2021 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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12/22/21
DATE

DECEMBER 2021

EXECUTIVE SUMMARY

Currituck County has commissioned a three-year Beach Monitoring and Beach Stability Assessment to investigate 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-2 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 wave runup analysis, which was added as an additional task through a change order executed in February 2021.

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 2021 (Year-2) report serves to provide an update to the County on the 3-year study in terms of data obtained through Year 2. 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 wave runup analysis. The conclusions provided in this Year-2 report are based on data collected in Year-1 and Year-2 of a 3-year study. Following the completion of Year-3 data acquisition and analysis, a final monitoring and beach stability assessment report will be submitted to the County.

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. 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 offroad 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 Project Area has been divided into four Sections for reporting purposes. The northernmost section is referred to as Carova, which encompasses approximately 4.9 miles of the Project Area from the northern County boundary to the northern boundary of the Currituck National Wildlife Refuge. The approximately 6.0-mile section of the Project 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 Corolla, 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 Project Area is referred to as Pine Island.

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. This linear change in the position of the shoreline moving either landward or seaward, is often easier for the general public to visualize. Six (6) data sets collected between 2009 and 2021 were analyzed to determine shoreline change rates over the past 12 years. These long-term rates were determined using a linear regression method that considers each of the six data sets available over this 12-year period. The shoreline change rates computed were then used to project future shoreline changes throughout the Project Area over a 10-, 20-, and 30-year time horizon.

The projection of the shoreline change rates indicated that in general, the Carova Section and the Reserve/Refuge Section of the Project Area would experience very little impacts based on projected shoreline change rates over a 30-year horizon. No oceanfront structures along the Pine Island Section were shown to be impacted by the projected shorelines over a 30-year horizon. Two portions of the Corolla Section included a high density of oceanfront structures shown to be impacted over the 30-year and 20-year horizon.

In the Carova Section, only four (4) oceanfront houses were shown to be impacted over the 30-year horizon. These four (4) structures were located along the northern 1,500 feet of the Carova Section between stations C-003 and C-001. Three (3) oceanfront houses within the Reserve/Refuge Section were shown to be impacted over the 30-year horizon. Two (2) of the houses are located between stations C-041 and C-044 and the third is located just north of the Currituck Banks Estuarine Reserve between stations C-050 and C-051. The house located between station C-043 and C-044 was also shown to be impacted over the 20-year horizon. 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. The oceanfront houses shown to be impacted along the Corolla Section are located withing two portions of the Section. In the northern portion of the Corolla Section from the horse gate south to approximately Carotank Drive (stations C-059 to station C-065), 49 structures were shown to be impacted over the 30-year horizon. Of these 49 structures, 18 were shown to be impacted over the 20-year horizon. The second portion where oceanfront houses were shown to be impacted by the projected shoreline change, was along the central portion of the Corolla Section between 891 Lighthouse Dr. and a point located approximately 450 feet north of Dolphin St. (station C-079 to station C-082). Nineteen (19) oceanfront houses along this section were shown to be impacted over the 30-year horizon. None of the 19 structures were shown to be impacted over the 20-year horizon. In total, 68 houses were shown to be impacted over the 30-year horizon, 18 were shown to be impacted over the 20-year horizon, and no houses were shown to be impacted over the 10-year horizon.

Volume Changes: A complete volumteric analyses was completed as part of the Year-2 Assessment through a comparison of Year 1 (May 2020) and Year 2 (June 2021) data. Volume change rates measured between 2020 and 2021 show the shoreline has been highly accretional over the recent 13-month period over the entire project area. The average volumetric change rate along the entire Project Area was approximately 9.3 cy/ft./yr. between 2020 and 2021; this equates to 1,188,000 cy. The Corolla Section had the lowest rate of accretion at 6.6 cy/ft./yr. and the Pine Island Section had the highest rate of accretion at 14.0 cy/ft./yr. Only 31 out of the 120 profiles over this recent period experienced erosion. The largest portion of the gains were experienced above the -12 ft. NAVD88 contour, which had an average rate of 13.2 cy/ft./yr.

Due to the volumetric gains over the recent period, the volume envelope has gained material since 2020. As of June 2021, the volume envelope contains 10 cy/ft. more, on average, than it did in May 2020. Over the entire Project Area, the volume envelope has gained approximately 1,169,400 cubic yards since May 2020.

The Pine Island Section is the only section where long-term change rates can be calculated using CSE data collected in September 2015 and October 2017. The long-term change rates in this section are slightly negative while the short-term rate is positive. During the 2015-2021 and 2017-2021 periods, between stations C-102 and C-120 the beach lost an average of -1.2 cy/ft./yr. and -3.0 cy/ft./yr., respectively. In the same section over the recent period the beach gained 14.0 cy/ft./yr. While some of this is attributed to seasonal variation, continued monitoring of the Project Area is important to determine whether short term variations in oceanographic parameters are driving these changes in observed long-term changes.

Based on comments received by the County Commission in February 2021, CPE analyzed dune changes between 2009 and 2021. Lidar data collected in 2009 and beach profile data collected in 2021 were used to determine volumetric changes, as well as changes in the position and elevation of the seaward dune crest along each profile south of the horse gate (station C-059 to station C-120). The volumetric analysis of the dunes south of the horse gate indicated very little gain in the dune volume (<0.5 cy/ft.) between 2009 and 2021. However, the position of the dune crest moved an average of 8 feet landward between 2009 and 2021 (station C-059 to station C-120). Over the same period, the dune crest elevation increased 2.4 feet in elevation on average. The impact of this landward movement of the dune crest and the increase in elevation suggests that the dune is being compressed. In a response to erosion of the toe of the dune and occasional scarping, as well as management strategies such as the installation of sand fencing, the dune crest is moving slightly landward and gaining elevation, on average. The average landward change in the dune crest position in the Corolla Section was slightly higher than the average for Pine Island. Likewise, the elevation increase of the dune crest was slightly higher in Corolla than in Pine Island.

Wave Runup Analysis: CPE assessed the Still Water Level (SWL) and wave runup elevation for a 5-year return period storm to determine the Total Water Level (TWL) associated with such an event. FEMA uses these levels to determine whether storm damages are eligible under Category B of their Public Assistance Program. Using astronomical tides and the rise in seawater level resulting from a 5-year storm, the SWL was determined to be 4.3 ft. NAVD88. For each profile surveyed along the County's oceanfront, the TWL was computed, which is the SWL + wave runup height. The waver runup height is a function of the slope of the beach from the toe of the dune out to the mean high water (MHW) contour. In that regard, an individual TWL can be computed for each profile.

The average TWL for the project area was 13.5 ft. NAVD88. Average TWL elevations were computed for each of the four Sections of the Project Area. The average TWL elevations ranged from 12.4 ft. NAVD88 in the Reserve/Refuge Section to 15.1 ft. NAVD88 in the Pine Island Section. Following future federally declared disasters, if the dune crest elevations were to fall below the TWL elevation, those portions of the County oceanfront could be eligible for damage repair funds through FEMA's Public Assistance program.

Year-2 Summary: At the conclusion of the Year-2 analysis associated with the County's 3-year Beach Monitoring and Beach Stability Assessment, a better understanding of the changes that are occurring in the beaches and information to assist the County in making informed decisions regarding beach management have already been gained. Long-term shoreline change rates have been established for the past 12-years, which can be compared to the shorter-term rates observed over the 3-year study. In addition, the Year-2 report provides the first comparison of subsequent beach profile surveys allowing for short term volumetric changes to be computed.

Recommendations: Based on the analysis conducted by CPE during Year-2 of the Assessment, the following recommendations are provided:

1. Continue Monitoring of the Beach Profiles: Data collection along all 120 of the established beach profiles should continue as part of the Year-3 data acquisition task. These profiles 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). The collection of these data will allow for a project wide evaluation of volumetric changes from Year-1, Year-2, and Year-3. The data will allow better evaluation of short-term shoreline change trends.

2. Consider Future Shore Parallel Surveys: As discussed within the Year-1 report, deep depressions, or troughs, and shore-oblique sandbars were identified along several different segments of the Project Area. However, most of the features appear to be located seaward of the depth of closure. In essence, that means that the features may not be impacting volumetric changes from year to year. CPE recommended against the collection of the shore parallel bathymetric data in Year 2 given the goals of the 3-year study. Moving into the 3rd year of the study, CPE recommends that the shore parallel survey conducted in Year-1 be replicated in Year-3. The supplemental data would serve several purposes. First, the data would allow the tracking of the depressions and shore-oblique sandbars to determine whether they are migrating and at what rate. Second, the data will allow a more detailed analysis of volumetric changes from year 1 to 3 with respect to cross shore sediment transport that may be associated with storm impacts or recovery.

Third, if following the conclusion of the 3-year study, the County determines it wants to evaluate shore protection alternatives, the supplemental data would enhance the setup and calibration of numerical modeling that would aid in the evaluation of those alternatives. The collection of the shore parallel survey is already included in the original work order and would not require authorization of additional funds.

3. Update Storm Vulnerability Analysis: Following the collection of the Year-3 profile data, an updated storm vulnerability analysis should be completed. This analysis will be similar to that completed in Year-1, but will use profile data collected in 2022. This work is included in the existing scope of work and will provide an update of storm vulnerability throughout the project area.

2021 BEACH MONITORING AND BEACH STABILITY ASSESSMENT
CURRITUCK COUNTY, NORTH CAROLINA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

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-2 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 wave runup analysis, which was added as an additional task through a change order executed in February 2021.

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 aims 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 represents the rate change as measured from aerial photos over 50 years. While these general trends may be sufficient for establishing construction setback guidance, more detailed shoreline and volume change analyses are 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

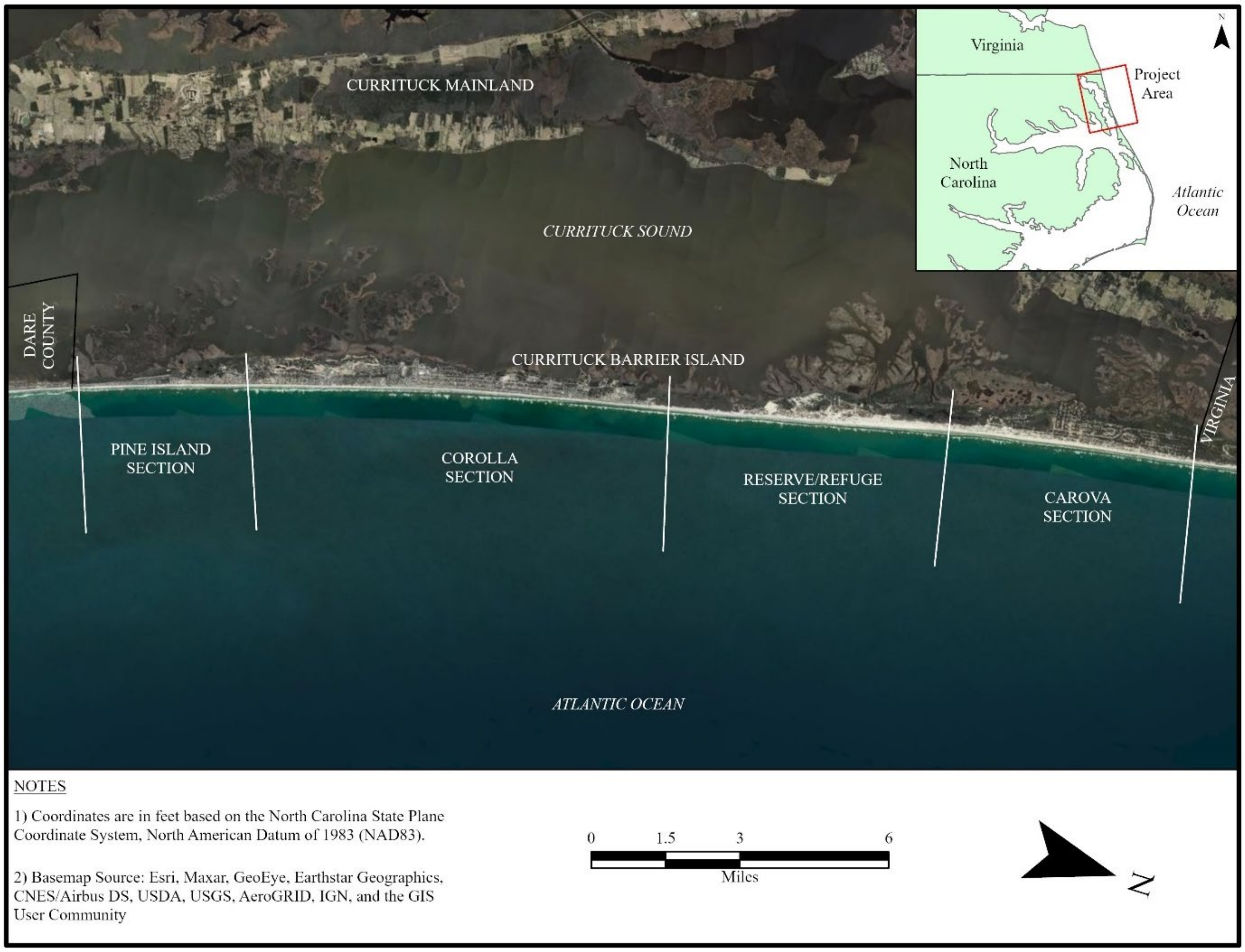
Currituck County is located on the Outer Banks of North Carolina just south of the Virginia border. The County encompasses approximately 527 square miles, which is divided by the Currituck Sound. This geographical division creates two distinct regions namely, the Currituck Mainland, and the Currituck 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 Project Area has been divided into four sections referred to throughout the report given the 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 Carova, which encompasses approximately 4.9 miles of the Project Area from the northern County boundary to the northern boundary of the Currituck National Wildlife Refuge. The approximately 6.0-mile section of the Project 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 Corolla, 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 Project Area is referred to as Pine Island. 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 location 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.



NOTES

1) Coordinates are in feet based on the North Carolina State Plane Coordinate System, North American Datum of 1983 (NAD83).

2) Basemap Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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

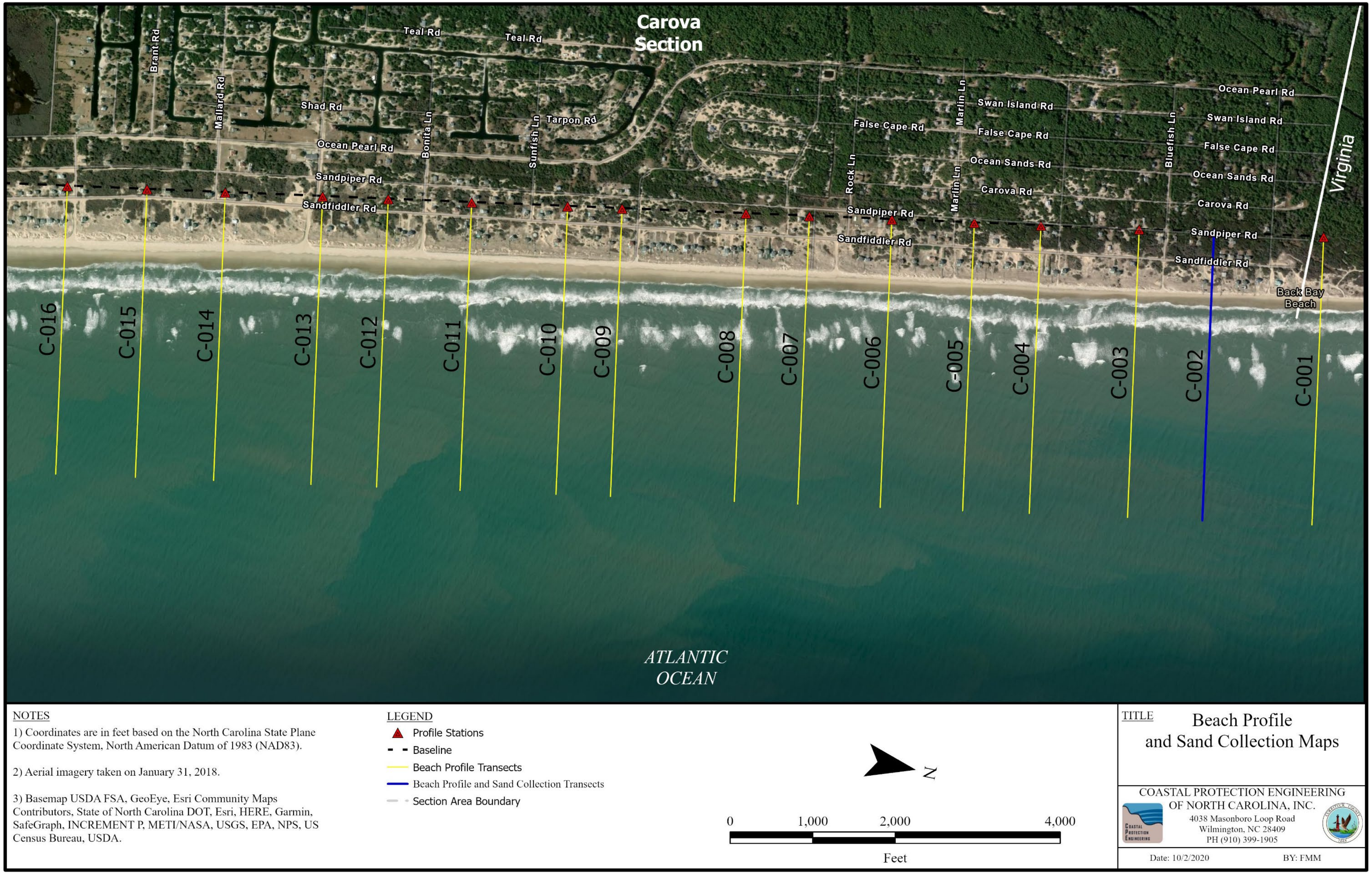
The data sets used include:

- The North Carolina Division of Coastal Management (NC DCM) long-term (approximately 50 years) average annual shoreline change rates;
- Beach profile data collected by 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);
- 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 Protection Engineering of North Carolina (CPE) in May 2020 and June 2021 along the entire oceanfront of Currituck County (station C-001 to station C-120).

Vertical data described in this report was either collected in, or converted to, the North American Vertical Datum of 1988 (NAVD88). All horizontal data is provided in the North Carolina State Plane Coordinate System, North American Datum of 1983(2011) (NAD83(2011)). Table 3 shows individual tide levels referenced to NAVD88. Beach profiles were established by CPE along a baseline that runs parallel to the Currituck County Beaches (CPE, 2020). 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



NOTES

1) Coordinates are in feet based on the North Carolina State Plane Coordinate System, North American Datum of 1983 (NAD83).

2) Aerial imagery taken on January 31, 2018.

3) Basemap USDA FSA, GeoEye, Esri Community Maps Contributors, State of North Carolina DOT, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, EPA, NPS, US Census Bureau, USDA.

LEGEND

- ▲ Profile Stations
- - - Baseline
- ― Beach Profile Transects
- ― Beach Profile and Sand Collection Transects
- - - Section Area Boundary

TITLE

Beach Profile
and Sand Collection Maps

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

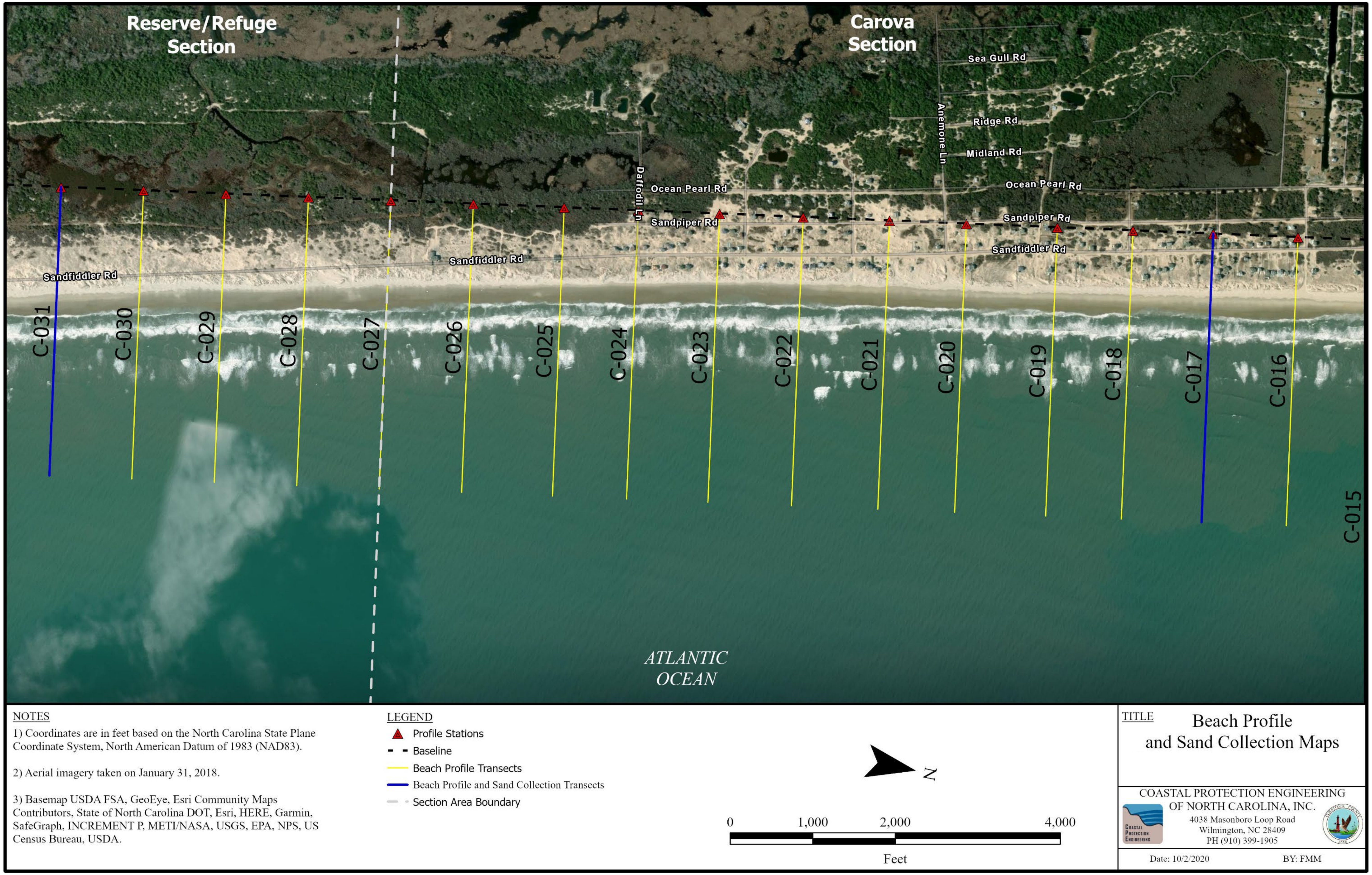

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Figure 3. Monitoring Transects Map Station C-016 to C-031

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

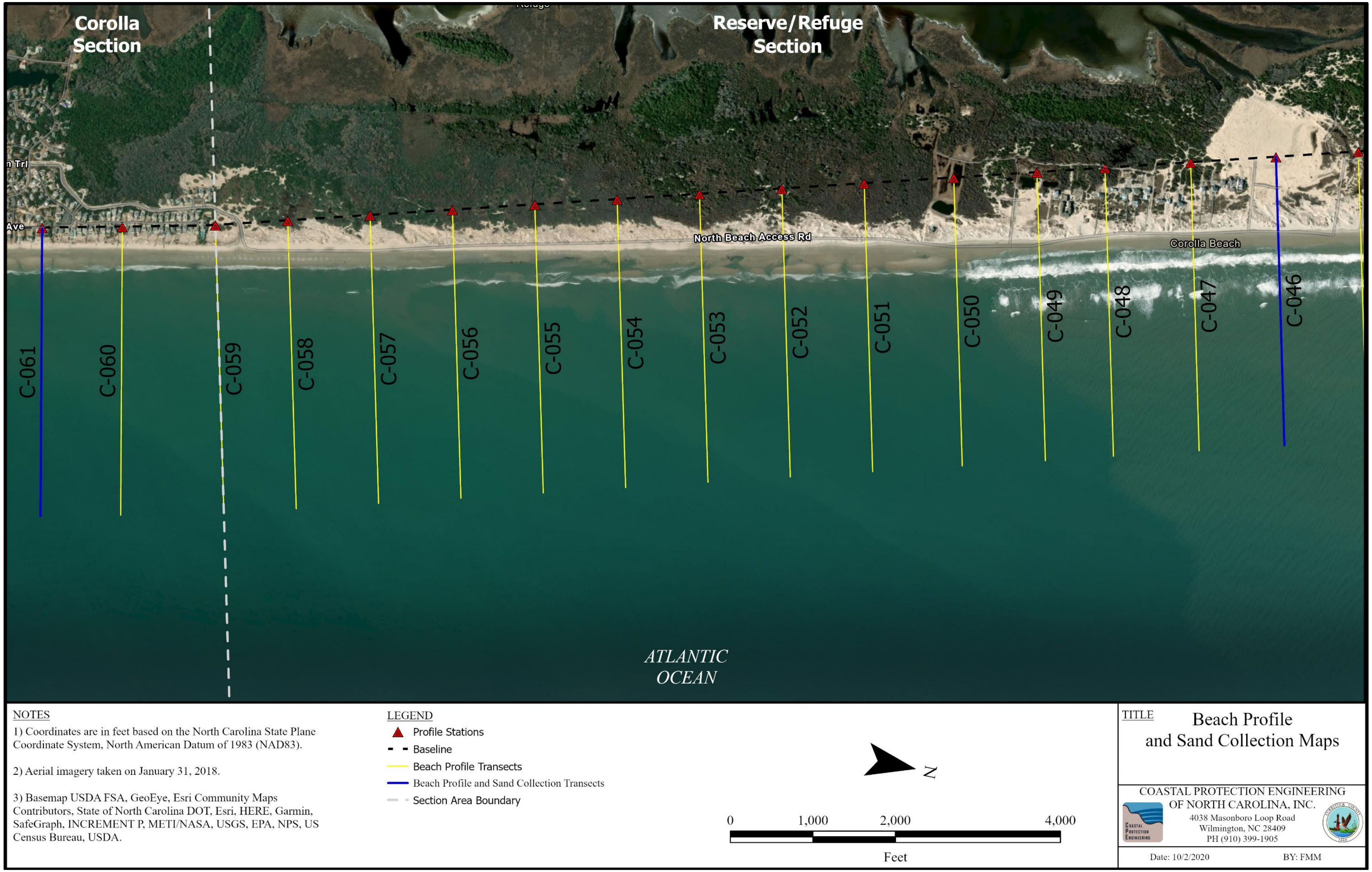

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Figure 5. Monitoring Transects Map Station C-046 to C-061

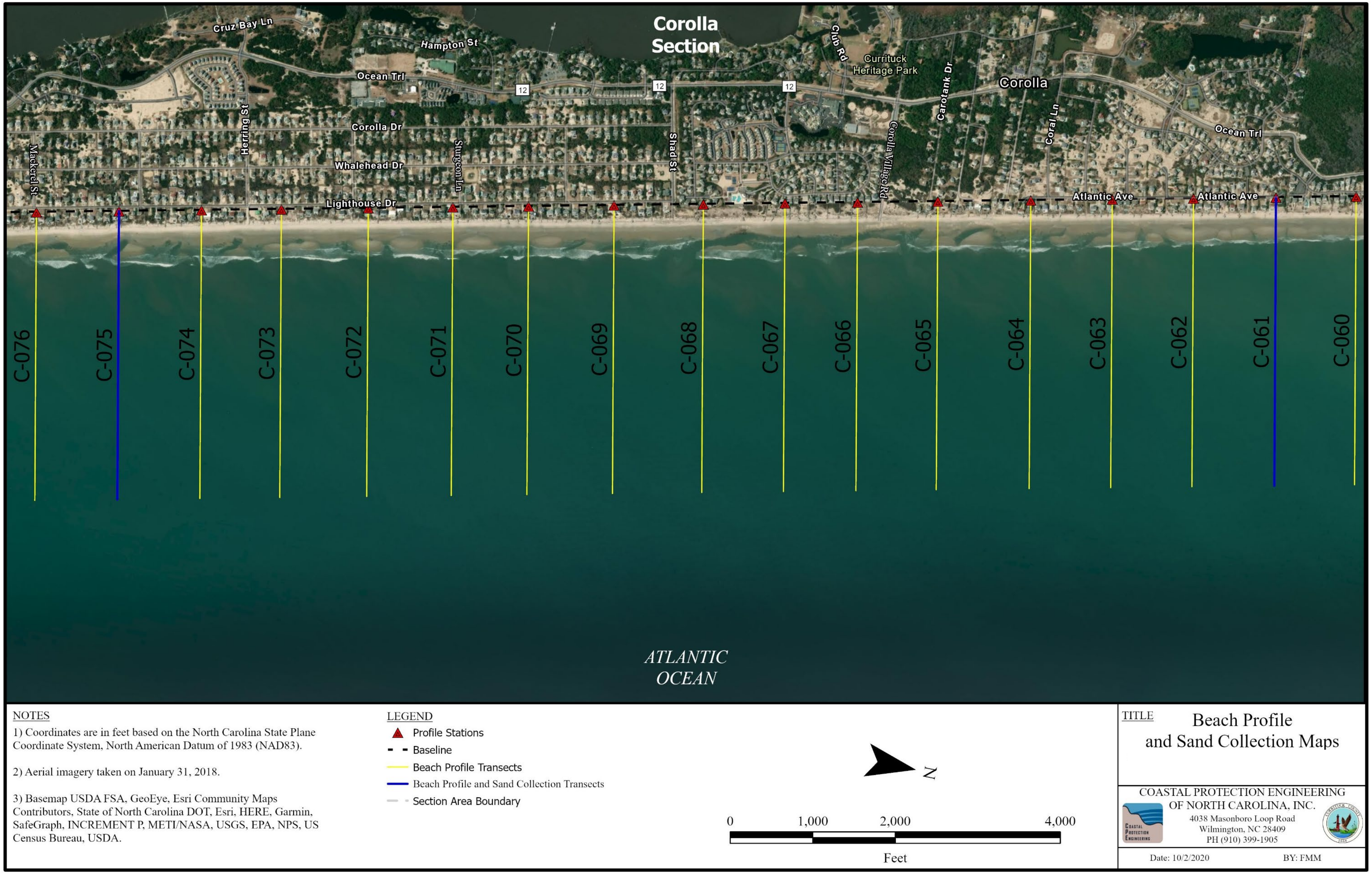

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Figure 6. Monitoring Transects Map Station C-061 to C-076

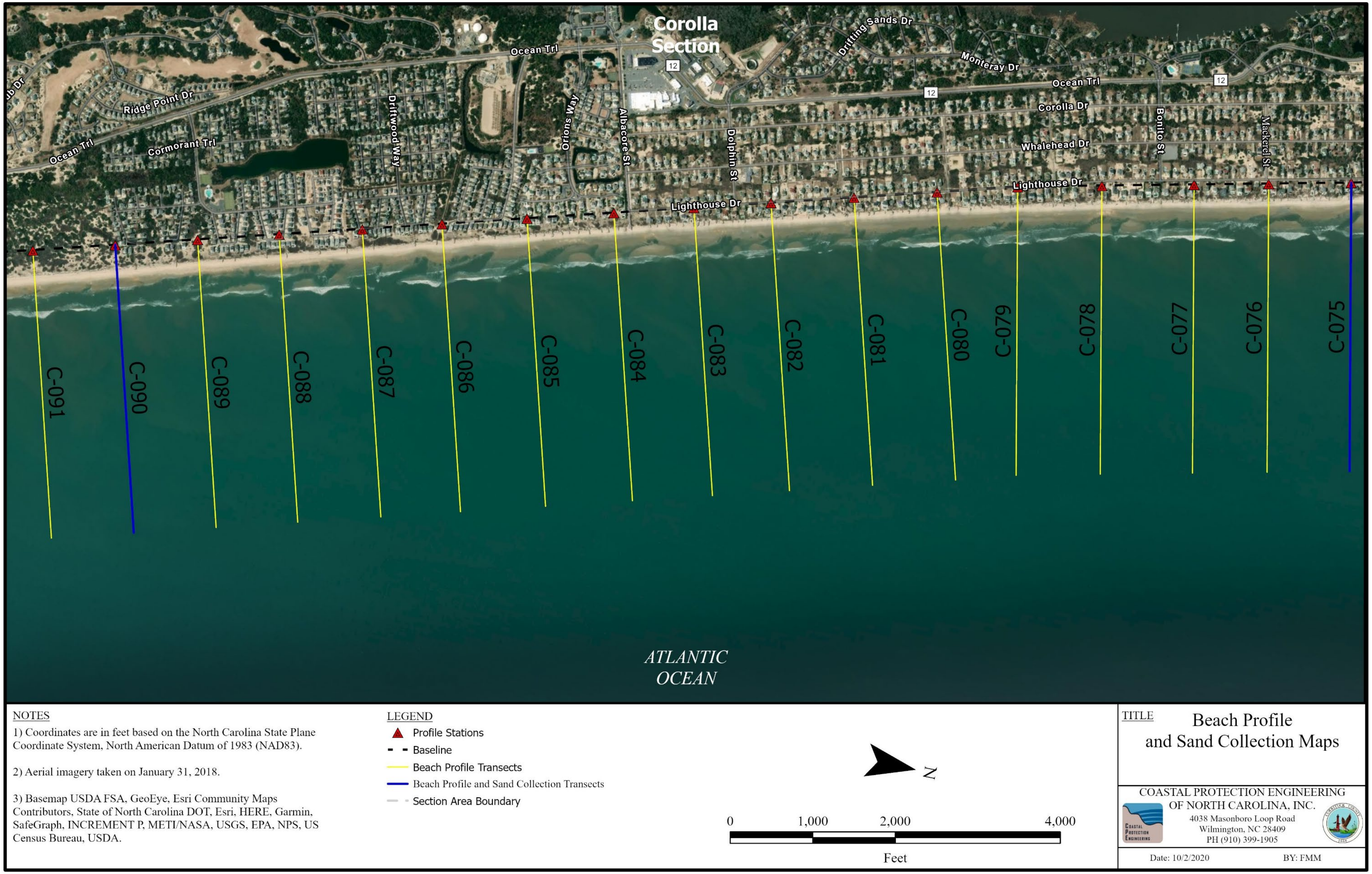

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Figure 7. Monitoring Transects Map Station C-076 to C-091

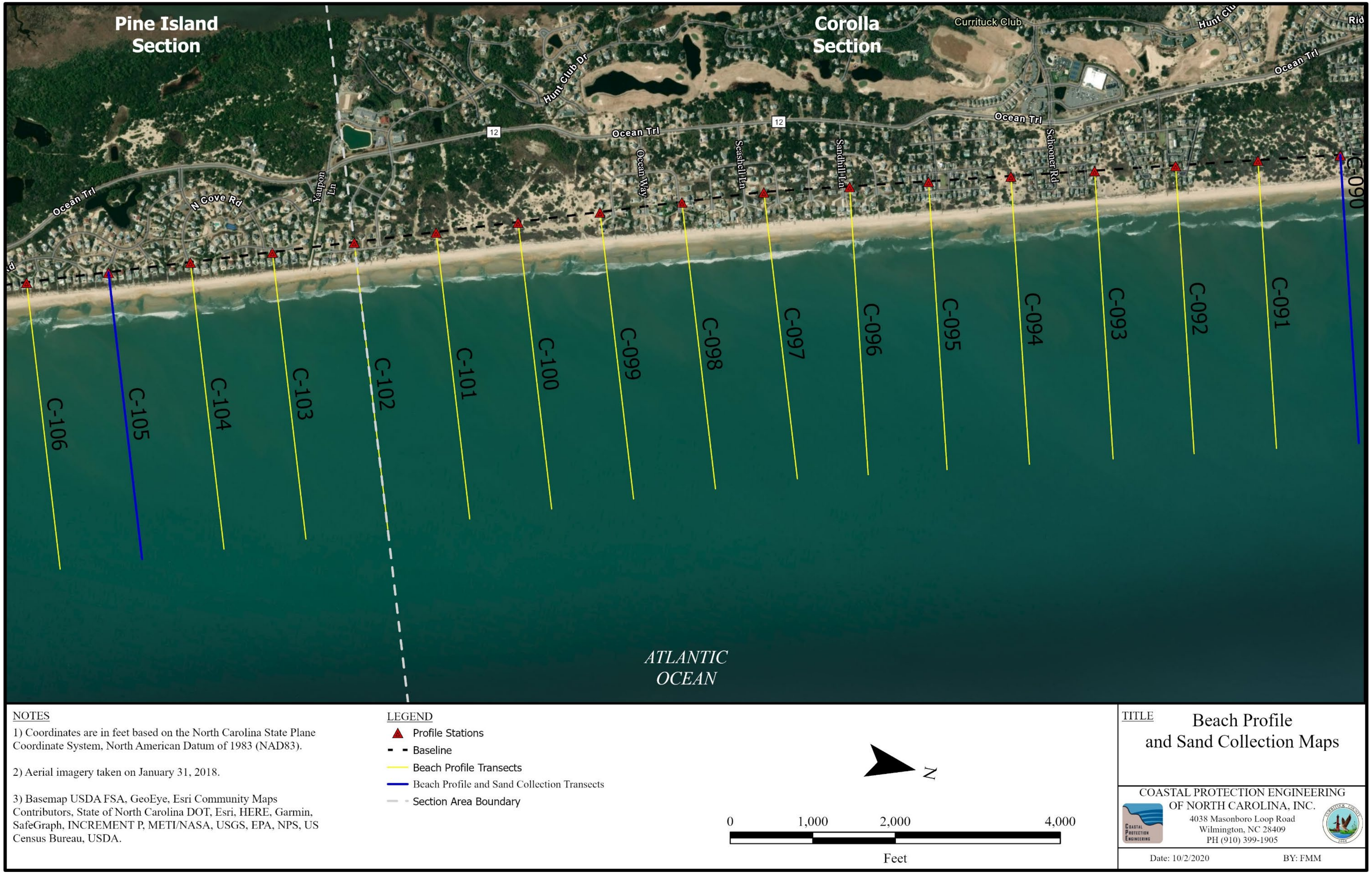

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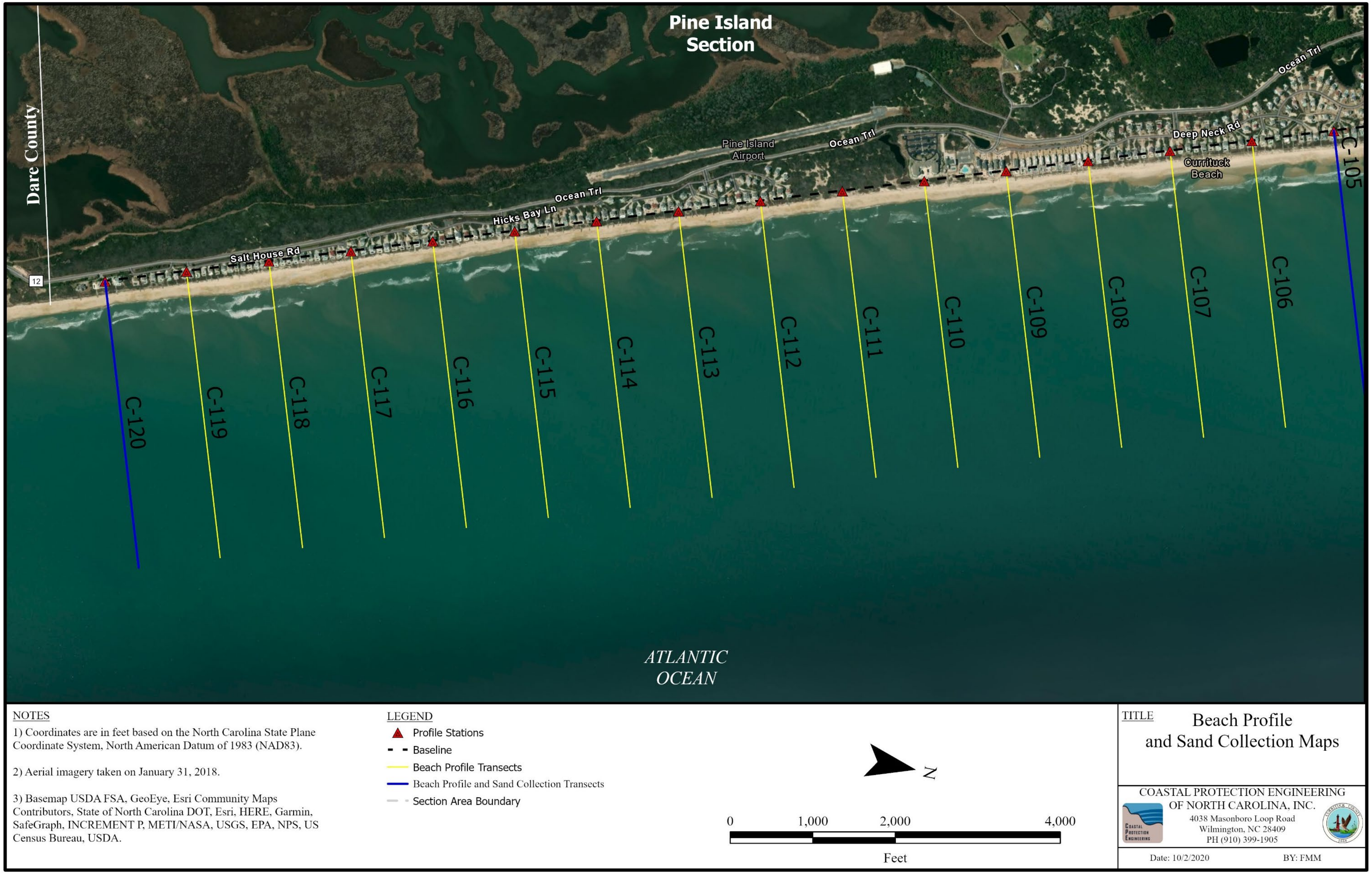
Figure 8. Monitoring Transects Map Station C-091 to C-106



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1) Coordinates are in feet based on the North Carolina State Plane Coordinate System, North American Datum of 1983 (NAD83).

2) Aerial imagery taken on January 31, 2018.

3) Basemap USDA FSA, GeoEye, Esri Community Maps Contributors, State of North Carolina DOT, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, EPA, NPS, US Census Bureau, USDA.

LEGEND

- ▲ Profile Stations
- - - Baseline
- 🟨 Beach Profile Transects
- 🟦 Beach Profile and Sand Collection Transects
- - - Section Area Boundary

TITLE

Beach Profile
and Sand Collection Maps

COASTAL PROTECTION ENGINEERING
OF NORTH CAROLINA, INC.
4038 Masonboro Loop Road
Wilmington, NC 28409
PH (910) 399-1905

Date: 10/2/2020 BY: FMM

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 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 North Carolina Division of Coastal Management (NC DCM) were used as a reference to the values that CPE computed.

2.2 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 mi 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 in by CPE for the County study. Table 4 shows a comparison between the CSE referenced stations and the names of the stations used in the County Study (C-097 through C-120). Additional information pertaining to the CSE survey methodology is available in the 2020 Beach Monitoring and Beach Stability Assessment (CPE, 2020).

2.3 USACE Lidar Data

Lidar stands for Light Detection and Ranging and 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.

Table 4. 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

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 had reliable topography data and was selected for the long-term analysis.

2.4 CPE Beach Profile Data

CPE conducted beach profile surveys for Currituck County in May 2020 and June 2021. 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: 2021 Currituck County Beach Monitoring And Beach Stability Study.

Beach profiles extended landward from the beach toward the baseline until a structure was encountered or a range of 25 feet beyond the dune was reached, whichever was more seaward. Elevation measurements were also taken seaward along the profile to a range of 2,500 feet beyond the shoreline or to the -30-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 an ODOM Hydrotrac sounder with digitizer (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 a TSS dynamic motion sensor was 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 navigation 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 (20) 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.

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. Shoreline change can be provided in terms of the actual linear change measured between surveys or as a rate in an annualized form. The rates 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 10 illustrates the approach showing shoreline positions (black dots) and the trendline for station C-059. These rates are described in terms of positive (+) for advance (shoreline moving seaward) and negative (-) for recession (shoreline moving landward).

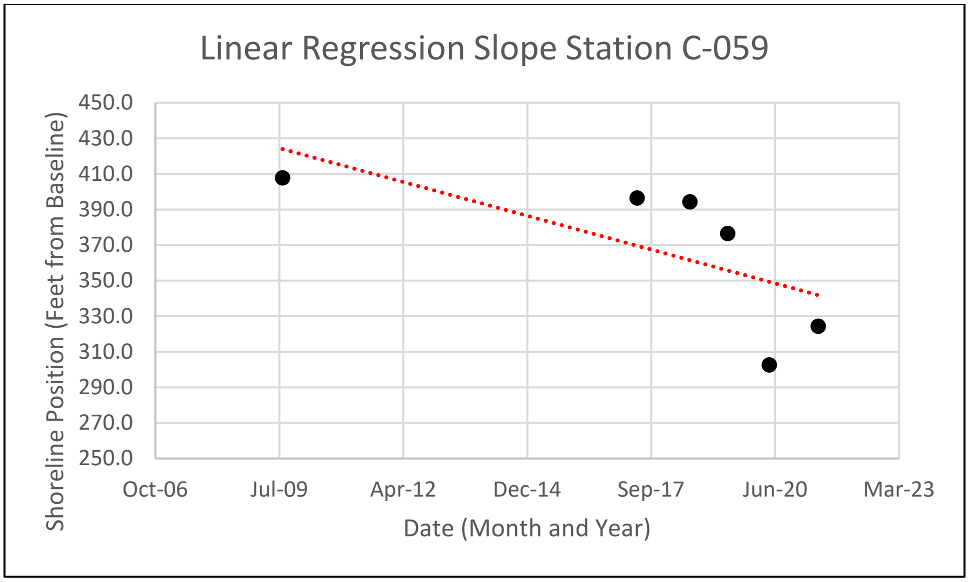

Figure 10. Example of Linear Regression Slope

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 11 shows an example of the State long-term average shoreline change rates. The Set Back Factor (SBF) 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., which means where erosion is less than 2 ft. per year, or accreting, the setback factors default to the minimum (2 ft./yr.) as defined by Rule 15 NCAC 07H.

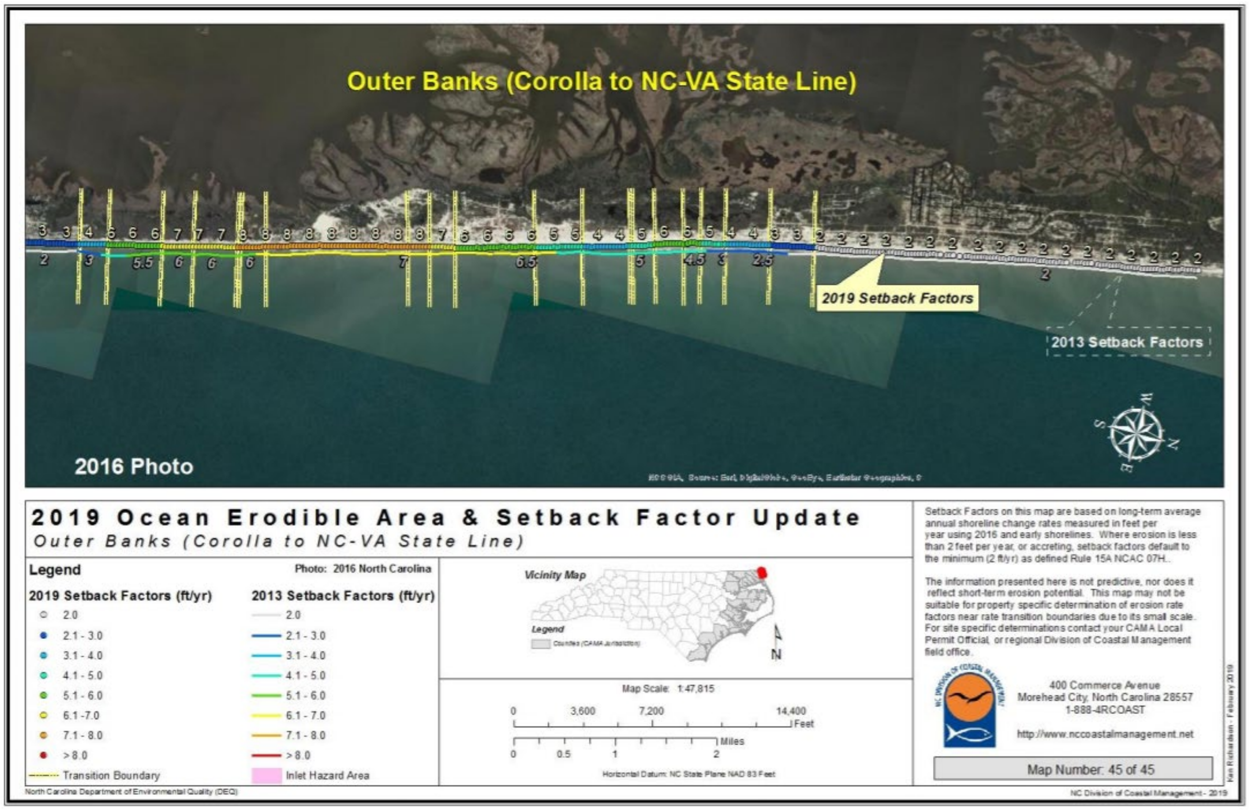

Figure 11. Map showing the SBF for Reserve/Refuge and Carova Sections of Currituck County

The average, maximum, and minimum SBF's for each of the 4 sections of the Project Area are provided in Table 5. As shown in the table, the average SBF for the Carova, Corolla, and Pine Island Sections are between 2 and 3 ft./yr., whereas the average SBF for the Reserve/Refuge area is over 6 ft./yr. However, as noted by the State in their disclaimer, the shoreline position change rates are not predictive and do not reflect short-term erosion that can occur over shorter periods of time (i.e. decadal, seasonally or during storm events).

Table 5. NC DCM 2019 Setback Factors

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

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

Using available beach profile and Lidar data, a shoreline change analysis was conducted to assess shoreline advance and recession where data were available 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 does appear to be reliably captured consistently along the Project Area. The second reason is that the +4 ft. NAVD88 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 12 shows a typical comparison plot of two beach profile surveys conducted approximately 10.6 years apart along station C-001, illustrating graphically how the shoreline change is measured.

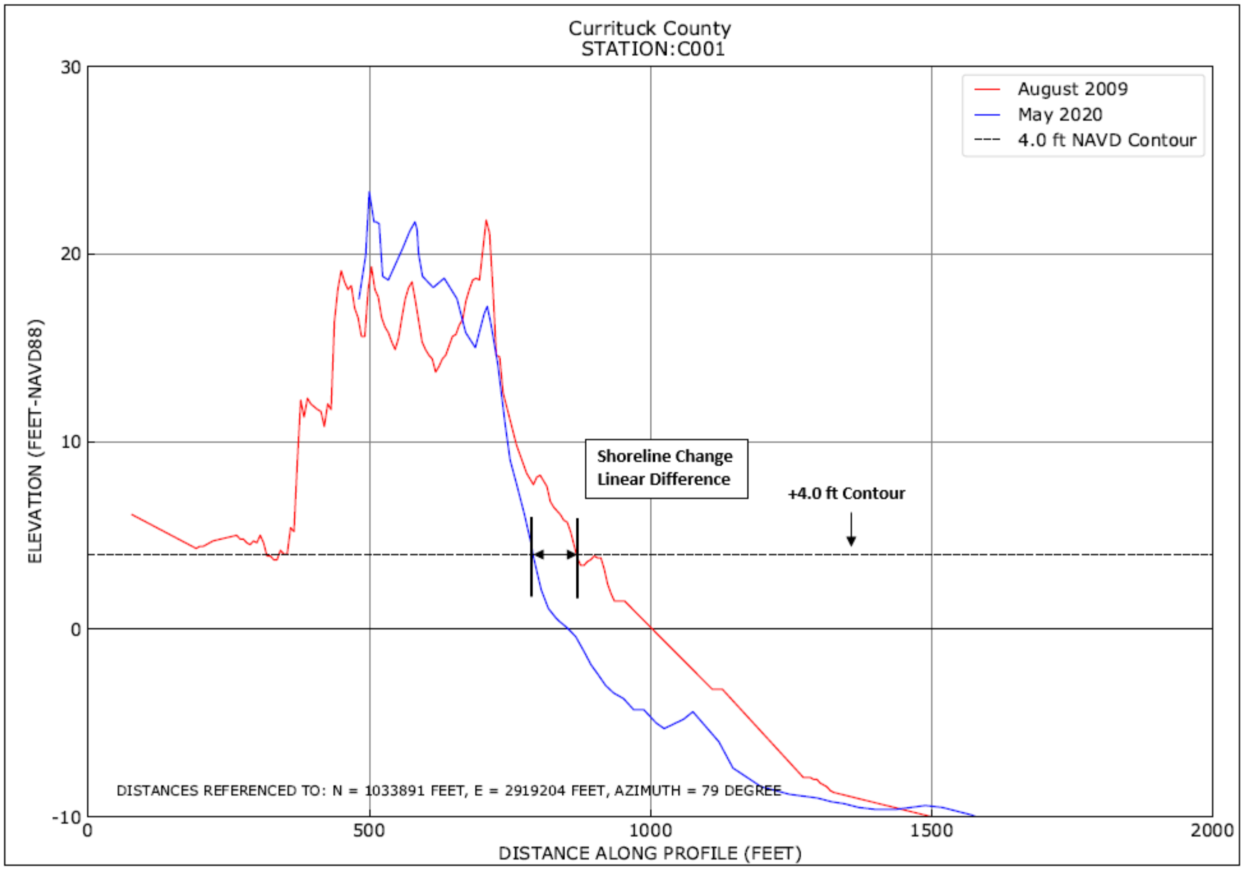

Figure 12. Beach Profile Cross Section Illustrating Shoreline Change

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 June 2021)

Data collected throughout the Project Area between August 2009 and June 2021 were examined to compare the positions of the +4 ft. NAVD88 contour and determine shoreline change rates. Shoreline change rates were determined using a linear regression method given the various data sets available between August 2009 and June 2021. These datasets included August 2009, June 2017, August 2018, June 2019, May 2020, and June 2021. While this report uses a linear regression method to determine shoreline change, the previous Year-1 report used the end-point method. 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. A comparison of shoreline change rates determined by the end-point method and the linear regression method are shown in Table 6.

Table 6. Long-Term Period Shoreline Change Rate Comparison: End-Point and Linear Regression Methods

Section	End-Point Method (ft./yr.)	Linear Regression Method (ft./yr.)
Carova (C-001 to C-027)	-1.1	-0.8
Reserve/Refuge (C-027 to C-059)	-4.7	-4.7
Corolla (C-059 to C-102)	-4.0	-3.5
Pine Island (C-102 to C-120)	-1.0	0.1
Total Project Area (C-001 to C-120)	**-3.1**	**-2.6**

The average long-term shoreline change rate along the entire Project Area (station C-001 to station C-120) between August 2009 and June 2021, was -2.6 ft./yr. Recent and long-term shoreline change rates at each station along the Project Area are provided in Table 7 and Table 8. 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 9.

Carova Section: The average long-term shoreline change rate calculated for the Carova Section was -0.8 ft./yr. The State determined the average setback factor in the Carova Section to be 2.49 ft./yr. (note setback factors infer a recession rate or movement of the shoreline landward). A profile-by-profile comparison shows shoreline change rates in this section ranging from -7.7 ft./yr. at station C-002 to +6.4 ft./yr. at station C-019. The northernmost 4,000 feet of the Carova Section (station C-001 to station C-005), north of Marlin Lane, had an average rate of -3.8 ft./yr. From Marlin Lane to just south of Gulf Hawk Blvd (station C-005 to station C-016), the shoreline was relatively stable, with an average shoreline change rate of -0.3 ft./yr. From Gulf Hawk Boulevard to just north of Anemone Lane (station C-016 to station C-020), the average shoreline change rate was positive (seaward), measuring +3.4 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 -1.7 ft./yr.

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

Station	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2021)	Recent Rate (ft./yr.) (May 2020 to June 2021)	Station	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2021)	Recent Rate (ft./yr.) (May 2020 to June 2021)
C-001	-6.5	-3.7	C-031	-5.3	41.4
C-002	-7.7	6.1	C-032	-2.0	29.4
C-003	-3.7	-7.4	C-033	-4.2	9.6
C-004	-0.3	-14.3	C-034	-3.9	44.5
C-005	-1.1	-2.2	C-035	-3.7	35.1
C-006	0.5	-6.4	C-036	-5.5	38.4
C-007	-1.1	14.6	C-037	-2.8	30.6
C-008	2.0	20.7	C-038	-3.1	21.0
C-009	2.0	18.5	C-039	-2.3	23.7
C-010	1.5	35.5	C-040	-1.1	17.8
C-011	-0.3	37.6	C-041	-0.9	5.6
C-012	0.9	34.8	C-042	-2.8	9.2
C-013	0.2	44.2	C-043	-2.4	20.8
C-014	-0.3	30.8	C-044	-1.9	62.7
C-015	-7.2	27.4	C-045	-4.9	14.7
C-016	-0.6	20.6	C-046	-3.0	-0.9
C-017	3.3	22.8	C-047	-2.5	0.9
C-018	4.3	16.1	C-048	-4.1	12.9
C-019	6.4	16.8	C-049	-5.8	13.4
C-020	3.4	18.0	C-050	-7.4	12.6
C-021	-1.3	25.3	C-051	-9.4	18.0
C-022	-2.4	22.6	C-052	-6.8	28.4
C-023	-2.3	11.2	C-053	-10.9	28.8
C-024	-0.4	21.0	C-054	-6.7	29.0
C-025	-4.5	14.5	C-055	-3.9	15.0
C-026	-3.1	14.3	C-056	-6.8	22.2
C-027	-2.8	22.9	C-057	-6.8	7.3
C-028	-5.1	-3.0	C-058	-8.1	31.2
C-029	-5.6	18.2	C-059	-6.9	20.2
C-030	-5.7	33.7	C-060	-9.0	7.0

Table 8. Summary of Currituck County Recent and Long-Term Shoreline Change Rates (Continued)

Station	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2021)	Recent Rate (ft./yr.) (May 2020 to June 2021)	Station	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2021)	Recent Rate (ft./yr.) (May 2020 to June 2021)
C-061	-7.1	-1.3	C-091	-2.1	28.7
C-062	-7.3	13.5	C-092	-3.0	22.8
C-063	-6.3	-2.4	C-093	-2.1	20.5
C-064	-3.4	23.0	C-094	-0.4	9.4
C-065	-4.8	27.2	C-095	-2.3	4.6
C-066	-4.6	16.2	C-096	-0.1	25.6
C-067	-1.9	25.6	C-097	-0.6	12.9
C-068	-3.9	17.7	C-098	-0.5	34.0
C-069	-3.6	14.5	C-099	-5.3	21.8
C-070	-1.1	19.0	C-100	-1.0	16.9
C-071	-1.6	6.4	C-101	-2.4	5.3
C-072	-3.5	7.4	C-102	-3.5	12.7
C-073	-3.4	25.8	C-103	-1.4	20.2
C-074	-2.5	16.4	C-104	0.9	21.2
C-075	-3.1	13.4	C-105	1.3	-9.4
C-076	-3.5	27.7	C-106	-0.1	7.9
C-077	-1.6	27.0	C-107	4.4	-12.5
C-078	-3.4	19.8	C-108	0.8	-19.5
C-079	-3.6	22.1	C-109	0.7	-9.6
C-080	-9.4	15.8	C-110	1.0	-24.7
C-081	-4.5	26.5	C-111	-3.1	-7.9
C-082	-4.2	9.4	C-112	-0.1	-13.3
C-083	-3.7	24.5	C-113	0.0	-14.9
C-084	-4.4	27.7	C-114	0.0	13.6
C-085	-3.4	29.5	C-115	-1.2	-6.6
C-086	-2.0	24.6	C-116	-1.8	-15.5
C-087	-3.3	15.5	C-117	-0.5	10.7
C-088	-4.8	15.3	C-118	4.9	-4.3
C-089	-2.1	14.5	C-119	1.5	23.9
C-090	-3.4	5.8	C-120	-2.1	17.1

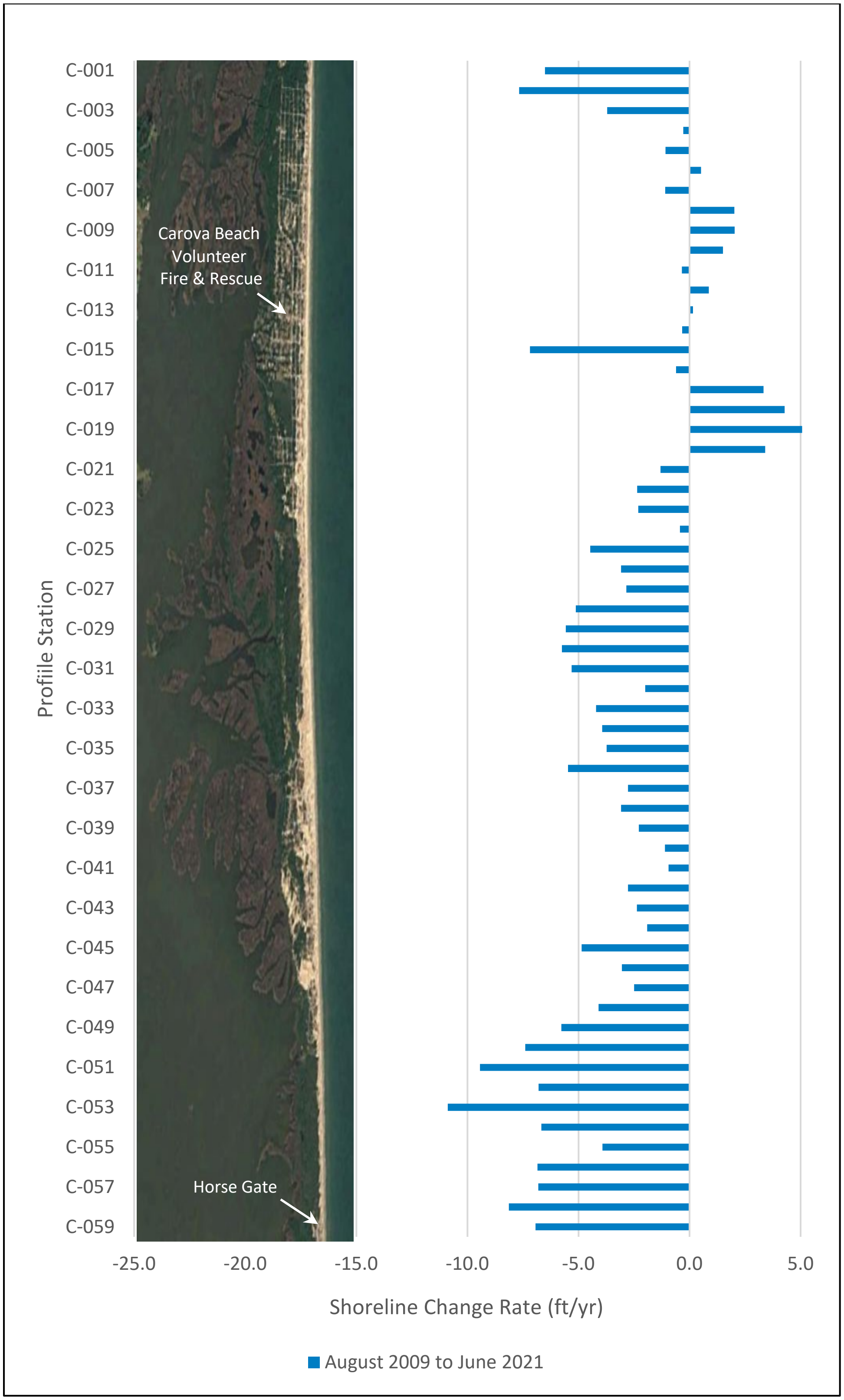

Figure 13. Shoreline Change Rate (+4 ft. NAVD88) North of the Horse Gate (C-001 to C-059)

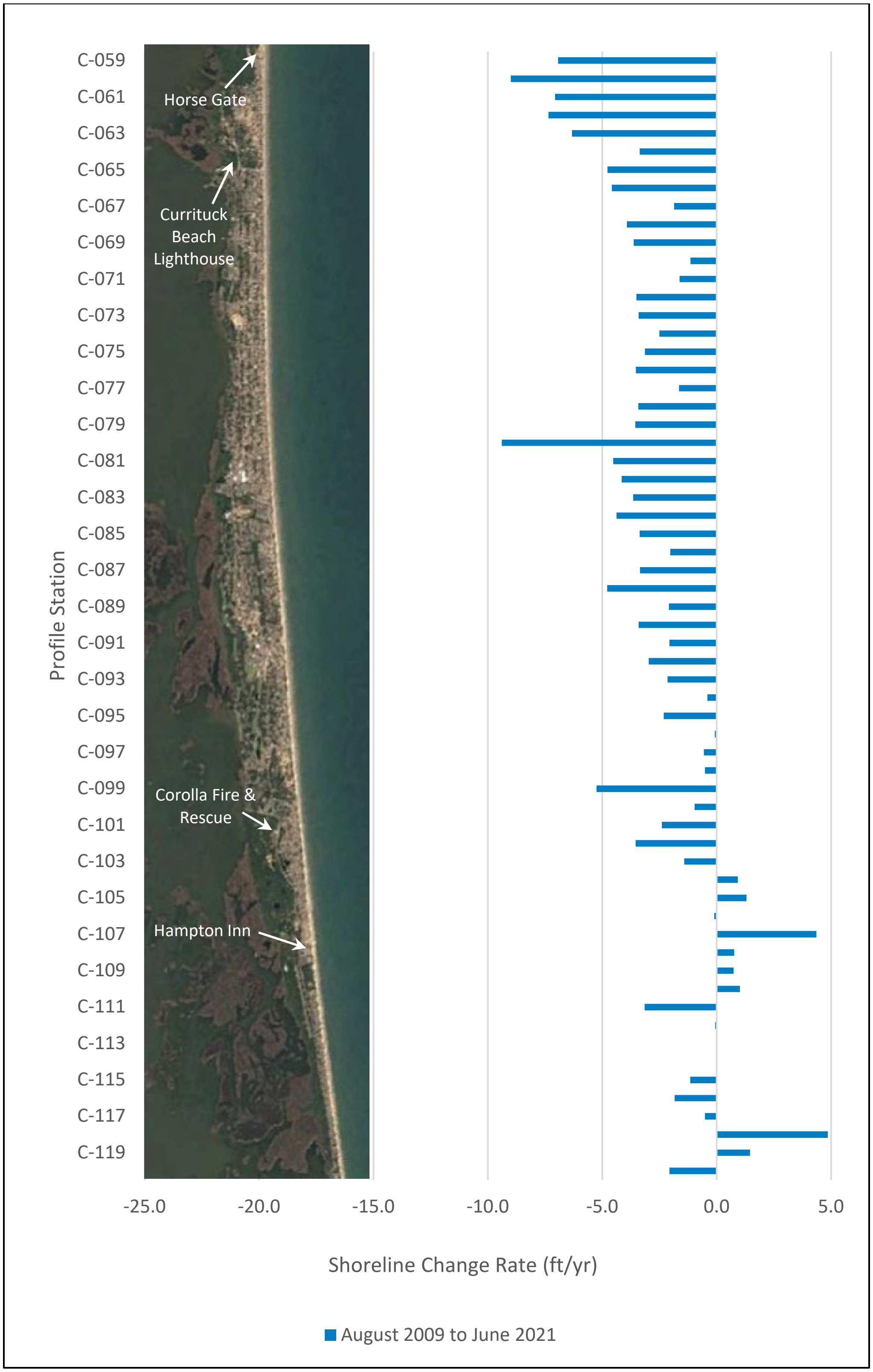

Figure 14. Shoreline Change Rate (+4 ft. NAVD88) South of the Horse Gate (C-059 to C-120)

Table 9. Summary of Average Recent and Long-Term Shoreline Change Rates By Monitoring Section

Section	Long-Term Rate (ft./yr.) (Aug. 2009 to June 2021)	Recent Rate (ft./yr.) (May 2020 to June 2021)
Carova (C-001 to C-027)	-0.8	17.1
Reserve/Refuge (C-027 to C-059)	-4.7	21.7
Corolla (C-059 to C-102)	-3.5	17.5
Pine Island (C-102 to C-120)	0.1	-0.6
Total Project Area (C-001 to C-120)	**-2.6**	**15.7**

Reserve/Refuge Section: The average long-term shoreline change rate calculated for the Reserve/Refuge Section was -4.7 ft./yr., which is the highest shoreline recession rate for any of the four sections. The State determined the average setback factor in the Reserve/Refuge Section to be 6.57 ft./yr. (note setback factors 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 -10.9 ft./yr. at station C-053 to -0.9 ft./yr. at station C-041. 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 -3.4 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 -6.6 ft./yr.

Corolla Section: The average long-term shoreline change rate calculated for the Corolla Section was -3.5 ft./yr. The State determined the average setback factor 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 setback factors infer a recession rate or movement of the shoreline landward). 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 -9.4 ft./yr. at station C-080 to -0.1 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 the south end of Atlantic Avenue (station C-059 to station C-064), the average shoreline change rate was -6.7 ft./yr. From the south end of Atlantic Avenue to a point located on the north side of 889 Lighthouse Dr. (station C-064 to station C-079), the average shoreline change rate was -3.1 ft./yr. From station C-079 south to station C-088, located along Wave Arch off Seabird Way, the average shoreline change rate was -4.3 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 -2.2 ft./yr.

Pine Island Section: The average long-term shoreline change rate between August 2009 and June 2021, in the Pine Island Section was 0.1 ft./yr. The State determined the average setback factor 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 setback factors 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 2021. Shoreline change rates varied along the Pine Island

Section from -3.5 ft./yr. at station C-102 (located approximately 500 feet north of Yaupon Lane) to +4.9 ft./yr. at station C-118 (located along the middle of Salt House Rd).

4.2 Recent Time Period (May 2020 to June 2021)

As previously stated, shoreline change indicates losses or gains of beach width at a given elevation contour; however, the nature of sand movement in response to wave and water level conditions makes shoreline position highly variable temporally. For this reason, evaluations of short-term changes in the shoreline may vary significantly from long-term rates.

The beach profile data collected by CPE in May 2020 and June 2021 were compared to measure short-term shoreline change with respect to the +4 ft. NAVD88 contour. The annualized average shoreline change rate measured between May 2020 and June 2021 for the entire shoreline was +15.7 ft./yr. As shown in Table 9, the Pine Island Section was the only section to experience a negative average shoreline change rate during this period (-0.6 ft./yr.); whereas the Reserve/Refuge Section had the highest rate at 21.7 ft./yr.

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 shoreline location of the +4 ft. NAVD88 contour was projected into the future for periods of 10, 20, and 30 years. While this report uses a linear regression method to determine shoreline change, the Year-1 report used the end-point method. Due to the availability of multiple datasets, it was determined that the linear regression method provides a better representation of long-term shoreline change rates. The shoreline change rates used to determine future positions were based on those rates previously discussed for the +4 ft. NAVD88 contour between 2009 and 2021 and were determined through the linear regression method. Maps showing the results of the projected shoreline change are included in Appendix B.

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 same method was used to determine the shoreline projections in the Year-1 report. For the stations on the north (station C-001) and south (station C-120) end of the Project Area, 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.

This analysis identified a structure 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 10 shows the number of structures 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 structures 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 10. Number of structures 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	4
Reserve/Refuge (C-027 to C-059)	0	1	3
Corolla (C-059 to C-102)	0	18	68
Pine Island (C-102 to C-120)	0	0	0
Total Project Area (C-001 to C-120)	**0**	**19**	**75**

Along the Carova Section, the only portion of the section where the projected shorelines directly impact oceanfront structures, is at the extreme north end, between the northern County Line and Bluefish Ln (station C-001 to station C-003). Four (4) oceanfront homes were shown to be impacted between the 20- and 30-year horizons. No oceanfront homes were shown to be impacted in this section over the 10- or 20-year horizons.

In the Reserve/Refuge Section, where the average long-term shoreline change rate was the greatest of the four project sections, the projected shoreline change indicates several portions of the section where impacts may occur. Two (2) houses located seaward of Sand Fiddler Road between Dove Ln. and La Mer Ln. (between station C-041 and station C-044), were shown to be impacted over the 30-year time horizon. The structure located seaward of Sandfiddler Rd. between station C-043 and C-044 was also shown to be impacted over the 20-year horizon. The southernmost oceanfront structure 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. No houses along the Reserve/Refuge Section were shown to be impacted over the 10-year horizon. With the amount of vehicular traffic transiting the oceanfront beaches along this section, the presence of oceanfront structures 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 the second highest of the four project sections. The projected shoreline change indicates extensive numbers of oceanfront structures may be impacted over a 30-year time horizon. Along the northern half of the Corolla Section (north of Carotank Drive or station C-065) to the horse gate (station C-059), a total of 49 structures were shown to be impacted over the 30-year horizon. Out of those 49 structures, 18 were impacted over the 20-year horizon. No impacts to oceanfront houses were shown to be impacted over the 30-year horizon between Persimmon Street (just south of station C-064) and 891 Lighthouse Dr. (station C-079). Along the central portion of the Corolla Section between 891 Lighthouse Dr. and a point located approximately 450 feet north of Dolphin St. (station C-079 to station C-082), a total of 19 oceanfront structures were shown to be impacted over the 30-year horizon. Out of those 19 structures, none were shown to be impacted over the 20-year horizon. No structures along the Corolla Section were shown to be impacted over the 10-year horizon.

To summarize, two portions within the Corolla Section (station C-059 to station C-065 and station C-079 to station C-082) included oceanfront structures shown to be impacted over the 30-year horizon. In total, 68 structures were shown to be impacted over the 30-year horizon in the Corolla Section. Out of these 68 structures, 18 structures located between station C-060 and station C-065 were shown to be impacted over the 20-year horizon. Many structures that were shown to be impacted by the projections provided in the Year-1 report are not indicated as impacted using the updated shoreline change rates, which utilized a linear regression method. Specifically, areas along Lighthouse Drive (station C-068 to station C-081), Sandcastle Drive (station C-059 to station C-061), and Atlantic Avenue (station C-061 to station C-064) have seen a significant reduction in the number of impacted structures based on the updated Year-2 projections. Furthermore, the updated maps indicate no impacted structures in the Corolla Section, south of Dolphin St., located between stations C-082 and C-083.

In the Pine Island Section of the Project Area, where the average long-term shoreline change rate was the lowest of the four project sections, no oceanfront structures were shown to be impacted by the projected shoreline change over the 10-, 20-, or 30-year horizons. 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 (from the dunes out to the depth of closure). The dry beach often observed above the water represents only a fraction of the active beach profile. Therefore, the volume of sand measured on the entire profile is an important parameter to track and to gauge the health of the beach. The volume of sand in place is the metric that defines the three-dimensional beach, which provides storm protection. Figure 15 shows the same profile shown in Figure 12 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.

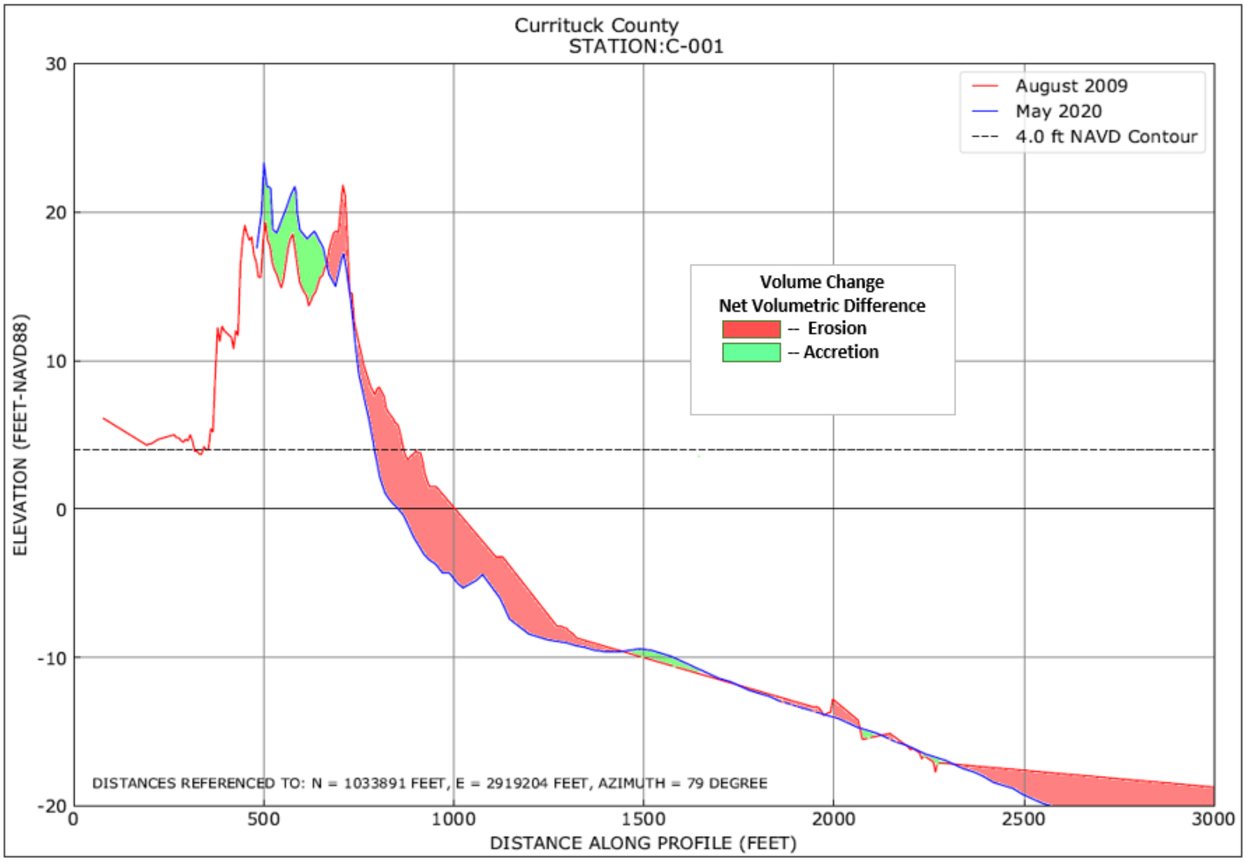

Figure 15. Beach Profile Cross Section Illustrating Volume Change

All volumetric changes along a profile, or averaged over multiple profiles, are given in cubic yards per linear foot. At times, this report also provides total volume in cubic yards measured between certain profiles. These volumes are 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 shoreline 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 for this study is -19 ft. NAVD88. Additional information on the determination of this depth can be found in the Year-1 report (CPE, 2020). In addition, dune evolution was also evaluated in response to several questions by County elected officials during the review of the Year-1 report. The description and results of the dune evolution analysis are provided in Section 5.4.

5.1 Volumetric Change Rates

With the collection of a second set of beach profile data along the entirety of the Currituck County beaches, short-term volumetric changes were computed between May 2020 and June 2021. Volumetric changes were not reported in the Year-1 report given only one data set was available that covered the entire Project Area out to the established depth of closure (-19 ft. NAVD88).

The average volumetric change rate measured between May 2020 and June 2021 was +9.3 cy/ft./yr., resulting in a cumulative positive volumetric change of approximately 1,188,000 cubic yards. Each of the four sections had a positive average volumetric change rate. The average volumetric change rate in the Carova Section was +12.3 cy/ft./yr., this section gained approximately 348,500 cy. The average volumetric change rate in the Reserve/Refuge Section was +8.4 cy/ft./yr., which equates to a volume gained of 292,700 cy. The average volumetric change rate in the Corolla Section was +6.6 cy/ft./yr., which is the lowest positive rate of any section over this period. This equates to a volume gain of approximately 297,400 cy. The average volumetric change rate in the Pine Island Section was +14.0 cy/ft./yr., which is the highest rate of any section over this period. This equates to a volume gain of approximately 249,400 cy. The rates and volumes above are summarized in Table 11.

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

Section	Average Volumetric Change Rate (cy/ft./yr.)	Total Volume Change (cy)
Carova (C-001 to C-027)	12.3	348,500
Reserve/Refuge (C-027 to C-059)	8.4	292,700
Corolla (C-059 to C-102)	6.6	297,400
Pine Island (C-102 to C-120)	14.0	249,400
Total Project Area (C-001 to C-120)	**9.3**	**1,188,000**

The volumetric rates were the lowest in the central Sections of the County (Reserve/Refuge and Corolla) while the Carova and Pine Island Sections experienced the highest rates of accretion. Table 12 lists the individual volumetric rates computed for each profile between May 2020 and June 2021. Figure 16 and Figure 17 show the 2020 to 2021 change rates graphically.

The average volumetric change rate in the Carova Section was +12.3 cy/ft./yr. A profile-by-profile comparison shows volumetric change rates in this section ranging from -50.5 cy/ft./yr. at station C-002 (600 feet north of Bluefish Lane) to +42.7 cy/ft./yr. at station C-013 (Shark Lane). The northernmost 4,000 feet of the Carova Section (station C-001 to station C-005), north of Marlin Lane, had a large negative average rate of -21.7 cy/ft./yr. South of station C-005 (Marlin Lane) in the Carova section, positive volumetric changes were measured along all profiles. From just north of Rock Lane to just south of Sunfish Lane (station C-006 to station C-010), modest gains in density were measured, with an average density change rate of +7.4 cy/ft./yr. From just south of Sunfish Lane to just south of Bitter Root Lane (station C-010 to station C-022), the average volumetric change rate was considerably higher, measuring +27.4 cy/ft./yr. The southern portion of the Carova Section from just south of Bitter Root Lane to 300 feet south of Sandfiddler Rd (station C-022 to station C-027), had a volumetric change rate of +12.7 cy/ft./yr.

The average volumetric change rate in the Reserve/Refuge Section was +8.4 cy/ft./yr. Negative volumetric change rates were only measured on 9 profiles in this section. A profile-by-profile comparison shows volumetric change rates in this section ranging from -13.0 cy/ft./yr. at station C-046 (300 feet north of Munson Lane) to +41.1 cy/ft./yr. at station C-044 (600 feet south of

Seagull Lane). From station C-027 to station C-032, the average volumetric change rate was +17.9 cy/ft./yr., which aligns with the trends observed in the area to the north in the Carova Section. From 1,400 feet south of Sandfiddler Rd to 700 feet south of Munson Lane (station C-033 to station C-047), the average volumetric change rate was +2.7 cy/ft./yr. As shown in Figure 16, this area experienced both positive and negative rates on a profile-by-profile basis; however, the average trend was a modest gain. The southern 13,000 ft. 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 volumetric change rate of +9.1 cy/ft./yr.

The average volumetric change rate in the Corolla Section was +6.6 cy/ft./yr. A profile-by-profile comparison shows volumetric change rates in this section ranging from -17.9 cy/ft./yr. at station C-074 to +35.8 cy/ft./yr. at station C-077. Between the northern boundary of the Corolla Section, which is located approximately 250 feet south of the horse gate, and the south end of Atlantic Ave (station C-059 to station C-064), the average volumetric change rate was +2.6 cy/ft./yr. station C-065, located approximately 100 feet north of Caro Tank Drive, is an outlier of the trend in this area. The volumetric change rate at station C-065 was +32.7 cy/ft./yr. From just south of Corolla Village Road to Mackeral Beach Access (station C-066 to station C-076), the average volumetric change rate was -2.9 cy/ft./yr. From station C-077 south to station C-085, located just north of Bonita St., to the south end of Voyager Rd, the average volumetric change rate was +13.0 cy/ft./yr. Negative volume change rates of -6.3 cy/ft./yr. and -14.9 cy/ft./yr. were measured at stations C-086 and C-087, located 200 feet north of Spinnaker Arch and the south end of Mainsail Arch. Along the southern portion of the Corolla Section, between station C-088 (Wave Arch) and station C-102, located approximately 500 feet north of Yaupon Lane, the average volumetric change rate was +12.0 cy/ft./yr.

The average volumetric change rate between August 2009 and June 2021, in the Pine Island Section was +14.0 cy/ft./yr. A negative volumetric change rate was only measured on 4 profiles in this section, those profiles are located at stations C-104, C-106, C-107, and C-116.

Table 12. Volumetric Change Rates (cy/ft./yr.)

Station	May 2020 to June 2021	Station	May 2020 to June 2021	Station	May 2020 to June 2021
C-001	3.2	C-041	10.8	C-081	22.1
C-002	-50.5	C-042	-14.9	C-082	5.3
C-003	-5.8	C-043	7.9	C-083	24.6
C-004	-22.6	C-044	41.1	C-084	5.0
C-005	-32.8	C-045	-12.0	C-085	0.4
C-006	5.5	C-046	-13.0	C-086	-6.3
C-007	7.4	C-047	-11.8	C-087	-14.9
C-008	6.7	C-048	25.9	C-088	22.7
C-009	1.6	C-049	-3.6	C-089	11.3
C-010	15.6	C-050	29.6	C-090	10.6
C-011	32.5	C-051	23.6	C-091	13.6
C-012	20.7	C-052	7.0	C-092	0.5
C-013	42.7	C-053	13.4	C-093	5.8
C-014	23.5	C-054	19.8	C-094	-0.1
C-015	24.9	C-055	-4.1	C-095	3.7
C-016	31.1	C-056	-4.6	C-096	29.4
C-017	37.4	C-057	4.1	C-097	9.1
C-018	32.5	C-058	13.6	C-098	13.1
C-019	29.8	C-059	5.4	C-099	2.4
C-020	25.5	C-060	2.7	C-100	13.0
C-021	26.9	C-061	-5.4	C-101	5.3
C-022	12.8	C-062	-4.2	C-102	39.2
C-023	17.4	C-063	8.2	C-103	7.7
C-024	20.1	C-064	8.6	C-104	-19.1
C-025	11.3	C-065	32.7	C-105	16.5
C-026	6.4	C-066	-13.5	C-106	-3.2
C-027	8.2	C-067	8.8	C-107	-0.2
C-028	20.4	C-068	-7.6	C-108	10.3
C-029	11.9	C-069	5.0	C-109	11.2
C-030	17.3	C-070	-9.8	C-110	6.7
C-031	20.4	C-071	-2.5	C-111	34.8
C-032	29.1	C-072	-7.6	C-112	20.1
C-033	-5.7	C-073	28.1	C-113	16.2
C-034	-8.2	C-074	-17.9	C-114	46.4
C-035	2.2	C-075	-12.6	C-115	17.5
C-036	1.7	C-076	-1.9	C-116	-12.5
C-037	12.7	C-077	35.8	C-117	15.7
C-038	6.6	C-078	14.5	C-118	6.6
C-039	10.7	C-079	20.5	C-119	20.0
C-040	13.2	C-080	-10.9	C-120	32.1

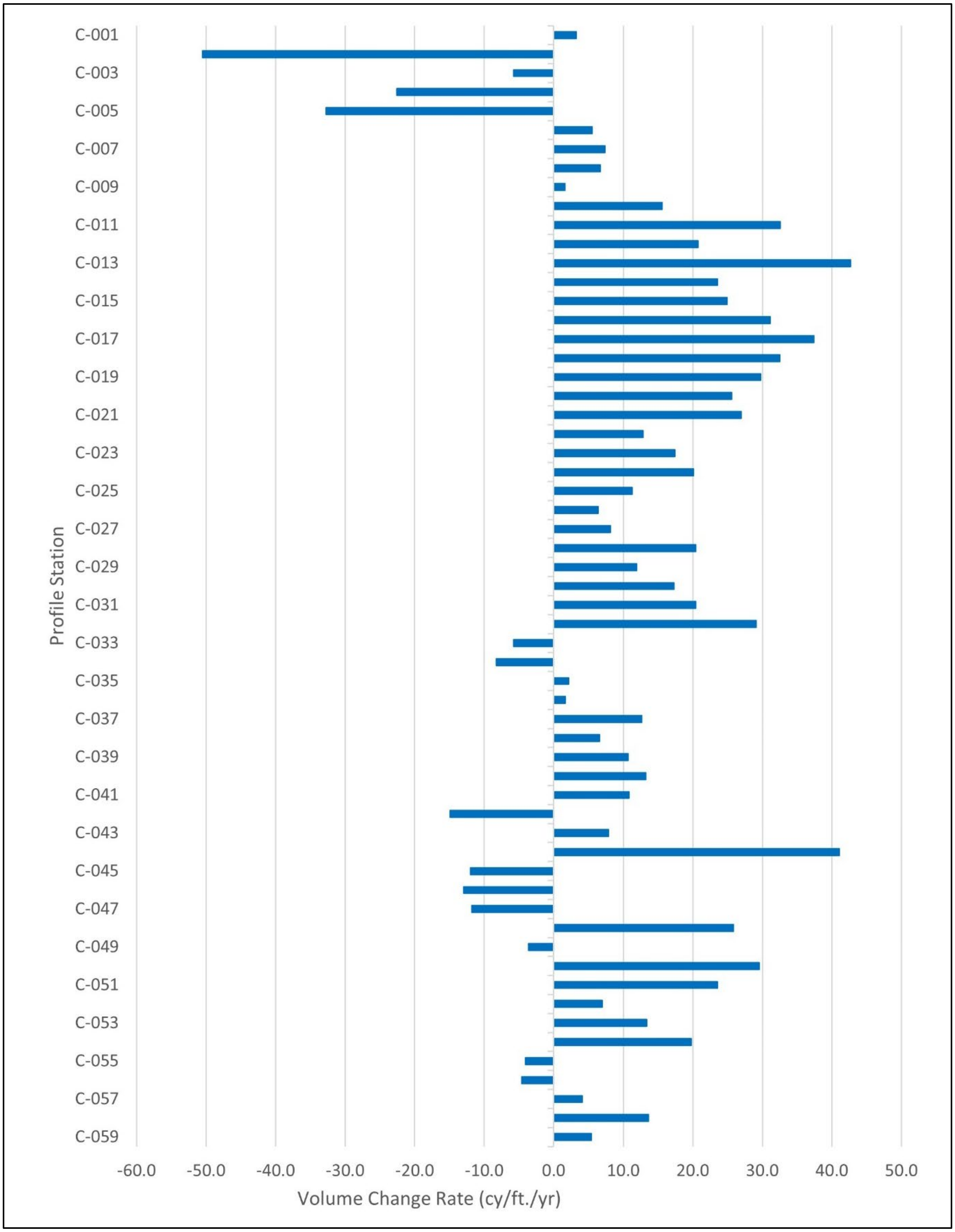

Figure 16. Volume Change Rate Above -19 ft. NAVD88 - North of the Horse Gate (May 2020 to June 2021)

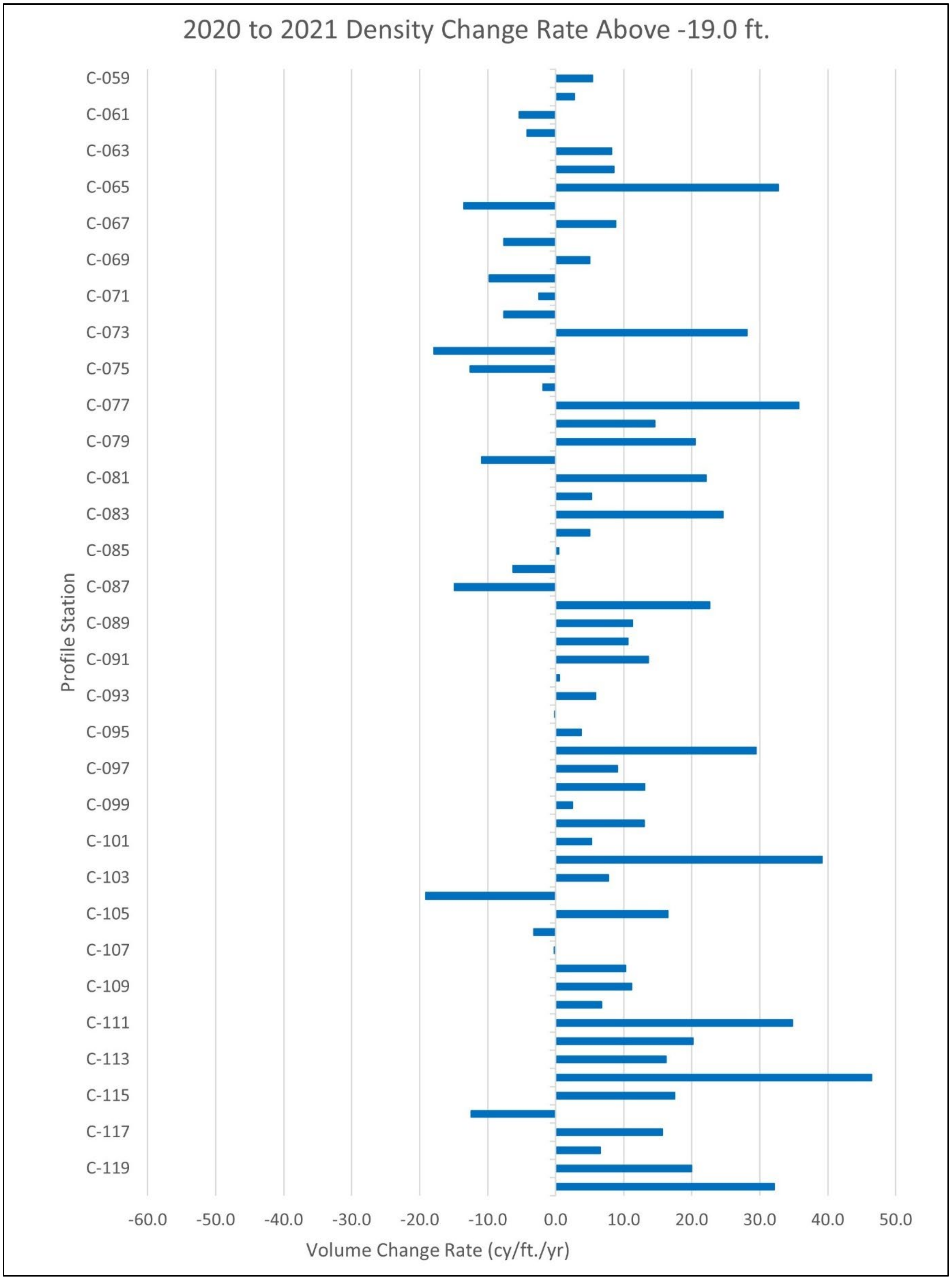

Figure 17. Volume Change Rate Above -19 ft. NAVD88 - South of Horse Gate (May 2020 to June 2021)

5.2 Volume Envelope Comparison

During the development of the Year-1 report, only one full set of beach profile data extending out to the depth of closure were available. In the absence of comparative data sets, a metric that can be evaluated to provide a relative comparison of beach volume along a profile was employed. This metric is referred to as the "volume envelope". This report provides updated volume envelope values as a comparison of the volume measured in Years-1 and -2.

The volume envelope was defined as the volume calculated along a profile above the -19 ft. NAVD88 contour (depth of closure) and seaward of the +18 ft. NAVD88 contour on the landward side of the dune (CPE, 2020). The landward limit of the volume envelope was chosen based on a review of beach profile cross sections and the need to define a contour that would both capture the volume contained in the primary dune and consistently be present along most of the profiles in the Project Area. However, on twelve (12) of the June 2021 profiles, a modified landward limit of the volume envelope was chosen due to the specific primary dune configuration and/or the availability of survey data.

Figure 18 and Figure 19 show a comparison of the volume measured within the volume envelope along the portion of the Project Area north of the horse gate (station C-001 to station C-059) and south of the horse gate (station C-059 to station C-120). Generally, the profiles in the northern half of the Project Area have a higher volume density than the southern half. Furthermore, the volume density values south of the horse gate have less variability than those north of the horse gate. Table 13 provides a summary of the average volume envelope densities for each of the four sections, the portions of the beach north and south of the horse gate, and for the overall Project Area.

Table 13. Average Density within the Volume Envelope

Section	Stations	Average Volume Envelope Density in 2020 (cy/ft.)	Average Volume Envelope Density in 2021 (cy/ft.)
Carova	(C-001 to C-027)	886.7	897.0
Reserve/Refuge	(C-027 to C-059)	817.0	828.6
Corolla	(C-059 to C-102)	612.3	619.2
Pine Island	(C-102 to C-120)	609.2	624.5
Area North of Horse Gate	(C-001 to C-059)	846.3	857.3
Area South of Horse Gate	(C-059 to C-120)	612.5	621.4
Total Project Area	(C-001 to C-120)	727.6	737.5

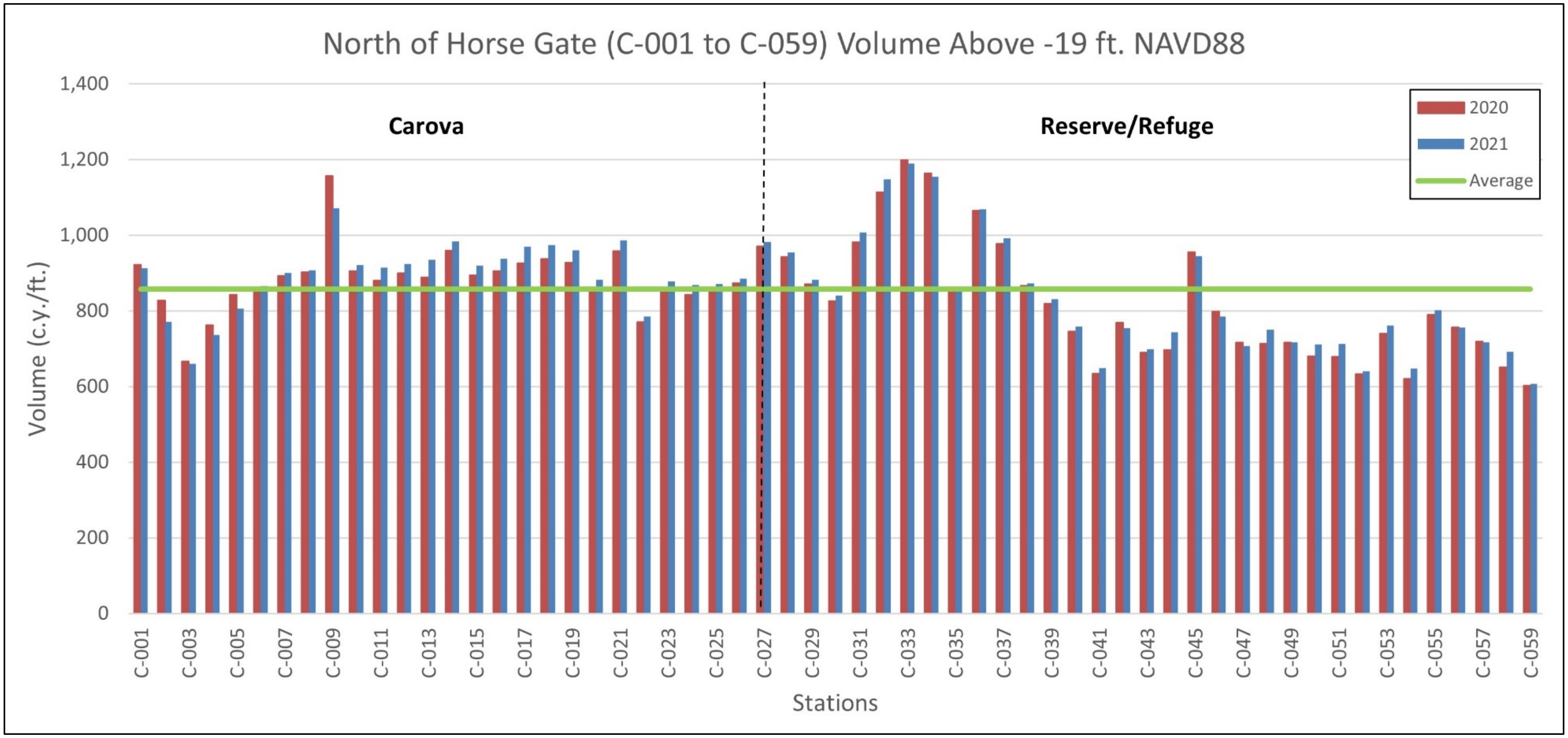

Figure 18. Volume Envelope Values along Profiles North of the Horse Gate (C-001 through C-059)
(The green line indicates the average volume envelope density north of the horse gate based on June 2021 data.)

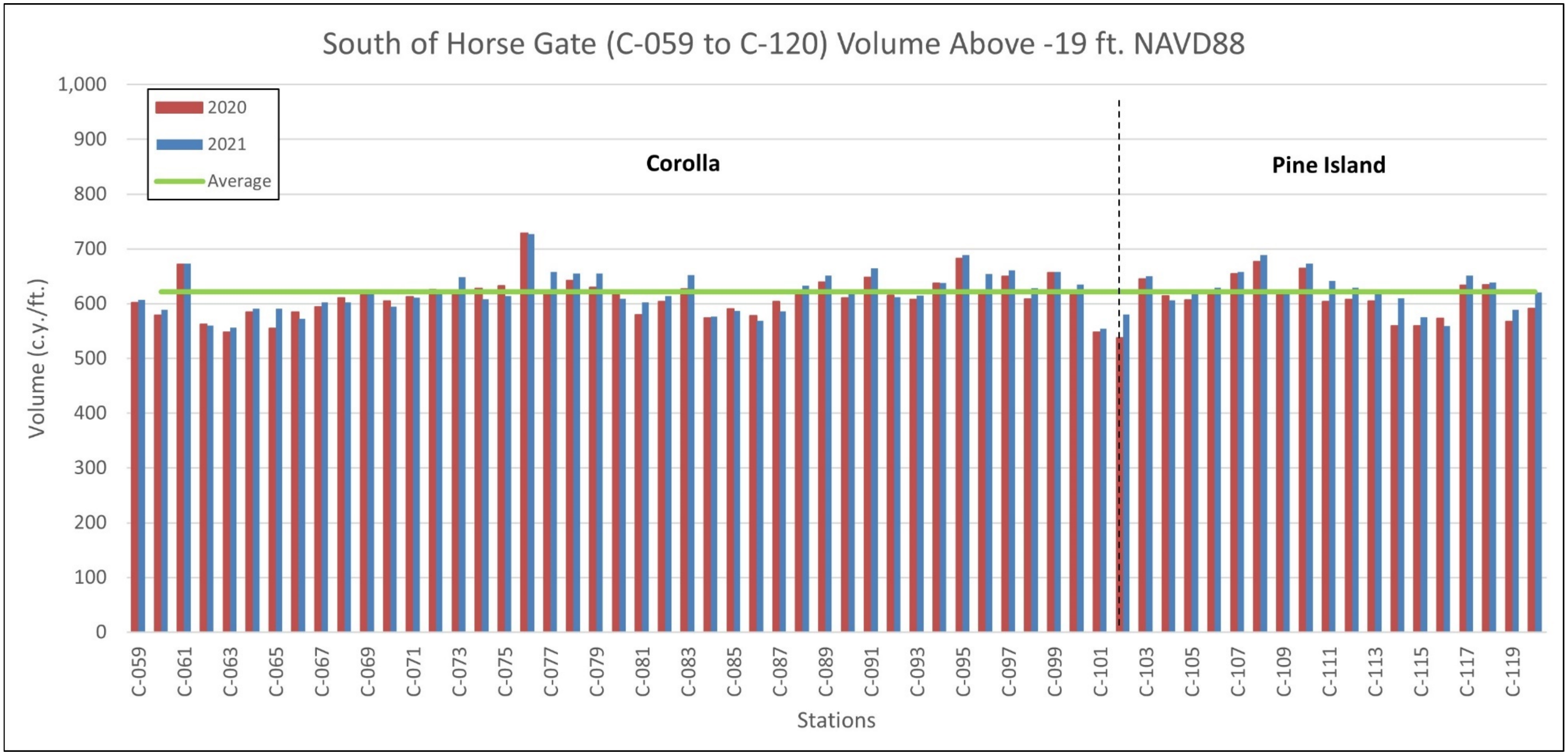

Figure 19. Volume Envelope Values along Profiles South of the Horse Gate (C-059 through C-120)

(The green line indicates the average volume envelope density south of the horse gate based on June 2021 data.)

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 Project Area in 2015 and 2017 (CSE, 2018). These profile surveys extended from stations C-097 through C-120. Volumetric change rates were computed for the periods between September 2015 (CSE) and June 2021 (CPE) as well as October 2017 (CSE) and June 2021 (CPE). The average volumetric change rate between September 2015 and June 2021 was -0.8 cy/ft./yr., resulting in a cumulative negative volumetric change of approximately -123,300 cubic yards. Similarly, the average volumetric change rate measured between October 2017 and June 2021 was -3.6 cy/ft./yr., resulting in a cumulative negative volumetric change of approximately -326,900 cubic yards. Table 14 lists the individual volumetric change rates computed for each profile between September 2015 and June 2021 as well as between October 2017 and June 2021.

Figure 20 shows a graphical comparison of the 2015 to 2021 rates and the 2017 to 2021 rates. The red bars, which reflect volumetric changes measured between 2017 and 2021 are primarily negative. Similarly, the blue bars, which reflect rates measured between 2015 and 2021 are more varied with some rates negative and some positive but are primarily negative. The transects north of station C-100 along which relatively high positive changes were measured between 2015 and 2021, are the same profiles along which the greatest negative changes were measured between 2017 and 2021. The changes measured south of station C-100 during the two periods generally follow similar trends with greater negative change rates measured between 2017 and 2021 and smaller negative rates measured between 2015 to 2021.

Table 14. Pine Island (C-097 to C-120) CSE and CPE Density Change Rate Comparison (cy/ft./yr.)

Stations	September 2015 to June 2021	October 2017 to June 2021
C-097	3.1	-3.2
C-098	3.7	-5.6
C-099	0.5	-6.6
C-100	1.0	-5.4
C-101	-4.8	-7.5
C-102	-3.7	0.9
C-103	-4.2	-1.9
C-104	-6.8	-12.3
C-105	-0.6	-4.2
C-106	-7.0	-0.6
C-107	1.1	1.4
C-108	-0.5	-8.4
C-109	-1.6	-11.1
C-110	-1.9	1.6
C-111	3.2	4.4
C-112	-0.6	0.7
C-113	1.1	-3.6
C-114	2.9	0.8
C-115	-0.9	-6.0
C-116	-6.2	-9.7
C-117	0.1	1.0
C-118	-0.4	-10.7
C-119	2.3	-9.7
C-120	0.5	10.3
Average	-0.8	-3.6
Max	3.7	10.3
Min	-7.0	-12.3

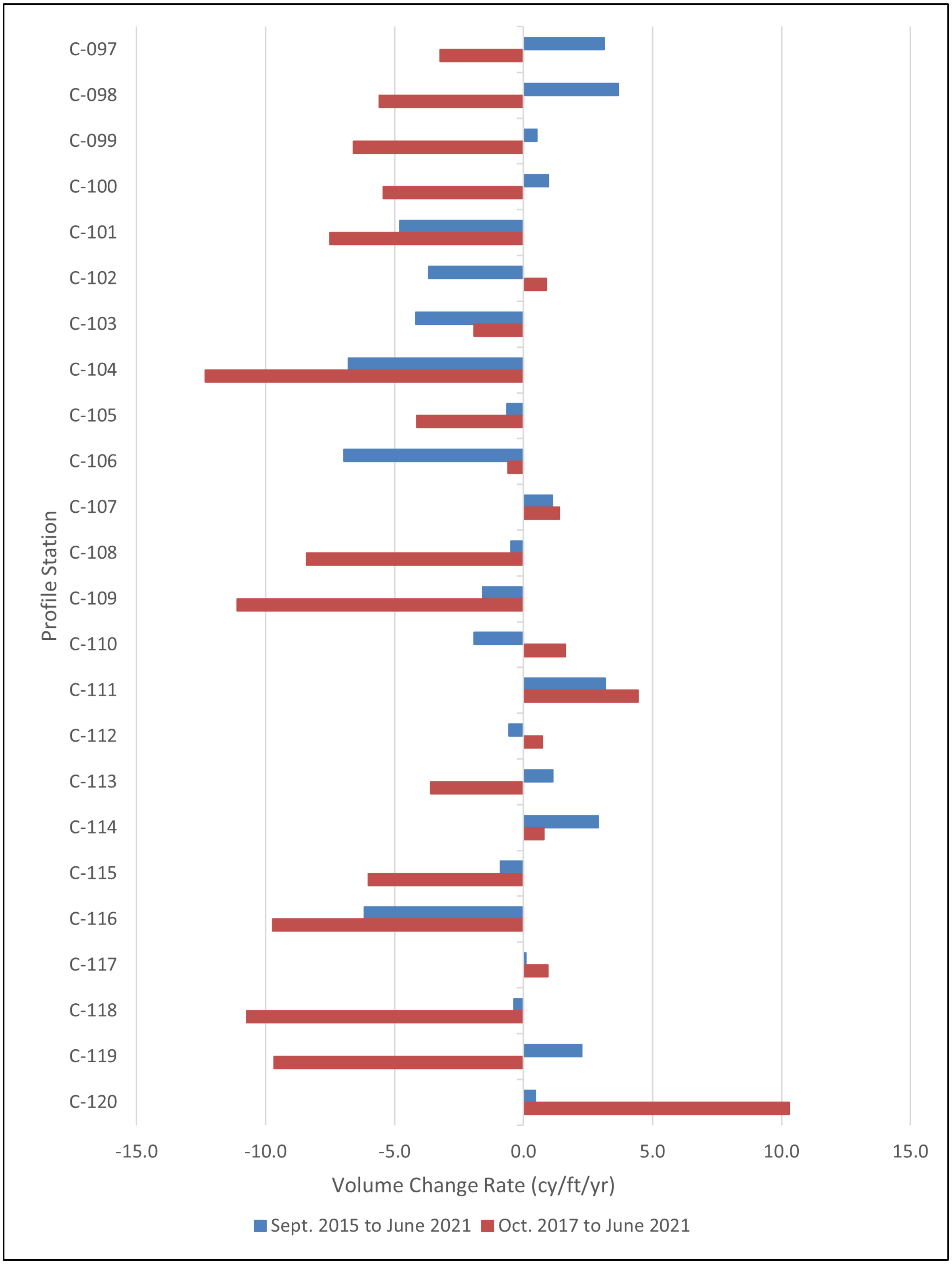

Figure 20. Pine Island (C-097 to C-120) Volume Change Rates Above -19.0 ft. NAVD88 – Sept. 2015 to June 2021 and Oct. 2017 to June 2021

5.4 Dune Analysis

Based on comments received by the County Commission in February 2021, CPE analyzed dune changes between 2009 and 2021. Lidar data collected in 2009 and beach profile data collected in 2021 were used to determine volumetric changes, as well as changes in the position and elevation of the seaward dune crest along each profile south of the horse gate (station C-059 to station C-120). The volumetric analysis of the dunes south of the horse gate indicated very little gain in the dune volume (<0.5 cy/ft.) between 2009 and 2021.

The positions and elevations of the dune crest in 2009 and 2021 were then compared to evaluate changes to the primary frontal dunes. On average, the dune crest has moved approximately 8 feet landward between 2009 and 2021 south of the horse gate (station C-059 to station C-120). An average increase of the dune crest elevation of approximately 2.4 feet was also measured between 2009 and 2021. The graph in Figure 21 illustrates the landward movement of the dune crest, the increase in the elevation of the dune crest, and relatively little net change in the volume of the dune.

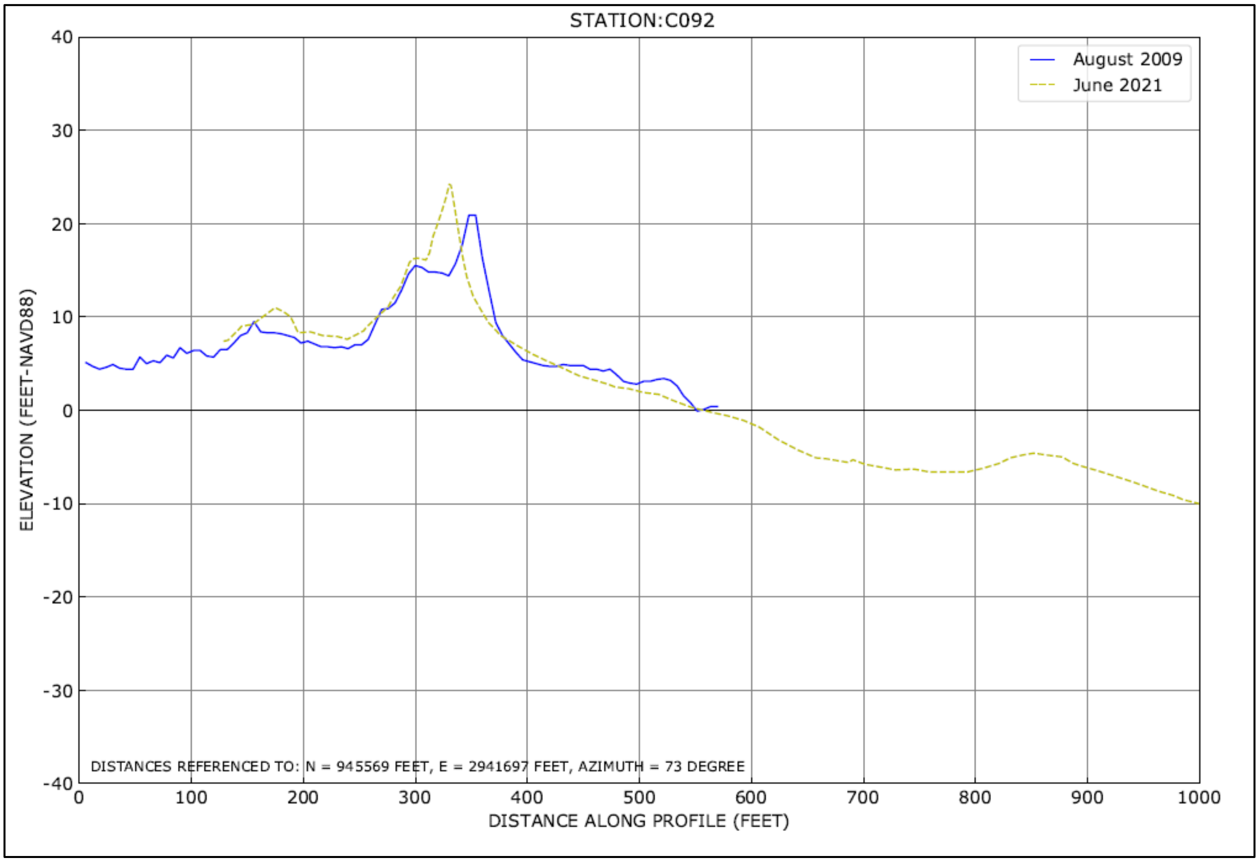

Figure 21. Dune Movement Example

Variations in the movement of the dune crest location and elevation were observed throughout the area evaluated. On average, the dune crest in the Corolla Section moved landward slightly more than the dune crest in the Pine Island Section, with an average change in the position of the dune crest of approximately 11 feet. The average increase in the crest elevation along the Corolla Section was 2.7 feet. In the Pine Island Section, the average dune crest position was more stable with an average landward movement of approximately 4 feet between 2009 and 2021. The dune crest elevation in Pine Island increased an average of 1.5 feet over the same time period.

6 WAVE RUNUP ANALYSIS

CPE conducted an initial assessment of the stillwater elevation and wave runup elevation for a 5-year return period storm. FEMA uses these levels to determine whether storm damages are eligible under Category B of their Public Assistance program. Chapter 7 Emergency Work Eligibility of FEMA's Public Assistance Program and Policy Guide (2020), Section II – Emergency Protective Measures (Category B) describes the eligibility of Emergency Berms and Beaches (Sub-section X. 4.) as follows:

> *If a natural or engineered beach has eroded to a point where flooding from a 5-year storm could damage improved property, cost-effective emergency protective measures on the beach that protect the improved property against damage from that 5-year storm are eligible. Eligible measures typically include the construction of emergency sand berms to protect against additional damage from a 5-year storm.*

FEMA defines the Stillwater Level (SWL) as the average water surface elevation of the rise in seawater level (surge) resulting from a 5-year storm, plus the astronomical tide (2020). Wave runup is defined as the uprush of water above the stillwater level caused by wave action on a beach or shore barrier (FEMA, 2018). When combined the elevation of the SWL plus the wave runup for a 5-year storm is the maximum storm-induced elevation, also referred to as the 5-year Total Water Level (TWL). The SWL and TWL are the benchmarks outlined in the FEMA Public Assistance Program and Policy Guide (2020) used to determine eligibility under Category B of the Public Assistance program. Sub-Section X. 4. – Emergency Berms on Beaches, goes on to describe how these benchmarks are applied as follows:

> *To show that a 5-year storm could damage improved property, the Applicant must demonstrate that the stillwater level plus wave runup elevation* (TWL) *as determined by computer modeling for a 5-year storm exceeds the post-incident elevation of the primary dune. Locations where the elevation of the post-incident profile is less than the TWL are eligible for placement of an emergency berm (*Figure 22*). Based on the average expected erosion for a 5-year storm, FEMA only provides PA funding for emergency berms constructed with up to 6 cubic yards per linear foot of sand above the 5-year SWL or the berm's pre-incident profile, whichever is less. In some cases, placing sand below the 5-year SWL may be necessary to provide a base for berm. The placement of that sand is also eligible as part of the emergency protective measure.*

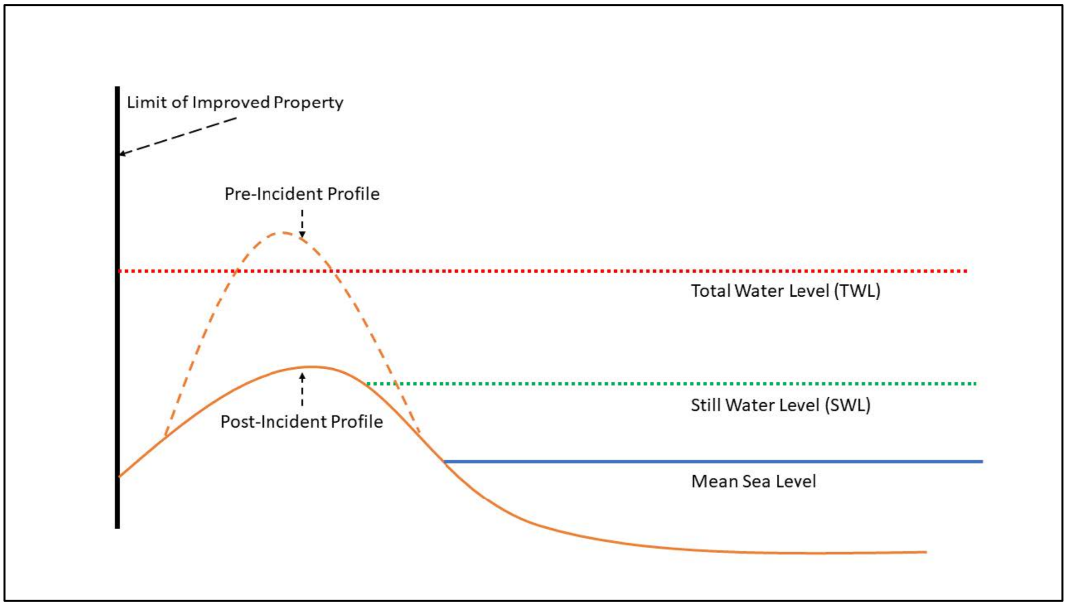

Figure 22. Determining Eligibility of Emergency Berms on Beaches (FEMA, 2020)

6.1 Methodology

In order to determine the wave runup, SWL, and TWL for a 5-year return period storm event, an extreme value analysis of wave height, wave period, and storm surge was completed using methodologies detailed in FEMA's Coastal Flood Frequency and Extreme Value Analysis guidance document for flood risk analysis and mapping (FEMA, 2016). Using publicly available water level, wave height, and wave period data as well as beach profile survey data collected in June 2021 as part of the Year 2 monitoring, Gumbel (Type 1) distributions were used to determine the best fit curve, which is then used to determine wave height, wave period, and storm surge extreme values for the selected return period. Data used in the extreme analysis included annual maxima extracted from 40 years (1980 to 2019) of hourly wave height and wave period data acquired from Wave Information Studies (WIS) Station 63216. The storm surge annual maxima time series created using the non-tidal residual, which is the difference between the measured tide level and predicted tide level, extracted from 40 years (1980 to 2019) of hourly tide data collected at the USACE FRF Pier in Duck, NC (NOAA Station 8651370). The 5-year return period storm values (wave height, wave period, and surge) extracted from the extreme analysis results were then used in the Stockdon equation (Stockdon, et al., 2006) to determine the 5-year wave run-up and ultimately the 5-year SWL and TWL elevations.

The Stockdon method was determined to be the most appropriate when considering the shoreline type, profile shape, wave climate, analysis goals, and study scope. Furthermore, this method was selected using the framework for evaluating different wave runup calculation methodologies detailed in FEMA's Guidance for Flood Risk Analysis and Mapping – Coastal Wave Runup and Overtopping (2018).

Wave runup is a function of beach slope. Considering it is likely that wave run-up processes will extend across the beach face and into the backshore during a storm event, the slope of each beach profile within the study area was calculated between the dune toe and the mean high water (MHW) shoreline. The toe of dune (TOD) was identified on a profile-by-profile basis and analyzed for general trends. It was found that station C-001 to station C-059 had a general TOD at the +8 ft. NAVD88 contour, and tation C-060 to station C-120 had a general TOD at the +9 ft. NAVD88 contour. The MHW shoreline was approximated using the +1.24 ft. NAVD88 contour.

The run-up elevation can be used to approximate the extent of run-up impacts. Specifically, FEMA defines TWL as being "equal to the elevation of the wave runup predicted for a 5-year storm plus the still water level (SWL)", where the SWL is defined as being "equal to the average water surface elevation of the rise in seawater level (surge) resulting from a 5-year storm and the astronomical tide" (FEMA, 2020). Considering a 5-year storm could potentially be characterized as a nor'easter, which are relatively long in duration when compared to a tidal cycle, then high tide is likely to occur at a time for which the surge is near its peak. Therefore, the tide level at the MHW elevation, relative to NAVD88, was chosen to represent the astronomical tide.

6.2 Results

The results of the extreme analysis show 5-year SWL to be +4.3 ft. NAVD88. The SWL is constant across the entire project area because it is a combination of the 5-year storm surge plus the astronomical tide. The TWL for a 5-year storm event is the sum of the the computed wave runup height for a 5-year storm plus the SWL. The computed 5-year wave runup height and the Total Water Level (TWL) elevations at each profile are provided in Table 15.

Table 16 provides a breakdown of the average wave runup height and TWL for a 5-year storm event along the four monitoring sections of the Currituck County shoreline and the overall Project Area. Appendix C contains the profile plots depicting the 5-year SWL and TWL elevations with respect to the primary dune and the profile as a whole.

Wave run-up is strongly influenced by the slope of the beach; given the same wave event and offshore bathymetry, steeper beaches will realize a higher wave run-up height when compared to that experienced on flatter beaches. The profile-based analysis shows that TWL is distinctly higher along the northernmost 1-mile of County shoreline between station C-001 and C-006 as well as at the southern end of the project between StationsC-102 and C-120. The average 5-year TWL elevations along the northern segment from station C-001 to station C-006 and the southern segment from sStation C-102 to station C-120 are 16.7 ft. NAVD88 and 15.1 ft. NAVD88, respectively.

Table 15. 5-Year Wave Runup Height and the Total Water Level for each profile along the Currituck County Shoreline

Station	5-year Wave Runup Height (ft.)	5-Year TWL Elevation (ft., NAVD88)	Station	5-year Wave Runup Height (ft.)	5-Year TWL Elevation (ft., NAVD88)
C-001	12.3	16.6	C-061	10.1	14.4
C-002	13.1	17.4	C-062	10.5	14.8
C-003	13.2	17.5	C-063	10.0	14.3
C-004	12.5	16.8	C-064	9.8	14.1
C-005	13.0	17.3	C-065	9.1	13.4
C-006	10.6	14.9	C-066	9.3	13.6
C-007	8.6	12.9	C-067	8.9	13.2
C-008	8.6	12.9	C-068	9.3	13.6
C-009	8.2	12.5	C-069	10.3	14.6
C-010	8.1	12.4	C-070	9.1	13.4
C-011	8.1	12.4	C-071	9.2	13.5
C-012	8.1	12.4	C-072	9.0	13.3
C-013	7.9	12.2	C-073	9.2	13.5
C-014	7.8	12.1	C-074	9.8	14.1
C-015	8.1	12.4	C-075	9.9	14.2
C-016	7.9	12.2	C-076	9.1	13.4
C-017	8.0	12.3	C-077	8.9	13.2
C-018	8.0	12.3	C-078	9.5	13.8
C-019	8.0	12.3	C-079	8.5	12.8
C-020	8.0	12.3	C-080	9.6	13.9
C-021	7.7	12.0	C-081	8.8	13.1
C-022	7.9	12.2	C-082	9.5	13.8
C-023	8.0	12.3	C-083	10.0	14.3
C-024	8.2	12.5	C-084	8.9	13.2
C-025	8.0	12.3	C-085	9.0	13.3
C-026	8.2	12.5	C-086	8.8	13.1
C-027	7.7	12.0	C-087	9.1	13.4
C-028	8.2	12.5	C-088	10.1	14.4
C-029	7.9	12.2	C-089	9.9	14.2
C-030	7.7	12.0	C-090	11.0	15.3
C-031	6.7	11.0	C-091	9.6	13.9
C-032	8.0	12.3	C-092	9.3	13.6
C-033	8.3	12.6	C-093	9.7	14.0
C-034	6.7	11.0	C-094	9.7	14.0
C-035	7.8	12.1	C-095	10.7	15.0
C-036	6.7	11.0	C-096	9.5	13.8
C-037	7.7	12.0	C-097	8.8	13.1
C-038	7.8	12.1	C-098	9.0	13.3
C-039	8.4	12.7	C-099	9.3	13.6
C-040	8.5	12.8	C-100	9.6	13.9
C-041	8.7	13.0	C-101	11.5	15.8
C-042	8.3	12.6	C-102	9.7	14.0
C-043	8.2	12.5	C-103	10.1	14.4
C-044	6.7	11.0	C-104	9.7	14.0
C-045	7.6	11.9	C-105	9.6	13.9
C-046	9.3	13.6	C-106	9.3	13.6
C-047	9.1	13.4	C-107	9.0	13.3
C-048	8.1	12.4	C-108	11.2	15.5
C-049	8.9	13.2	C-109	14.0	18.3
C-050	8.4	12.7	C-110	14.2	18.5
C-051	8.8	13.1	C-111	11.5	15.8
C-052	8.1	12.4	C-112	10.2	14.5
C-053	7.7	12.0	C-113	10.0	14.3
C-054	8.1	12.4	C-114	10.2	14.5
C-055	8.3	12.6	C-115	10.3	14.6
C-056	8.2	12.5	C-116	12.8	17.1
C-057	8.5	12.8	C-117	9.7	14.0
C-058	8.2	12.5	C-118	10.6	14.9
C-059	8.8	13.1	C-119	12.3	16.6
C-060	9.6	13.9	C-120	11.0	15.3

Table 16. Average 5-Year Wave Runup Height and the Total Water Level Elevations by Monitoring Section

Section	5-year Wave Runup Height (ft.)	5-Year TWL Elevation (ft., NAVD88)
Carova (C-001 to C-027)	9.0	13.3
Reserve/Refuge (C-027 to C-059)	8.1	12.4
Corolla (C-059 to C-102)	9.5	13.8
Pine Island (C-102 to C-120)	10.8	15.1
Total Project Area (C-001 to C-120)	**9.2**	**13.5**

Assuming the application of the TWL would likely only be used to establish eligibility for Public Assistance in areas where development is present, the average 5-year TWL was also computed for the portion of the Reserve/Refuge Sections where oceanfront development is present. In this regard, the average 5-year TWL for the portion of the Reserve/Refuge Section between stations C-37 and C-49 was determined to be 12.6 ft. NAVD88.

A profile-by-profile comparison of the 5-year TWL elevation and the actual elevation to the primary dune crest was performed to identify any potential profiles where the dune is currently below the calculated 5-year TWL. In review of the profile plots in Appendix C, only one profile was identified where the 5-year TWL surpassed the primary dune elevation. The 5-year TWL calculated for station C-004 was 0.5 ft. higher than the highest peak of the dunes.

7 CONCLUSIONS

An update of long and short-term shoreline changes and an initial evaluation of short-term volumetric changes were conducted following the Year-2 surveys conducted in June 2021. The stated goals of the 3-year study are to better understand the changes that are occurring in the beaches and to assist the County in making informed decisions regarding beach management. Following the completion of Year-3 data acquisition and analysis, a final monitoring and beach stability assessment report will be submitted to the County.

7.1 Shoreline Change

Shoreline change rates measured between 2009 and 2021 were used to project future shoreline changes throughout the Project Area over a 10-, 20-, and 30-year time horizon. These long-term rates were determined using a linear regression method that considers various shoreline position data available. The projections show that in general, the Carova Section and the Reserve/Refuge Section of the Project Area would experience very little impacts based on projected shoreline change rates over a 30-year horizon. No oceanfront structures along the Pine Island Section were shown to be impacted by the projected shorelines over a 30-year horizon. Two portions of the Corolla Section included a high density of oceanfront structures shown to be impacted over the 30-year and 20-year horizon.

In the Carova Section, only four (4) oceanfront houses were shown to be impacted over the 30-year horizon. These four (4) structures were located along the northern 1,500 feet of the Carova Section between stations C-003 and C-001. Three (3) oceanfront houses within the Reserve/Refuge Section were shown to be impacted over the 30-year horizon. Two (2) of the houses are located between stations C-041 and C-044 and the third is located just north of the Currituck Banks Estuarine Reserve between stations C-050 and C-051. The house located between station C-043 and C-044 was also shown to be impacted over the 20-year horizon. 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. The oceanfront houses shown to be impacted along the Corolla Section are located withing two portions of the Section. In the northern portion of the Corolla Section from the horse gate south to approximately Carotank Drive (stations C-059 to station C-065), 49 structures were shown to be impacted over the 30-year horizon. Of these 49 structures, 18 were shown to be impacted over the 20-year horizon. The second portion where oceanfront houses were shown to be impacted by the projected shoreline change, was along the central portion of the Corolla Section between 891 Lighthouse Dr. and a point located approximately 450 feet north of Dolphin St. (station C-079 to station C-082). Nineteen (19) oceanfront houses along this section were shown to be impacted over the 30-year horizon. None of the 19 structures were shown to be impacted over the 20-year horizon. In total, 68 houses were shown to be impacted over the 30-year horizon, 18 were shown to be impacted over the 20-year horizon, and no houses were shown to be impacted over the 10-year horizon.

The analysis of projected shoreline changes based on rates developed as part of the Year-2 analysis suggest the most vulnerable areas along the County's oceanfront beach in terms of long-term shoreline retreat are the northern portions of the Corolla Section, north of Carotank Drive (station C-065) and the central portion of the Corolla Section between 891 Lighthouse Dr. and a point located approximately 450 feet north of Dolphin St. (station C-079 to station C-082). Sixty-Eight (68) oceanfront homes in the Corolla Section were shown to be impacted over the 30-year horizon with 18 of those shown to be impacted over the 20-year horizon. North of the horse gate, seven (7) oceanfront structures were shown to be impacted by the projected shoreline retreat over the 30-year horizon, with one (1) of these located between stations C-043 and C-044 shown to be impacted over the 20-year horizon. Four (4) of those houses north of the horse gate that were shown to be impacted over the 30-year horizon were located along the northernmost 1,500 feet of the County oceanfront. The other three (3) houses, located in the Reserve/Refuge Section, have the potential to impact traffic north and south along that section of beach.

While long-term shoreline change projections provide useful information to determine future potential impacts, oceanographic conditions can change (water levels, storm frequency, dominate wind direction), which may result in short-term trends that differ from long-term trends observed. The evaluation of short-term shoreline changes that occurred between May 2020 and June 2021 indicate much different rates than those measured long-term between 2009 and 2021. While some of this is attributed to seasonal variation, continued monitoring of the Project Area is important to determine whether short term variations in oceanographic parameters are driving these changes in observed long-term changes.

7.2 Volume Change

Volume change rates measured between 2020 and 2021 show the project area has been accretional over the recent 13-month period. The average volumetric change rate along the entire Project Area was approximately +9.3 cy/ft./yr. between 2020 and 2021; this equates to a net volume gain of 1,188,000 cy. While the average rate of volumetric change was positive in each of the four sections, the Corolla Section had the lowest rate at +6.6 cy/ft./yr. and the Pine Island Section had the highest rate at +14.0 cy/ft./yr. The Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills in Dare County also experienced positive volumetric changes between 2020 and 2021. This suggests that the wave climate may have been such that net cross-shore transport may have resulted in a net increase in volume within the active beach (landward of the depth of closure).

CPE also specifically analyzed how the primary frontal dunes along the Corolla and Pine Island Sections have evolved since 2009 in terms of volume change, dune crest location, and dune crest elevation. The volume of sand in the dunes has remained relatively stable between 2009 and 2021. However, the position of the dune crest moved an average 8 feet landward between 2009 and 2021 (station C-059 to station C-120). Over the same period, the dune crest elevation increased 2.4 feet on average. The impact of this landward movement of the dune crest and the increase in elevation suggests that the dune is being compressed. In a response to erosion of the toe of the dune and occasional scarping, as well as management strategies such as the installation of sand fencing, the dune crest is moving slightly landward and gaining elevation on average. The average landward change in the dune crest position in the Corolla Section was slightly higher than the average for Pine Island. Likewise, the increase of the dune crest elevation was slightly higher in Corolla than in Pine Island.

The Pine Island Section is the only section where long-term change rates could be calculated given the availability of profile data collected by CSE in September 2015 and October 2017. The longer-term average volumetric change rate measured between 2015 and 2021 in this section was -0.8 cy/ft./yr., or relatively stable. The shorter-term average volumetric change rate measured between 2017 and 2021 was -10.2 cy/ft./yr. even though positive volume changes were measured between May 2020 and June 2021. While some of this is attributed to seasonal variation, continued monitoring of the Project Area is important to determine whether short term variations in oceanographic parameters are driving these changes in observed long-term changes.

7.3 Wave Runup Analysis

CPE assessed the Still Water Level (SWL) and wave runup for a 5-year return period storm to determine the Total Water Level (TWL) associated with such an event. FEMA uses these levels to determine whether storm damages are eligible under Category B of their Public Assistance program. Using astronomical tides and the rise in seawater level (surge) resulting from a 5-year storm, the SWL was determined to be 4.3 ft. NAVD88. For each profile surveyed along the County's oceanfront, the TWL was computed, which is the SWL + wave runup height. The wave runup height is a function of the slope of the beach from the toe of the dune out to the mean high water (MHW) contour. In that regard, an individual TWL can be computed for each profile.

The average TWL for the Project Area was +13.5 ft. NAVD88. Average TWL elevations were computed for each of the four sections of the Project Area. The average TWL elevations ranged from +12.4 ft. NAVD88 in the Reserve/Refuge Section to +15.1 ft. NAVD88 in the Pine Island Section. Following future federally declared disasters, if the dune crest elevations were to fall below the TWL elevation, those portions of the County oceanfront could be eligible for damage repair funds through FEMA's Public Assistance program.

8 RECOMMENDATIONS

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

1. Continue Monitoring of the Beach Profiles: Data collection along all 120 of the established beach profiles should continue as part of the Year-3 data acquisition task. These profiles 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). The collection of these data will allow for a project wide evaluation of volumetric changes from Year-1, Year-2, and Year-3. The data will allow better evaluation of short-term shoreline change trends.

2. Consider Future Shore Parallel Surveys: As discussed within the Year-1 report, deep depressions or troughs and shore-oblique sandbars were identified along several different segments of the Project Area. However, most of the features appear to be located seaward of the depth of closure. In essence, that means that the features may not be impacting volumetric changes from year to year. CPE recommended against the collection of the shore parallel bathymetric data in Year 2 given the goals of the 3-year study. Moving into the 3rd year of the study, CPE recommends that the shore parallel survey conducted in Year-1 be replicated in Year-3. The supplemental data would serve several purposes. First, the data would allow the tracking of the depressions and shore-oblique sandbars to determine whether they are migrating and at what rate. Second, the data will allow a more detailed analysis of volumetric changes from year 1 to 3 with respect to cross shore sediment transport that may be associated with storm impacts or recovery. Third, if following the conclusion of the 3-year study, the County determines it wants to evaluate shore protection alternatives, the supplemental data would enhance the setup and calibration of numerical modeling that may be necessary to evaluate those alternatives.

The collection of the shore parallel survey is already included in the original work order and would not require authorization of additional funds.

3. Update Storm Vulnerability Analysis: Following the collection of the Year-3 profile data, an update of the storm vulnerability analysis conducted in Year-1 should be conducted. This work is included in the existing scope of work and will provide an update of storm vulnerability throughout the project area.

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