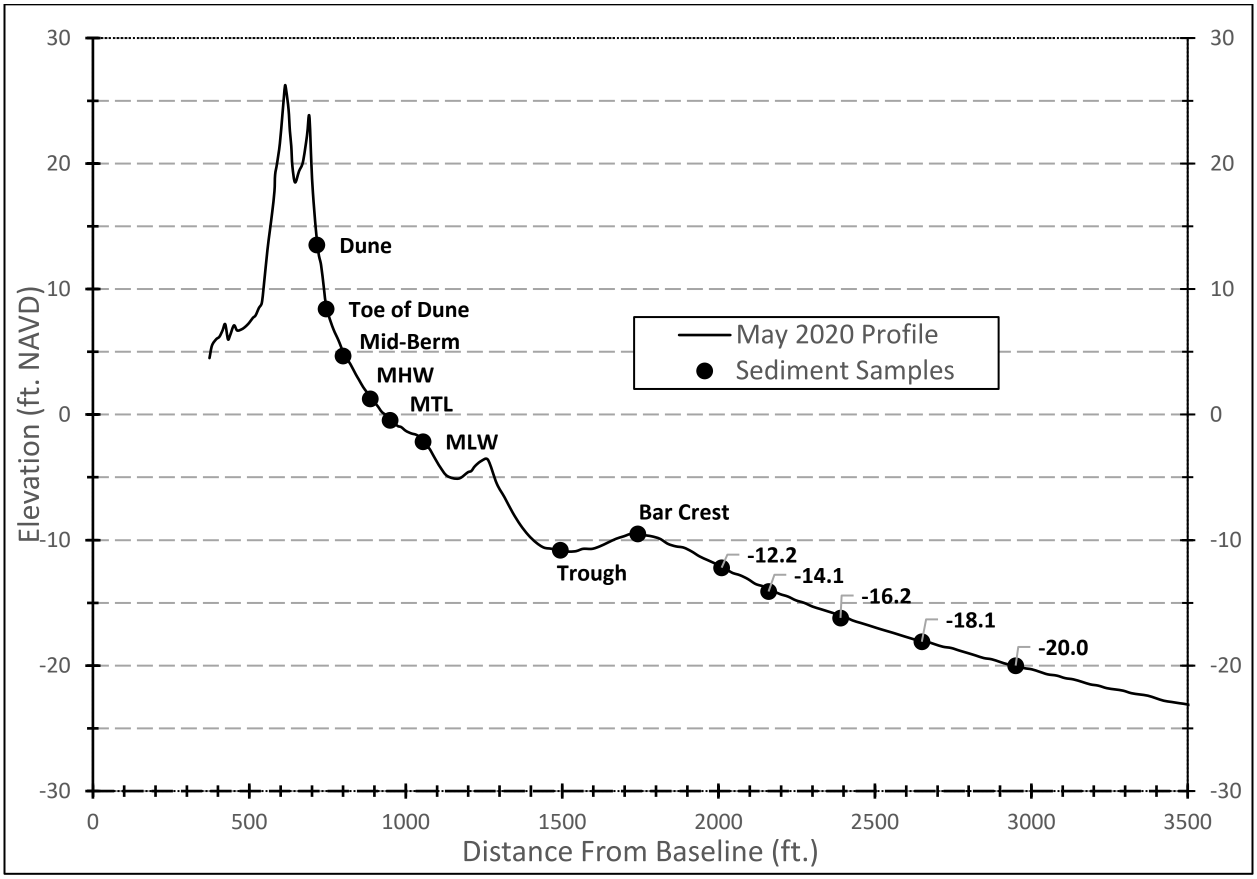

Figure 10. Representative cross section showing the location of samples collected along beach profile at C-017 to characterize existing beach.

The overall average mean grain size for the entire Assessment Area was 0.21 mm. The southern half of the project had a slightly higher mean grain size value with the Corolla Section and Pine Island Section having an average mean grain size of 0.21 mm and 0.26 mm, respectively. The northern half had smaller mean grain sizes with the Carova Section and Refuge/Reserve Section having a mean grain size of 0.20 mm and 0.19 mm, respectively. A closer examination of Table 8 shows a markedly greater mean grain size for the four (4) southern-most profiles sampled. These profiles were collected between station C-075, located approximately 550 feet south of Perch St. in Whalehead Beach, to station C-120, located at the southern County boundary. The average of the mean grain size values for these 4 profiles is 0.24 mm.

Table 7. Sieve Sizes used for Grain Size Analysis

Classification	Sieve Size (number)	Sieve Size (phi)	Sieve Size (mm)
	3/4"	**-4.25**	**19**
	5/8"	-4	16
gravel	7/16"	-3.5	11.2
	5/16"	-3	8
	3 1/2"	-2.5	5.6
	4	**-2.25**	**4.75**
	5	-2	4
granular	7	-1.5	2.8
	10	-1	2
	14	-0.5	1.4
	18	**0**	**1**
	25	0.5	0.71
	35	**1**	**0.5**
	45	1.5	0.36
sand	***60***	**2**	**0.25**
	80	**2.5**	**0.18**
	120	**3**	**0.13**
	170	3.5	0.09
	200	3.75	0.08
	230	**4**	**0.06**
fine	pan	-	-

* Classifications are Based on Percent Retained in each Sieve

Table 8. Sediment Analysis Summary

Sample Locations	Mean Grain Size[1] (mm)	Mean Grain Size[1] (phi)	Sorting[2] (phi)	Silt[2] (%)	Dry Munsell Color Value[3]
C-002 Composite	0.21	2.22	0.99	1.30	6
C-017 Composite	0.18	2.48	0.75	1.76	7
C-031 Composite	0.18	2.44	0.68	1.43	7
C-046 Composite	0.20	2.29	0.82	1.73	7
C-061 Composite	0.20	2.34	0.85	1.74	7
C-075 Composite	0.21	2.26	0.72	2.20	7
C-090 Composite	0.22	2.19	1.25	2.44	7
C-105 Composite	0.26	1.96	1.45	2.03	7
C-120 Composite	0.26	1.94	1.19	1.19	7
Carova	0.20	2.35	0.87	1.53	7
Refuge/Reserve	0.19	2.37	0.75	1.58	7
Corolla	0.21	2.26	0.94	2.13	7
Pine Island	0.26	1.95	1.32	1.61	7
Total Beach	0.21	2.24	0.97	1.76	7

(1) Sieve analyses were conducted on all sediment samples in accordance with American Society for Testing and Materials Standard Materials Designation D422-63 for particle size analysis of soils. Grain size data were entered into the gINT® software program, which computes the mean and median grain size, sorting, and silt/clay percentages for each sample using the moment method (Folk, 1974).

(2) Silt content is defined as the percentage of material finer than 0.0625 mm (F.A.C. 62 B-41.007).

(3) Dry sand colors were evaluated using the Munsell color system. The Munsell notation for color consists of separate notations for Hue (combination of red, yellow, green, blue, and purple colors), Value (lightness of the sand color) and Chroma.

The higher mean grain size is indicative of generally coarser grained sand comprising the beach from the dune out to a water depth of approximately 20 feet. Conversely, lower mean grain size indicates that the beach is composed of finer grain sand. In general, a higher mean grain size can result in steeper beach slope than may be observed along beaches with lower mean grain sizes. A detailed reviewing of the data included in Appendix B indicates that the primary variance in the mean grain size of samples resulting in the variation of composite grain sizes throughout the Project Area, occurs in the swash zone located between the mean high water (MHW) and mean low water (MLW) samples.

The variance in mean grain size observed along the southern portion of the profiles is likely geologically influenced as opposed to being influenced by beach management activities that have taken place along the Pine Island Section or along the Town of Duck. There appears to be a natural increase in mean grain size of the beach sand moving south which continues into Dare County and the Town of Duck. Samples collected from the beach in Duck in 2014 indicated a mean grain size of 0.28 and 0.36 along profiles sampled approximately 2,300 feet (station D-03) and 7,200 feet (station D-08) south of the County line, respectively (CPE-NC, 2015). The area nourished in 2017 in Duck, which is approximately 1.7 to 3.3 miles south of the southern County boundary, had a pre-project native mean grain size of 0.33 based on samples collected in 2014.

3.2 2022 Large Clasts Survey

On May 23, 2022, CPE conducted visual observation surveys for large sediments and shell material along the same nine (9) sampling transects on Currituck County's beaches where sediment sampling for grain size analysis was conducted in 2020 (Figure 2 to Figure 9). The surveys were conducted in accordance with the CRC's adopted amendments to the Rule 15A NCAC 07H .0312 – Technical Standards for Beach Fill Projects. Sediments greater than or equal to one inch in diameter and shell material greater than or equal to three inches in diameter were counted during the survey. Following the survey, an arithmetic mean was computed for both large sediments and shell material in each section.

At each transect, a 10,000 square foot area was staked out between the toe of dune and the mean tide level. Currituck County's mean tide level is -0.41 feet, referenced to NAVD88. The coordinates of the four (4) corners of each survey area were measured using a Real Time Kinematic (RTK) Global Positioning System (GPS) and are presented Appendix C. Horizontal data were collected in the North Carolina State Plane Coordinate System, North American Datum of 1983 (NAD83). Vertical data were collected in the North American Vertical Datum of 1988 (NAVD88). To ensure the accuracy of the RTK GPS equipment, horizontal and vertical positioning checks were conducted at the beginning and end of each day using a minimum of two 2nd order monuments from the National Geodetic Survey (NGS) in the Project Area. These monuments include ADRIATIC and RADIO. The RTK GPS was used within a virtual reference station (VRS) network to locate and confirm survey control for this project. The horizontal and vertical accuracy of control data meets the accuracy requirements as set forth in the Engineering and Design Hydrographic Surveying Manual (EM 1110-2-1003). Results from 2nd order control checks are presented in the Monument Information Report in Appendix C, which includes information such as northing, easting, monument elevation, inverse, horizontal and vertical root mean square error, location description, and photographs.

After the survey area was delineated, sediments greater than or equal to one inch and shell material greater than or equal to three inches in diameter were counted by a visual observation survey (Figure 11, Figure 12, and Figure 13). Upon completion of the surveys, an arithmetic mean was computed for both sediments and shells.

Figure 11. Photo of CPE Representatives Performing Large Clasts Survey

A total of 181 sediments greater than or equal to one inch and 843 shells greater than or equal to three inches were counted across all nine transects surveyed (C-002, C-017, C-031, C-046, C-061, C-075, C-090, C-105, C-120). Table 9 includes the values determined for each station as well as the arithmetic mean along the entire Assessment Area and each of the four Sections. The arithmetic mean for sediments (≥ 1 inch) and shell material (≥ 3 inches) along the nine (9) transects were 20.1 and 93.7, respectively. Values determined along the stations north of the Horse Gate (C-002, C-017, C-031, C-046) were relatively small and consistent suggesting few sediments greater than 1 inch and shell material greater than 3 inches. Values determined south of the Horse Gate in the Corolla Section indicated the greatest variability for both sediments greater than 1 inch and shell material greater than 3 inches. The relatively higher values determined for C-075 and C-090, heavily influenced the overall average for the entire Project Area. The values determined for the Pine Island Section were relatively consistent; however, the values for shell material were significantly higher than the values determined along the Carova and Reserve/Refuge Sections.

Figure 12. Photo of Large Clasts Survey Area

Figure 13. Photo of Shells and Rocks Counted at Sta. C-090

Table 9. Large Clasts Survey Results

Station	Number of Clasts	
	Sediments (≥ 1 inch)	Shell Material (≥ 3 inches)
C-002	0	14
C-017	0	5
C-031	3	5
C-046	1	6
C-061	24	62
C-075	138	546
C-090	7	132
C-105	3	38
C-120	5	35
Total Project Sum	**181**	**843**
Total Project Mean	**20.1**	**93.7**
Carova Mean	**0.0**	**9.5**
Reserve/Refuge Mean	**2.0**	**5.5**
Corolla Mean	**56.3**	**246.7**
Pine Island Mean	**4.0**	**36.5**

4 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 14 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.

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 15 shows an example of the State long-term average shoreline change rates. The Set Back Factor (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.

The average, maximum, and minimum SBF's for each of the 4 sections of the Assessment Area are provided in Table 10. 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. However, as noted by the State in their disclaimer, the shoreline position change rates are not predictive and do not reflect short-term erosion that can occur over shorter periods of time (i.e. decadal, seasonally or during storm events).

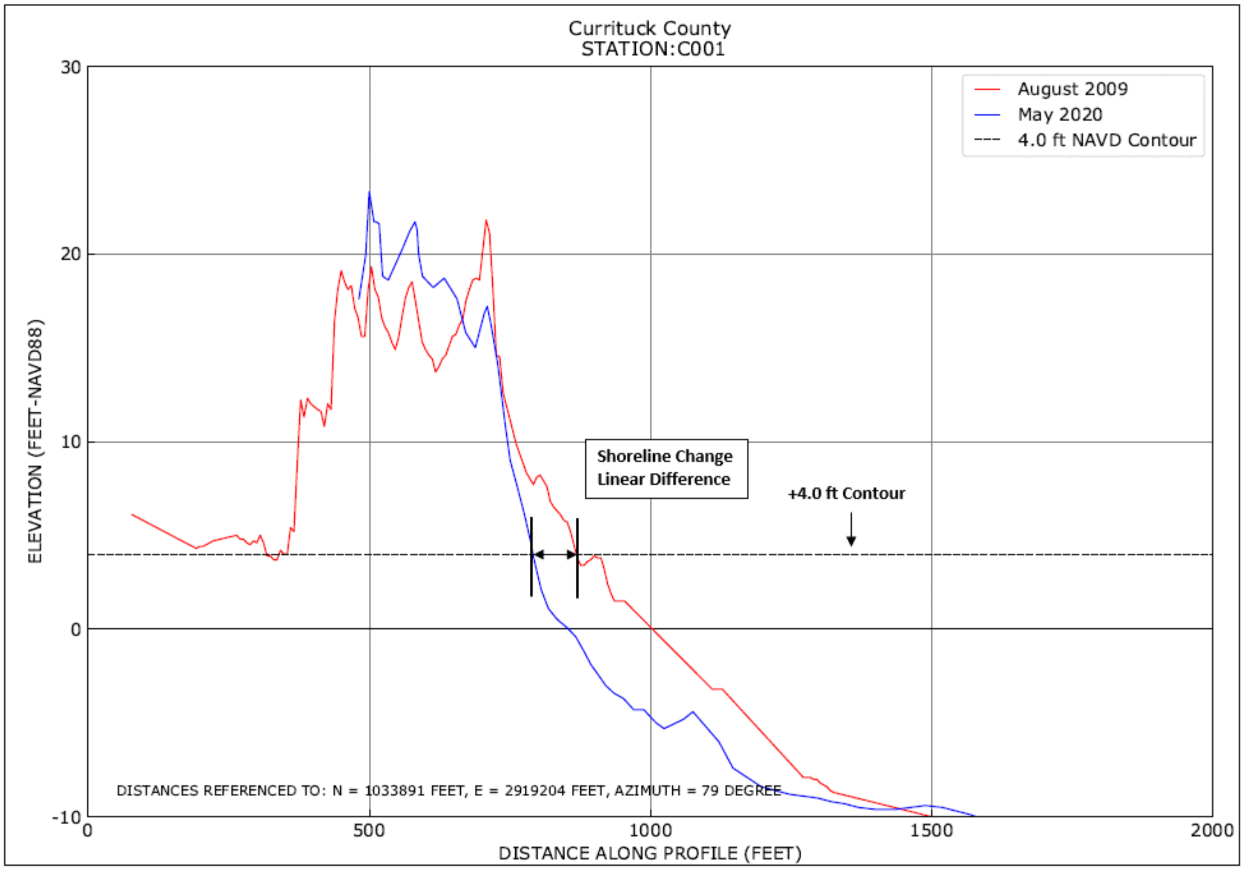

Figure 14. Beach Profile Cross Section Illustrating Shoreline Change.

Rates computed for the Currituck County Beach Monitoring and Beach Stability 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 16 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).

Using available beach profile and Lidar data, a shoreline change analysis was conducted to assess shoreline advance and recession along the study 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 Project 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.

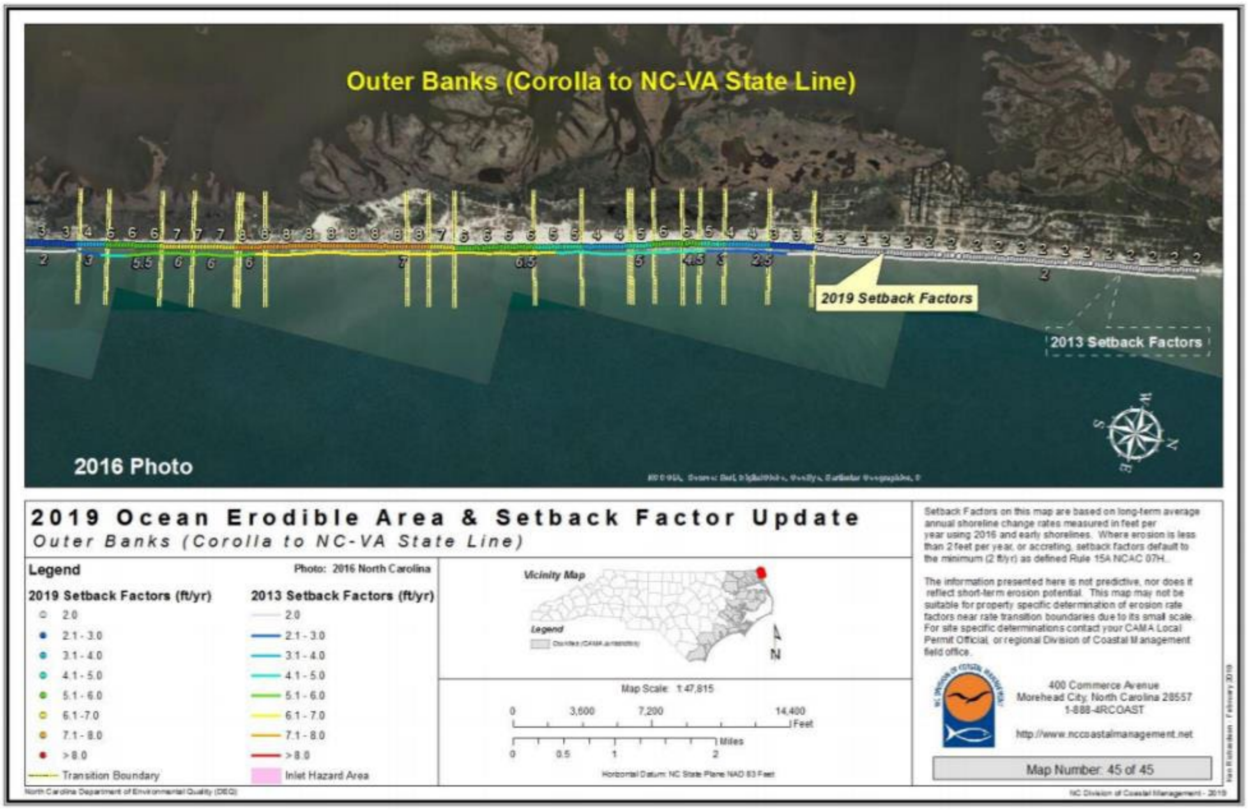

Figure 15. Map showing the SBF for Reserve/Refuge and Carova Sections of Currituck County

Table 10. 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

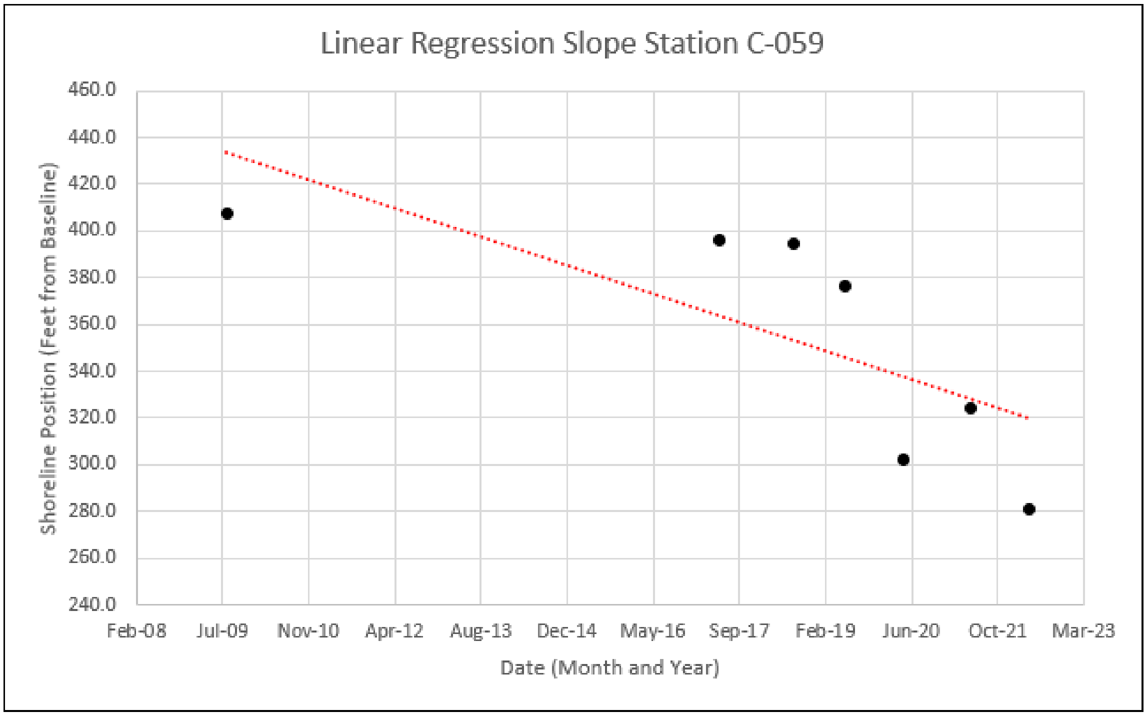

Figure 16. Example of Linear Regression Slope

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.

4.1 Long-Term Time Period (August 2009 to May 2022)

Data collected throughout the Assessment Area between August 2009 and May 2022 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 May 2022. These datasets included August 2009, June 2017, August 2018, June 2019, May 2020, June 2021, and May 2022. A summary of the average long-term shoreline change rates are provided in Table 11. The average long-term shoreline change rate along the entire Assessment Area (station C-001 to station C-120) between August 2009 and May 2022, was -3.3 ft./yr. The average long-term shoreline change rates in the Carova and Pine Island Sections were -0.3 ft./yr. and -0.4 ft./yr., respectively. An average long-term shoreline change rate of -5.1 ft./yr. was measured along both the Reserve/Refuge Section and the Corolla Section.

Table 11. Summary of Average Recent and Long-Term Shoreline Change Rates By Monitoring Section

Section	Long-Term Rate (ft./yr.) (Aug. 2009 to May 2022)	Recent Rate (ft./yr.) (May 2020 to May 2022)
Carova (C-001 to C-027)	-0.3	+20.7
Reserve/Refuge (C-027 to C-059)	-5.1	+12.9
Corolla (C-059 to C-102)	-5.1	-3.4
Pine Island (C-102 to C-120)	-0.4	+4.6
Total Assessment Area (C-001 to C-120)	**-3.3**	**+7.4**

Long-term and recent shoreline change rates at each station along the Assessment Area are provided in Table 12 and Table 13. Long-term shoreline change rates are shown graphically in Figure 17 and Figure 18. The recent shoreline change rates represent changes observed during the course of the Currituck County Beach Monitoring and Beach Stability Assessment conducted between 2020 and 2022. 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 Project Area, as well as an overall project average, are provided in Table 11.

While this report and the Year-2 report (CPE, 2021a) use a linear regression method to determine shoreline change, the Year-1 report used the end-point method. The end point method involves the measurement of shoreline change between two datasets and dividing that change by the time period between the datasets to determine a rate. Due to the availability of multiple datasets, it was determined that a linear regression method provides a better representation of long-term shoreline change rates.

<u>Carova Section:</u> The average long-term shoreline change rate calculated for the Carova Section was relatively stable, measuring -0.3 ft./yr. The State determined the average SBF in the Carova Section to be 2.49 ft./yr. (note SBF's infer a recession rate or movement of the shoreline landward). A profile-by-profile comparison shows shoreline change rates in this section ranging from -7.3 ft./yr. at station C-015 to +4.5 ft./yr. at station C-019. The northernmost 4,000 feet of the Carova Section (station C-001 to station C-007), north of Shad Lane, had an average rate of -2.6 ft./yr. From Shad Lane to just north of Mallard Lane (station C-007 to station C-014), the shoreline was relatively stable, with an average shoreline change rate of +1.4 ft./yr. (seaward). From Mallard Lane to just south of Elder Road (station C-014 to station C-017), the average shoreline change rate was -1.7 ft./yr. From Elder Road to Daffodil Lane (station C-017 to station C-024), the average shoreline change rate was positive (seaward), measuring +1.7 ft./yr. The southern portion of the Carova Section from Daffodil Lane south (station C-024 to station C-027), had an average shoreline change rate of -1.9 ft./yr.

Table 12. Summary of Currituck County Recent and Long-Term Shoreline Change Rates

Station	Long-Term Rate (ft./yr.) (Aug. 2009 to May 2022)	Recent Rate (ft./yr.) (May 2020 to May 2022)	Station	Long-Term Rate (ft./yr.) (Aug. 2009 to May 2022)	Recent Rate (ft./yr.) (May 2020 to May 2022)
C-001	-5.4	12.3	C-031	-3.4	44.1
C-002	-6.7	7.4	C-032	-2.4	15.7
C-003	-4.0	-7.4	C-033	-3.9	18.1
C-004	-0.7	-2.1	C-034	-3.6	30.1
C-005	-0.8	12.2	C-035	-3.8	27.8
C-006	-0.7	-11.2	C-036	-5.2	33.1
C-007	-0.1	20.6	C-037	-1.9	29.8
C-008	2.1	15.9	C-038	-3.4	20.2
C-009	2.3	16.1	C-039	-4.0	-3.2
C-010	2.3	29.6	C-040	-3.4	-16.3
C-011	0.6	35.1	C-041	-4.1	-21.3
C-012	1.7	35.2	C-042	-5.8	-20.8
C-013	1.6	44.4	C-043	-4.5	-3.1
C-014	0.5	36.3	C-044	-2.7	18.3
C-015	-7.3	9.6	C-045	-4.8	26.9
C-016	-1.5	9.1	C-046	-3.0	16.3
C-017	1.4	-2.5	C-047	-3.0	11.4
C-018	3.1	8.6	C-048	-6.3	-11.6
C-019	4.5	4.2	C-049	-7.5	-7.2
C-020	2.4	10.6	C-050	-7.9	7.4
C-021	1.7	56.5	C-051	-8.1	37.8
C-022	0.0	41.2	C-052	-8.8	-4.4
C-023	-0.7	32.2	C-053	-10.7	18.1
C-024	1.1	34.6	C-054	-7.5	13.6
C-025	-2.3	41.3	C-055	-5.3	-1.0
C-026	-1.4	38.6	C-056	-7.6	7.6
C-027	-1.9	31.2	C-057	-7.5	1.8
C-028	-2.7	31.8	C-058	-8.8	5.0
C-029	-3.4	33.1	C-059	-8.9	-9.7
C-030	-3.1	46.4	C-060	-9.8	-0.4

Table 13. Summary of Currituck County Recent and Long-Term Shoreline Change Rates (Continued)

Station	Long-Term Rate (ft./yr.) (Aug. 2009 to May 2022)	Recent Rate (ft./yr.) (May 2020 to May 2022)	Station	Long-Term Rate (ft./yr.) (Aug. 2009 to May 2022)	Recent Rate (ft./yr.) (May 2020 to May 2022)
C-061	-9.8	-23.1	C-091	-3.7	-5.2
C-062	-8.8	-8.7	C-092	-3.4	10.6
C-063	-7.9	-15.1	C-093	-3.9	-8.2
C-064	-3.9	8.0	C-094	-0.8	12.4
C-065	-7.0	-10.4	C-095	-4.5	-14.2
C-066	-5.7	-2.3	C-096	-0.3	15.4
C-067	-4.6	-12.5	C-097	-3.5	-17.6
C-068	-5.8	-5.3	C-098	-0.6	24.2
C-069	-5.2	-4.0	C-099	-7.7	-9.5
C-070	-1.5	17.2	C-100	-2.7	-2.1
C-071	-4.4	-16.3	C-101	-4.2	-4.1
C-072	-5.6	-11.6	C-102	-3.3	20.8
C-073	-4.1	13.1	C-103	-2.8	1.9
C-074	-5.0	-8.5	C-104	-0.1	10.9
C-075	-5.3	-10.9	C-105	0.5	-3.1
C-076	-5.7	-6.7	C-106	-1.7	-9.5
C-077	-3.6	-4.4	C-107	2.9	-1.2
C-078	-4.8	-1.5	C-108	-0.8	-10.6
C-079	-5.7	-8.8	C-109	1.5	22.2
C-080	-10.4	-3.1	C-110	0.9	3.6
C-081	-6.3	-4.6	C-111	-2.8	8.8
C-082	-6.0	-7.8	C-112	-0.5	1.3
C-083	-5.6	-2.1	C-113	0.0	2.5
C-084	-4.6	12.7	C-114	-0.5	7.7
C-085	-5.9	-6.8	C-115	-1.7	0.3
C-086	-4.4	-11.5	C-116	-2.6	-3.9
C-087	-5.9	-13.9	C-117	-1.1	5.9
C-088	-6.2	-0.7	C-118	3.8	-3.6
C-089	-3.5	-0.7	C-119	1.5	16.6
C-090	-5.3	-10.8	C-120	-1.7	16.4

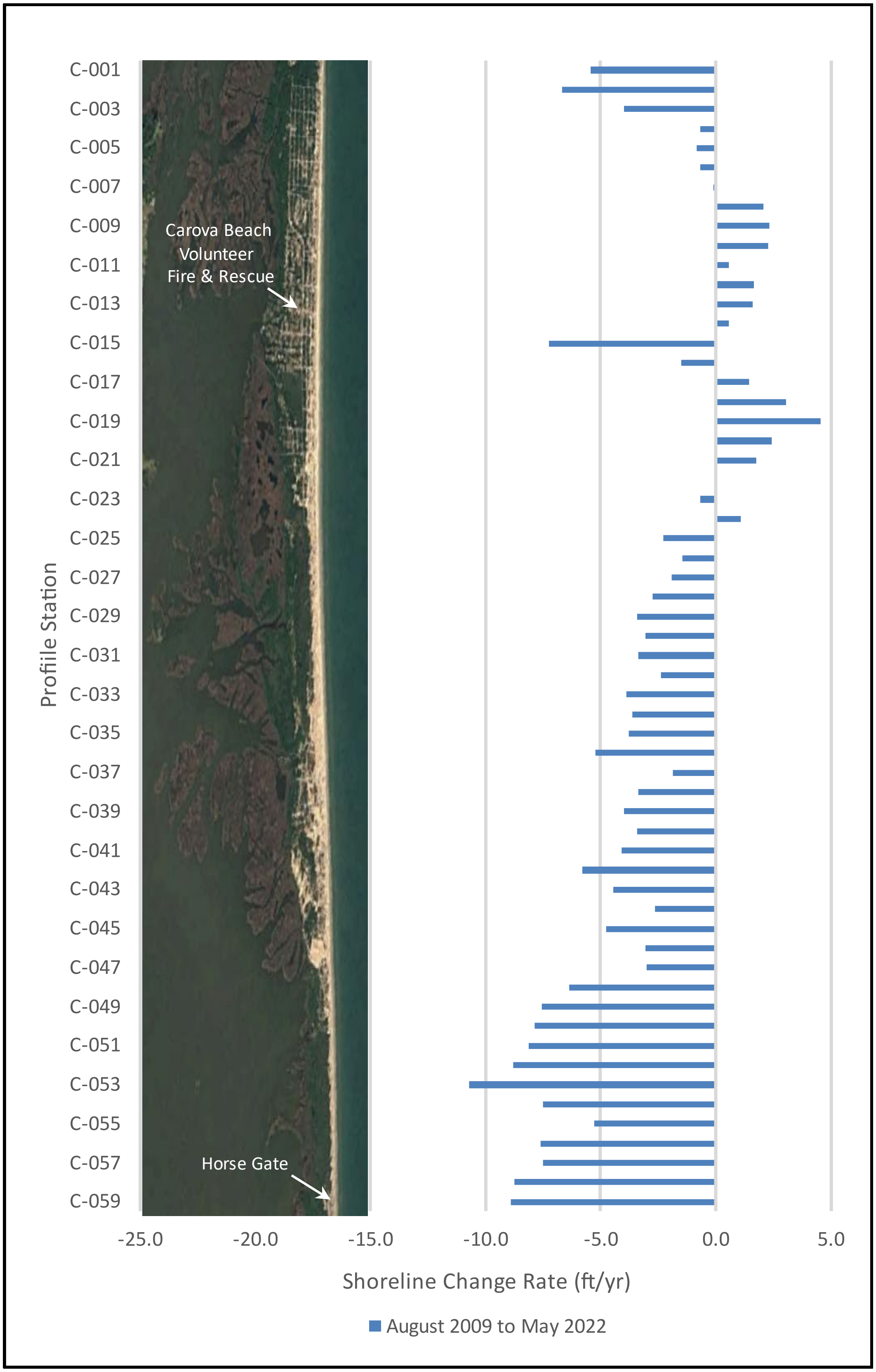

Figure 17. Shoreline Change Rate (+4 ft. NAVD88) North of the Horse Gate (C-001 to C-059)

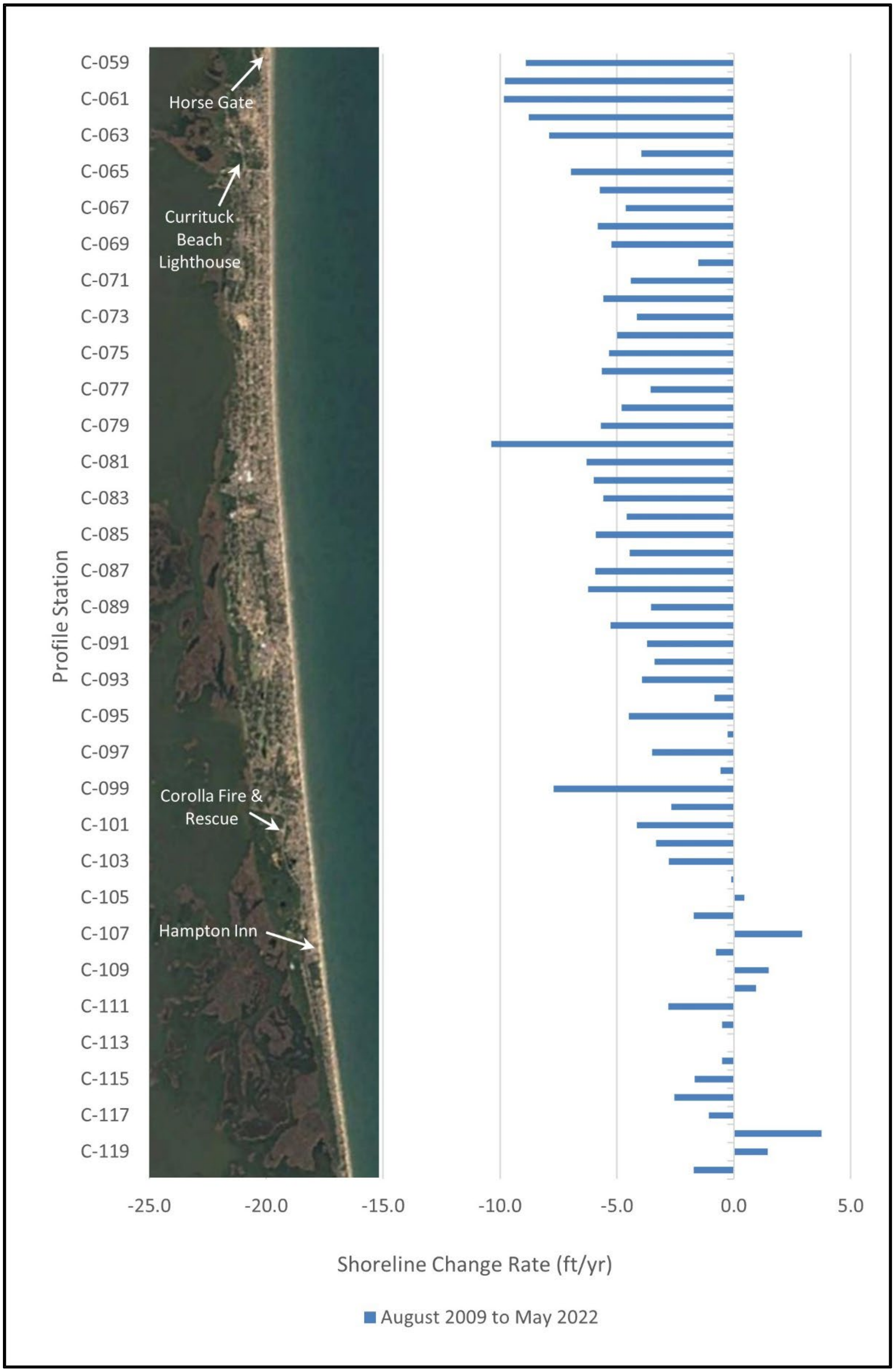

Figure 18. Shoreline Change Rate (+4 ft. NAVD88) South of the Horse Gate (C-059 to C-120)

Reserve/Refuge Section: The average long-term shoreline change rate calculated for the Reserve/Refuge Section was -5.1 ft./yr. This average rate is the same average rate measured along the Corolla Section, which is the highest average rate measured along the various sections of the Project Area. The State determined the average SBF in the Reserve/Refuge Section to be 6.57 ft./yr. (note SBF's infer a recession rate or movement of the shoreline landward). A negative shoreline change rate was measured along each profile along this section of the Project Area, ranging from -10.7 ft./yr. at station C-053 to -1.9 ft./yr. at station C-037. The average shoreline change rate along the northern 3.8 miles of this section, from the northern boundary of the Currituck Wildlife Refuge to approximately 700 feet south of Munson Lane (station C-027 to station C-047), was -3.5 ft./yr. The southern portion of the Reserve/Refuge Section, from approximately 700 feet south of Munson Lane to approximately 250 feet south of the Horse Gate (station C-047 to station C-059), had an average shoreline change rate of -7.5 ft./yr.

Corolla Section: The average long-term shoreline change rate calculated for the Corolla Section was -5.1 ft./yr. This average rate is the same average rate measured along the Reserve/Refuge Section, which is the highest rate measured along the various sections of the Project Area. The State determined the average SBF in the Corolla Area (station C-059 located near the Horse Gate to station C-102 located near Spindrift Trail) to be 2.28 ft./yr. (note SBF's infer a recession rate or movement of the shoreline landward). This represents the largest discrepancy between the State rates and the rates calculated by CPE between 2009 and 2022. As with the Reserve/Refuge Section, a negative shoreline change rate was measured at each profile along the Corolla Section of the Project Area, ranging from -10.4 ft./yr. at station C-080 to -0.3 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 Caro Tank Drive (station C-059 to station C-065), the average shoreline change rate was -8.0 ft./yr. From just north of Caro Tank 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 -4.9 ft./yr. From station C-079 south to station C-088, located along Wave Arch off Seabird Way, the average shoreline change rate was -6.1 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 -3.6 ft./yr.

Pine Island Section: The average long-term shoreline change rate between August 2009 and May 2022, in the Pine Island Section was relatively stable, measuring -0.4 ft./yr. The State determined the average SBF in the Pine Island Section (station C-102 located near Spindrift Trail to station C-120 located near Station 1 Lane) to be 2.0 ft./yr. (note SBF's infer a recession rate or movement of the shoreline landward). Shoreline change rates varied along the Pine Island Section from -3.3 ft./yr. at station C-102 (located approximately 500 feet north of Yaupon Lane) to +3.8 ft./yr. at station C-118 (located along the middle of Salt House Rd).

4.2 Recent Rate (May 2020 to May 2022)

Shoreline change rates were determined using a linear regression method given the June 2021 dataset available between May 2020 and May 2022. The average shoreline change rate between May 2020 and May 2022 along the entire Assessment Area (station C-001 to station C-120) was

+7.4 ft./yr. Recent shoreline change rates at each station along the Assessment Area are provided in Table 12 and Table 13. 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 Project Area, as well as an overall project average, are provided in Table 11.

Carova Section: The average shoreline change rate calculated for the Carova Section between May 2020 and May 2022 was +20.7 ft./yr. A profile-by-profile comparison shows shoreline change rates in this section ranging from -11.2 ft./yr. at station C-006 to +56.5 ft./yr. at station C-021. The northernmost 4,000 feet of the Carova Section (station C-001 to station C-006), north of Rock Lane, had an average rate of +1.9 ft./yr. From Rock Lane to just north of Mallard Lane (station C-006 to station C-014), an average shoreline change rate of +24.6 ft./yr. was measured. From Mallard Lane to just north of Anemone Lane (station C-014 to station C-020), the average shoreline change rate was +10.8 ft./yr. The southern portion of the Carova Section from Anemone Lane south (station C-020 to station C-027), had a shoreline change rate at +35.8 ft./yr.

Reserve/Refuge Section: The average shoreline change rate calculated for the Reserve/Refuge Section between May 2020 and May 2022 was +12.9 ft./yr. A profile-by-profile comparison shows shoreline change rates in this section ranging from -21.3 ft./yr. at station C-041 to +46.4 ft./yr. at station C-030. The average shoreline change rate along the northern 2.3 miles of this section, from the northern boundary of the Currituck Wildlife Refuge to approximately 600 feet north of Canary Lane (station C-027 to station C-039), was +27.6 ft./yr. From Canary Lane to approximately 250 feet north of Seagull Lane (station C-039 to station C-043), the average shoreline change rate was negative (landward), measuring -12.9 ft./yr. The southern portion of the Reserve/Refuge Section, from approximately 250 feet north of Seagull Lane to approximately 250 feet south of the Horse Gate (station C-043 to station C-059), had an average shoreline change rate of +7.5 ft./yr.

Corolla Section: The average shoreline change rate calculated for the Corolla Section between May 2020 and May 2022 was -3.4 ft./yr. This is the only Section of the four Sections to experience an average negative (landward) rate during this period. A profile-by-profile comparison shows shoreline change rates in this section ranging from -23.1 ft./yr. at station C-061 to +24.2 ft./yr. at station C-098. Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the Horse Gate, and Wave Arch (station C-059 to station C-088), the average shoreline change rate was -5.3 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 relatively stable, measuring +0.7 ft./yr.

Pine Island Section: The average shoreline change rate calculated for the Pine Island Section between May 2020 and May 2022 was +4.6 ft./yr. Shoreline change rates varied along the Pine Island Section from -10.6 ft./yr. at station C-108 (located near north end of Lindsey Lane) to +22.2 ft./yr. at station C-109 (located near south end of Lindsey Lane).

4.3 Shoreline Projections

As part of this study, a projected shoreline change analysis was conducted to evaluate potential impacts of long-term shoreline changes. The May 2022 shoreline location of the +4 ft. NAVD88 contour was projected into the future for periods of 10-, 20-, and 30-years using the long-term rates measured between August 2009 and May 2022. While these rates were computed using a linear regression method, it should be noted that the rates used to develop the projections provided in the Year-1 report (CPE, 2020) used the end-point method.

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 Project Area, while maintaining the observed trends. This is the same method used for shoreline projections presented in the Year-1 (CPE, 2020) and Year-2 (CPE, 2021a) reports. For the stations on the north end of the Assessment Area (station C-001) 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 D.

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 14 shows the number of houses in each of the four 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 14. Number of houses shown to be impacted over the 10-, 20-, and 30-year time horizons.

Section	10-Year	20-Year	30-Year
Carova (C-001 to C-027)	0	0	0
Reserve/Refuge (C-027 to C-059)	3	4	5
Corolla (C-059 to C-102)	11	66	158
Pine Island (C-102 to C-120)	0	0	0
Total Assessment Area (C-001 to C-120)	**14**	**70**	**163**

In the Carova Section of the Project Area, where the average long-term shoreline change rate was the lowest of the four project sections, no oceanfront houses were shown to be impacted by the projected shoreline change over the 10-, 20-, or 30-year horizons. In the Year-1 and Year-2 analysis, houses north of Bluefish Lane were impacted by the 30-year horizon, but these houses are no longer impacted based on the updated projected shoreline.

In the Reserve/Refuge Section, where the average long-term shoreline change rate was tied for the highest of the four project sections, the projected shoreline change indicates several houses where impacts may occur. Four (4) houses located seaward of Sandfiddler Road along an approximately 4,000-foot portion of the oceanfront south of Canary Ln. (between station C-040 and station C-044), were shown to be impacted over the 30-year and 20-year time horizon. Three (3) of these houses located seaward of Sandfiddler Rd. between station C-041 and C-044 were also shown to be impacted over the 10-year horizon. The southernmost oceanfront house located north of the Currituck Banks Estuarine Reserve (between station C-050 and C-051) was shown to be impacted over the 30-year horizon. With the amount of vehicular traffic transiting the oceanfront beaches along this section, the presence of oceanfront houses sitting on the open beach as shorelines retreat could impact vehicular traffic (including Emergency Vehicles) traveling north and south along the open beach. Although no other structural impacts are indicated by the shoreline projections along the Reserve/Refuge Section, the relatively high shoreline change rates measured between stations C-049 and C-059, along the Currituck Banks Estuarine Reserve, show that the 30-year shoreline projection may begin to impact maritime shrub and maritime forest habitat as they transition into more active dune environments.

In the Corolla Section of the Project Area, the average long-term shoreline change rate was tied for the highest of the four project sections. The projected shoreline change indicates extensive numbers of oceanfront houses may be impacted over a 30-year time horizon. Along the northern portion of the Corolla Section (north of Corolla Village Rd or station C-066) to the Horse Gate (station C-059), a total of 67 houses were shown to be impacted over the 30-year horizon. Out of those 67 houses, 38 were impacted over the 20-year horizon and 11 were impacted over the 10-year horizon. Along the portion of the Corolla Section between Shad St (station C-068) to 913 Lighthouse Drive (station C-078), a total of 32 houses were shown to be impacted over the 30-year horizon. One house was shown to be impacted just north of Perch St. by the 20-year horizon. 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 47 oceanfront houses were shown to be impacted over the 30-year horizon. Out of those 47 houses, 27 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), a total of 4 houses were 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. No houses were impacted south of this point in the Corolla Section.

To summarize, the northern two thirds within the Corolla Section (station C-059 to station C-088) included oceanfront houses 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 in the Corolla Section. Out of these 158 houses, 66 were shown to be impacted over the 20-year horizon and 11 houses were shown to be impacted over the 10-year horizon just south of the Horse Gate between station C-063 and station C-061. All the oceanfront houses north of station C-065 in the Corolla Section were shown to be impacted by the 30-year horizon. Many houses that were shown not to be impacted by the projections provided in the Year-1 and Year-2 reports are indicated as impacted using the updated shoreline change rates, which utilized a linear regression method. Specifically, the area between station C-

066 to station C-088 that showed only 4 houses impacted in the Year-1 report now show 91 houses to be impacted using the updated shoreline change rates. The same area showed only 19 houses were impacted in the Year-2 report.

In the Pine Island Section of the Project Area, where the average long-term shoreline change rate was the second lowest of the four project sections, no oceanfront houses were shown to be impacted by the projected shoreline change over the 10-, 20-, or 30-year horizons. The same results were shown in the Year-2 report. In the Year-1 analysis, houses north of Yaupon Lane along Land Fall Ct. were impacted by the 30-year horizon, but these houses are no longer impacted based on the updated projected shoreline.

5 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 the Year-1 and Year-2 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. The results of this volumetric analysis are detailed in Section 5.1. After reviewing the available data collected over the three-year study, 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 5.2 and discussed further in Section 8.0.

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

As discussed above, volumetric change was computed using the 2022 data out to the -19 ft. NAVD88 depth contour, which was established as the “Depth of Closure” in the 2020 and 2021 Beach Assessment reports (CPE, 2020 and CPE, 2021a). Figure 19 shows the same profile shown in Figure 14 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.

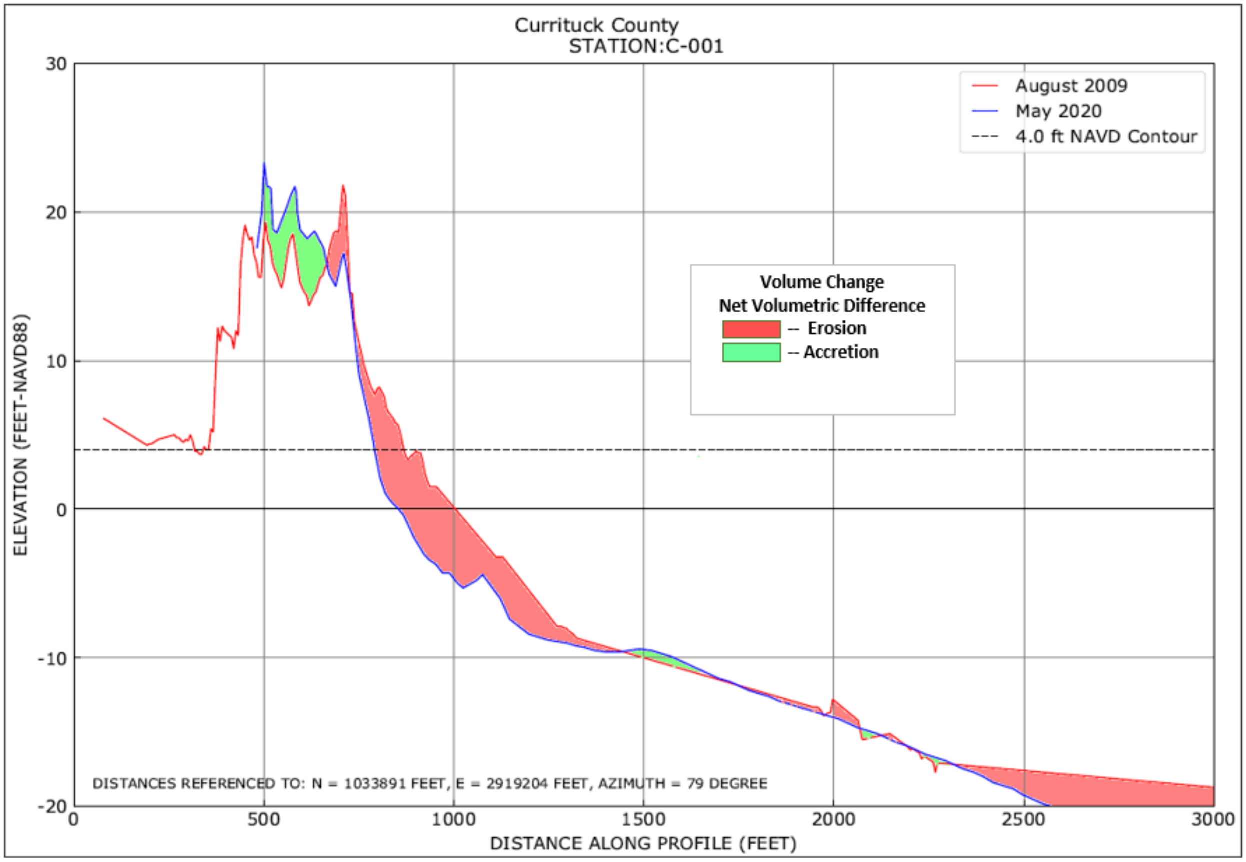

Figure 19. Beach Profile Cross Section Illustrating Volume Change

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 exists. The established depth of closure used in this analysis is -19 ft. NAVD88. Additional information on the determination of this depth can be found in the Year-1 report (CPE, 2020).

With the collection of a third set of beach profile data along the entirety of the Currituck County beaches, short-term volumetric changes were computed between May 2020 and May 2022 and June 2021 and May 2022. Volumetric changes were not reported in the Year-1 report given only one data set was available that covered the entire Assessment Area out to the previously established depth of closure (-19 ft. NAVD88). The average density change rate and total volumetric change for each Section and the overall Assessment Area are provided in Table 15.

Table 15. Summary of Average Volumetric Change Rates and Total Volume Changes Measured to -19 ft. NAVD88.

Section	Average Density Change Rate (cy/ft./yr.)		Total Volume Change (cy)	
	May 2020 to May 2022	June 2021 to May 2022	May 2020 to May 2022	June 2021 to May 2022
Carova	12.4	11.7	624,800	255,200
Reserve/Refuge	8.8	8.7	551,200	243,800
Corolla	4.1	2.7	363,500	125,000
Pine Island	-5.9	-28.6	-224,800	-459,000
Total Project Area	**5.5**	**1.4**	**1,314,600**	**165,000**

5.1.1 May 2020 to May 2022

The average volumetric change rate measured between May 2020 and May 2022 was +5.5 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 1,314,600 cubic yards (Table 15). Three of the four sections had a positive average volumetric change rate. The volumetric rates were negative in the Pine Island Section while the Carova, Reserve/Refuge, and Corolla Sections experienced rates of accretion. Table 16 lists the individual volumetric rates computed for each profile between May 2020 and May 2022. Figure 20 and Figure 21 show the 2020 to 2022 change rates graphically.

Carova Section: The average volumetric change rate in the Carova Section was +12.4 cy/ft./yr., which is the highest positive rate of any section over this period. This equates to a net volume gain of approximately 624,800 cy over the two-year period. Negative volumetric change rates were only measured on 6 profiles in this section (Table 16 and Figure 20). A profile-by-profile comparison shows volumetric change rates in this section ranging from -31.0 cy/ft./yr. at station C-003 (300 feet south of Bluefish Lane) to +28.8 cy/ft./yr. at station C-021 (400 feet north of Bitter Root Lane). The northernmost 7,000 feet of the Carova Section (station C-001 to station C-008), north of Red Snapper Road, had a negative average rate of -4.5 cy/ft./yr. South of station C-008 (Red Snapper Road) in the Carova section, positive volumetric changes were measured along all profiles. From just south of Sturgeon Lane to 300 feet south of Sandfiddler Rd (station C-009 to station C-027), gains in density were measured, with an average density change rate of +19.6 cy/ft./yr.

Reserve/Refuge Section: The average volumetric change rate in the Reserve/Refuge Section was +8.8 cy/ft./yr., which equates to a net volume gain of 551,200 cy over the two year period. Negative volumetric change rates were only measured on 6 profiles in this section (Table 16 and Figure 20). A profile-by-profile comparison shows volumetric change rates in this section ranging from -10.4 cy/ft./yr. at station C-055 (3,580 feet north of the Horse Gate) to +24.0 cy/ft./yr. at station C-029 (5,400 feet south of Daffodil Lane). From station C-027 to station C-031, the average volumetric change rate was +20.4 cy/ft./yr., which aligns with the trends observed in the area to the north in the Carova Section. From 400 feet south of Sandfiddler Rd to 380 feet north of Bobolink Road (station C-032 to station C-038), the average volumetric change rate was +3.4

Table 16. Volumetric Change Rates (May 2020 to May 2022) (cy/ft./yr.)

Station	May 2020 to May 2022	Station	May 2020 to May 2022	Station	May 2020 to May 2022
C-001	9.0	C-041	9.3	C-081	7.9
C-002	-15.8	C-042	-2.3	C-082	4.2
C-003	-31.0	C-043	18.0	C-083	5.4
C-004	1.6	C-044	-7.5	C-084	0.4
C-005	0.8	C-045	14.1	C-085	-0.3
C-006	-2.9	C-046	10.0	C-086	11.2
C-007	18.5	C-047	2.8	C-087	-10.0
C-008	-16.5	C-048	8.7	C-088	14.4
C-009	6.9	C-049	4.4	C-089	5.6
C-010	12.8	C-050	19.1	C-090	10.0
C-011	17.6	C-051	23.5	C-091	3.6
C-012	14.9	C-052	3.4	C-092	-8.6
C-013	24.5	C-053	-1.5	C-093	-14.8
C-014	20.7	C-054	10.6	C-094	-5.9
C-015	24.9	C-055	-10.4	C-095	-12.0
C-016	20.3	C-056	3.2	C-096	-2.3
C-017	27.0	C-057	4.0	C-097	-11.8
C-018	23.1	C-058	17.6	C-098	4.0
C-019	18.6	C-059	4.6	C-099	-1.4
C-020	22.9	C-060	8.4	C-100	6.5
C-021	28.8	C-061	-9.5	C-101	5.3
C-022	25.3	C-062	7.1	C-102	2.5
C-023	19.7	C-063	11.3	C-103	-11.1
C-024	17.0	C-064	3.8	C-104	-18.0
C-025	8.5	C-065	13.2	C-105	-2.5
C-026	15.4	C-066	-6.3	C-106	-4.1
C-027	22.8	C-067	6.9	C-107	-12.6
C-028	19.6	C-068	1.6	C-108	5.4
C-029	24.0	C-069	13.4	C-109	3.0
C-030	16.1	C-070	6.5	C-110	4.9
C-031	19.6	C-071	6.5	C-111	7.7
C-032	-2.5	C-072	6.5	C-112	4.7
C-033	2.4	C-073	15.2	C-113	5.9
C-034	-1.8	C-074	1.1	C-114	5.7
C-035	7.2	C-075	5.9	C-115	-20.5
C-036	8.6	C-076	13.0	C-116	-21.5
C-037	9.3	C-077	17.5	C-117	-59.9
C-038	0.5	C-078	18.0	C-118	-1.9
C-039	18.9	C-079	17.0	C-119	2.8
C-040	12.5	C-080	6.8	C-120	-3.5

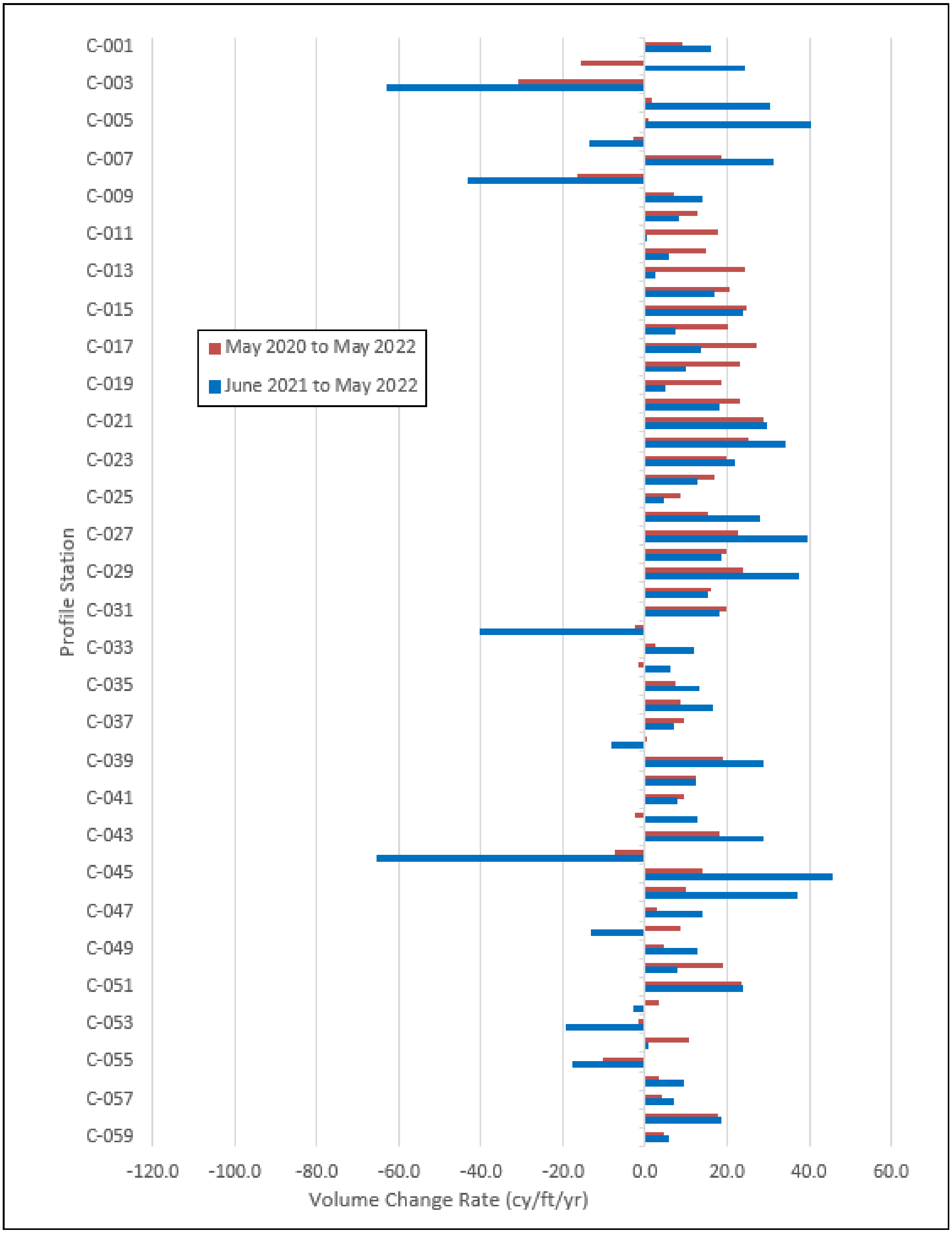

Figure 20. Volume Change Rate Above -19 ft. NAVD88 - North of the Horse Gate May 2020 to May 2022 and June 2021 to May 2022

cy/ft./yr. From 600 feet north of Canary Lane to 300 feet north of Munson Lane (station C-039 to station C-046), the average volumetric change rate was +9.1 cy/ft./yr. In this area volumetric changes varied from large volumetric gains to modest volumetric losses. South of station C-046 (300 feet north of Munson Lane) in the Reserve/Refuge section, all profiles varied between large and modest positive volumetric gains and modest volumetric losses. The southern 13,900 ft. of the Reserve/Refuge Section, from 700 feet north of Munson Lane to approximately 250 feet south of the Horse Gate (station C-047 to station C-059), had an average volumetric change rate of +6.9 cy/ft./yr.

Corolla Section: The average volumetric change rate in the Corolla Section was +4.1 cy/ft./yr., which equates to a net volume gain of 363,500 cy. Negative volumetric change rates were measured on 11 profiles in this section (
Table 16 and Figure 21). A profile-by-profile comparison shows volumetric change rates in this section ranging from -14.8 cy/ft./yr. at station C-093 to +18.0 cy/ft./yr. at station C-078. Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the Horse Gate, and 300 feet south of Perch Street (station C-059 to station C-075), the average volumetric change rate was +5.7 cy/ft./yr. From Mackerel Beach Access to 889 Lighthouse Drive (station C-076 to station C-079), the average volumetric change rate was a significant +16.3 cy/ft./yr. From station C-080 south to station C-085, located just north of Sailfish Street, to south end of Voyager Road, the average volumetric change rate was +4.1 cy/ft./yr. From 200 ft north of Spinnaker Arch to 250 feet north of Sea Shell Lane (station C-086 to station C-097), the average volumetric change rate was relatively stable at -1.7 cy/ft./yr. Along the southern portion of the Corolla Section, between station C-098 (North end of Breakers Arch) and station C-102, located approximately 500 feet north of Yaupon Lane, the average volumetric change rate was +3.4 cy/ft./yr.

Pine Island Section: The average volumetric change rate in the Pine Island Section was -5.9 cy/ft./yr., which is the only section where a negative change rate was measured on average over the two-year period. This equates to a net volume loss of approximately -224,800 cy. Negative volumetric change rates were measured on more than half of the profiles (
Table 16 and Figure 21). A profile-by-profile comparison shows volumetric change rates in this section ranging from -59.9 cy/ft./yr. at station C-117 to +7.7 cy/ft./yr. at station C-111. Between the northern boundary of the Pine Island Section, which is located approximately 500 feet north of Yaupon Lane, and just south of Pine Gate Road (station C-102 to station C-107), the average volumetric change rate was -7.6 cy/ft./yr. From north end of Lindsey Lane to north end of Hicks Bay Lane (station C-108 to station C-114), the average volumetric change rate was +5.3 cy/ft./yr. Along the southern portion of the Pine Island Section, between station C-115 (just north of Ogein Lane) and station C-120, located approximately at 101 Station 1 Lane, the average volumetric change rate was -17.4 cy/ft./yr. This average rate was heavily influenced by the large negative outlier at station C-117 of -59.9 cy/ft./yr.

Table 17. Volumetric Change Rates (June 2021 to May 2022) (cy/ft./yr.)

Station	June 2021 to May 2022	Station	June 2021 to May 2022	Station	June 2021 to May 2022
C-001	16.0	C-041	7.6	C-081	-6.6
C-002	24.3	C-042	12.5	C-082	4.8
C-003	-62.7	C-043	28.7	C-083	-15.2
C-004	30.3	C-044	-65.2	C-084	-0.5
C-005	40.2	C-045	45.6	C-085	4.4
C-006	-13.5	C-046	36.9	C-086	35.7
C-007	31.2	C-047	13.9	C-087	-2.3
C-008	-42.9	C-048	-13.1	C-088	-1.0
C-009	14.0	C-049	12.6	C-089	5.8
C-010	8.0	C-050	7.7	C-090	11.5
C-011	0.1	C-051	23.8	C-091	-7.0
C-012	5.7	C-052	-2.6	C-092	-14.3
C-013	2.2	C-053	-19.0	C-093	-36.6
C-014	16.9	C-054	0.4	C-094	-10.5
C-015	23.7	C-055	-17.6	C-095	-28.7
C-016	7.4	C-056	9.5	C-096	-38.5
C-017	13.4	C-057	6.7	C-097	-35.6
C-018	9.7	C-058	18.2	C-098	-12.5
C-019	4.8	C-059	5.4	C-099	-4.6
C-020	17.9	C-060	10.1	C-100	-0.5
C-021	29.6	C-061	-9.5	C-101	6.1
C-022	33.8	C-062	17.9	C-102	-40.1
C-023	21.6	C-063	17.4	C-103	-29.0
C-024	12.7	C-064	-0.4	C-104	-23.5
C-025	4.3	C-065	-9.6	C-105	-16.9
C-026	27.8	C-066	2.3	C-106	-23.7
C-027	39.2	C-067	6.5	C-107	-28.9
C-028	18.5	C-068	14.5	C-108	0.7
C-029	37.4	C-069	29.6	C-109	6.3
C-030	14.8	C-070	26.6	C-110	3.1
C-031	17.9	C-071	16.6	C-111	-24.1
C-032	-40.3	C-072	24.5	C-112	-13.3
C-033	11.9	C-073	3.4	C-113	-3.9
C-034	5.9	C-074	25.9	C-114	-41.0
C-035	12.9	C-075	28.5	C-115	-53.4
C-036	16.1	C-076	33.7	C-116	-31.6
C-037	6.6	C-077	-6.2	C-117	-149.5
C-038	-8.0	C-078	26.1	C-118	-10.4
C-039	28.7	C-079	12.2	C-119	-18.6
C-040	12.0	C-080	28.1	C-120	-46.0

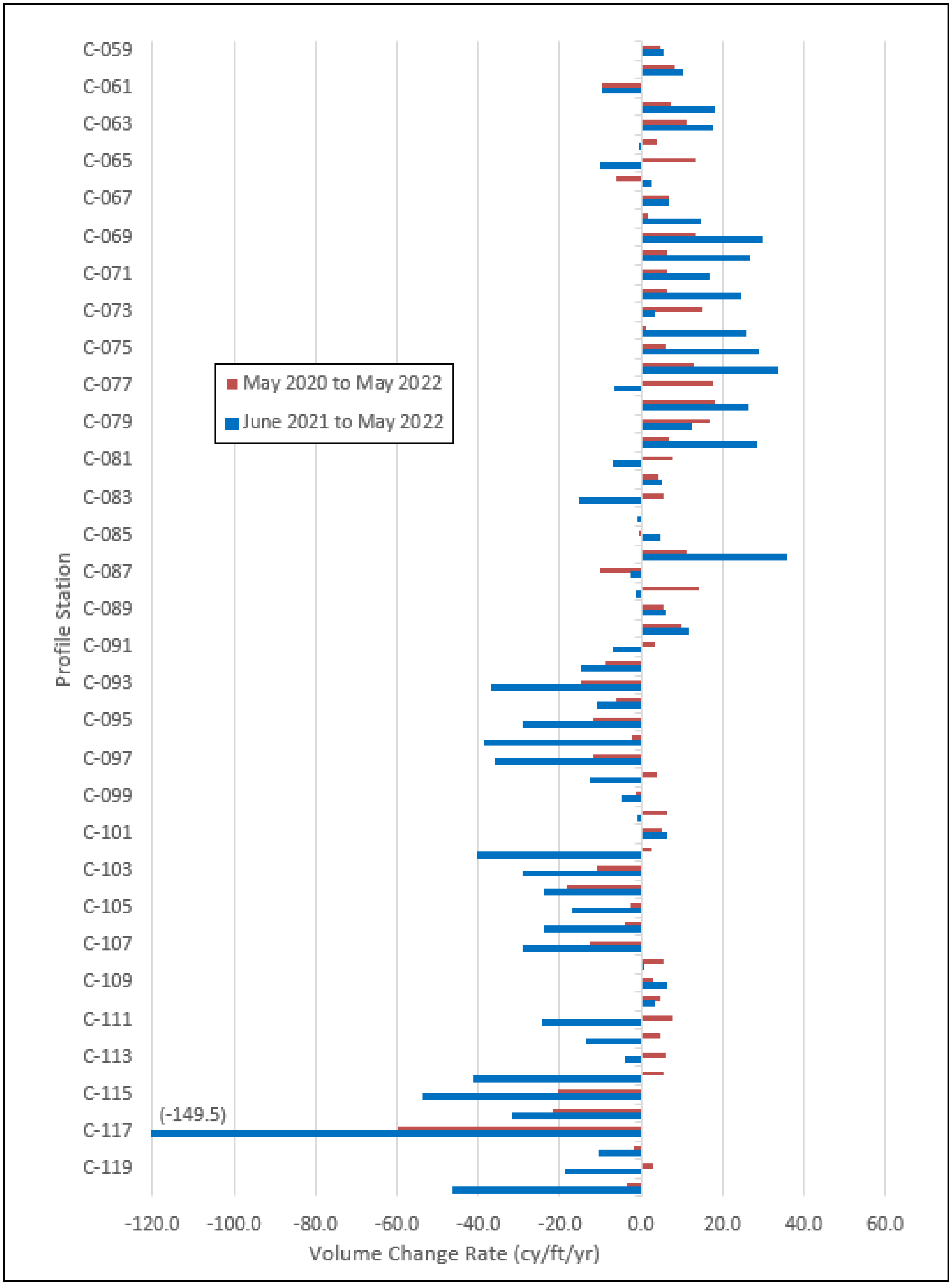

Figure 21. Volume Change Rate Above -19 ft. NAVD88 - South of Horse Gate May 2020 to May 2022 and June 2021 to May 2022

5.1.2 Recent Period June 2021 to May 2022

The average volumetric change rate measured along the entire Project Area, between June 2021 and May 2022 was +1.4 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 165,000 cubic yards. The Pine Island Section was the only section to have a negative average volumetric change. Table 17 lists the individual volumetric rates computed for each profile between June 2021 and May 2022. Figure 20 and Figure 21 show the 2021 to 2022 change rates graphically.

Carova Section: The average volumetric change rate in the Carova Section was +11.7 cy/ft./yr., this section gained approximately 255,200 cy between June 2021 and May 2022. This average change is similar to the rate measured between May 2020 and June 2021, which was +12.3 cy/ft./yr. Negative volumetric change rates were only measured on 3 profiles in this section (Table 17 and Figure 20). A profile-by-profile comparison shows volumetric change rates in this section ranging from -62.7 cy/ft./yr. at station C-003 (300 feet south of Bluefish Lane) to +40.2 cy/ft./yr. at station C-005 (Marlin Lane). The northernmost 7,000 feet of the Carova Section (station C-001 to station C-008), north of Red Snapper Road, had relatively stable average rate of +2.9 cy/ft./yr. This average rate was heavily influenced by large negative outliers at stations C-003 and C-008 of -62.7 and -42.9 cy/ft./yr., respectively. From just south of Sturgeon Lane to just north of Dump Road (station C-009 to station C-019), modest gains in density were measured, with an average density change rate of +9.6 cy/ft./yr. A relatively large average volumetric change rate of +23.4 cy/ft./yr. was measured along the southern portion of the Carova Section from 260 feet north of Anemone Lane to 300 feet south of Sandfiddler Rd (station C-020 to station C-027).

Reserve/Refuge Section: The average volumetric change rate between June 2021 and May 2022 in the Reserve/Refuge Section was +8.7 cy/ft./yr., which equates to a net volume gain of 243,800 cy. This average change is similar to the rate measured between May 2020 and June 2021, which was +8.4 cy/ft./yr. Negative volumetric change rates were only measured on 7 profiles in this section (Table 17 and Figure 20). A profile-by-profile comparison shows volumetric change rates in this section ranging from -65.2 cy/ft./yr. at station C-044 (600 feet south of Seagull Lane) to +45.6 cy/ft./yr. at station C-045 (Catesbys Run). From station C-027 to station C-031, the average volumetric change rate was +25.6 cy/ft./yr., which aligns with the trends observed in the area to the north in the Carova Section. From 400 feet south of Sandfiddler Rd to 380 feet north of Bobolink Road (station C-032 to station C-038), the average volumetric change rate was relatively stable +0.7 cy/ft./yr. This average rate was heavily influenced by large negative outlier at station C-032 of -40.3 cy/ft./yr. From 600 feet north of Canary Lane to 300 feet north of Munson Lane (station C-039 to station C-046), the average volumetric change rate was +13.4 cy/ft./yr. This average rate was heavily influenced by large negative outlier at station C-044 of -65.2 cy/ft./yr. There were also large positive rates in this area of +45.6, +36.9, and +28.7 cy/ft./yr. The southern 12,000 ft. of the Reserve/Refuge Section (C-047 to C-059) had an average volumetric change rate of +3.5 cy/ft./yr.

Corolla Section: The average volumetric change rate in the Corolla Section was +2.7 cy/ft./yr. This equates to a net volume gain of approximately 125,000 cy. This recent period average change rate is less than half what was measured during the last recent period (May 2020 to June 2021) which measured +6.6 cy/ft./yr. A profile-by-profile comparison shows volumetric change rates in this section ranging from -40.1 cy/ft./yr. at station C-102 to +35.7 cy/ft./yr. at station C-086 (Table 17 and Figure 21). Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the Horse Gate, and Morris Drive (station C-059 to station C-068), the average volumetric change rate was +5.5 cy/ft./yr. From 550 feet north of Tuna Street to 120 feet south of Sailfish Street (station C-069 to station C-080), the average volumetric change rate was relatively large at +20.7 cy/ft./yr. From station C-081 south to station C-092, located just north of Marlin Beach Access, to just north of Sandfiddler Circle, the average volumetric change rate was relatively stable at +1.3 cy/ft./yr. Along the southern portion of the Corolla Section, between station C-093 (just north of Topsail Arch) and station C-102 (located approximately 500 feet north of Yaupon Lane), the average volumetric change rate was -20.2 cy/ft./yr. This area contained multiple profiles with rates over -30 cy/ft./yr.

Pine Island Section: The average volumetric change rate in the Pine Island Section was -28.6 cy/ft./yr., which is the only negative average volumetric change rate of any section over this period. This equates to a net volume loss of approximately 459,000 cy. The negative average change rate for this recent period was a reverse from the positive average change rate measured between May 2020 and June 2021 (+14.0 cy/ft./yr.). Positive rates were only measured on three of the profiles in this section. A profile-by-profile comparison shows volumetric change rates in this section ranging from -149.5 cy/ft./yr. at station C-117 to +6.3 cy/ft./yr. at station C-109. Between the northern boundary of the Pine Island Section, which is located approximately 500 feet north of Yaupon Lane, and just south of Pine Gate Road (station C-102 to station C-107), the average volumetric change rate was -27.0 cy/ft./yr. From the north end of Lindsey Lane to 200 feet south of Ballast Point (station C-108 to station C-113), the average volumetric change rate was -5.2 cy/ft./yr. Along the southern portion of the Pine Island Section, between station C-114 (north end of Hicks Bay Lane) and station C-120, located approximately at 101 Station 1 Lane, the average volumetric change rate was -50.1 cy/ft./yr. This average rate was heavily influenced by the large negative outlier at station C-117 (north end of Salthouse Road) of -149.5 cy/ft./yr. associated with the formation of a large nearshore trough and truncated bar, which was not present in June 2021.

5.2 Volumetric Change (Lens Calculations)

A second volumetric analysis was conducted in Year-3 of the study after observing cross-shore volumetric changes beyond the established depth of closure (-19 ft. NAVD88) between June 2021 and May 2022. While the volumetric analysis reported on in Section 5.1 provides a basis for measuring long-term 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 22 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 Project Area. 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).

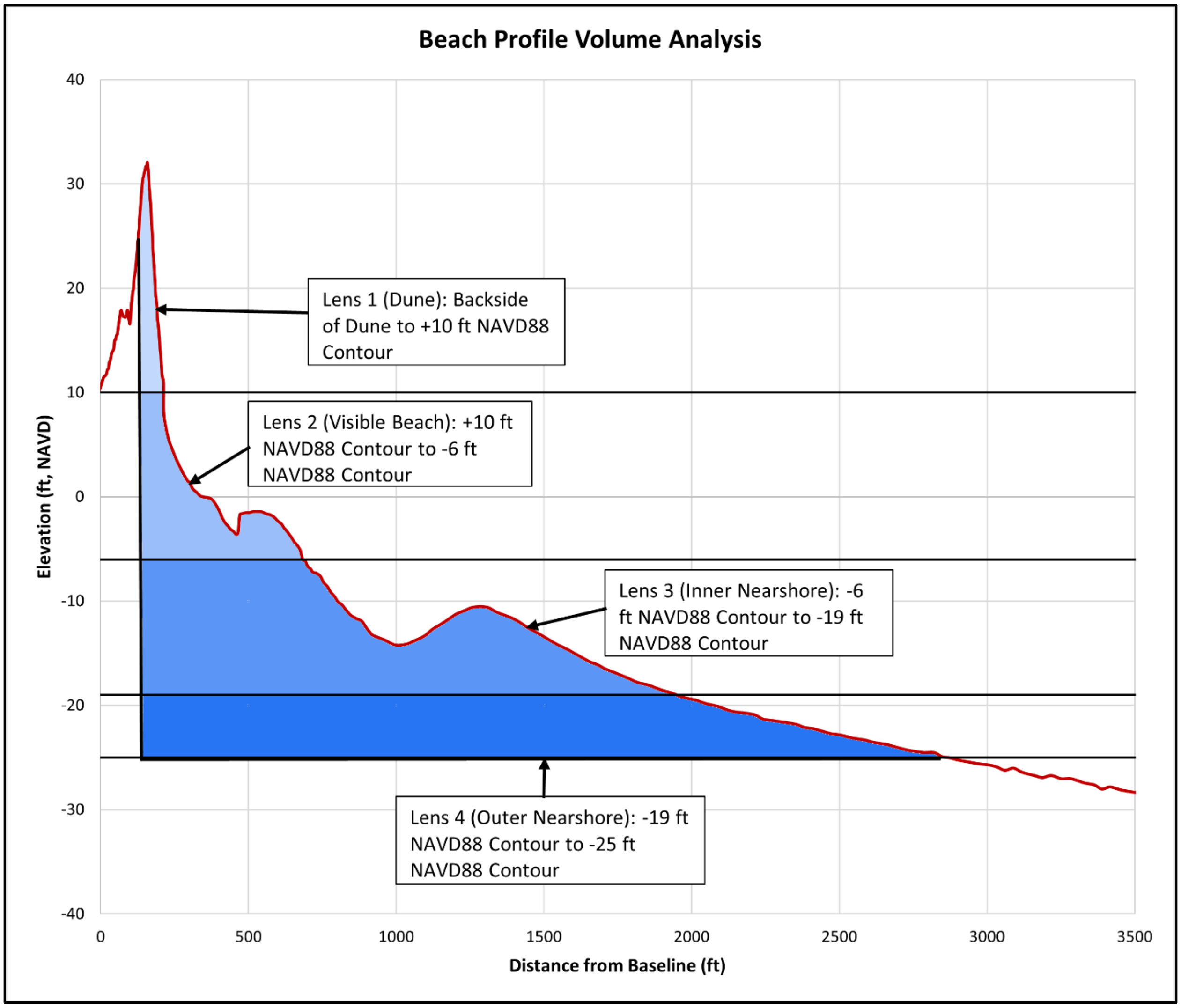

Figure 22. Beach Profile Cross Section Illustrating Lenses

- **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 −22 ft. NAVD88 north of the Horse Gate and -19 ft. to -25 ft. NAVD88 south of the Horse Gate) — This lens represents the underwater part of the beach profile in and around the various observed depths of closure during this study.

5.2.1 May 2020 to May 2022

Lens 1 (Dune): The average volumetric change rate measured between May 2020 and May 2022 in the Dune Lens was +0.8 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 201,700 cubic yards along the entire Project Area. Positive volumetric changes in the Dune were calculated in each of the four Sections of the Project Area. The average volumetric change rate calculated for both the Carova Section and the Reserve/Refuge Section was +1.3 cy/ft./yr. The average volumetric change rate in the Corolla Section was +0.1 cy/ft./yr., which is the lowest rate of any section over this period. The average volumetric change rate in the Pine Island Section was +0.9 cy/ft./yr. The average rates of volumetric change and total volumetric change calculated for the Dune Lens along the entire Assessment Area and each of the four (4) Sections are provided in Table 18. The rates of volumetric change for each station are provided in Table 19 and are shown graphically in Figure 23.

A profile-by-profile comparison shows volumetric change rates computed for the Dune Lens range from -5.6 cy/ft./yr. at station C-061 (North end of Atlantic Avenue) to +6.6 cy/ft./yr. at station C-037 (200 feet north of Albatrose Lane). A graphical representation of the volumetric changes in the Dune and Visible Beach Lenses is provided in Figure 23. In general, volumetric changes were positive along the Project Area. As shown in Figure 23, the majority of the profiles where a negative change was measured within the Dune Lens were located between station C-052 (approximately 1,800 feet south of the house at 1401 Ocean Pearl Road) and C-067 (north of Strong Ct.). These negative volumetric changes appear 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 24.

Table 18. Summary of Average Volumetric Change Rates and Total Volume Changes

Sections	May 2020 to May 2022 Density Change Rate (cy/ft./yr.)			
	Lens 1 Dune	Lens 2 Visible Beach	Lens 3 Inner Nearshore	Lens 4 Outer Nearshore
Carova	1.3	0.3	10.8	0.9(1)
Reserve/Refuge	1.3	-2.8	10.2	2.6(1)
Corolla	0.1	-2.7	6.7	10.1(2)
Pine Island	0.9	-3.5	-3.4	7.3(2)
Total	0.8	-2.2	6.9	5.7(3)
May 2020 to May 2022 Volume (cy)				
Carova	66,300	8,800	549,700	47,800(1)
Reserve/Refuge	89,600	-176,000	637,600	165,500(1)
Corolla	13,100	-233,900	584,200	880,100(2)
Pine Island	32,700	-133,400	-124,100	258,200(2)
Total	201,700	-534,500	1,647,400	N/A(4)

(1) Calculations made between -19 ft. NAVD88 and -22 ft NAVD88

(2) Calculations made between -19 ft. NAVD88 and -25 ft NAVD88

(3) Average includes calculations made between -19 ft NAVD88 to -22 ft NAVD88 north of the Horse Gate and -19 ft NAVD88 to -25 ft NAVD88 south of the Horse Gate.

(4) No volume listed due to the differences in the offshore limits used north and south of the Horse Gate.

Lens 2 (Visible Beach): The average volumetric change rate measured between May 2020 and May 2022 within the Visible Beach Lens was -2.2 cy/ft./yr., resulting in a cumulative negative volumetric change of approximately 534,500 cubic yards. The Visible Beach Lens was the only one of the four (4) lenses analyzed in which the average rate of change was negative throughout the entire Project Area. As shown in Table 18, the average rate of change and total volumetric change was negative in all Sections, except for the Carova Section. The positive volumetric change in the Carova Section (+0.3 cy/ft./yr.) was driven by positive volumetric changes measured within the Visible Beach Lens from station C-009 (200 feet south of Sturgeon Lane) and C-022 (south of Bitter Root Lane) (Figure 23). Along this portion of the Assessment Area the average volumetric change rate, measured between May 2020 and May 2022, was +3.1 cy/ft./yr./yr. The average volumetric change rates within the Visible Beach Lens in the Reserve/Refuge Section and Corolla Sections were -2.8 cy/ft./yr. and -2.7 cy/ft./yr., respectively. Within the Corolla Section, from station C-072 (just north of Barracuda Street) to station C-082 (430 feet north of Dolphin Street) the average volumetric change rate of +2.4 cy/ft./yr. This section is the only other section of considerable length where the average volumetric change was positive other than the portion previously mentioned within the Carova Section. The average volumetric change rate in the Pine Island Section was -3.5 cy/ft./yr., which was the highest negative rate of the four (4) Sections over the two-year period. The average rates of volumetric change and total volumetric change calculated for the Visible Beach Lens along the entire Assessment Area and each of the four (4) Sections of the project are provided in Table 18. The rates of volumetric change for each station are provided in Table 19 and are shown graphically in Figure 23.

Table 19. Lens Volumetric Change Rates (May 2020 to May 2022) (cy/ft./yr.)

Station	Lens 1 Dune	Lens 2 Visible Beach	Lens 3 Inner Nearshore	Lens 4 Outer Nearshore[(1)]	Station	Lens 1 Dune	Lens 2 Visible Beach	Lens 3 Inner Nearshore	Lens 4 Outer Nearshore[(2)]
C-001	1.0	1.8	6.2	-13.8	C-061	-5.6	-16.6	12.7	5.6
C-002	-1.3	-3.4	-11.1	-40.7	C-062	-2.2	-4.6	13.9	4.4
C-003	-0.2	-9.4	-21.3	10.4	C-063	-1.2	-0.3	12.8	8.4
C-004	-0.3	-5.4	7.3	5.0	C-064	-0.9	-1.0	5.6	6.9
C-005	0.3	-2.2	2.7	-0.6	C-065	-0.3	-6.9	20.4	11.3
C-006	1.0	-14.5	10.5	2.0	C-066	-1.9	-11.7	7.4	7.6
C-007	0.8	4.9	12.8	2.6	C-067	-2.0	0.9	8.0	11.0
C-008	1.9	-4.8	-13.5	1.6	C-068	0.5	-1.4	2.5	6.0
C-009	1.4	0.9	4.6	1.5	C-069	0.1	-0.3	13.6	9.3
C-010	2.4	0.8	9.7	1.2	C-070	0.6	4.0	1.9	7.3
C-011	2.5	4.3	10.7	3.1	C-071	0.0	-6.8	13.3	11.8
C-012	2.1	2.8	10.0	3.1	C-072	0.3	2.3	3.9	9.4
C-013	1.7	8.2	14.6	3.8	C-073	1.4	1.4	12.4	13.7
C-014	2.3	0.9	17.5	4.6	C-074	-0.5	1.0	0.6	10.7
C-015	1.2	6.1	17.7	4.1	C-075	0.5	0.0	5.4	13.0
C-016	1.1	1.5	17.7	4.4	C-076	0.8	5.0	7.2	10.5
C-017	0.2	-2.0	28.8	4.1	C-077	1.1	5.5	10.9	14.7
C-018	0.1	4.4	18.6	3.3	C-078	1.2	7.6	9.1	14.7
C-019	2.8	2.1	13.7	3.2	C-079	0.8	2.1	14.1	17.5
C-020	1.6	3.6	17.7	3.5	C-080	0.2	4.1	2.4	14.5
C-021	2.6	6.9	19.3	0.2	C-081	0.0	-2.0	9.9	17.9
C-022	1.2	2.6	21.5	1.6	C-082	-0.5	-0.3	5.0	13.4
C-023	2.1	-4.9	22.5	4.3	C-083	1.2	-7.8	12.1	17.1
C-024	1.9	1.3	13.8	4.0	C-084	0.5	0.0	-0.1	14.2
C-025	0.8	-1.5	9.3	3.4	C-085	-0.9	-6.1	6.8	14.1
C-026	1.1	1.3	12.9	2.6	C-086	0.0	3.2	7.9	10.9
C-027	2.5	1.7	18.6	2.78	C-087	0.0	-13.7	3.7	8.1
C-028	4.9	-3.4	18.2	3.2	C-088	0.5	4.4	9.4	11.5
C-029	2.3	-2.3	24.0	3.6	C-089	1.4	4.3	0.0	7.9
C-030	2.1	-2.2	16.3	3.3	C-090	0.8	-2.2	11.4	10.9
C-031	5.5	7.1	7.0	4.2	C-091	1.4	0.2	1.9	9.2
C-032	3.1	-9.7	4.1	4.4	C-092	0.5	-11.3	2.3	9.3
C-033	1.9	-1.8	2.3	3.6	C-093	0.7	-14.7	-0.8	9.1
C-034	-4.2	-8.6	11.0	2.9	C-094	1.3	-10.3	3.1	9.3
C-035	1.6	1.9	3.7	2.3	C-095	1.3	-11.8	-1.4	7.8
C-036	6.1	0.1	2.4	1.9	C-096	1.7	-6.9	2.9	6.0
C-037	6.6	1.7	1.0	-1.1	C-097	0.9	-14.5	1.8	6.0
C-038	4.1	-11.2	7.6	5.7	C-098	3.5	-5.4	5.9	10.1
C-039	5.2	-1.8	15.4	1.2	C-099	0.5	0.0	-1.8	6.9
C-040	-0.3	-10.7	23.6	2.4	C-100	0.7	1.0	4.8	10.0
C-041	0.4	-11.1	20.0	1.8	C-101	0.0	1.1	4.2	9.5
C-042	0.0	-11.4	9.1	5.9	C-102	-0.7	3.3	-0.1	11.3
C-043	0.5	4.1	13.4	4.5	C-103	-0.3	-3.7	-7.2	4.7
C-044	1.2	0.6	-9.3	-0.8	C-104	0.8	-8.3	-10.6	7.3
C-045	1.3	3.0	9.8	-2.7	C-105	0.6	-4.0	0.8	4.8
C-046	-0.1	-2.0	12.1	1.6	C-106	0.8	-1.8	-3.1	5.0
C-047	1.2	-2.6	4.3	2.0	C-107	2.6	-9.2	-6.0	4.1
C-048	-0.1	-1.8	10.6	1.9	C-108	2.2	1.0	2.2	10.2
C-049	3.6	-10.1	10.8	1.8	C-109	1.1	2.7	-0.9	9.2
C-050	1.3	3.6	14.1	2.1	C-110	1.9	-8.6	11.6	9.9
C-051	1.9	4.6	17.0	1.6	C-111	1.1	0.0	6.6	7.9
C-052	-4.1	-1.7	9.2	2.2	C-112	1.7	-4.2	7.2	12.1
C-053	2.4	-11.5	7.6	2.8	C-113	-0.1	-2.9	8.9	3.2
C-054	-2.8	4.2	9.2	4.0	C-114	-0.2	1.4	4.5	9.3
C-055	2.3	-14.3	1.6	4.3	C-115	0.0	-11.7	-8.8	6.0
C-056	-1.4	1.3	3.3	2.1	C-116	0.4	-7.7	-14.2	6.7
C-057	-2.5	-4.6	11.1	3.7	C-117	1.0	-14.4	-46.4	1.1
C-058	0.6	4.0	13.0	3.4	C-118	1.4	-0.1	-3.1	14.2
C-059	-2.7	-7.0	14.3	3.0	C-119	1.2	3.6	-2.0	3.1
C-060	-0.2	-6.9	15.5	5.2[(2)]	C-120	0.9	-1.2	-3.2	9.3

(1) Calculations made between -19 ft. NAVD88 and -22 ft NAVD88
(2) Calculations made between -19 ft. NAVD88 and -25 ft NAVD88

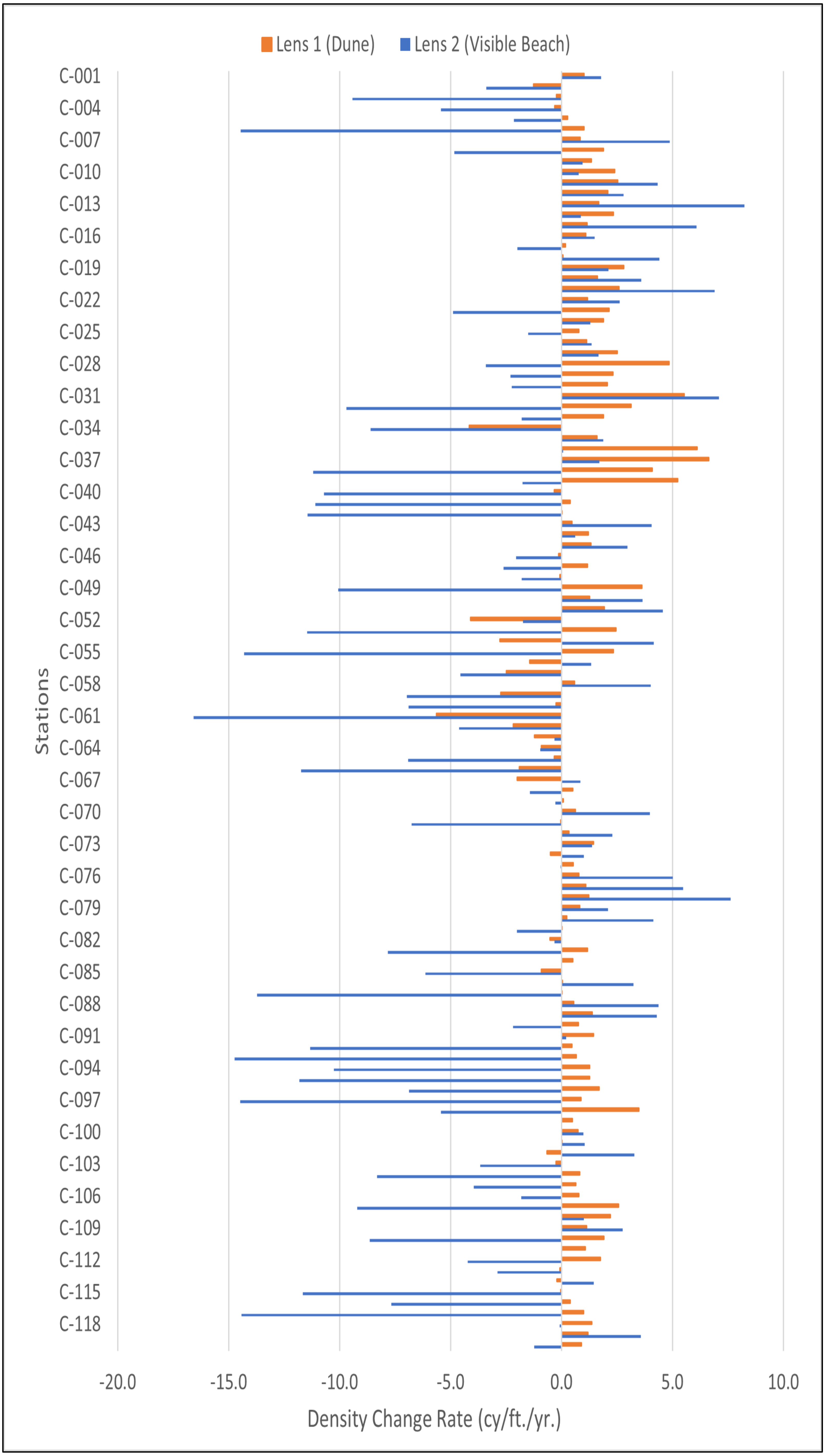

Figure 23. Volume Change Rate Lens 1 and Lens 2 - May 2020 to May 2022

Figure 24. 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 May 2022 within the Inner Nearshore Lens was +6.9 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 1,647,400 cubic yards. As shown in Table 18, the average rate of change and total volumetric change was positive in all Sections of the project, except for the Pine Island Section. The average volumetric change rates within the Inner Nearshore Lens in the Carova and Reserve/Refuge Sections were +10.8 cy/ft./yr. and +10.2 cy/ft./yr., respectively. The average volumetric change rate in the Corolla Section was +6.7 cy/ft./yr. The average volumetric change rate in the Pine Island Section was -3.4 cy/ft./yr., which is the only section to experience a negative change within the Inner Nearshore Lens. Negative volumetric changes were measured along twelve (12) of the nineteen (19) profiles along the Pine Island Section within the Inner Nearshore lens (Figure 25). A negative volumetric change of -46.4 cy/ft./yr. was measured along the profile at the north end of Salt House Road (C-117). This rate is more than twice the next highest negative rate measured along any of the profiles along the Assessment Area between May 2020 and May 2022. The significant volumetric loss appears to be due to the formation of a deep trough, which can be seen in Figure 26. The average rates of volumetric change and total volumetric change calculated for the Inner Nearshore Lens along the entire Assessment Area and each of the four (4) Sections are provided in Table 18. The rates of volumetric change for each station are provided in Table 19 and are shown graphically in Figure 25.

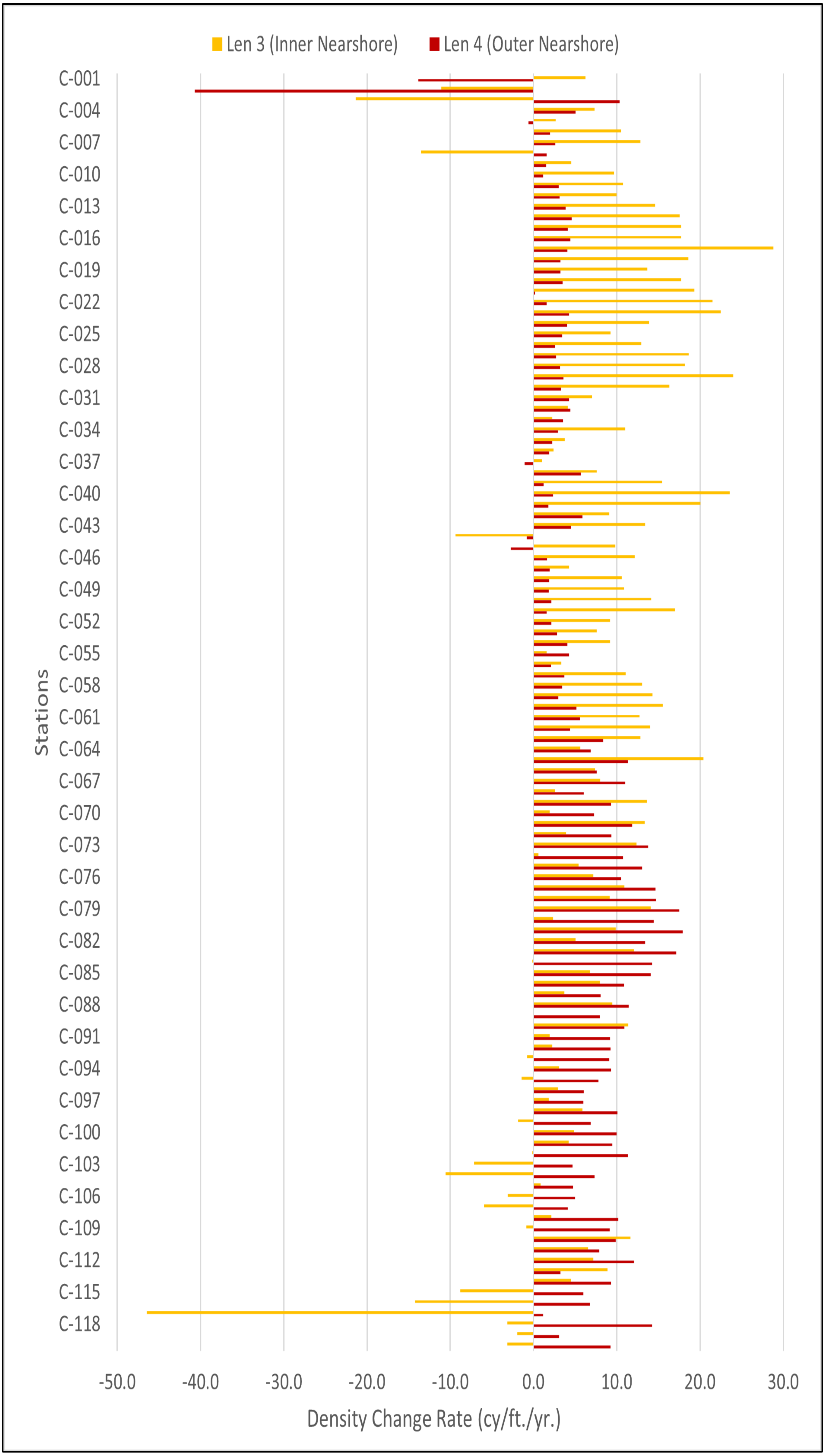

Figure 25. Volume Change Rate Lens 3 and Lens 4 - May 2020 to May 2022

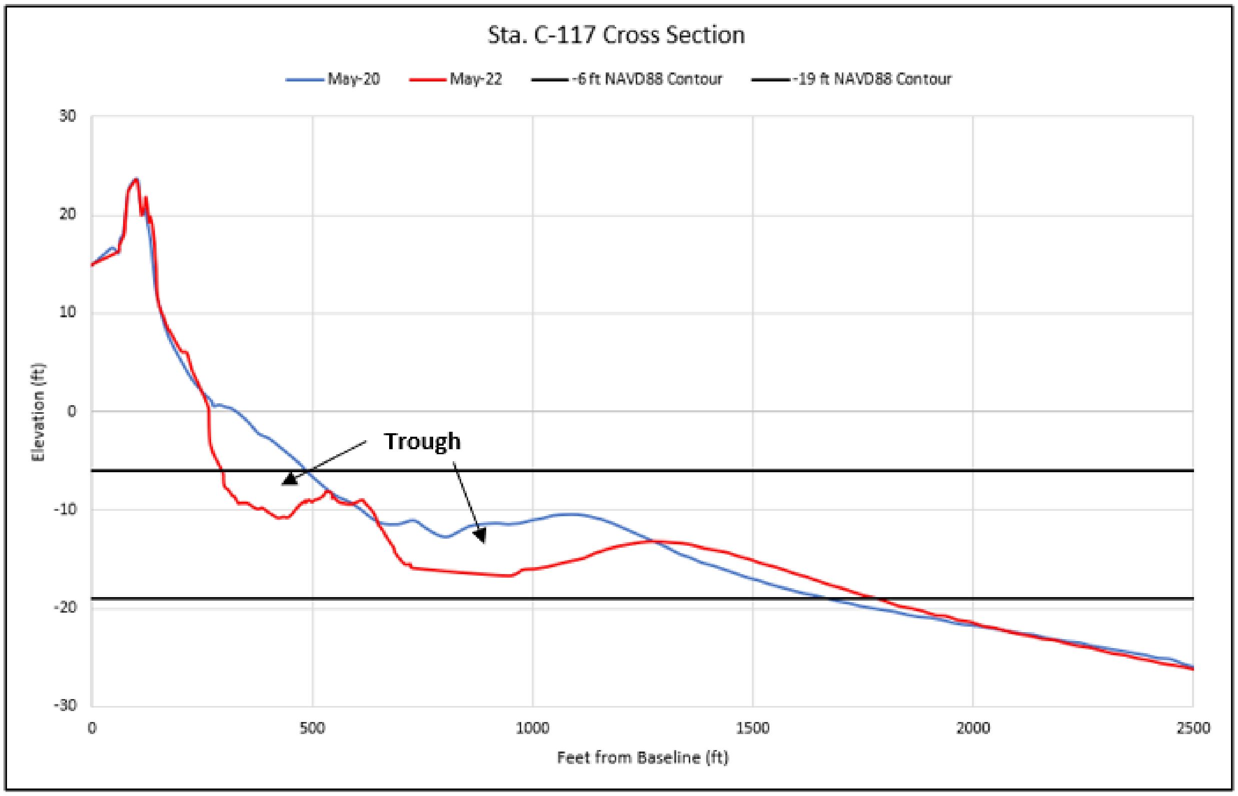

Figure 26. Cross Section of Sta. C-117 Depicting the Deep Trough that Formed between May 2020 and May 2022.

Lens 4 (Outer Nearshore): The average volumetric change rate measured between May 2020 and May 2022 within the Outer Nearshore Lens was +5.7 cy/ft./yr. Note that for the Carova and Reserve/Refuge Sections the offshore limit of the Outer Nearshore Lens is -22 ft. NAVD88 and for the Corolla and Pine Island Sections the offshore limit is -25 ft. NAVD88. Positive volumetric changes in the Outer Nearshore Lens were calculated in each of the four (4) Sections of the Project Area. The average volumetric change rates measured along the Carova, and Reserve/Refuge Sections were +0.9 cy/ft./yr. and +2.6 cy/ft./yr., respectively. South of the Horse Gate, in the Corolla and Pine Island Sections, the volumetric change rates measured were +10.1 cy/ft./yr. and +7.3 cy/ft./yr., respectively. The lower rates measured north of the Horse Gate is likely a function of the offshore limit of the Outer Nearshore Lens in the Carova and Reserve/Refuge Sections being shallower (-22 ft. NAVD88) compared to the offshore limit of the Outer Nearshore Lens used for the Corolla and Pine Island Sections (-25 ft. NAVD88). The average rates of volumetric change and total volumetric change calculated for the Outer Nearshore Lens along the entire Assessment Area and each of the four (4) Sections of the project are provided in Table 18. The rates of volumetric change for each station are provided in Table 19 and are shown graphically in Figure 25.

5.3 Pine Island Section Long-Term 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 5.2 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 May 2022 (CPE) to provide additional long-term volumetric change trends where data exists. The average volumetric change rate between September 2015 and May 2022 along the Pine Island Section was -5.0 cy/ft./yr., resulting in a cumulative negative volumetric change of approximately 586,000 cubic yards. Table 20 lists the individual volumetric change rates computed for each profile out to the -19 ft. NAVD88 contour between September 2015 and May 2022. The rates provided in Table 20 represent volumetric changes out to the -19 ft. NAVD88 contour.

Table 20. Pine Island (C-102 to C-120) CSE and CPE Density Change Rate Comparison (cy/ft./yr.)

Stations	September 2015 to May 2022
C-102	-8.5
C-103	-7.6
C-104	-9.1
C-105	-2.9
C-106	-9.3
C-107	-3.3
C-108	-0.4
C-109	-0.5
C-110	-1.2
C-111	-0.6
C-112	-2.5
C-113	0.5
C-114	-3.2
C-115	-8.1
C-116	-9.6
C-117	-20.5
C-118	-1.8
C-119	-0.7
C-120	-5.9
Average	-5.0
Max	0.5
Min	-20.5

Figure 27 shows a graphical comparison of the 2015 to 2022 rates. Negative volumetric changes were measured along eighteen (18) of the nineteen (19) profiles along the Pine Island section. A negative volumetric change of -20.5 cy/ft./yr. was measured along the profile at the north end of Salt House Road (C-117). This rate is more than twice the next highest rate measured along any of the profiles along the Pine Island Section between September 2015 and May 2022. The significant negative volumetric change along this profile appears to be due to the formation of a deep trough, which occurred between May 2020 and May 2022 (Figure 26).

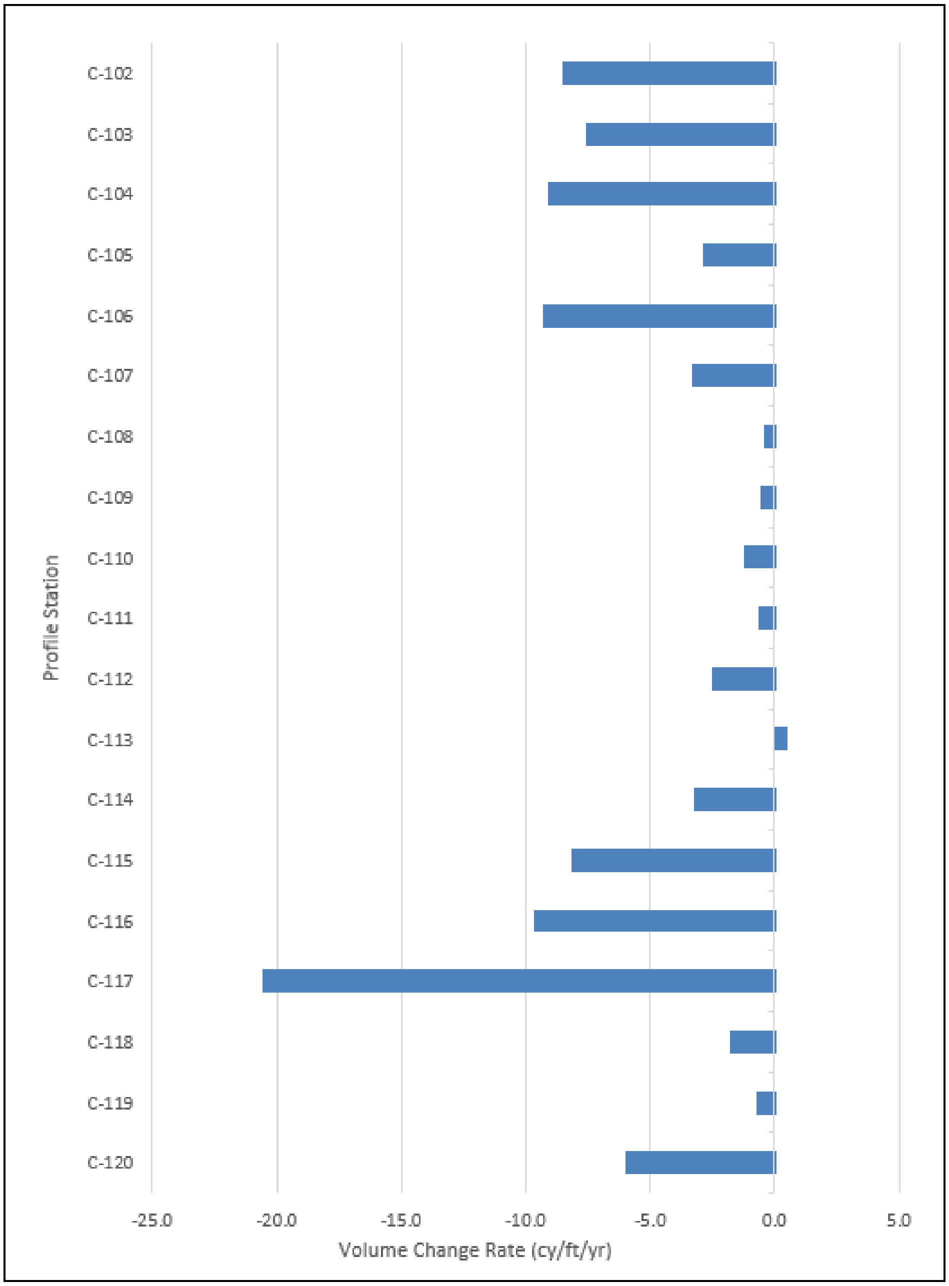

Figure 27. Pine Island (C-102 to C-120) Volume Change Rates Above -19.0 ft. NAVD88 – Sept. 2015 to May 2022

6 NEARSHORE BATHYMETRIC ANALYSIS

As discussed in Section 2.5, beach profile data are typically used to calculate volume changes using the average end area method which assumes that bathymetric contours running parallel to shore between the profiles are relatively parallel to the shoreline. While this is generally a safe assumption along many beaches, several studies conducted offshore of the Outer Banks over the past 20 years have identified deep depressions or troughs and shore oblique sandbars. These features have been observed and studied offshore of Kitty Hawk and Kill Devil Hills (APTIM, 2019a and APTIM, 2019b). Furthermore, the previously cited CSE study commissioned by The Pine Island Property Owner's Association (PIPOA), included offshore data suggesting that similar features may be present offshore of Currituck County (CSE, 2018).

As part of both the Year-1 (2020) and Year-3 (2022) data acquisition campaign, a shore-parallel bathymetric survey was conducted along the entire Assessment Area to supplement shore-perpendicular beach profile data collected approximately every 1,000 feet. The total length of the survey area was approximately 119,500 ft. (approximately 22.6 miles). The shore-parallel bathymetric data were collected from approximately the -12 ft. NAVD88 contour out to approximately 3,000 ft. offshore. Survey lines were laid out to run parallel to shore and spaced approximately 200 ft. apart. Data acquired along the shore-parallel tracklines were post processed, combined with bathymetric data collected along the 120 beach profiles surveyed and incorporated into bathymetric charts. The bathymetric charts developed using the 2022 data are included in Appendix E. The bathymetric charts developed using the 2020 data were included in Appendix A of the Data Acquisition Report: 2020 Currituck County Beach Monitoring and Beach Stability Study (CPE, 2020).

A review of the bathymetric surface developed from the 2022 data shows the presence of deep depressions or troughs and shore oblique sandbars similar to those identified offshore Dare County. Those features are located along the following positions of the Project Area:

- Carova Section – Between the northern County boundary and Sturgeon Lane (C-001 to C-009).
- Carova Section – Between Mallard Lane and Bitter Root Lane (C-015 to C-022).
- Reserve/Refuge Section – Between Albatrose Lane and Munson Lane (C-037 to C-046).
- Pine Island Section – Between the Pine Gate Road and the southern County boundary (C-107 to C-120).

A qualitative comparison of the bathymetric surface developed from the 2022 data and the Year-1 monitoring bathymetric surface developed from the beach profile data and shore-parallel data collected in 2020, indicates that the depressions and troughs observed offshore of the Assessment Area are mobile. In general, between May 2020 and May 2022, the features appear to have migrated south between 500 and 1,000 feet. Furthermore, the inshore extent of these features appears to have migrated landward over the monitoring period. The bathymetric data collected does not extend far enough seaward to resolve the full extent of these features, but the inshore extent of the features have clearly moved landward over the period. The landward movement of these features over the monitoring period aligns with the observations of positive volumetric changes measured in the nearshore portion of the Project Area, which is discussed in greater detail in Section 8.2.

7 BEACH VULNERABILITY ANALYSIS

7.1 Introduction

To assess the impact of storm damage on the existing beach, a vulnerability analysis was conducted to determine the degree to which oceanfront development may be vulnerable to a specific design storm. The nature of this vulnerability analysis is comparable to the vulnerability analysis employed by CPE in the evaluation of storm vulnerability for the neighboring Outer Banks communities of Duck (CPE-NC, 2013), Southern Shores (APTIM, 2018), and Kill Devil Hills (CPE-NC, 2015). The approach focuses on potential damage associated with a "design storm" or a range of potential "design storms". Given the overall goal of the County in commissioning this study is to assess the stability and conditions of the beach, CPE recommended that the initial vulnerability analysis use a "design storm" having similar characteristics as Hurricane Isabel, which impacted the Outer Banks in 2003. The relatively recent occurrence of this particular storm, which resulted in widespread impacts to the Outer Banks, provides those with firsthand knowledge of the event, a tangible frame of reference to understand the vulnerability analysis.

The analysis utilized the Storm Induced Beach Change Model, SBEACH, developed by Larson and Kraus (Larson and Kraus, 1989) for the US Army Corps of Engineers (USACE). SBEACH is a two-dimensional model which simulates changes in the beach profile that could result from coastal storms of varying intensity in terms of storm tide levels, wave heights, wave periods, and storm duration. Information required as input to run the SBEACH model includes the beach cross-section, the median sediment grain size, and time histories of the wave height, wave period, and water elevation for the design storm.

An initial vulnerability analysis was conducted in Year-1 (2020) of the study (CPE, 2020). The initial study utilized the Year-1 (2020) beach profile data and a previously calibrated model used by CPE for similar studies for the Towns of Duck, Southern Shores, and Kill Devil Hills. As described in Section 7.2, the updated vulnerability analysis presented in this report using May 2022 conditions, used a different method to develop wave data for the model. This method built on lessons learned from recent studies conducted in Northern Dare County that used a similar method (CPE, 2021c).

The results of the SBEACH model are used to assess the relative health of the beach and dune system in terms of providing a particular level of storm damage reduction to public and private development along the County's oceanfront shoreline. Specifically, the results are used to identify houses within the Assessment Area that could be impacted by the design storm under existing conditions. Note this analysis only identifies which houses could experience damage due to storm induced erosion caused by a storm having similar characteristics to Hurricane Isabel. The analysis is based on the impacts to the beach system as a result of the oceanographic conditions generated by the design storm.

7.2 Methods

The design storm used in the vulnerability assessment was based off Hurricane Isabel which impacted the Outer Banks in early September 2003. The initial SBEACH evaluations conducted as part of the Year-1 (2020) vulnerability analysis used wave data from USACE Wave Information Studies (WIS) Station 63216, located offshore Currituck County (Easting: 2979699.565 ft., Northing: 988235.374 ft. NAD83) in 72 ft of water. However, wave modeling conducted for the 4 Towns of Dare County (CPE, 2021b, CPE, 2021c, and CPE, 2021d) indicated that offshore features off the coast of North Carolina influence wave transformation in deeper water depths and therefore, the WIS data may not adequately reflect wave conditions for SBEACH simulations.

A multistep process was developed to account for variability in wave characteristics offshore of Currituck County. A Delft3D-WAVE model was set up consisting of two grids; a coarse offshore grid to transform waves from deep water to shallow water and a finer nearshore grid nested in the coarser grid to simulate wave conditions nearshore. Wave characteristics for each Currituck County profile were then extracted from the Delft3D model output at -30 ft. water depth and used to force the SBEACH simulation.

The output from the SBEACH simulations represent post-storm conditions along the profiles. These output data were evaluated to identify the most landward point of the profile at which the post-storm profile elevation was one (1) foot lower in elevation than the pre-storm profile. Comparing the location of this "impact point" to the position of oceanfront houses and public infrastructure, provided insight into the vulnerability of said houses and infrastructure to the design storm conditions.

7.3 Application

The SBEACH analysis conducted as a part of this study identifies structures that could be impacted due to storm induced beach erosion caused by a storm having similar characteristics to Hurricane Isabel. A one (1) foot vertical change in profile elevation from the pre-storm to the post-storm condition has been identified as a reasonable threshold for estimating when structures become vulnerable to wave damage, including undermining and/or inundation (Larson, et al., 1998). This analysis identified a house as "impacted" if any part of the structure was within 15 feet of the landward most location where the profile was lowered by 1-foot in the storm simulation.

The following basic assumptions underlie the SBEACH model:

- Breaking waves and variations in water level are the major causes of sand transport and profile response.

- The median sediment grain diameter along the profile is reasonably uniform across the shore.
- The shoreline is straight (i.e. the longshore effects are negligible during simulation period).
- Linear wave theory is applicable throughout the beach profile.

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 houses. If the County requires this type of economic impact, additional analyses will be required.

7.4 Data

Datasets employed in this analysis include oceanographic, meteorological, and bathymetric /topographical. Oceanographic and meteorological data collected during Hurricane Isabel were used to define the storm event simulated in the modeling analysis; storm data were obtained between August 30 and September 22, 2003. The May 2022 beach profile data collected as part of this study are the primary source of bathymetric/topographical data. Details regarding each dataset used in this analysis are discussed in the following sections. Where applicable, the location of the measurement devices (wave gauges, tide gauges, etc.) are referenced to the North Carolina State Plane Coordinate System.

7.4.1 Wave Data

For the SBEACH analysis done in 2020, data such as wave height, wave period, and wave direction were taken from USACE Wave Information Studies (WIS) Station 63216, located offshore of Currituck County (Easting: 2979699.565, Northing: 988235.374, feet NAD83) in 72 ft of water. However, it was found that features off the coast of North Carolina influence wave transformation in deeper water depths and therefore, the WIS data may not adequately reflect wave conditions for SBEACH simulations.

A multistep process was used to develop modified wave data more representative of conditions off Currituck County as a result of Hurricane Isabel. The process began with the setup of a Delft3D-WAVE model consisting of a coarse offshore wave grid with a resolution of about 500 m to 530 m, and a nearshore grid with a finer resolution of about 150 m to 240 m along the shoreline nested in the coarser grid. Figure 28 shows the extent of both the coarse offshore wave grid and the finer resolution nearshore wave grid.

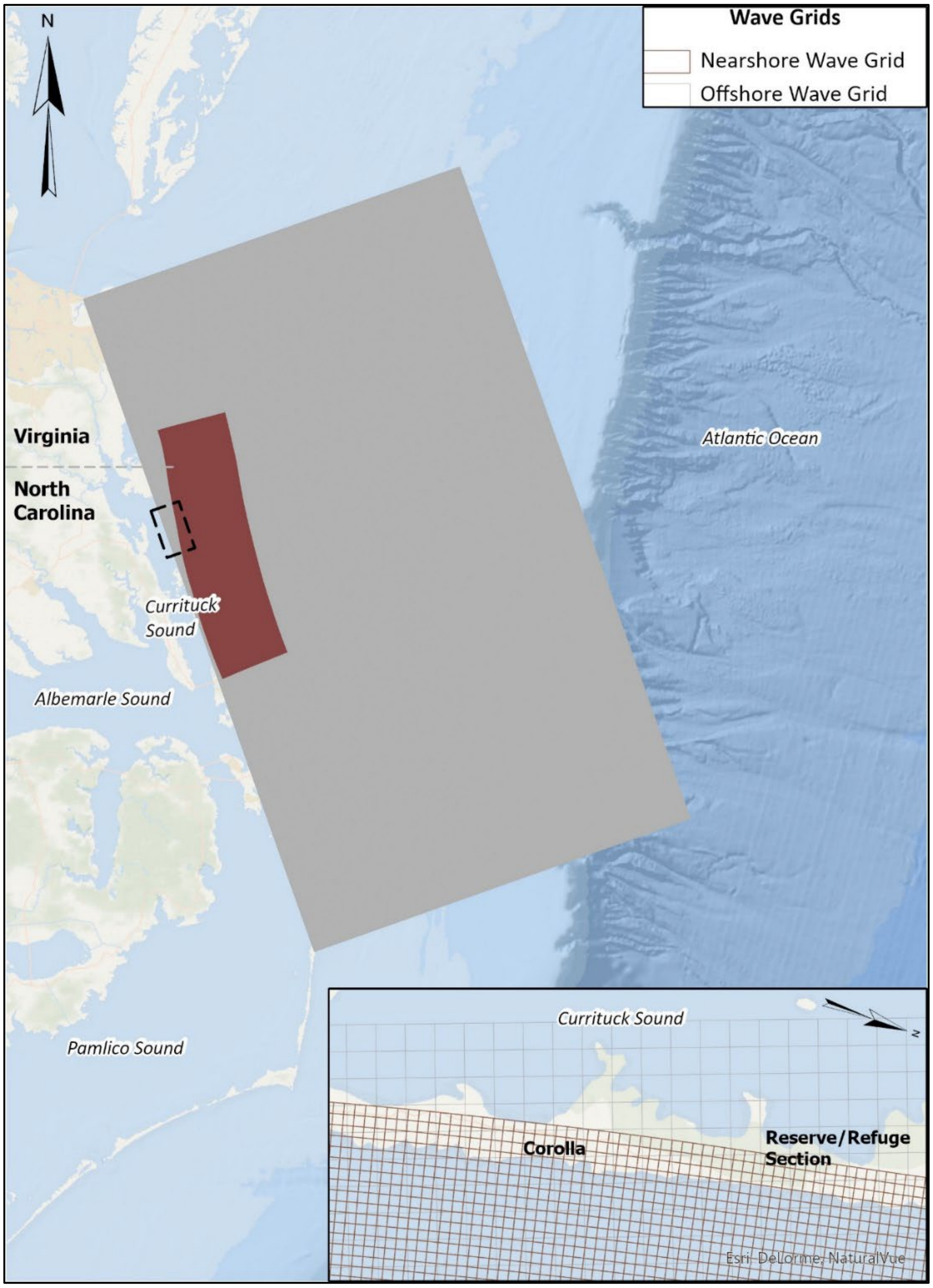

Figure 28. Location map showing the offshore wave grid (gray) and nearshore wave grid (brown).

Wave data offshore of Currituck County was obtained from a hindcast system, calibrated with 41 years of past data, which was developed by CPE for wave modeling offshore of the northern Outer Banks. The methodology used to develop the system is referred to as the hypercube methodology and was based on Bonanata, R. *et al.*, (2010). Boundary conditions at a depth of approximately 164 feet of water (50 meters) were obtained from the hindcast system to force the Delft3D model. Waves were transformed throughout the model domain and were then compared to measured data collected from the FRF630 buoy (55 feet of water). The Delft3D model was calibrated to produce simulated wave data similar to the measured data from the FRF630 buoy.

Once the Delft3D-WAVE model was calibrated, boundary conditions for Hurricane Isabel were obtained from the hindcast system and were used to force the wave model. Graphical representations of this data are provided in Figure 29. The model transformed the wave data throughout the model domain, which included the offshore portion of Currituck County. Model results were compared to measured data collected at FRF630 buoy for model verification (Figure 30). The Pearson's correlation coefficient for significant wave height was 0.92, with 1 representing a perfect correlation. The satisfactory agreement between measurement and simulation indicates that the wave model was effectively able to simulate Hurricane Isabel conditions in the study area.

Simulated wave data were then extracted from the model at the most seaward point at which beach profile data were collected during the May 2022 surveys (approximately -30 ft. NAVD88). Significant wave heights obtained from the Delft3D model at the -30 ft. NAVD88 depth contour at the peak of Hurricane Isabel across Currituck County are illustrated in Figure 31. These wave parameters were then used as the offshore wave condition to force the SBEACH model.

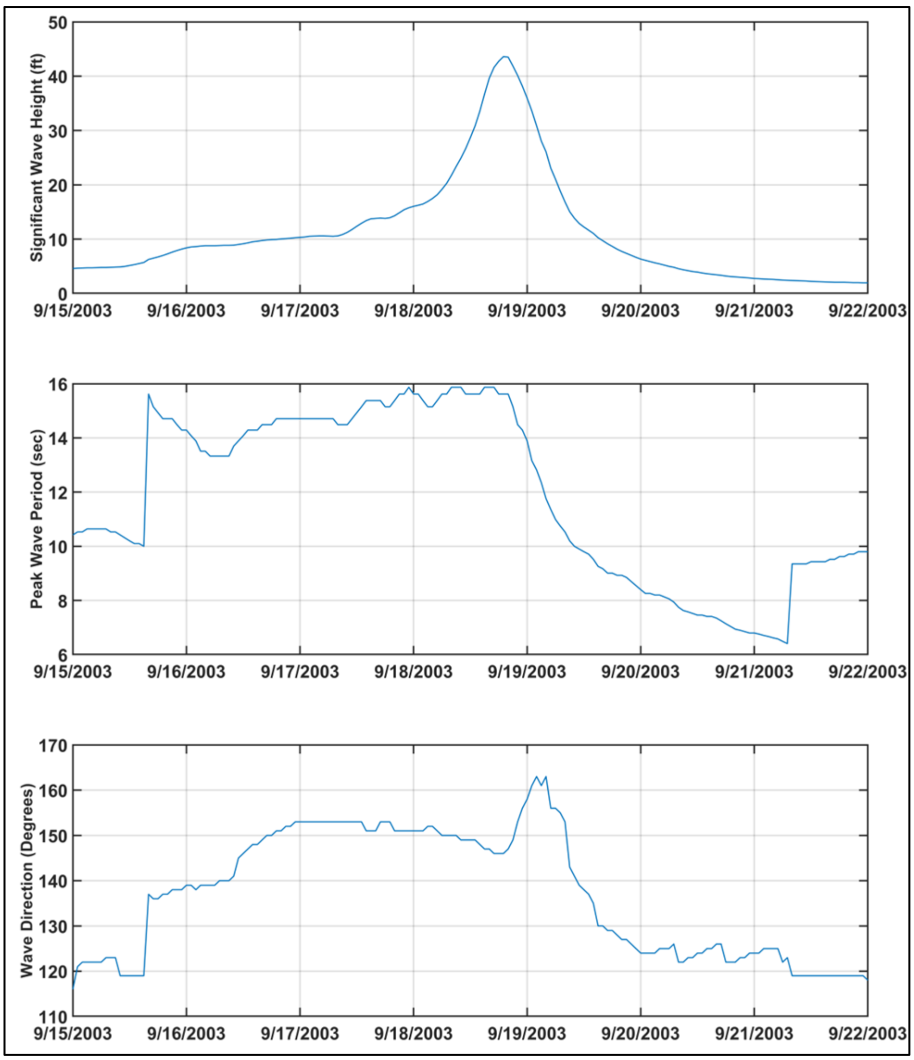

Figure 29. Wave input boundary conditions from the hindcast system representing offshore conditions for Hurricane Isabel.

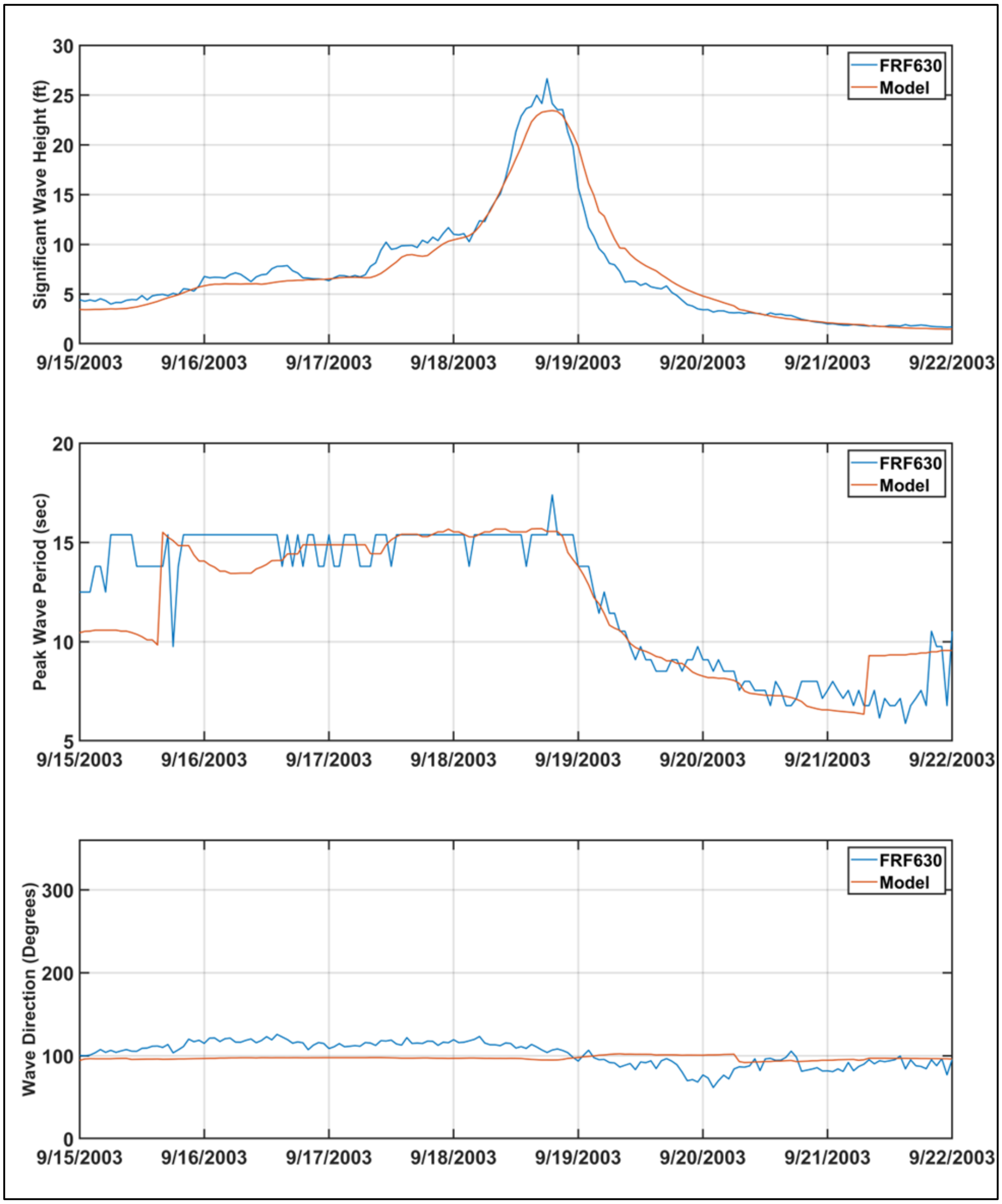

Figure 30. Comparison of measured and simulated wave parameters using the FRF630 gauge located in approximately 55 feet of water.

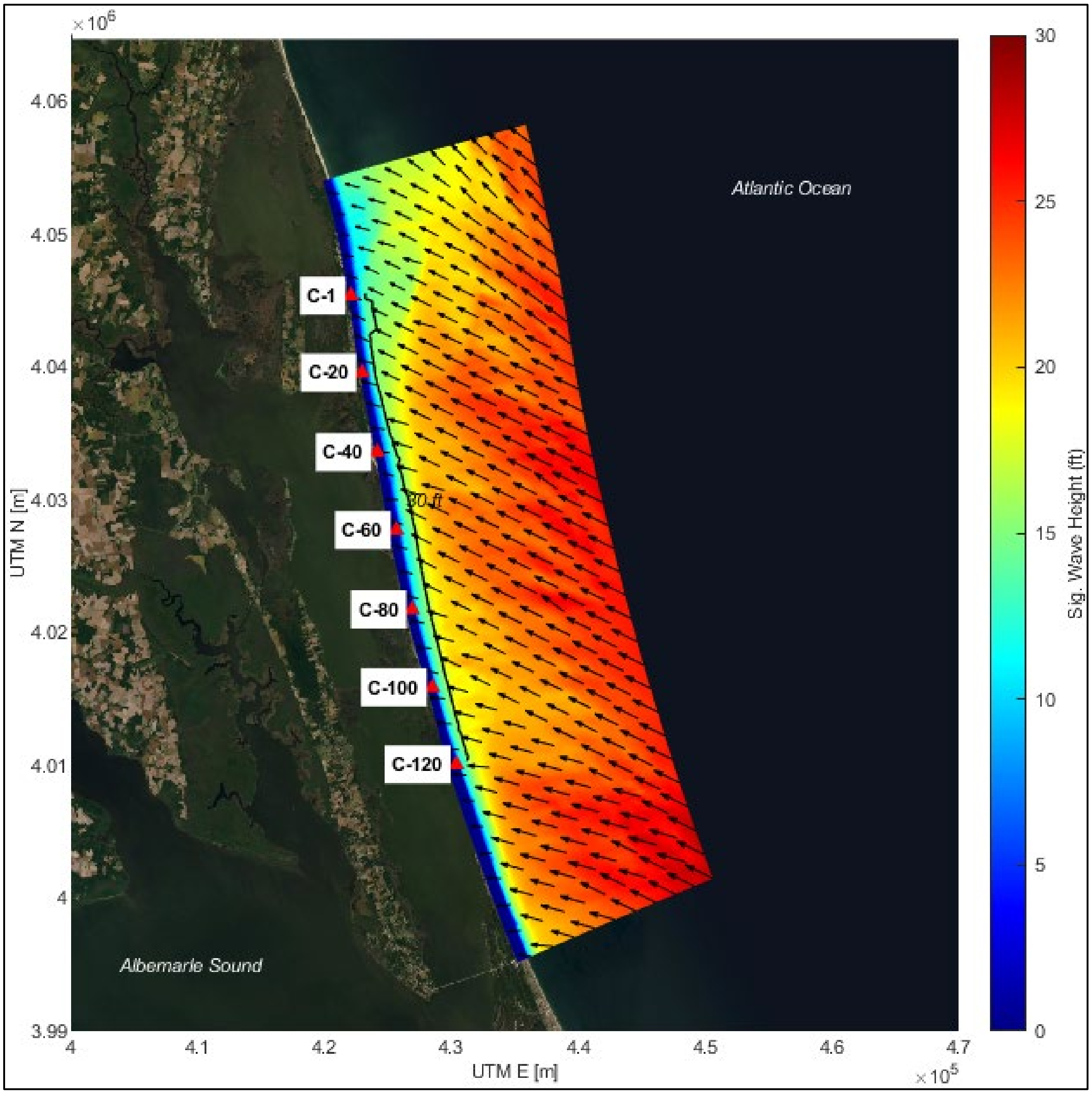

Figure 31. Significant wave height variation and wave direction for the nearshore wave grid. Note the black shore parallel line represents the -30-ft. NAVD88 depth contour.

7.4.2 Meteorological Data

The initial SBEACH analysis conducted in 2020 used meteorological data such as wind speed and wind direction from WIS station 63216. For consistency, the same values were used for the updated analysis presented herein. Since the WIS meteorological data is formulated using hindcast data it was compared to the data from NOAA Station 8651370 located on the USACE FRF pier. When plotted together the data show good agreement with a Pearson's correlation coefficient of 0.96 for wind speed. The meteorological data is hindcast at an elevation of 10 m above the surface of the water.

7.4.3 Water Level Data

Water Level input data for the SBEACH model were obtained from the NOAA tide gauge at Duck, NC - Station ID: 8651370. In order to account for the increase in water level due to sea level rise over the past 19 years (2003 to 2022), sea level rise at the rate of 0.0156 (ft./yr.) was added to the 2003 water level values. The aforementioned sea level rise rate was obtained from the same NOAA tide gauge referenced above.

7.4.4 Topographic/Bathymetric Data

In order to define current conditions along the shore in Currituck County, beach profile data collected as part of this study were used as the primary topographic and bathymetric data input to run the model. Collection of these data are described in Section 2.4 and Appendix A. These data were acquired in May 2022, along each of the transect referred to in Table 4.

The modeled profiles were further developed using supplemental survey datasets to extend the profile from the landward extent of expected overwash to an offshore location beyond the depth of closure. Extending the profiles beyond the extent of the 2022 beach profile data was necessary to ensure model stability. The supplemental data used to extend the profiles landward included publicly available Lidar data collected in 2019 by the USACE. Supplemental data used to extend the profiles seaward included historic bathymetric data dating from 1939 to present, which is available within the NOAA Bathymetric Data Viewer (NOAA, 2020). Effectively, the 2022 CPE data were extended approximately 1,000 ft landward of the baseline and approximately 18,000 ft seaward. Figure 32 is an example of a modified profile used in the SBEACH model.

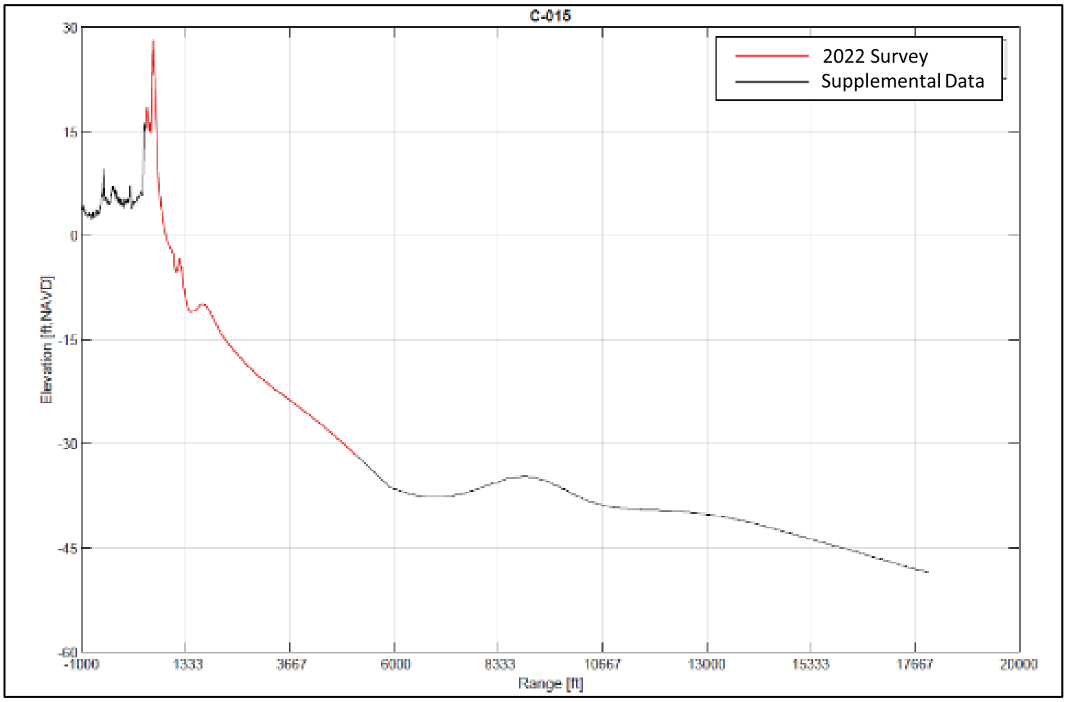

Figure 32. Typical SBEACH Profile

7.5 Model Configuration

7.5.1 Set-up

As previously described, SBEACH is a two-dimensional model which simulates beach profile changes that result from varying storm waves and water levels. These profile changes include the formation and movement of morphological features such as longshore bars, troughs, berms, and dunes. SBEACH assumes that the simulated profile changes are produced only by cross-shore processes, while longshore sediment transport processes are neglected. Simulated profile changes are driven by the cross-shore variation in wave height and wave setup calculated at discrete points along the profile from the offshore zone to the landward survey limit.

Considering that profiles are gridded within the SBEACH model, a variable grid was used to provide fine resolution to adequately detail topographic and nearshore features in the model simulation while less variable offshore bathymetry was gridded using a coarser resolution to improve model efficiency. Table 21 details the grid spacing and associated limits used within the SBEACH model.

Table 21. SBEACH Grid

Cell		Range Limits (ft)	
Width (ft)	No. of Cells	Nearshore	Offshore
5	500	-900	1,600
10	200	1,600	3,600
20	100	3,600	5,600
50	50	5,600	8,100
100	50	8,100	13,100
200	20	13,100	17,100

The acquired data described in Section 7.4 were imported into the program and sediment transport parameters were defined. The beach and sediment transport parameters must be defined by the user. Initially, the parameters chosen were those determined through a calibration and verification process undertaken by CPE for the Town of Duck in 2013 (CPE-NC, 2013). These parameters were further evaluated to determine applicability for use in the Currituck County Project Area.

7.5.2 Sensitivity Analysis

A sensitivity analysis was performed to account specifically for differences in the sediment characteristics between the Currituck County Assessment Area and the previous study in Duck, NC. With the exception of the effective grain size parameter, all other model parameters were taken from previous study in Duck, NC (CPE-NC, 2013). The effective grain size parameter was determined through an analysis of three effective grain sizes based on composites combined from sediment samples collected along the Currituck County Assessment Area during the 2020 field campaign. The three effective grain sizes were evaluated to test the sensitivity of the model to changes in grain size. The three effective grain sizes for Currituck County that were used in the sensitivity analysis corresponded to the average mean grain size of a composite of specific sediment samples collected along the Project Area, namely the Toe of Dune Composite, Subaerial Composite 1, and Subaerial Composite 2. The mean grain size of the Toe of Dune Composite, was 0.24 mm. The Subaerial Composite 1, which consists of the average mean grain size of samples collected at the Dune, Toe of Dune, Mid Berm, MHW, MTL, and MLW Composite, had a mean grain size of 0.32 mm. The Subaerial Composite 2, which consists of everything in Subaerial Composite 1 except the Dune Composite, had a mean grain size of 0.34 mm.

Based on the results of the sensitivity analysis, each of the 3 grain size composites provided reasonable model results suggesting that the other calibrated parameters were appropriate to use for the Currituck County Project Area. Given the fact that the original model was calibrated using a grain size comparable to the Toe of Dune Composite, the Currituck Toe of Dune Composite mean grain size of 0.24 mm was used as the effective grain size parameter for the model.

7.5.3 Model Parameters

The beach and sediment transport parameters used in the SBEACH production runs are summarized in Table 22.

Table 22. SBEACH Model Parameters

Parameter	Units	Value
Landward Surf Zone Depth	Ft	1
Effective Grain Size*	mm	0.24
Maximum Slope Prior to Avalanching	Deg	45
Transport Rate Coefficient	m^4/N	$2.50E^{-06}$
Overwash Transport Parameter	m^2/N	$5.00E^{-03}$
Coefficient of Slope Dependent Term	-	$2.50E^{-03}$
Transport Decay Coefficient Multiplier	-	0.5
Water Temperature	°C	20

*Variable factor between simulations

7.6 Results

As previously described, this analysis identified a house as “impacted” if any part of the structure was seaward of the most landward point of the profile at which the post-storm profile elevation was one (1) foot lower in elevation than the pre-storm profile. This point along the profile was extracted from model results along each of the simulated profiles to identify impact points. These impact points were then connected to create an impact line that was used to identify houses deemed vulnerable to the design storm parameters along the Project Area. Considering the nature of the SBEACH analysis, houses located within 15 feet of the impact lines shown on the maps included in Appendix D were considered vulnerable. This is consistent with the analyses performed by CPE for the Towns of Duck (CPE-NC, 2015) and Southern Shores (APTIM, 2018).

Using the 1-foot erosion criteria and the 15-foot buffer, the selected model simulation indicates 43 oceanfront houses are at risk of damage due to a storm similar to Hurricane Isabel. Four (4) houses along the Reserve/Refuge Section were identified as vulnerable. These houses are the same four (4) houses that were described in regard to projected shoreline recession located seaward of Sandfiddler Road along an approximately 4,000-foot portion of the oceanfront south of Canary Ln. (between station C-040 and station C-044). The largest section is comprised of 29 houses spanning along an approximate 1.0-mile portion of the Corolla Section between the northern end of Atlantic Avenue and Corolla Village Road (between stations C-061 and C-066). Farther south, all nine (9) of the oceanfront houses along Land Fall Court in the Spindrift community are also indicated as vulnerable. Four (4) of the houses are located in the Corolla Section and four (4) are located in the Pine Island Section, and the ninth house falls right on station C-102. That house is counted as one of the 34 houses listed in the Corolla Section in Table 23. One additional house was indicated as vulnerable within the Pine Island Section near the north end of Salt House Road (station C-117). The houses identified as vulnerable according to the criteria established, are highlighted on the maps included in Appendix D. The number of vulnerable houses identified in each of the four Sections of the Assessment Area are provided in Table 23.

Table 23. Number of Vulnerable House by Project Section

Section	Number of Houses Impacted
Carova (C-001 to C-027)	0
Reserve/Refuge (C-027 to C-059)	4
Corolla (C-059 to C-102)	34
Pine Island (C-102 to C-120)	5
Total Assessment Area (C-001 to C-120)	**43**

Other than identifying which buildings are vulnerable to storm damage, the analysis does not account for other potential damages that are associated with flooding and storm surge, wave impacts, or wind. The risk of a storm comparable to the design storm (Hurricane Isabel) impacting the area over the next 30 years was evaluated to provide guidance for planning purposes. In this regard, assuming Hurricane Isabel has a 4% (25-year storm) to 5% (20-year storm) chance of occurring any given year, the risk of a similar storm impacting the Currituck County Assessment Area within the next 5 years would be between 18% and 23%. Over the next 15 years, the risk would increase to between 46% and 54%. The risk of several return period events (design storms) occurring within various time periods is provided in Table 24.

Table 24. Percent Chance of the Modeled Storm Reoccurring

Time Period	Return Period Event					
(years)	1-Year	5-Year	10-Year	20-Year	25-Year	50-Year
1	100%	20%	10%	5%	4%	2%
2	100%	36%	19%	10%	8%	4%
3	100%	49%	27%	14%	12%	6%
4	100%	59%	34%	19%	15%	8%
5	100%	67%	41%	**23%**	**18%**	10%
10	100%	89%	65%	40%	34%	18%
15	100%	96%	79%	**54%**	**46%**	26%
20	100%	99%	88%	64%	56%	33%
25	100%	100%	93%	72%	64%	40%
30	100%	100%	96%	79%	71%	45%

8 CONCLUSIONS

Currituck County commissioned this three-year Beach Monitoring and Beach Stability Assessment to evaluate long-term and short-term shoreline and volumetric changes occurring along the County's beaches. The stated goals of the Assessment were 1) to better understand the changes that are occurring to the beaches and 2) to assist the County in making informed decisions regarding beach management. Furthermore, the study aimed to assess trends and provide a foundation for future coastal management of the County's oceanfront beaches through County wide data collection and beach analysis.

The conclusions provided in this section were drawn from the results of the various analyses described in this report. Furthermore, these conclusions are those most relevant to the stated goals of this study.

8.1 Shoreline Change and Projected Shorelines

Shoreline change rates measured between 2009 and 2022 were computed using a linear regression method that considers various shoreline position data available between 2009 and 2022 including shoreline positions measured during each of the three surveys conducted as part of this study (May 2020, June 2021, and May 2022). The average shoreline change rates measured along the Carova Section (Northern County boundary to Currituck Wildlife Refuge) and the Pine Island Section (500 feet north of Yaupon Lane to Southern County boundary) were -0.3 ft./yr. and -0.4 ft./yr., respectively. The average shoreline change rates measured along the Reserve/Refuge Section (Northern boundary of Currituck Wildlife Refuge to 250 feet south of the Horse Gate) and the Corolla Section (250 feet south of the Horse Gate to 500 feet north of Yaupon Lane) were -5.1 ft./yr.

Shoreline change rates measured along the Assessment Area between 2009 and 2022 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 D. The projected shorelines were then compared to the footprint of oceanfront houses and roads to evaluate potential impacts over the various time horizons. Given the relatively low shoreline change rates measured along the Carova and Pine Island Sections, no houses were shown to be impacted over the 10-, 20-, or 30-year time horizon based on the shoreline projections.

Given the higher shoreline change rates in the Reserve/Refuge and Corolla Sections as well as the relatively small setback from the shoreline to the oceanfront houses along some portions of these Sections, a number of houses were identified as impacted in both Sections. Five (5) oceanfront houses within the Reserve/Refuge Section were shown to be impacted over the 30-year horizon. These houses are all located between Canary Lane and the County owned property at the south end of Ocean Pearl Road. Of the five (5) houses shown to be impacted over the 30-year horizon, four (4) of the houses were shown to be impacted over the 20-year horizon and three (3) were shown to be impacted over the 10-year horizon. While the number of houses shown to be impacted by the projected shorelines over the various time horizons along the Reserve/Refuge Section may not seem significant, the continued retreat of the shoreline may create pinch points for traffic transiting north and south through these areas as the homes end up out on the dry sand beach.

The greatest number of impacts from projected shoreline changes were observed within the Corolla Section. In total, 158 houses were shown to be impacted over the 30-year horizon throughout the Corolla Section. These houses are all located between the Horse Gate and Wave Arch in the Ocean Lake community (C-080). Of the 158 houses shown to be impacted over the 30-year horizon, 66 of the houses were shown to be impacted over the 20-year horizon and 11 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. Along this approximately 1.3 mile stretch of beach, nearly every ocean front house was shown to be impacted over the 30-year horizon. Approximately 40% of the oceanfront houses along this section were shown to be impacted over the 20-year horizon and all 11 of the houses in the Corolla Section shown to be impacted over the 10-year horizon are along this stretch of beach. Furthermore, portions of the road along both Atlantic Avenue and Sandcastle Drive are shown as impacted over the 30-year horizon.

Moving south along the Corolla Section, 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 1.9 miles of Lighthouse Drive, approximately 30% of the oceanfront houses were shown to be impacted over the 30-year horizon, and only one of those oceanfront houses was shown to be impacted over the 20-year horizon. Along the southern 1.0 mile of Lighthouse Drive, over 95% of the oceanfront houses were shown to be impacted over the 30-year horizon and approximately 55% were shown to be impacted over the 20-year horizon.

The southernmost cluster of oceanfront houses within the Corolla Section that were shown to be impacted over the various time horizons based on projected shoreline change rates, are located in the Crown Point community (between station C-085 and C-086) and the Ocean Lake community (between station C-087 and C-088). Four (4) of the oceanfront houses in the Crown Point community were shown to be impacted over the 30-year time horizon. All eight (8) of the oceanfront houses along Tide Arch within the Ocean Lake community were also shown to be impacted over the 30-year time 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 May 2022 indicate average positive shoreline change rates along the Carova, Reserve/Refuge, and Pine Island Sections. However, the average shoreline change rate along the Corolla Section was -3.4 ft./yr. While some of the variation between recent rates and longer-term rates (2009 to 2022) is attributed to seasonal variation, continued monitoring of the Assessment Area is important to track changes in trends and plan accordingly.

8.2 Volume Change

On average, the data collected in 2020, 2021, and 2022 indicate positive volumetric changes along the Project Area. The average volumetric change rate along the entire Assessment Area was +5.5 cy/ft./yr. between 2020 and 2022; this equates to a net volume gain of 1,314,600 cy. The majority of the volumetric gains were measured north of the Horse Gate along the Carova and Reserve/Refuge Sections. In those two sections, a net positive volume change of approximately 1,176,000 cy was measured between May 2020 and May 2022. South of the Horse Gate, a net positive change of approximately 138,700 cy was measured between 2020 and 2022. A positive volumetric change of approximately 363,500 cy was measured along the Corolla Section during this time period; whereas along the Pine Island Section, a negative volumetric change of approximately 224,800 cy was measured.

The negative volumetric changes measured over the monitoring period in the Pine Island Section were primarily driven by changes that occurred between the +6.0 ft. NAVD88 contour and the -19.0 ft. NAVD88 contour. Furthermore, most of the volumetric changes measured occurred between June 2021 and May 2022. A net volume loss of approximately 459,000 cy was measured along the Pine Island Section between June 2021 and May 2022. Also of note regarding volumetric changes in the Pine Island Section is the anomalous negative volumetric change rate of -149.5 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 formation of a large nearshore trough and truncated bar, which was not present in June 2021.

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 Project 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 Project 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 is scheduled to be re-nourished in 2023. Despite the need for renourishment projects north and south of Currituck County, the data collected between 2020 and 2022 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 May 2022, 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 +0.8 cy/ft./yr. Gains in the Dune portion along the Carova, Reserve Refuge, and Pine Island Sections were similar ranging from +1.3 cy/ft./yr. in the Carova and Reserve Refuge Section to +0.9 cy/ft./yr. in the Pine Island Section. However, the rate of volumetric gain was only +0.1 cy/ft./yr. in the Dune portion of the Corolla Section. This lower average rate in the Corolla Section was likely influenced by negative volume changes measured in the dune from the Horse Gate south to just north of Strong Ct. (stations C-059 to C-067).

Of the four different lenses evaluated, the only lens in which negative volume changes were measured on average along the entire Assessment Area was the Visible Beach. This portion of the beach extends from the +10.0 ft. NAVD88 contour seaward to the -6.0 ft. NAVD88 contour. Between May 2020 and May 2022, the average volumetric change rate within the Visible Beach portion of the Project Area, was -2.2 cy/ft./yr. The average rate of change was negative in each of the four (4) Sections, except for the Carova Section.

When combined, the positive volume change observed in the Dunes and the negative volume change observed within the Visible Beach resulted in a net negative volume change of approximately 332,700 cy along the entire Project Area. However, significant positive volumetric changes measured in the Inner Nearshore portion of the beach resulted in a net positive volumetric change along the Assessment Area between May 2020 and May 2022. 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 May 2022 along the Inner Nearshore portion of the beach was +6.9 cy/ft./yr., which equates to 1,647,400 cy. This significant increase in volume in the Inner Nearshore portion of the beach, which is nearly five (times) greater than the negative 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 May 2022. More specifically, south of the Horse Gate in the Corolla and Pine Island Sections, a net positive volumetric change of approximately 1,138,300 cy was measured between May 2020 and May 2022 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 project 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 (May 2020 to May 2022) differed significantly from the wave climate during the study period. Figure 33 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.

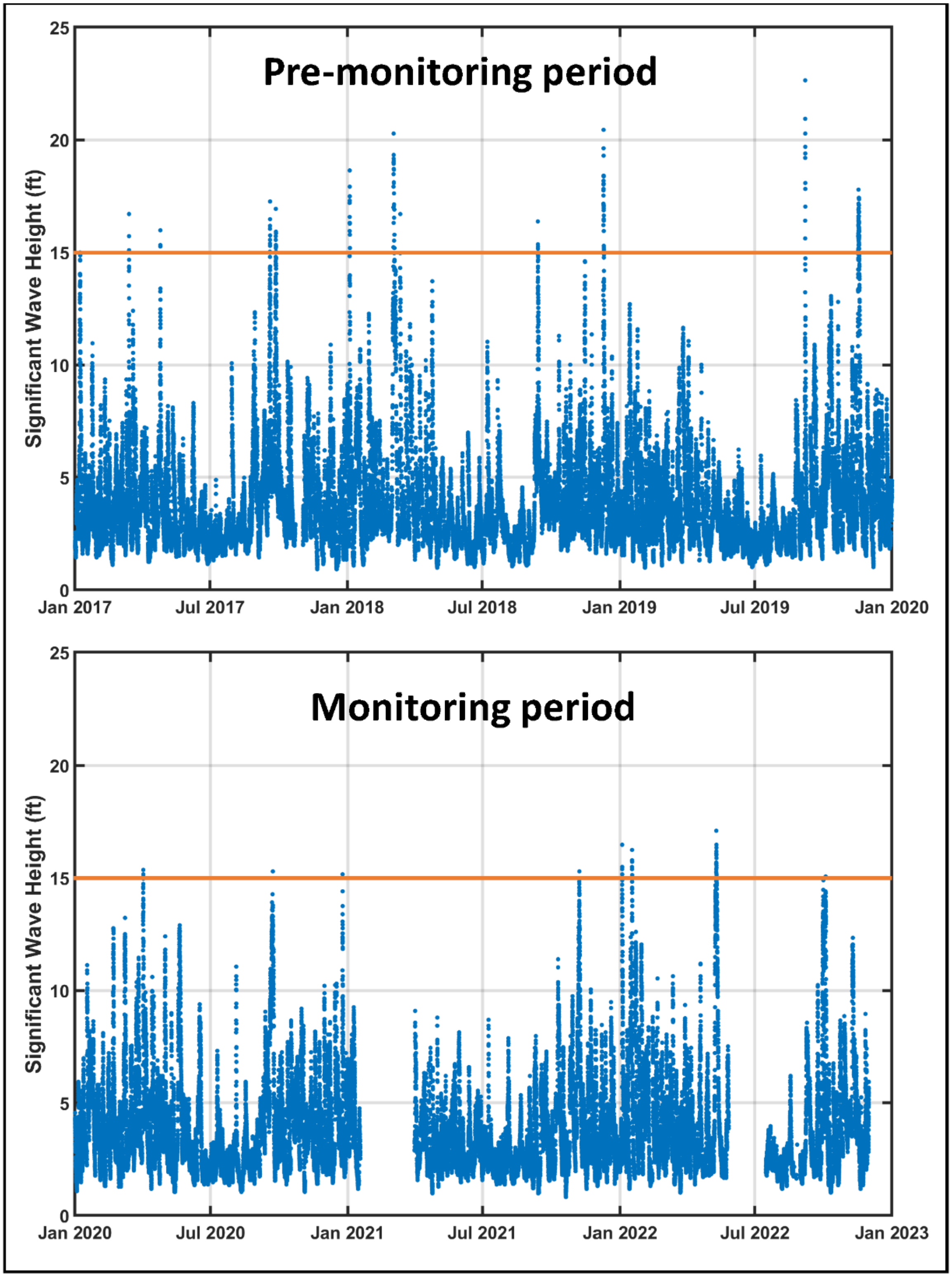

Figure 33. Significant Wave Height data for waverider buoy located in 26 m of water offshore Duck, NC (Station 44100) prior to and during the monitoring period.

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 January 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 33, indicates that generally, the monitoring period (May 2020 to May 2022) 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 proceeding three years (January 2017 to January 2020).

A closer examination of monitoring data collected from Sandbridge, Virginia and in Southern Shores, Kitty Hawk, and Kill Devil Hills, North Carolina, indicated positive volumetric changes between 2020 and 2022. 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 May 2022 monitoring period may be explained as a recovery following storm induced migration of sand into deeper depths offshore of the Project Area. Furthermore, if this explanation holds true, then negative volume change trends may follow this temporary period of recovery.

8.3 Beach Vulnerability

The Vulnerability Analysis conducted through the use of the SBEACH model, coupled with the results of the shoreline projections provides useful information to determine future vulnerability of public and private development along the County's oceanfront beach. In total, 43 oceanfront homes were determined to be vulnerable from a storm similar in characteristics to Hurricane Isabel, which impacted the County in 2003. These houses were spread throughout the Project

Area, and primarily located in areas where shoreline change projections also indicated potential impacts.

No houses were identified as impacted by the SBEACH vulnerability analysis or the projected shorelines over the 30-year horizon in the Carova Section of the Project Area. In the Reserve/Refuge Section, four (4) houses located seaward of Sandfiddler Road along an approximately 4,000-foot portion of the oceanfront south of Canary Lane (stations C-040 to C-044) were identified as vulnerable through both the SBEACH analysis and projection of shoreline change rates. A fifth house, which is the southernmost oceanfront house located north of the Currituck Banks Estuarine Reserve (between station C-050 and C-051), was shown to be impacted by the shoreline change projections over the 30-year horizon; however, was not identified as vulnerable through the SBEACH analysis. These houses could impact traffic through this section of beach should a storm or continued shoreline recession result in the homes being situated on the dry or wet sand beach.

Thirty-nine (39) homes were identified as impacted by the Vulnerability analysis south of the Horse Gate in the Corolla and Pine Island Sections of the Project Area. The majority (34) are located within the Corolla Section. The largest stretch of impacted homes is located along an approximate 1.0-mile portion of the Corolla Section between the northern end of Atlantic Avenue and Corolla Village Road (between stations C-061 and C-066). Twenty-nine (29) oceanfront houses identified as vulnerable and several other oceanfront pools are located within this portion of the Project Area. This is generally the same stretch of beach in which projected shoreline recession impacts were indicated at both the 10- and 20- year horizon between the Horse Gate and Corolla Village Road.

The Vulnerability Analysis conducted as part of the Year-1 (2020) assessment indicated several houses within the Whalehead Beach community were vulnerable. The updated analysis conducted using 2022 conditions and the updated wave data do not indicate any of the oceanfront houses along the Whalehead Beach Community along Lighthouse Drive (C-069 to C-084) as vulnerable based on the established criteria. The proximity of the impact line to the oceanfront pools along this portion of the Assessment Area suggests that several pools may be vulnerable based on the established criteria.

All nine (9) oceanfront homes located along the Spindrift community were determined to be vulnerable based on the established criteria. As previously stated, the Spindrift Community was split between the Pine Island and Corolla Section. While none of these 9 homes were shown to be impacted by projected shoreline recession between the 10- and 30-year time horizons described in Section 4.3, the lack of suggested impacts due to shoreline retreat is primarily a factor of the location of the +4.0 contour in May 2022. While the average shoreline change rate along the Spindrift community (station C-101 to C-103) was -3.4 ft./yr. between 2009 and 2022, between May 2020 and May 2022, a shoreline change rate of +20.8 ft./yr. was measured along station C-102.

Although no projected shoreline recession impacts were identified along the Pine Island Section south of Yaupon Lane, one oceanfront home was identified as vulnerable through the SBEACH analysis. That home is located near the north end of Salt House Road (station C-117). The volumetric change measured at C-117 was more than twice as high as the volume change measured along any other profile in the Project Area. The significant volumetric loss appears to be due to the formation of a deep trough, which is illustrated in Figure 26.

9 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 3-year Beach Monitoring and Beach Assessment (2020 through 2022) has 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, CPE recommends the County continue to monitor on an annual basis.

   The Corolla and Pine Island Sections of the Assessment Area should be monitored on an annual basis. This recommendation is based on several factors. The first is that the majority of the houses indicated as vulnerable through both the SBEACH analysis and the projected shoreline change rates, are located south of the Horse Gate. Secondly, 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 is important to track whether the beach is still in a state of recovery or whether it reverts to a trend of volume loss. A third reason to monitor the area south of the Horse Gate on an annual basis is 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 will 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, monitoring could be conducted every other year. This recommendation is 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.

If the County decides to continue with a monitoring program, the same profiles established through this assessment 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 governments 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 recommends 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.

3. <u>Coordinate with Dare County on Regional Sand Resource Investigation:</u> Dare County recently commissioned a two-year regional sand investigation study to locate sand for future beach nourishment projects. The investigation is slated to occur over a two year period in 2023 and 2024. 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 should coordinate with Dare County on this regional sand resource investigation.

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