# 2020 BEACH MONITORING AND BEACH STABILITY ASSESSMENT

# CURRITUCK COUNTY, NORTH CAROLINA

CURRITUCK COUNTY
1668

PREPARED FOR
CURRITUCK COUNTY

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

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# EXECUTIVE SUMMARY

Currituck County has commissioned a three-year Beach Monitoring and Beach Stability Assessment to 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. The beach stability assessment includes an assessment of volume and shoreline change trends, projected shoreline changes into the future over a 10, 20, and 30-year period and a vulnerability analysis.

The stated goals of the Assessment are 1) to better understand the changes that are occurring in the beaches and 2) to assist the County in making informed decisions regarding beach management. The three-year study aims to assess trends and provide a foundation for future coastal management in the County through data collection and beach analyses.

This 2020 (Year-1) report serves to establish a baseline for future monitoring, which will further evaluate long-term and short-term trends in shoreline movement, volume change, and coastal vulnerability. The report provides an assessment of both long-term and short-term shoreline change trends, an analysis of the impact of projected long-term shoreline change over 10-, 20-, and 30-year horizons, and an assessment of storm vulnerability. These conclusions provided in this Year-1 report were only based on data collected in Year-1 of a 3-year study. As data are acquired in Years 2 and 3, additional analyses will be conducted to better assess the Currituck County oceanfront beaches. 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 5.0 miles of the Project Area from the northern County boundary to the northern boundary of the Currituck National Wildlife Refuge. The approximately 6.1-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 3.4 miles of the Project Area is referred to as Pine Island.

The ideal method for determining temporal changes in the beach is to conduct volumetric change analyses, which requires multiple beach profile data sets that extend out to the Depth of Closure. Given the beach profile surveys collected in April and May 2020 was the first such survey completed along the entiriety of the County Beaches, a full volumetric analysis was not possible. These types of analyses will be completed for Year-2 and Year-3 of the Assessment.

Projected Shoreline Changes: Although a complete volumteric analyses could not be completed as part of the Year-1 Assessment, the availability of publicly available LiDAR data allowed for a 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. LiDAR data collected in 2009 were compared to beach profile data collected in 2020 as part of the Year-1 Assessment to determine shoreline change rates over the past 11 years. These shoreline change rates 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 Pine Island Section of the Project Area would experience very little impacts in terms of projected shorelines directly impacting oceanfront structures or roads. In the Carova Section, only the northernmost five (5) oceanfront homes appeared to be impacted by the projected shoreline over the 30-year horizon. No impacts were indicated over the 20-year horizon. In the Pine Island Section, the only structures shown to be impacted by the shoreline change projections over the 30-year horizon are homes located north of Yaupon Lane. These houses were technically included in the Pine Island numbers, only because the boundary line between the Corolla and Pine Island Sections is approximately 500 feet north of Yaupon Lane to align with the nearest beach profile transect.

Within the Reserve/Refuge Section, in which the average long-term shoreline change was greatest, projected shoreline change indicates five (5) houses in total that could be impacted by shoreline change over the 30-year horizon. One house is located just south of Albatrose Ln. The other four (4) houses are those located seaward of Sandfiddler Road between Canary Ln. and La Mer Ln. All four houses could be impacted by the 30-year projected shoreline. Two (2) of the houses could be impacted by the 10-year projected shoreline. While the number of houses 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. One other consideration in terms of projected shoreline changes along the Reserve/Refuge Section is that the relatively high shoreline change rates measured between C-051 and C-058, along the Currituck Banks Estuarine Reserve, show that the 30-year shoreline projection may begin to impact maritime shrub and maritime forest habitat.

The greatest number of impacts from projected shoreline changes were observed within the Corolla Section of the Project Area. More specifically, most of those projected impacts were observed north of Seabird Way in Ocean Sands. The only portion of this area in which no impacts to shoreline projections were observed over the 30-year horizon, were along the Corolla Light development between Corolla Village Road and Shad St., and the oceanfront homes along Spinnaker and Mainsail Arch off Marine Drive. Several oceanfront houses along Lighthouse Drive in Whalehead Beach were also shown to have no impact from the shoreline change projection over the 30-year horizon, however, most of the homes could be impacted. Not only did the projected shoreline over the 30-year horizon impact many of the houses in this portion of the Project Area, but portions of Sandcastle Drive, Atlantic Avenue, and Lighthouse Drive were also impacted. While projected shoreline retreat over a 10-year horizon appear to impact less than 5 houses along this area., 20-years of projected shoreline retreat appears to impact most of the oceanfront houses between the Ocean Hills clubhouse and Corolla Village Road and most of the oceanfront houses between Bonito St. and Albacore St. along Lighthouse Drive.

South of Seabird Way, within the Corolla Section, oceanfront structures impacted by the projected shoreline changes over the 30-year horizon were only observed within the Spindrift developments. These oceanfront structures appear to be impacted by the projected shoreline change over the 20-year horizon as well.

**Vulnerability Analysis:** The Vulnerability Analysis conducted through the use of the numerical model SBEACH, also provides useful information to determine future vulnerability of public and private development along the County's oceanfront beach. In total, 40 oceanfront homes were determined to be vulnerable from a storm similar in characteristics to Hurricane Isabel, which impacted the County in 2003. These houses were spread throughout the Project Area and were primarily located in areas where shoreline change projections also indicated potential impacts.

No structures were identified as impacted by the SBEACH vulnerability analysis in the Carova Section of the Project Area, however four (4) houses along the Reserve/Refuge Section were identified. These houses are the same four (4) houses located between Canary Lane and La Mer Lane that were shown to be impacted by the projected shoreline recession. These structures could impact traffic through this section of beach should storm impacts and/or continued shoreline recession, result in the homes being situated on the dry or wet sand beach.

The remaining 36 homes identified as impacted by the SBEACH Vulnerability analysis are located in the Corolla and Pine Island Sections of the Project Area; however, the majority (31) are located within the Corolla Section. The largest number of impacted homes (22) is located between the Ocean Hills clubhouse and Corolla Village Road. These only include oceanfront houses, and do not include the several oceanfront pools indicated as vulnerable through the analysis. Within the Whalehead Beach community, four oceanfront homes and several oceanfront pools associated with other homes were indicated as impacted along Lighthouse Drive. All nine (9) oceanfront homes located along the Spindrift community were determined to be vulnerable based on the established criteria. As previously stated, the Spindrift Community was split between the Pine Island and Corolla Section. One oceanfront home south of Yaupon Lane within the Pine Island

Section of the Project Area was identified as vulnerable. That home is located near Ogein Drive south of the Hampton Inn.

**Year-1 Summary:** At the conclusion of the Year-1 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. A baseline dataset to which future beach surveys can be compared to evaluate volumetric changes has been established. Long-term shoreline change rates have been established for the past 11-years, which can be compared to shorter-term rates observed over the 3-year plan. In addition, the Year-1 report provides several areas in which continued shoreline recession rates and/or future storms may impact oceanfront development.

**Recommendations:** Based on the analysis conducted by CPE during Year-1 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-2 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 to Year 2. The data will allow better evaluation of short-term shoreline change trends.

2. Consider Future Shore Parallel Surveys: As discussed within this 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 does not believe that repeating the shore parallel survey in Year 2 will provide tangible value in terms of the goals of this 3-year study. However, it is recommended that a repeat survey be considered for Year-3 after reviewing results of the Year-2 analysis. It may also be of value to have a second dataset comparable to the robust data coverage acquired during Year-1 in the event that numerical modeling is required to evaluate future shoreline management alternatives.

3. Coordinate results of Year-1 Analysis with Currituck Banks Reserve Management Staff: One of the findings of the Shoreline Change Projections was that over the 30-year horizon, long-term shoreline change rates may result in transitions of some of the maritime forest and maritime shrub habitat to more of an active dune environment. It may not be of concern to them but may be of interest.

4. Consider an Evaluation to determine the 5-Year Stillwater and Wave Runup Elevation: Following the impacts of federally declared disasters such as Hurricanes, oceanfront communities are eligible for emergency flood protection measures through FEMA's Public Assistance Program. FEMA describes the public funding eligibility as follows: *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 stillwater level or the berm's pre-incident profile, whichever is less. In some cases, placing sand below the 5-year stillwater level may be necessary to provide a base for the berm. The placement of that sand is also eligible as part of the emergency*

*protective measure.* Based on current conditions of the dune along the Project Area, and the potential impacts of storms, it may serve the County to determine the 5-Year maximum storm-induced water-surface elevation along the Project Area. Having this elevation at hand following a storm may allow rapid evaluation of whether the County may be eligible for Public Assistance funding to provide emergency Berms and Beaches.

# 2020 BEACH MONITORING AND BEACH STABILITY ASSESSMENT CURRITUCK COUNTY, NORTH CAROLINA

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# 1 INTRODUCTION

Coastal Protection Engineering of North Carolina, Inc. (CPE) was contracted by Currituck County to perform three years of beach monitoring and vulnerability assessments (2020-2022) to investigate long-term and short-term shoreline and volumetric changes occurring along Currituck's oceanfront beaches. The scope of work was developed through coordination with County staff and includes anticipated 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. The beach stability assessment includes an assessment of volume and shoreline change trends, projected shoreline changes into the future over a 10-, 20-, and 30-year period and a vulnerability analysis.

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. This 2020 Year-1 report serves to establish a baseline for future monitoring, which will further evaluate long-term and short-term trends in shoreline movement, volume change, and coastal vulnerability.

The State of North Carolina's Division of Environmental Quality publishes long-term average annual shoreline change rates for the entire coast of North Carolina, for the sole purpose of establishing oceanfront construction setback factors. The change rates, which utilize the endpoint method, typically represents the rate change as measured from aerial photos over 50 years. While these general trends may be sufficient for establishing construction setback guidance, more detailed shoreline and volume change analyses are 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. The northernmost 10.9 miles of the Currituck County Beaches, are only accessible via offroad driving. Of this 10.9-mile segment, the northernmost 5.0 miles of oceanfront is privately owned by various landowners and is referred to locally as Carova. South of Carova, is an approximate 1.8-mile section of beach owned by Currituck County, which separates the Atlantic Ocean from the Currituck National Wildlife Refuge. South of this County owned section of beach is an approximate 2.6-mile section that is privately owned and developed residentially. The southernmost approximate 1.6-mile stretch of the Currituck County Beaches north of N. Beach Access Road and the "horse gate", is publicly owned by a combination of the State of North Carolina, the Nature Conservancy, and Currituck County. The southern 0.6 miles of this section is part of the Currituck Banks Estuarine Reserve.

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. For the purposes of this study, this southern 11.7 miles has been split into two separate reaches. The northernmost reach extends approximately 8.3 miles from the horse gate to Yaupon Lane. The southernmost reach extends along approximately 3.4 miles from Yaupon Ln. south to the southern County border. This section of beach is managed by the Pine Island Property Owners Associations.

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 referred to throughout the report. The northernmost section is referred to as Carova, which encompasses approximately 5.0 miles of the Project Area from the northern County boundary to the northern boundary of the Currituck National Wildlife Refuge. The approximately 6.1-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 8.3 miles from approximately 250 feet south of the horse gate to approximately 500 feet north of Yaupon Lane. The southernmost 3.4 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 (C-120). Caffey's Inlet is believed to have been open between 1770 and 1811. Though little is known of the specifics of the inlet, it has been theorized that the extensive back barrier marsh west of this portion of the barrier beach is built upon the relic flood tide delta system of

Caffey's Inlet. Research conducted by Moran et al., (2015) suggested that Caffey's inlet "accommodated a significant tidal prism", meaning that it was a significant inlet for the region.

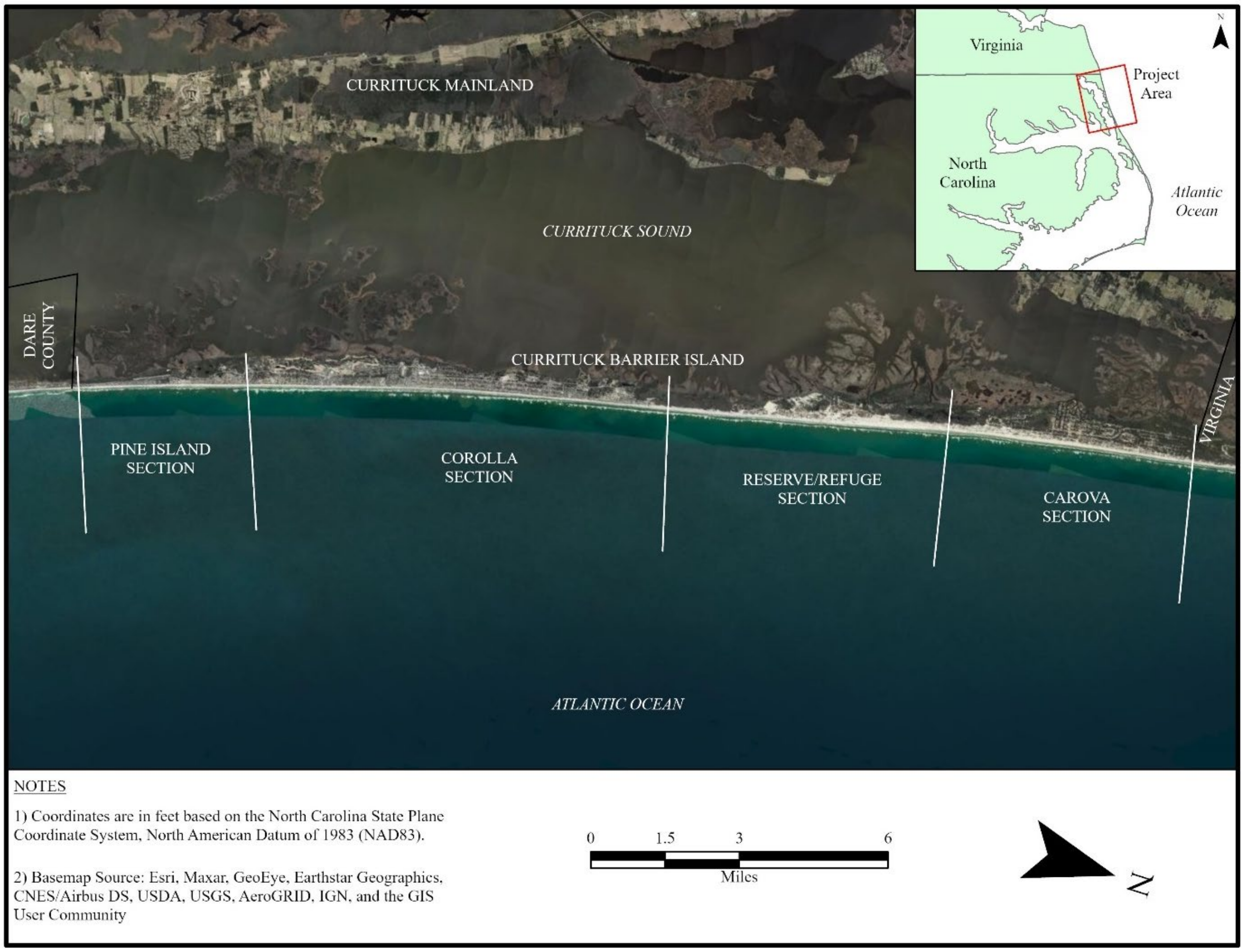


Figure 1. Currituck Project Location Map

Table 1. Section Descriptions

| Section Name | Approximate Length | Geographic Extent | Baseline Stations |
|---|---|---|---|
| Carova | 5.0 Miles | Northern County Boundary to Currituck Wildlife Refuge | C-001 to C-027 |
| Reserve/Refuge | 6.1 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-050 to C-102 |
| Pine Island | 3.4 Miles | 500 feet north of Yaupon Lane to southern County boundary | C-102 to C-120 |

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 closed in 1731 and though the opening of New Currituck Inlet is unknown, it was thought to have been closed around 1828

(Moran et al., 2015). 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.

# 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.

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 (C-097 to 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 (C-001 to C-120).
- Beach profile data collected by Coastal Protection Engineering of North Carolina (CPE) in May 2020 along the entire oceanfront of Currituck County (C-001 to C-120).

Table 2. Dataset Descriptions

| Agency/Firm | Survey Type | Date Range |
|---|---|---|
| USACE | LIDAR | 6/18/2009-6/25/2009 |
| CSE | Profile Survey | 15-Sep |
| USACE | LIDAR | 6/9/2017-9/16/2017 |
| CSE | Profile Survey | 17-Oct |
| 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 |

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. Table 4 lists each beach profile, the coordinates in which the profile intersects the baseline, and the azimuth at which the profile extends seaward from the baseline. Coordinates shown in Table 4 are referenced to the North Carolina State Plane coordinate system in feet NAD83 and the profile azimuth refers to degrees referenced to true north. Transects listed in Table 4 are shown visually along the oceanfront in Figure 2 through Figure 9.

Table 3. Tidal Datums

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

Table 4. Currituck County Transects List

| Station | Easting (ft) | Northing (ft) | Azimuth (°) | Station | Easting (ft) | Northing (ft) | Azimuth (°) |
|---|---|---|---|---|---|---|---|
| C-001 | 2919204 | 1033891 | 79 | C-031 | 2924974 | 1004210 | 79 |
| C-002 | 2919458 | 1032586 | 79 | C-032 | 2925164 | 1003228 | 79 |
| C-003 | 2919631 | 1031695 | 79 | C-033 | 2925457 | 1002272 | 75 |
| C-004 | 2919858 | 1030525 | 79 | C-034 | 2925749 | 1001315 | 75 |
| C-005 | 2920013 | 1029732 | 79 | C-035 | 2926042 | 1000359 | 75 |
| C-006 | 2920203 | 1028750 | 79 | C-036 | 2926334 | 999402.8 | 75 |
| C-007 | 2920394 | 1027769 | 79 | C-037 | 2926607 | 998511 | 75 |
| C-008 | 2920541 | 1027014 | 79 | C-038 | 2926919 | 997490.1 | 75 |
| C-009 | 2920828 | 1025539 | 79 | C-039 | 2927217 | 996515.5 | 75 |
| C-010 | 2920954 | 1024890 | 79 | C-040 | 2927541 | 995453.2 | 75 |
| C-011 | 2921176 | 1023748 | 79 | C-041 | 2927796 | 994621.2 | 75 |
| C-012 | 2921369 | 1022754 | 79 | C-042 | 2928088 | 993664.9 | 75 |
| C-013 | 2921521 | 1021972 | 79 | C-043 | 2928396 | 992658.1 | 75 |
| C-014 | 2921746 | 1020814 | 79 | C-044 | 2928700 | 991664.7 | 75 |
| C-015 | 2921927 | 1019882 | 79 | C-045 | 2928965 | 990796 | 75 |
| C-016 | 2922112 | 1018934 | 79 | C-046 | 2929258 | 989839.7 | 75 |
| C-017 | 2922307 | 1017926 | 79 | C-047 | 2929560 | 988849.5 | 75 |
| C-018 | 2922493 | 1016971 | 79 | C-048 | 2929865 | 987854.5 | 75 |
| C-019 | 2922668 | 1016070 | 79 | C-049 | 2930106 | 987063.9 | 75 |
| C-020 | 2922879 | 1014987 | 79 | C-050 | 2930401 | 986098.7 | 75 |
| C-021 | 2923057 | 1014072 | 79 | C-051 | 2930720 | 985058.2 | 75 |
| C-022 | 2923256 | 1013044 | 79 | C-052 | 2931012 | 984101.9 | 75 |
| C-023 | 2923450 | 1012050 | 79 | C-053 | 2931304 | 983145.6 | 75 |
| C-024 | 2923638 | 1011081 | 79 | C-054 | 2931597 | 982189.3 | 75 |
| C-025 | 2923809 | 1010199 | 79 | C-055 | 2931889 | 981233 | 75 |
| C-026 | 2924020 | 1009118 | 79 | C-056 | 2932181 | 980276.7 | 75 |
| C-027 | 2924210 | 1008136 | 79 | C-057 | 2932474 | 979320.3 | 75 |
| C-028 | 2924401 | 1007155 | 79 | C-058 | 2932766 | 978364 | 75 |
| C-029 | 2924592 | 1006173 | 79 | C-059 | 2933023 | 977523.9 | 75 |
| C-030 | 2924783 | 1005191 | 79 | C-060 | 2933302 | 976430.5 | 77 |

Table3. Currituck County Transects List (Continued)

| Station | Easting (ft) | Northing (ft) | Azimuth (°) | Station | Easting (ft) | Northing (ft) | Azimuth (°) |
|---|---|---|---|---|---|---|---|
| C-061 | 2933537 | 975487.8 | 77 | C-091 | 2941405 | 946526.2 | 73 |
| C-062 | 2933779 | 974518 | 77 | C-092 | 2941698 | 945569.9 | 73 |
| C-063 | 2934017 | 973563.3 | 77 | C-093 | 2941985 | 944629.4 | 73 |
| C-064 | 2934256 | 972604.6 | 77 | C-094 | 2942282 | 943657.3 | 73 |
| C-065 | 2934528 | 971512 | 77 | C-095 | 2942575 | 942700.9 | 73 |
| C-066 | 2934764 | 970567.6 | 77 | C-096 | 2942855 | 941785.1 | 73 |
| C-067 | 2934977 | 969714.8 | 77 | C-097 | 2943160 | 940788.3 | 70 |
| C-068 | 2935216 | 968754.5 | 77 | C-098 | 2943507 | 939850.5 | 70 |
| C-069 | 2935478 | 967704.8 | 77 | C-099 | 2943854 | 938912.6 | 70 |
| C-070 | 2935729 | 966698.8 | 77 | C-100 | 2944201 | 937974.7 | 70 |
| C-071 | 2935950 | 965808.9 | 77 | C-101 | 2944548 | 937036.8 | 70 |
| C-072 | 2936198 | 964814.8 | 77 | C-102 | 2944895 | 936098.9 | 70 |
| C-073 | 2936453 | 963793 | 77 | C-103 | 2945242 | 935161 | 70 |
| C-074 | 2936687 | 962853.3 | 77 | C-104 | 2945589 | 934223.2 | 70 |
| C-075 | 2936929 | 961883 | 77 | C-105 | 2945936 | 933285.3 | 70 |
| C-076 | 2937171 | 960912.7 | 77 | C-106 | 2946283 | 932347.4 | 70 |
| C-077 | 2937390 | 960035.7 | 77 | C-107 | 2946630 | 931409.5 | 70 |
| C-078 | 2937660 | 958951.4 | 77 | C-108 | 2946977 | 930471.6 | 70 |
| C-079 | 2937909 | 957962.1 | 77 | C-109 | 2947324 | 929533.7 | 70 |
| C-080 | 2938195 | 957025.3 | 73 | C-110 | 2947671 | 928595.9 | 70 |
| C-081 | 2938490 | 956061.5 | 73 | C-111 | 2948018 | 927658 | 70 |
| C-082 | 2938785 | 955096.6 | 73 | C-112 | 2948364 | 926720.1 | 70 |
| C-083 | 2939059 | 954201.9 | 73 | C-113 | 2948711 | 925782.2 | 70 |
| C-084 | 2939343 | 953273 | 73 | C-114 | 2949058 | 924844.3 | 70 |
| C-085 | 2939651 | 952264 | 73 | C-115 | 2949405 | 923906.5 | 70 |
| C-086 | 2939953 | 951276.5 | 73 | C-116 | 2949752 | 922968.6 | 70 |
| C-087 | 2940236 | 950351.4 | 73 | C-117 | 2950099 | 922030.7 | 70 |
| C-088 | 2940531 | 949386.4 | 73 | C-118 | 2950446 | 921092.8 | 70 |
| C-089 | 2940821 | 948438.8 | 73 | C-119 | 2950796 | 920149.2 | 70 |
| C-090 | 2941113 | 947482.5 | 73 | C-120 | 2951140 | 919217 | 70 |

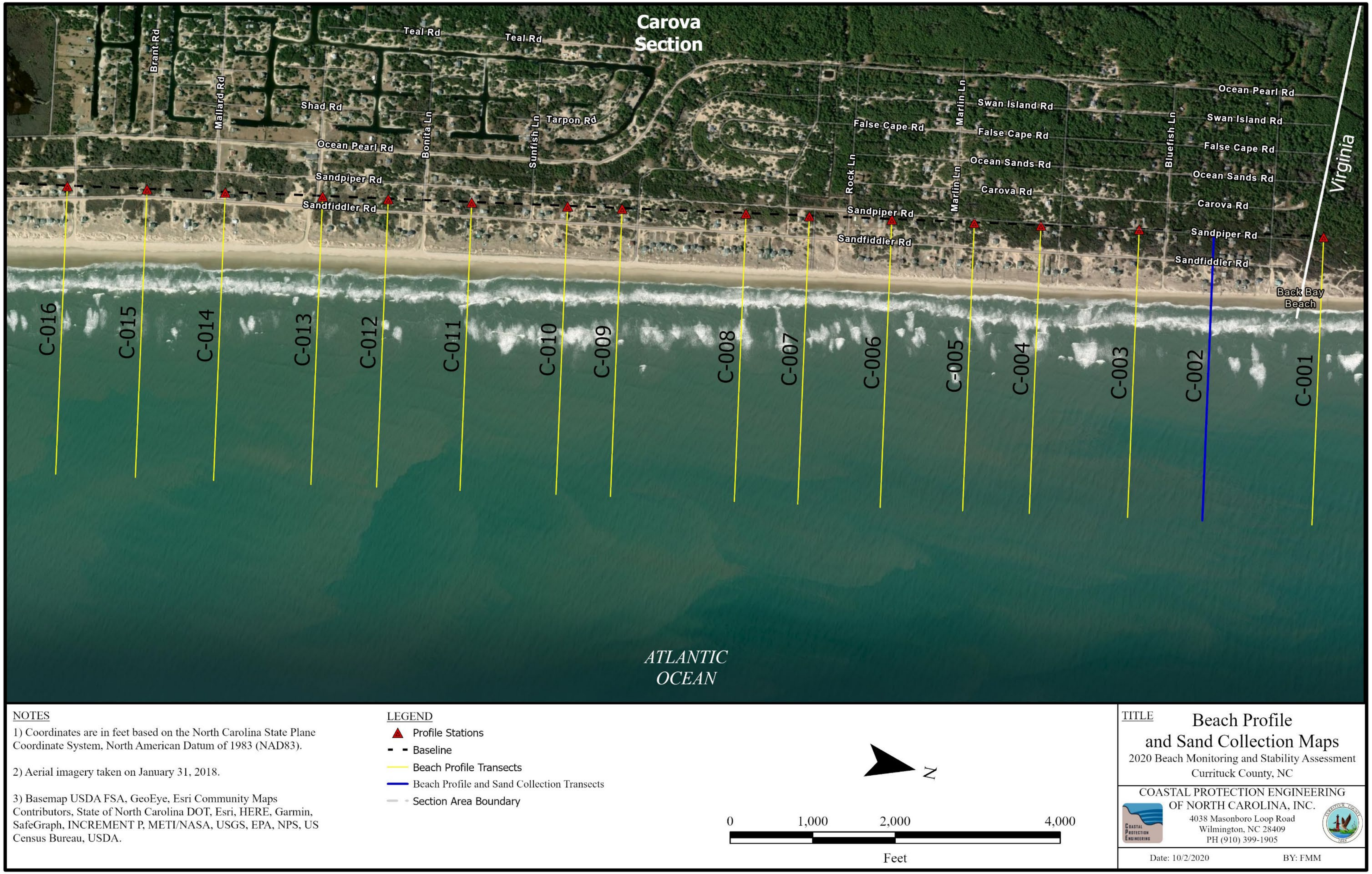


Figure 2. Monitoring Transects Map Station C-001 to C-016

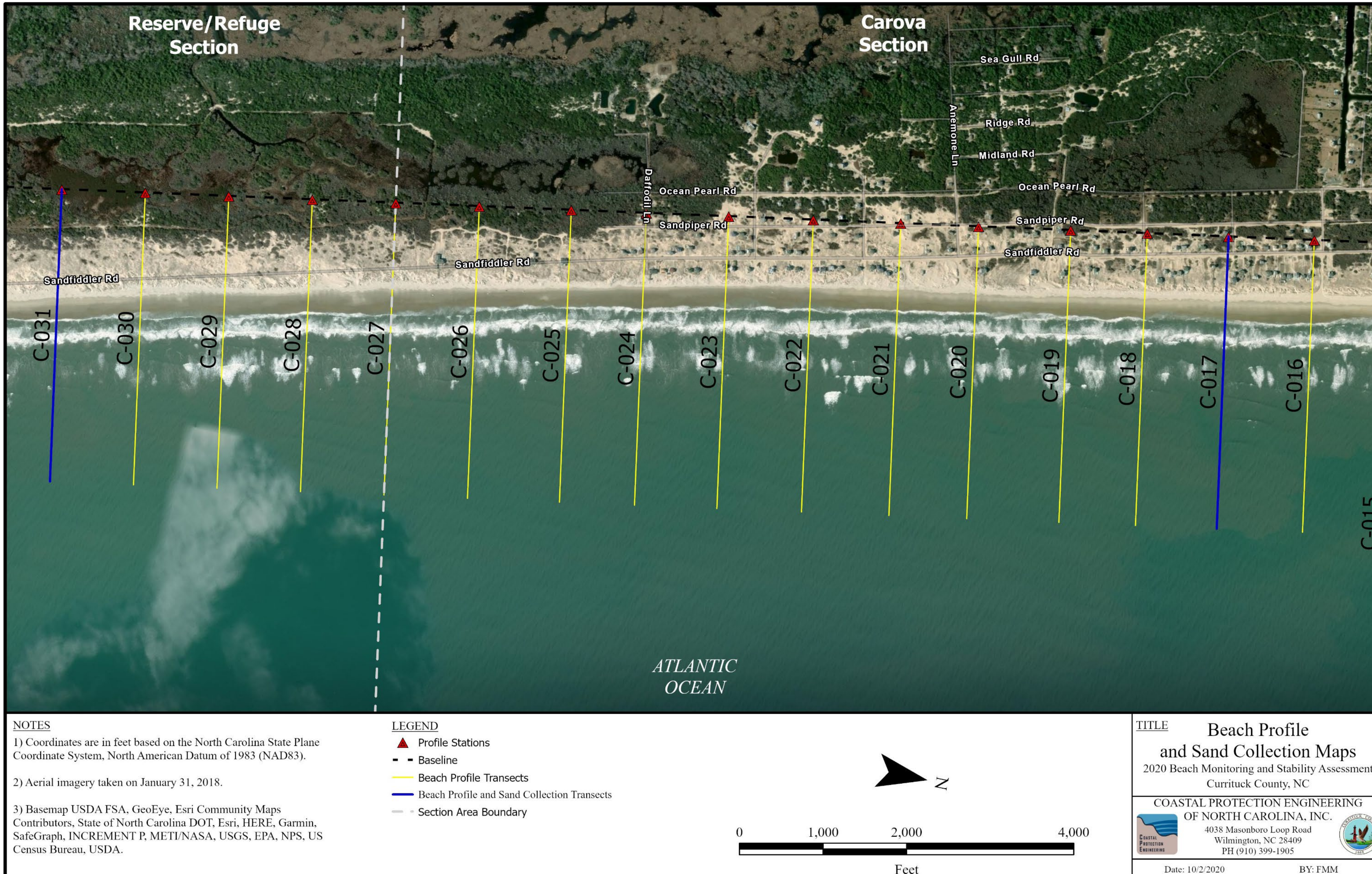


Figure 3. Monitoring Transects Map Station C-016 to C-031

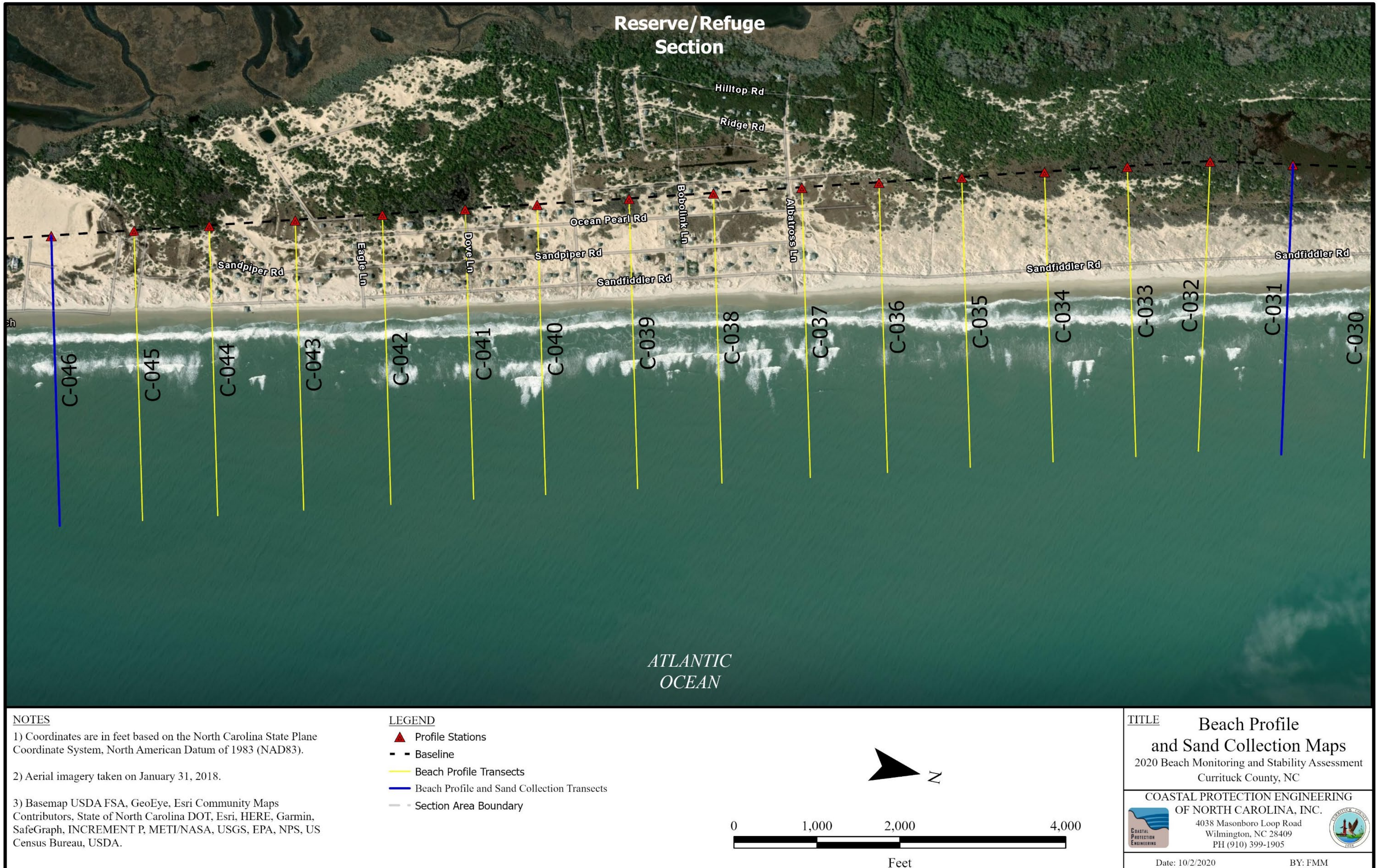


Figure 4. Monitoring Transects Map Station C-031 to C-046

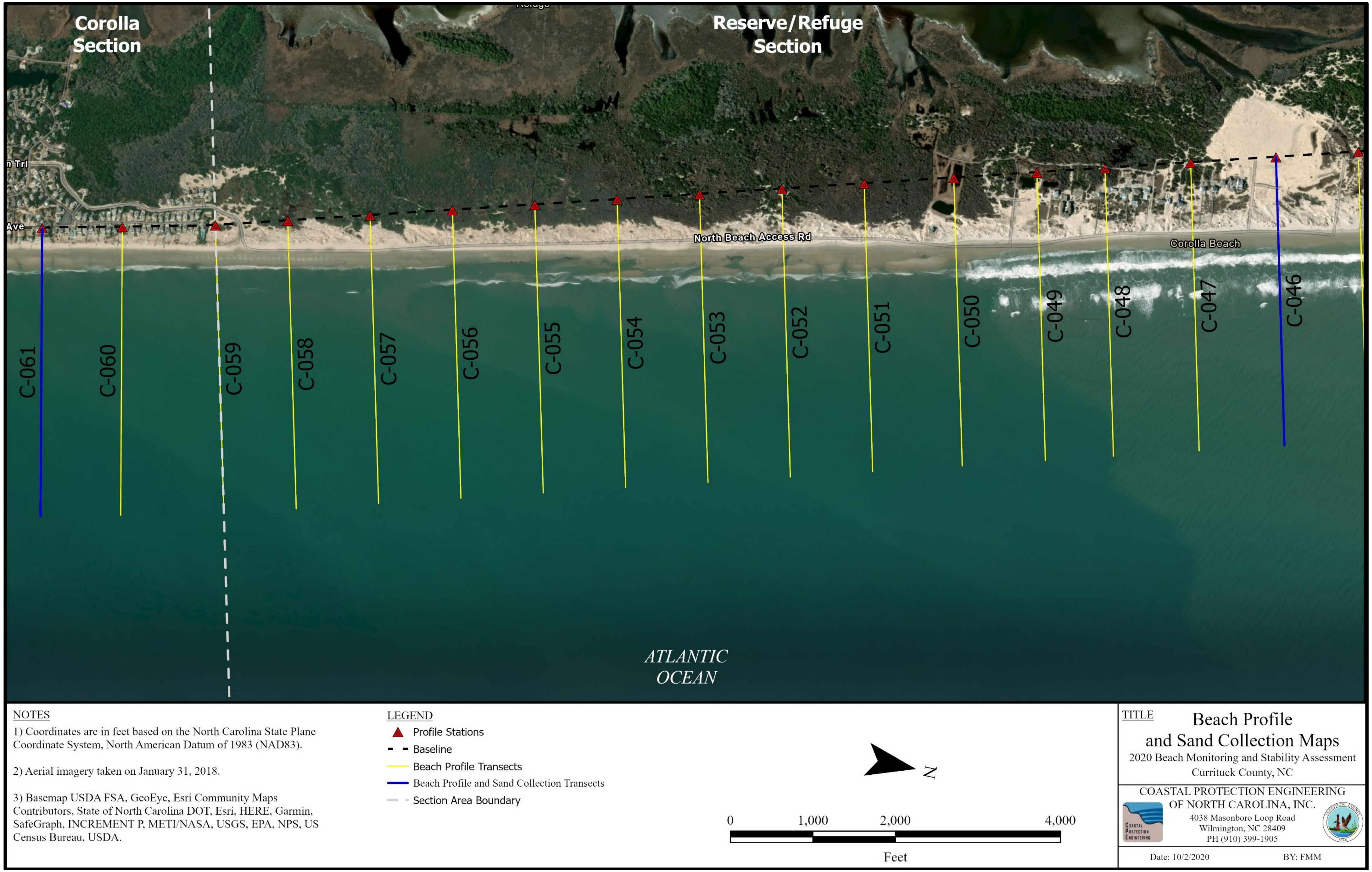


Figure 5. Monitoring Transects Map Station C-046 to C-061

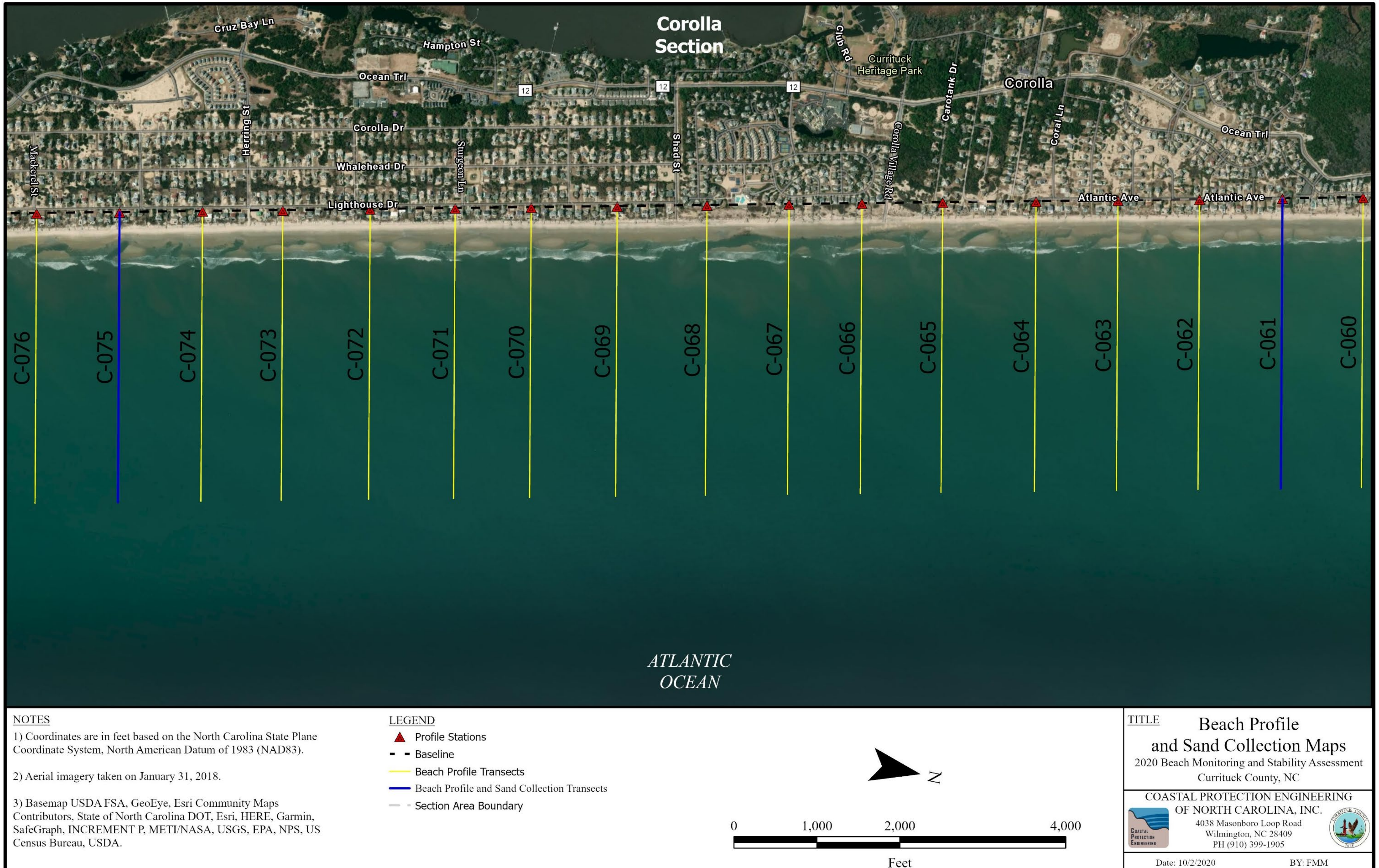


Figure 6. Monitoring Transects Map Station C-061 to C-076

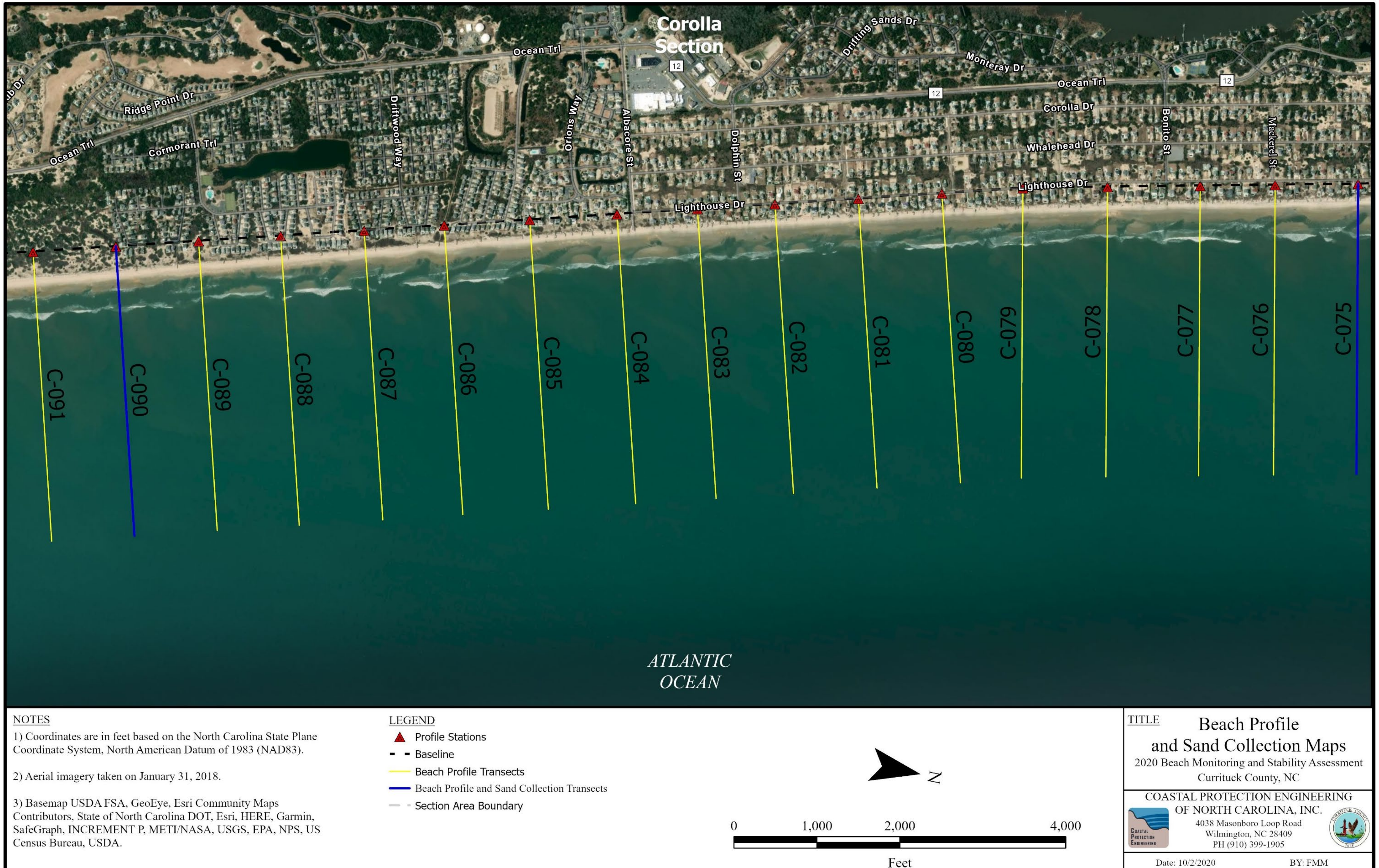


Figure 7. Monitoring Transects Map Station C-076 to C-091

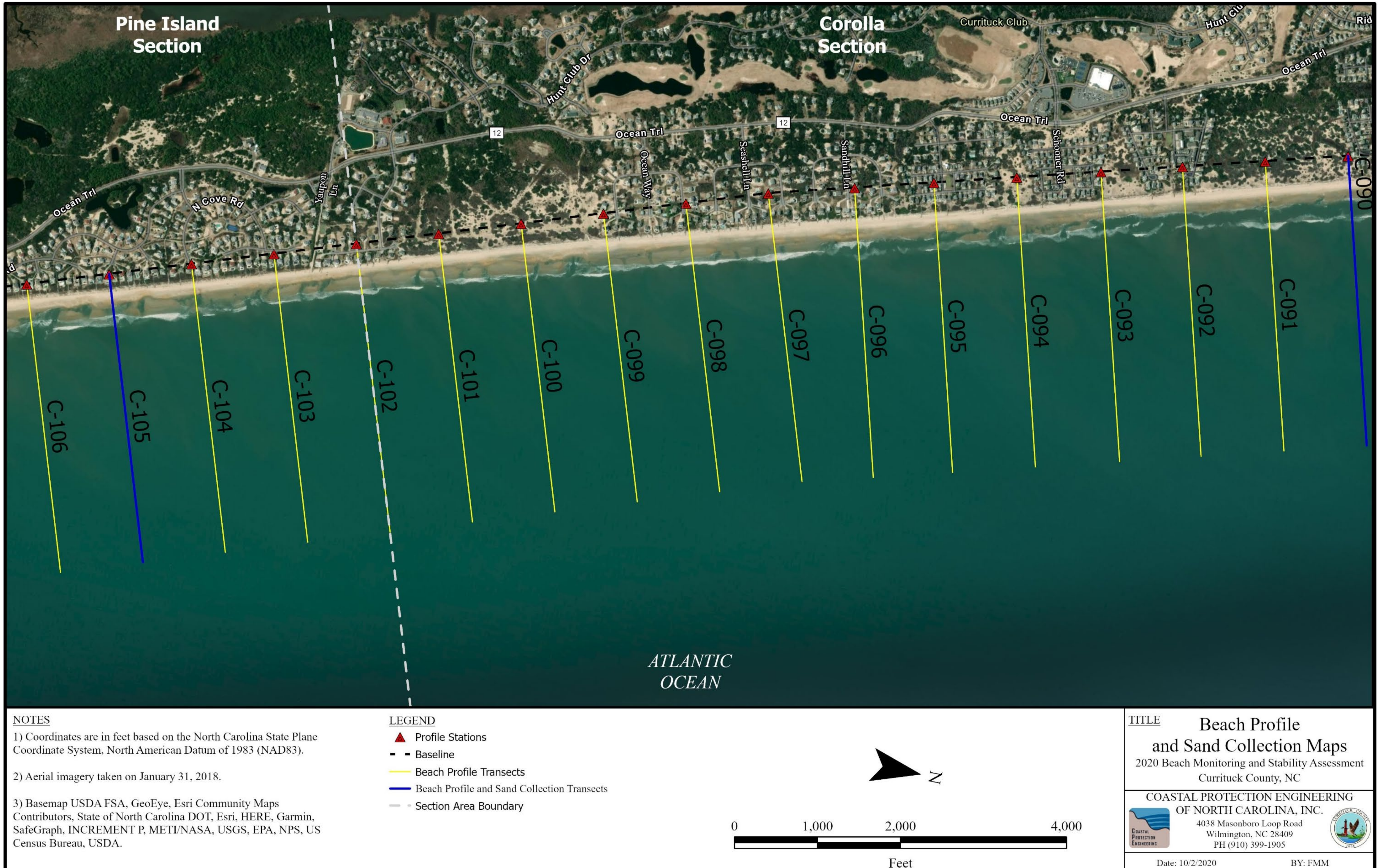


Figure 8. Monitoring Transects Map Station C-091 to C-106

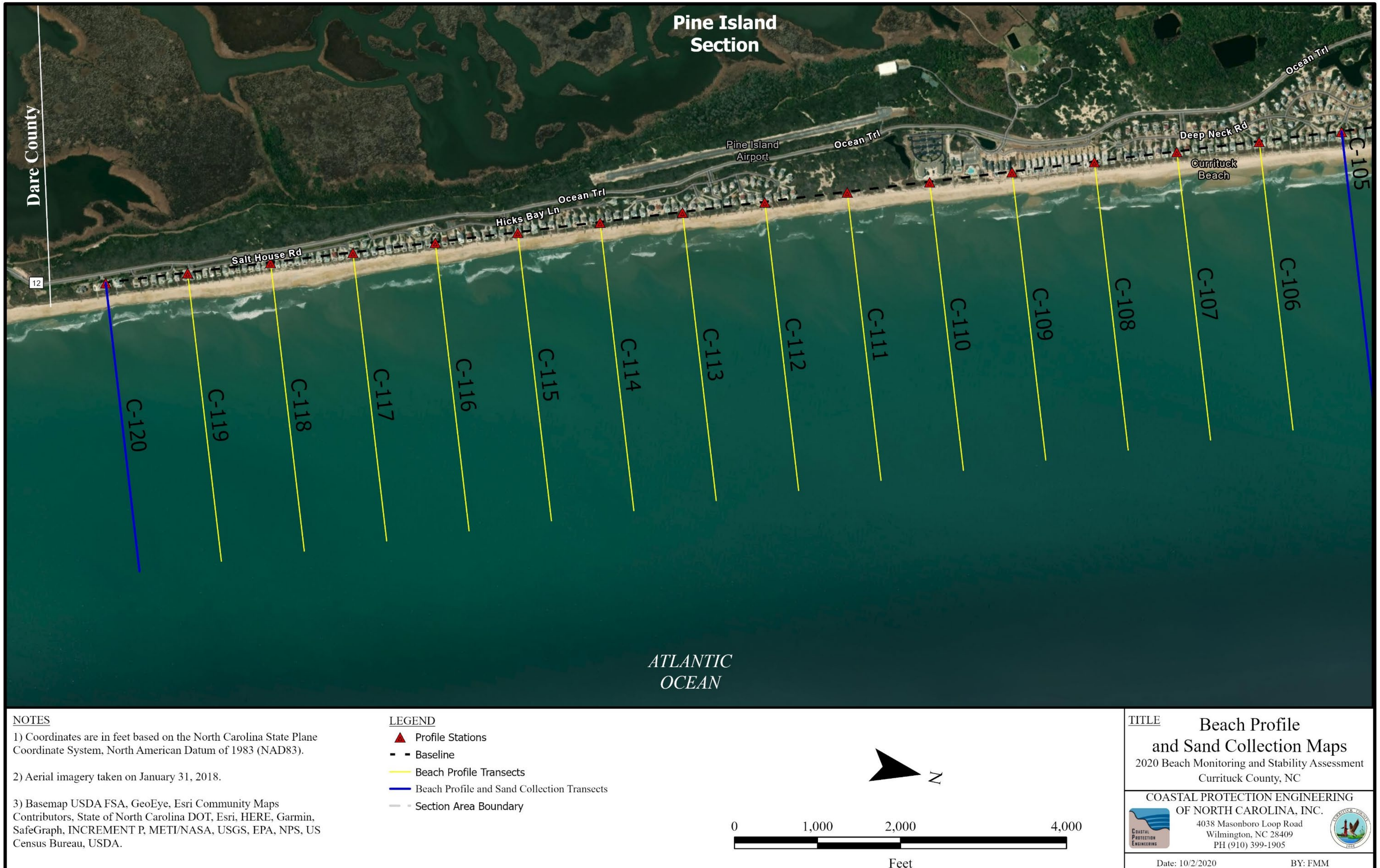


Figure 9. Monitoring Transects Map Station C-106 to C-120

## 2.1 NC DCM Long-Term Average Annual Shoreline Change Rates

As described on the North Carolina Division of Environmental Quality'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 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 (ft) 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 5 shows a comparison between the CSE referenced stations and the names of the stations used in the County Study (C-097 through C-120).

According to the CSE report, two RTK-GPS (Trimble Model R10 GNSS) units were used for data collection. The offshore work was performed using an Applanix™ POSMV inertial motion unit for positioning, which provides centimeter-level precision for positioning and corrects for vessel heave, pitch, and roll in real time. The Applanix™ POSMV was linked to a Teledyne Odom™ CV100 echo sounder, which provided soundings at 50 Hz and 0.1-ft precision. With the two systems linked by computer and data processing using Hypack™ 2016, there was no need for tide and wave corrections. Measurements over the visible portions of Pine Island beach extended to low-tide wading depth. Offshore profiles were collected at high tide to provide overlap with the visible beach data. The offshore and onshore elevation measurements were filtered in the office to eliminate spikes and to provide a floating average. Smoothed offshore data were edited to a manageable size and merged with subaerial data (CSE, 2018).

## 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.

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, to assist in emergency response operations, and in many other applications. Lidar data from August 2009 had reliable topography data and was selected for long term analysis. Lidar data from June 2019 had reliable topography and bathymetry data and was selected for short-term analysis.

## 2.4 CPE Beach Profile Data

In 2020, CPE conducted beach profile surveys for Currituck County. The survey conducted in May 2020 included 120 profiles (C-001 to C-120) along the beachfront of Currituck County. See Table 4 above for transect list. 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: 2020 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 survey 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 (PFD). This system allowed the surveyors to obtain 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 shall also be 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 to the projected depth of closure. Depth of closure (DOC) is a theoretical depth along a beach profile where sediment transport is very small or non-existent; see Section 5.1 for more information. The offshore data collection landward limit was based on a safe approach distance for the survey vessel based on conditions. All offshore data had a minimum overlap of fifty (50) feet with the nearshore beach profile.

## 2.5 CPE Shore Parallel Bathymetric Data

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

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

As part of the Year-1 data acquisition, a shore-parallel bathymetric survey was conducted along the entire Project Area. The total length of the survey area was approximately 119,500 ft. (approximately 22.6 miles). Survey data were collected from approximately the -12 ft. contour out to approximately 3,000 ft. offshore. Survey lines were laid out to run parallel to shore and spaced approximately 200 ft. apart. Data were post processed and used to generate a series of bathymetric charts that are included in Appendix A - Data Acquisition Report: 2020 Currituck County Beach Monitoring and Beach Stability Study.

A review of the bathymetric surface developed from the shore parallel data collected during the Year-1 monitoring, shows the presence of deep depressions or troughs and shore oblique sandbars similar to those identified offshore Dare County. Those features are located along the following positions of the Project Area:

- Carova Section – Between the northern County boundary and Sturgeon Lane (C-001 to C-009).
- Carova Section – Offshore of Anemone Lane near C-020.
- Reserve/Refuge Section – Between Albatrose Lane and Malbon Drive (C-037 to C-049).
- Pine Island Section – Between the south end of Hicks Bay Lane and the southern County boundary (C-116 to C-120).

# 3 BEACH SEDIMENT ANALYSIS

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

As part of this analysis, CPE collected representative sediment samples along nine (9) evenly spaced lines throughout the Project Area to determine grain size distribution, mean grain size, mineralogy, and color. The sediment characteristic data were used both in the setup of the storm vulnerability model described in Section 6.0 and to evaluate factors that may contribute to variable beach slopes throughout the Project Area. The results of the grain size analysis have also been archived in this report, as this type of data will be necessary to determine sediment compatibility if the County were to implement a program of sand placement on the County beaches. The transects along which sediment samples were collected are shown in Figure 2 through Figure 9.

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

Table 5. 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 |

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

The sediment samples collected along each profile were individually analyzed to determine color and grain size distribution. During sieve analysis, the wet, dry, and washed Munsell colors were noted. Sieve analysis of the sediment samples was performed in accordance with the American Society for Testing and Materials (ASTM) Standard Methods Designation D 422-63 for particle size analysis of soils. This method covers the quantitative determination of the distribution of sand size particles. For sediment finer than the No. 230 sieve (4.0 phi) the ASTM Standard Test Method, Designation D1140-00 was followed. Mechanical sieving was accomplished using calibrated sieves with a gradation of half phi intervals. Table 6 shows those sieves used in the analysis. Additional sieves representing key ASTM sediment classification boundaries were included to meet North Carolina technical standards for beach fill projects (15A NCAC 07H .0312 (d)). Weights retained on each sieve were recorded cumulatively. Grain size results were entered into the gINT® software program, which computes the mean and median grain size, sorting, silt/clay percentages for each sample using the moment method. Upon completion of individual sediment analysis, composite sediment characteristics were calculated for each profile. Granularmetric reports, grain size distribution curves, and composite tables were compiled for each sample and are included in Appendix B. The summary of the results are shown in Table 7.

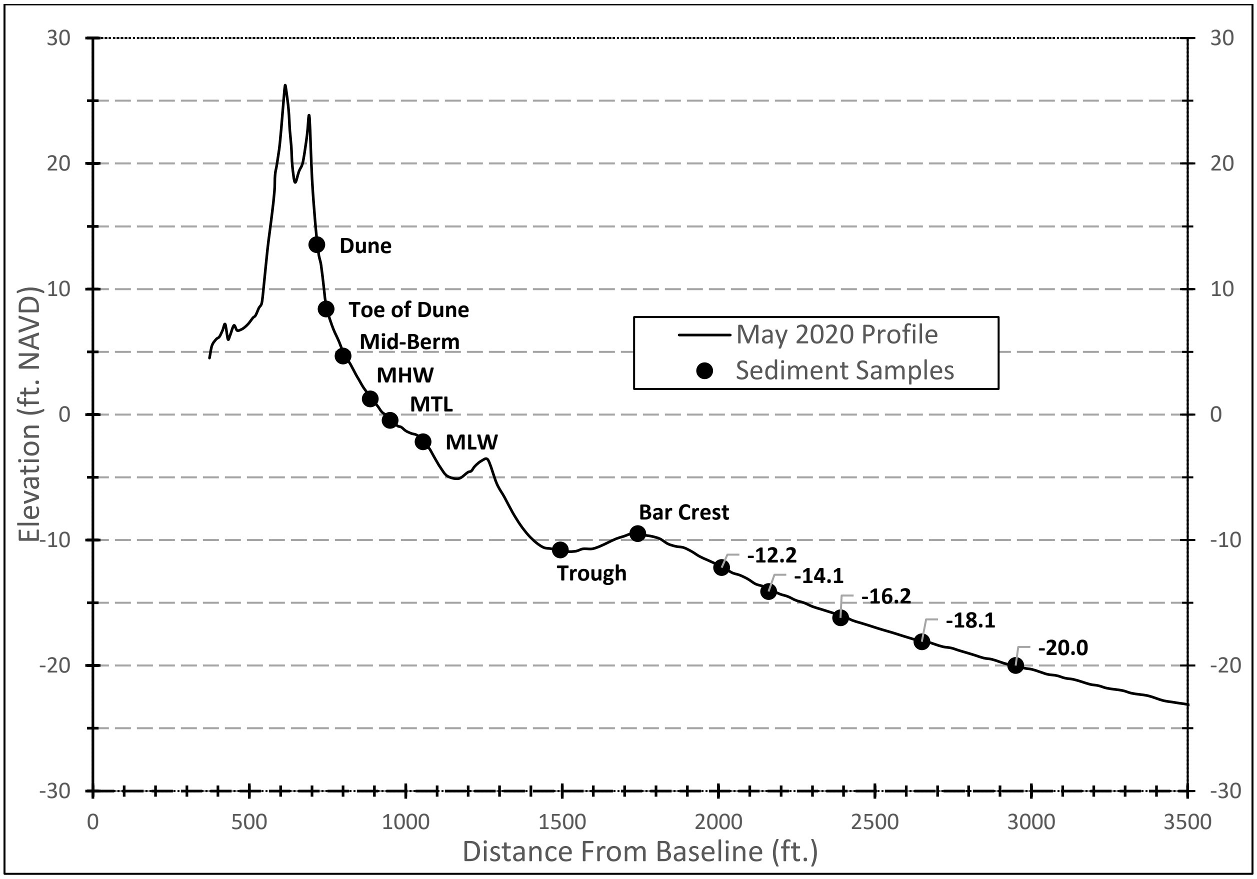


Figure 10. Representative cross section showing the location of samples collected along beach profile at C-017 to characterize existing beach.

Table 6. Sieve Sizes used for Grain Size Analysis

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

* Classifications are Based on Percent Retained in each Sieve

Table 7. Sediment Analysis Summary

| Sample Locations | Mean Grain Size(1) (mm) | Mean Grain Size(1) (phi) | Sorting(2) (phi) | Silt(2) (%) | Dry Munsell Color Value(3) |
|---|---|---|---|---|---|
| C-002 Composite | 0.21 | 2.22 | 0.99 | 1.3 | 6 |
| C-017 Composite | 0.18 | 2.48 | 0.75 | 1.76 | 7 |
| C-031 Composite | 0.18 | 2.44 | 0.68 | 1.43 | 7 |
| C-046 Composite | 0.20 | 2.29 | 0.82 | 1.73 | 7 |
| C-061 Composite | 0.22 | 2.34 | 0.85 | 1.74 | 7 |
| C-075 Composite | 0.25 | 2.26 | 0.71 | 2.2 | 7 |
| C-090 Composite | 0.35 | 2.19 | 1.25 | 2.44 | 7 |
| C-105 Composite | 0.48 | 1.96 | 1.45 | 2.03 | 7 |
| C-120 Composite | 0.26 | 1.94 | 1.19 | 1.19 | 7 |
| Carova | 0.2 | 2.35 | 0.89 | 1.53 | 7 |
| Refuge/Reserve | 0.19 | 2.36 | 0.76 | 1.57 | 7 |
| Corolla | 0.21 | 2.26 | 0.97 | 2.12 | 7 |
| Pine Island | 0.26 | 1.95 | 1.33 | 1.61 | 7 |
| Total Beach | 0.21 | 2.23 | 1.02 | 1.76 | 7 |

(1) Sieve analyses were conducted on all sediment samples in accordance with American Society for Testing and Materials Standard Materials Designation D422-63 for particle size analysis of soils. Grain size data were entered into the gINT® software program, which computes the mean and median grain size, sorting, and silt/clay percentages for each sample using the moment method (Folk, 1974).
(2) Silt content is defined as the percentage of material finer than 0.0625 mm (F.A.C. 62 B-41.007).
(3) Wet sand colors were evaluated using the Munsell color system. The Munsell notation for color consists of separate notations for Hue (combination of red, yellow, green, blue, and purple colors), Value (lightness of the sand color) and Chroma.

The overall average mean grain size for the entire Project Area was 0.21 mm. The southern half of the project had a slightly higher mean grain size value with the Corolla Section and Pine Island Section having an average mean grain size of 0.21 mm and 0.26 mm, respectively. The northern half had smaller mean grain sizes with the Carova Section and Refuge/Reserve Section having a mean grain size of 0.20 mm and 0.19 mm, respectively. A closer examination of Table 7 shows a markedly greater mean grain size for the four southern-most profiles sampled. These profiles were collected between station C-075, located approximately 550 feet south of Perch St. in Whalehead Beach, to station C-120, located at the southern County boundary. The average of the mean grain size values for these 4 profiles is 0.34 mm.

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

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

# 4 SHORELINE ANALYSES

The ideal method for determining temporal changes in the beach is to conduct volumetric change analyses. However, this requires multiple beach profile data sets that extend out to the Depth of Closure. Often times, when a community is conducting an initial evaluation of changes to the beach, such data sets are not readily available, as is the case with the Currituck County Beaches. Given the availability of publicly available LiDAR data as previously discussed, a shoreline change analysis can provide 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. Shoreline change can be provided in terms of the actual linear change measured between surveys or as a rate in an annualized form. The rate is calculated by dividing the measured distance of shoreline change by the time period (number of years) between survey events (i.e. feet per year). These rates are described in terms of positive (+) for advance (shoreline moving seaward) and negative (-) for recession (shoreline moving landward).

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 (C-102 located near Spindrift Trail to C-120 located near Station 1 Lane) is 2.0 ft/yr., which means that the calculated long-term shoreline change rate is 2 feet or less per year over the long term as measured by the State. The average, maximum, and minimum SBFs for each of the 4 Sections of the Project Area are provided in Table 8. 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 7 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 8. NCDCM 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 |

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) is chosen as the representative contour. For this study, the shoreline was defined as the +4.0 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 +4.0 ft NAVD88 contour does appear to be reliably captured consistently along the Project Area. The second reason is that the +4.0 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.

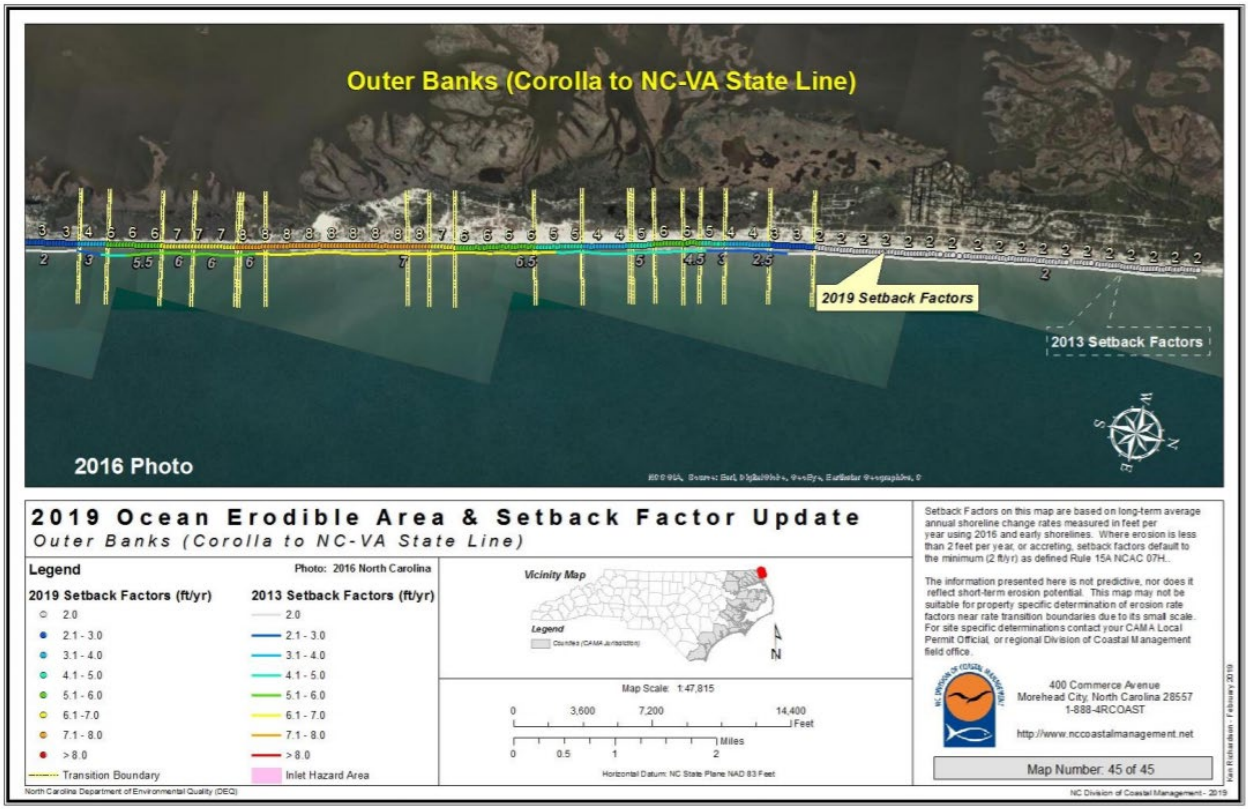


Figure 11. Map showing the SBF for Reserve/Refuge and Carova Sections of Currituck County

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.

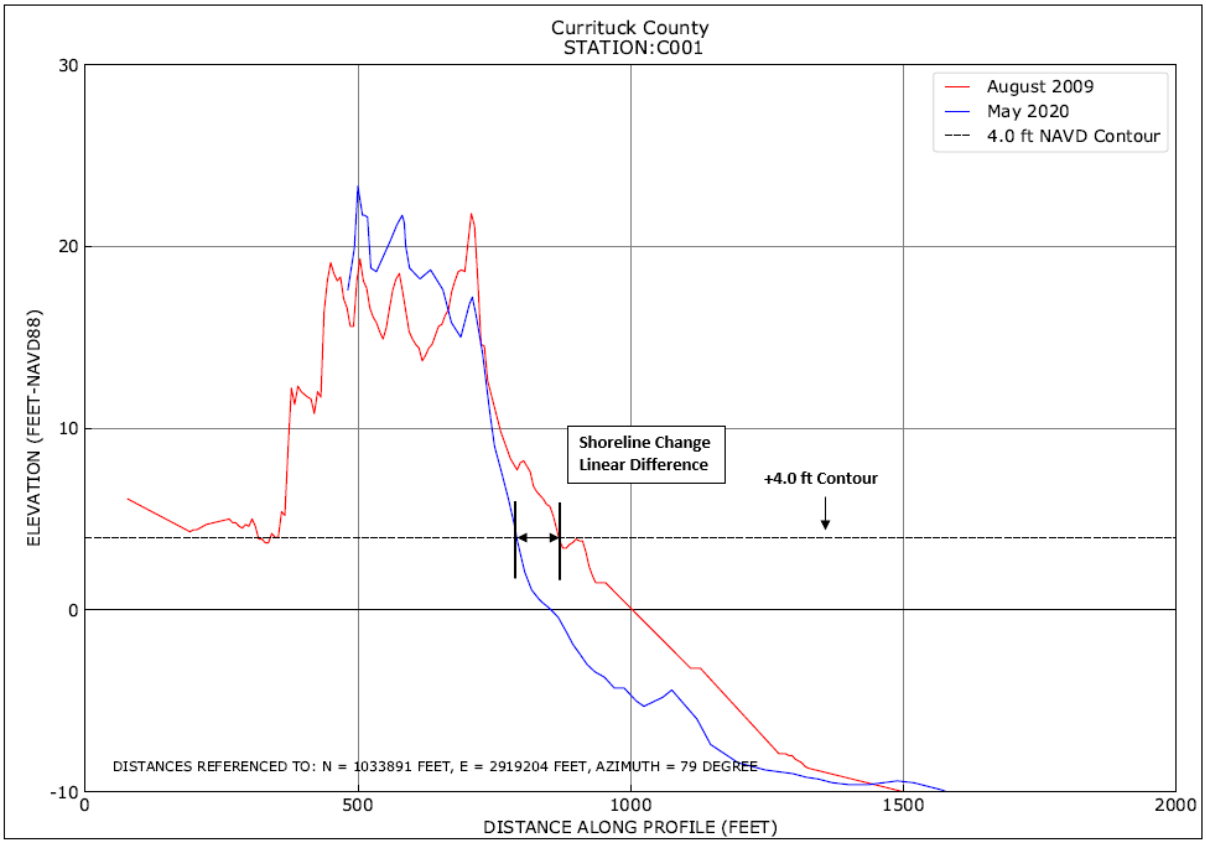


Figure 12. Beach profile cross section illustrating shoreline change

## 4.1 August 2009 to May 2020 Analysis

Data collected throughout the Project Area in August 2009 and May 2020 were examined to compare the positions of the +4 ft NAVD88 contour and determine shoreline change rates. The August 2009 data were collected by the USACE using LiDAR, whereas the May 2020 data were collected by CPE along the 120 beach profile transects, during the Year-1 monitoring survey.

The average shoreline change rate along the entire Project Area (C-001 to C-120) between August 2009 and May 2020, was -4.9 ft./yr. Individual rates of change measured between 2009 and 2020 for each profile are shown in Table 9. Figure 13 and Figure 14 show the shoreline change rates measured from August 2009 – May 2020. Table 10 shows the average shoreline change rates for each of the four sections of the Project Area.

The average shoreline change rate in the Carova Section was -2.8 ft./yr. The State long-term shoreline change rate for this section is -2.49 ft/yr. A profile by profile comparison shows shoreline change rates in this section ranging from -9.8 ft./yr. at Station C-015 to +4.1 ft./yr. at Station C-019. The northernmost 3,000 feet of the Carova Section (C-001 to C-004), north of Pompano Lane, had an average rate of -4.8 ft./yr. From Pompano Lane to just north of Sunfish Lane (C-004 to C-010), the shoreline was relatively stable, with an average shoreline change rate of -0.6 ft./yr. From just north of Sunfish Lane to Gulf Hawk Boulevard (C-010 to C-016), the average shoreline change rate was -3.7 ft./yr. From Gulf Hawk Boulevard to just north of Anemone Lane (C-016 to C-020), the average shoreline change rate was positive (seaward), measuring +1.0 ft./yr. The southern portion of the Carova Section from Anemone Lane south (C-020 to C-027), had the greatest negative shoreline change rate at -4.3 ft./yr. This trend continued into the Reserve/Refuge Section.

Table 9. +4 ft NAVD Shoreline Change Rates for the 2009 to 2020 and 2019 to 2020 Period (ft/yr.)

| Station | August 2009 to May 2020 | June 2019 to May 2020 | Station | August 2009 to May 2020 | June 2019 to May 2020 |
|---|---|---|---|---|---|
| C-001 | -7.2 | -11.7 | C-031 | -9.3 | -77.8 |
| C-002 | -8.5 | -13.1 | C-032 | -4.5 | -45.2 |
| C-003 | -3.5 | -25.3 | C-033 | -5.6 | -42.7 |
| C-004 | 0.1 | -6.8 | C-034 | -7.6 | -62.0 |
| C-005 | -2 | -38.4 | C-035 | -7.9 | -123.2 |
| C-006 | 0.3 | -20.5 | C-036 | -10 | -122.6 |
| C-007 | -2.3 | -23.4 | C-037 | -5.3 | -30.7 |
| C-008 | 0.3 | -37.3 | C-038 | -6.2 | -99.4 |
| C-009 | 0.4 | -41.9 | C-039 | -4.8 | -91.6 |
| C-010 | -1.3 | -57.1 | C-040 | -2.7 | -58.1 |
| C-011 | -3.7 | -74.2 | C-041 | -2.9 | -94.5 |
| C-012 | -2.1 | -75.0 | C-042 | -4.9 | -70.7 |
| C-013 | -3.3 | -80.0 | C-043 | -5.3 | -91.9 |
| C-014 | -3 | -72.2 | C-044 | -5.7 | -21.6 |
| C-015 | -9.8 | -61.9 | C-045 | -8 | -120.7 |
| C-016 | -3 | -79.0 | C-046 | -4.6 | -76.4 |
| C-017 | 1.1 | -74.0 | C-047 | -4.3 | -85.7 |
| C-018 | 2.1 | -73.1 | C-048 | -6.6 | -90.6 |
| C-019 | 4.1 | -74.8 | C-049 | -8.2 | -89.3 |
| C-020 | 0.5 | -79.4 | C-050 | -9.6 | -65.8 |
| C-021 | -4.6 | -80.3 | C-051 | -12.9 | -117.2 |
| C-022 | -5.1 | -73.9 | C-052 | -10.4 | -106.3 |
| C-023 | -4.8 | -80.7 | C-053 | -14.1 | -68.7 |
| C-024 | -2.7 | -51.1 | C-054 | -10.4 | -111.6 |
| C-025 | -6.7 | -49.9 | C-055 | -6 | -59.5 |
| C-026 | -5.6 | -67.7 | C-056 | -9.8 | -86.8 |
| C-027 | -5.5 | -55.7 | C-057 | -8.5 | -58.9 |
| C-028 | -6.2 | -14.9 | C-058 | -10.9 | -66.2 |
| C-029 | -7.7 | -15.2 | C-059 | -9.9 | -86.8 |
| C-030 | -8.7 | -33.1 | C-060 | -11.1 | -60.2 |

Table 9. +4 ft NAVD Shoreline Change Rates for the 2009 to 2020 and 2019 to 2020 Period (ft/yr.) (Continued)

| Station | August 2009 to May 2020 | June 2019 to May 2020 | Station | August 2009 to May 2020 | June 2019 to May 2020 |
|---|---|---|---|---|---|
| C-061 | -9.5 | -121.2 | C-091 | -5.2 | -73.6 |
| C-062 | -9.6 | -75.8 | C-092 | -5.8 | -89.0 |
| C-063 | -7.5 | -45.6 | C-093 | -4.9 | -74.8 |
| C-064 | -5.9 | -59.3 | C-094 | -2.7 | -93.7 |
| C-065 | -8.3 | -98.9 | C-095 | -3.6 | -44.2 |
| C-066 | -6.6 | -40.5 | C-096 | -2.1 | -44.9 |
| C-067 | -5.1 | -89.6 | C-097 | -2.8 | -76.1 |
| C-068 | -6.8 | -89.5 | C-098 | -3.5 | -78.5 |
| C-069 | -6.2 | -103.4 | C-099 | -8.8 | -128.6 |
| C-070 | -3.8 | -89.0 | C-100 | -3.1 | -77.3 |
| C-071 | -3.8 | -92.8 | C-101 | -4.6 | -115.2 |
| C-072 | -5.4 | -73.1 | C-102 | -6.2 | -103.1 |
| C-073 | -6.3 | -80.4 | C-103 | -3.9 | -74.5 |
| C-074 | -5.4 | -101.6 | C-104 | -2.1 | -94.8 |
| C-075 | -5.3 | -76.2 | C-105 | 0.7 | -36.1 |
| C-076 | -6.8 | -89.1 | C-106 | -1.5 | -41.2 |
| C-077 | -5.5 | -120.4 | C-107 | 3.6 | -88.1 |
| C-078 | -5.9 | -72.7 | C-108 | 0.3 | -87.1 |
| C-079 | -7 | -114.8 | C-109 | 0.1 | -43.8 |
| C-080 | -12.2 | -86.8 | C-110 | 1.5 | -26.0 |
| C-081 | -8 | -106.1 | C-111 | -4 | -54.8 |
| C-082 | -6.9 | -97.5 | C-112 | -0.3 | -47.0 |
| C-083 | -7.1 | -108.1 | C-113 | -0.1 | -47.2 |
| C-084 | -7.8 | -87.0 | C-114 | -2.3 | -82.0 |
| C-085 | -7.2 | -116.2 | C-115 | -1.9 | -63.8 |
| C-086 | -5.4 | -97.7 | C-116 | -2.4 | -66.9 |
| C-087 | -6.3 | -96.7 | C-117 | -2.1 | -41.8 |
| C-088 | -7.8 | -100.1 | C-118 | 4.7 | -21.4 |
| C-089 | -4.4 | -67.0 | C-119 | -0.7 | -62.9 |
| C-090 | -5.2 | -66.4 | C-120 | -4.3 | -68.3 |

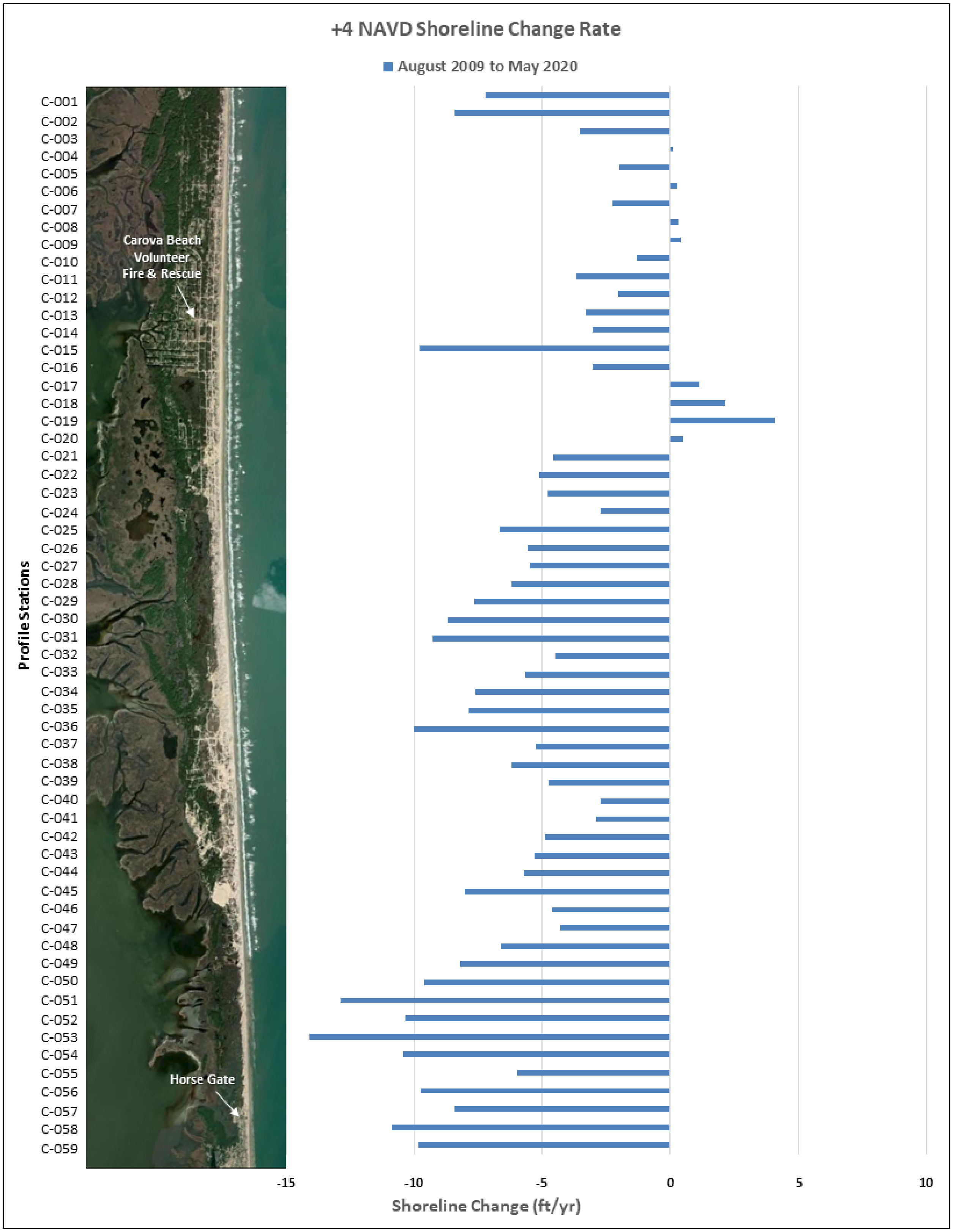


Figure 13. North of Horse Gate +4 ft NAVD88 Shoreline Change Rate

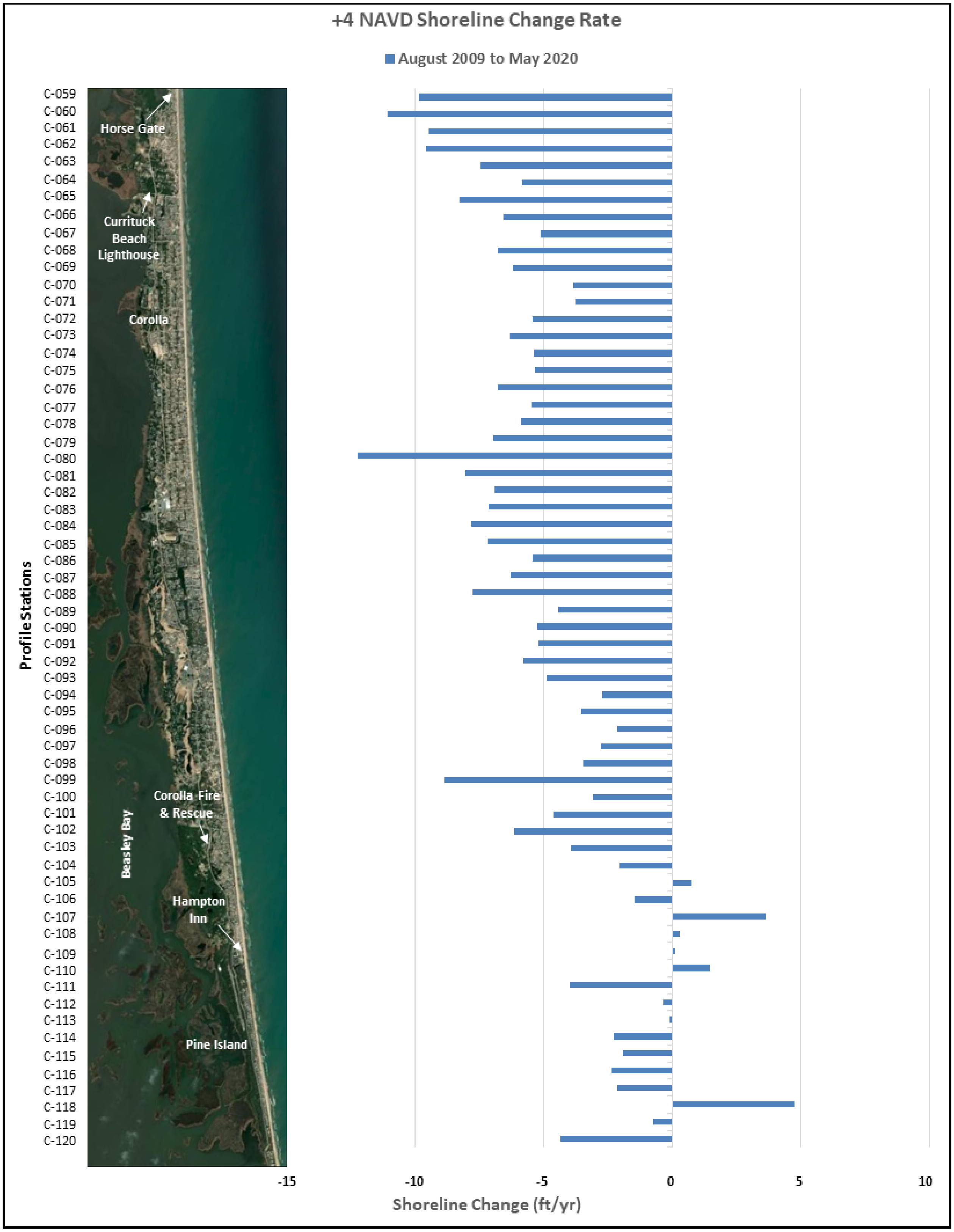


Figure 14. South of Horse Gate +4 ft NAVD88 Shoreline Change Rate

Table 10. Average +4 ft NAVD Shoreline Change Rate for August 2009 to May 2020 and June 2019 to May 2020 Period (ft/yr.)

| Section | August 2009 to May 2020 | June 2019 to May 2020 |
|---|---|---|
| Carova | -2.8 | -54.8 |
| Reserve/Refuge | -7.4 | -74.0 |
| Corolla | -6.2 | -86.6 |
| Pine Island | -1.1 | -60.6 |
| Total Project | -4.9 | -72.0 |

The average shoreline change rate in the Reserve/Refuge Section was -7.4 ft./yr., which is the highest shoreline recession rate for any of the four sections. The State determined the average recession rate in the Reserve/Refuge Section to be 6.8 ft/yr. A negative shoreline change rate was measured along each profile along this section of the Project Area, ranging from -14.1 ft./yr. at Station C-053 to -2.7 ft./yr. at Station C-040. 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 (C-027 to C-047), was -6.1 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 (C-047 to C-059), had an average shoreline change rate of -9.3 ft./yr.

The average shoreline change rate in the Corolla Section was -6.2 ft./yr. The State determined the average erosion rate in the Corolla Area (C-059 located near the horse gate to C-102 located near Spindrift Trail) to be 2.0 ft/yr. This represents the largest discrepancy between the State rates and the rates calculated by CPE between 2009 and 2020. 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 -12.2 ft./yr. at Station C-080 to -2.1 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 (C-059 to C-064), the average shoreline change rate was -8.9 ft./yr. From the south end of Atlantic Avenue to a point located approximately 700 feet south of Bonito St. (C-064 to C-078), the average shoreline change rate was -5.8 ft./yr. From C-078 south to C-088, located along Wave Arch off Seabird Way, the average shoreline change rate was -7.4 ft./yr. Along the southern portion of the Corolla Section, between C-088 (Wave Arch) and C-102, located approximately 500 feet north of Yaupon Lane, the average shoreline change rate was -4.7 ft./yr.

The average shoreline change rate between August 2009 and May 2020, in the Pine Island Section was -1.1 ft./yr. The State determined the average erosion rate in Pine Island Section (C-102 located near Spindrift Trail to C-120 located near Station 1 Lane) to be -2.0 ft/yr. The Pine Island Section is the only section of the four for which the August 2009 to May 2020 rates are less than the State rates. However, it should be noted that the minimum SBF the State publishes on their maps is 2.0 ft. Shoreline change rates varied along the Pine Island Section from -6.2 ft./yr. at

Station C-102 (located approximately 500 feet north of Yaupon Lane) to +4.7 ft./yr. at Station C-118 (located along the middle of Salt House Rd). The greatest negative shoreline change rate along the Pine Island Section was measured along the northernmost 2,000 feet between C-102 and C-104 (located at the south end of N. Cove Road), which was -4.1 ft./yr. Between the south end of N. Cove Road and the Hampton Inn (C-110), the average shoreline change rate was positive (seaward), measuring 0.4 ft./yr. From the Hampton Inn to the southern end of the Project Area (C-110 to C-120), the average shoreline change rate was -1.1 ft./yr.

## 4.2 June 2019 to May 2020 Analysis

LiDAR data collected by the USACE in June 2019 and the beach profile data collected by CPE in May 2020 were compared to measure short-term shoreline change with respect to the +4 ft NAVD88 contour. The annualized average shoreline change rate measured between the June 2019 and May 2020 surveys for the entire shoreline was -72 ft./yr. As shown in Table 10, the Carova Section had the lowest average shoreline change rate based on the June 2019 and May 2020 data (-54.8 ft/yr.); whereas the Corolla Section had the highest rate at -86.6 ft./yr.

The shoreline change rates measured between June 2019 and May 2020 were significantly larger than those measured for the period between August 2009 and May 2020. A thorough evaluation of these data suggest that the significantly higher rates of shoreline change measured along the +4 ft. NAVD88 contour between June 2019 and May 2020, may be more indicative of a seasonal adjustment in the beach slope, rather than actual erosion of the shoreline. The June 2019 LiDAR data were collected in late June, and likely the beach profile had adjusted to a summertime profile in which the dry sand beach tends to be wider and the beach slope tends to be more gradual. In contrast, the CPE data was collected earlier in the year between late April and mid-May 2020. Prior to and during this time, several winter storms impacted the Project Area, resulting in a beach profile that resembled a more typical winter profile with a relatively narrow dry sand beach and a steeper beach slope.

This comparison of the short-term shoreline change rate vs. long-term shoreline change rate illustrates the need to evaluate volumetric changes along a beach to better resolve erosional and accretional changes.

## 4.3 Shoreline Projections

As part of this Beach Monitoring and Beach Stability Study, a projected shoreline change analysis was conducted to evaluate potential impacts of long-term shoreline changes. The shoreline location of the +4 ft NAVD contour was projected for the future periods of 10, 20, and 30 years into the future. The shoreline change rates used to determine future positions were based on those rates previously discussed for the +4 ft NAVD between 2009 and 2020. Maps showing the results of the projected shoreline change are included in Appendix C - Impact Line and Projected Shoreline Maps.

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. For the stations on the north (C-001) and south (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 value was positive, indicating seaward shoreline change rate, no shoreline change is shown.

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 (C-001 to C-003). The five (5) oceanfront homes that appear to be impacted by the projected shoreline change could be impacted between the 20- and 30-year horizon. Projected shoreline changes over the 20-year horizon do not appear to impact any of the oceanfront structures in this Section.

In the Reserve/Refuge Section, where the average long-term shoreline change rate was the greatest of the four project Sections, projected shoreline change indicates several portions of the Section where impacts may occur. One house just south of Albatross Ln nears station C-037 could be impacted by the 30-year projected shoreline. There are four (4) houses located seaward of Sand Fiddler Road between Canary Ln. and La Mer Ln. (between C-040 and C-044). All four of the houses could be impacted by the 30-year projected shoreline. Two (2) of the houses could be impacted by the 10-year projected shoreline and three (3) of the four (4) are impacted by the 20-year projected shoreline. With the amount of vehicular traffic transiting the ocean front 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 C-051 and C-058, 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, where 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 and portions of some roads may be impacted over a 30-year time horizon. Along the northern half of the Corolla Section (north of Buck Island), the only area in which no shoreline change projections over the 30-year horizon impact oceanfront structures is along the Corolla Light development between Corolla Village Road and Shad St. (in the vicinity of C-066 to C-068). Several oceanfront houses along Lighthouse Drive in Whalehead Beach are shown to have no impact from the shoreline change projection over the 30-year horizon; however, most of the homes appear to be impacted over the 30-year horizon. While less than 5 houses north of Buck Island indicate shoreline change impacts over the 10-year horizon, most of the houses between the Ocean Hills clubhouse and Corolla Village Road (between C-060 and C-066) are impacted by the projected shoreline change over the 20-year horizon. The projected shoreline over the 30-year horizon also indicates impacts to portions of Sandcastle Drive (C-059 to C-061), Atlantic Avenue (C-061 to C-063), and Lighthouse Drive (C-080 to C-081).

Along the southern half of the Corolla Section, which includes the Buck Island, Crown Point, Ocean Sands, Ocean Sands South, and Spindrift communities, oceanfront structures impacted by the projected shoreline changes over the 30-year horizon are primarily located within the Buck Island (In the vicinity of C-084 and C-085), Crown Point (between C-085 and C-086), and Spindrift developments (between C-101 and C-103). The only oceanfront structures that appear to be impacted by the projected shoreline over the 30-year horizon within the Ocean Sands development are those located off of Ocean Lake Trail on Ocean Front Arch, Wave Arch, and Tide Arch (between C-087 and C-089). Only the oceanfront structures within the Spindrift development between C-101 and C-102 appear to be impacted by the projected shoreline change over the 20-year horizon. No impacts were indicated from projected shoreline changes over the 10-year horizon along the southern half of the Corolla Section.

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, the only oceanfront structures impacted by the projected shoreline change over the 30-year horizon are those few houses that are included in the Pine Island Section due to the location of station C-102, but are actually located north of Yaupon Lane in Spindrift.

# 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 color coded to show gains (green-accretion) and losses (red-erosion) in volume along the profile. The net difference between these gains and losses is referred to as the volume change.

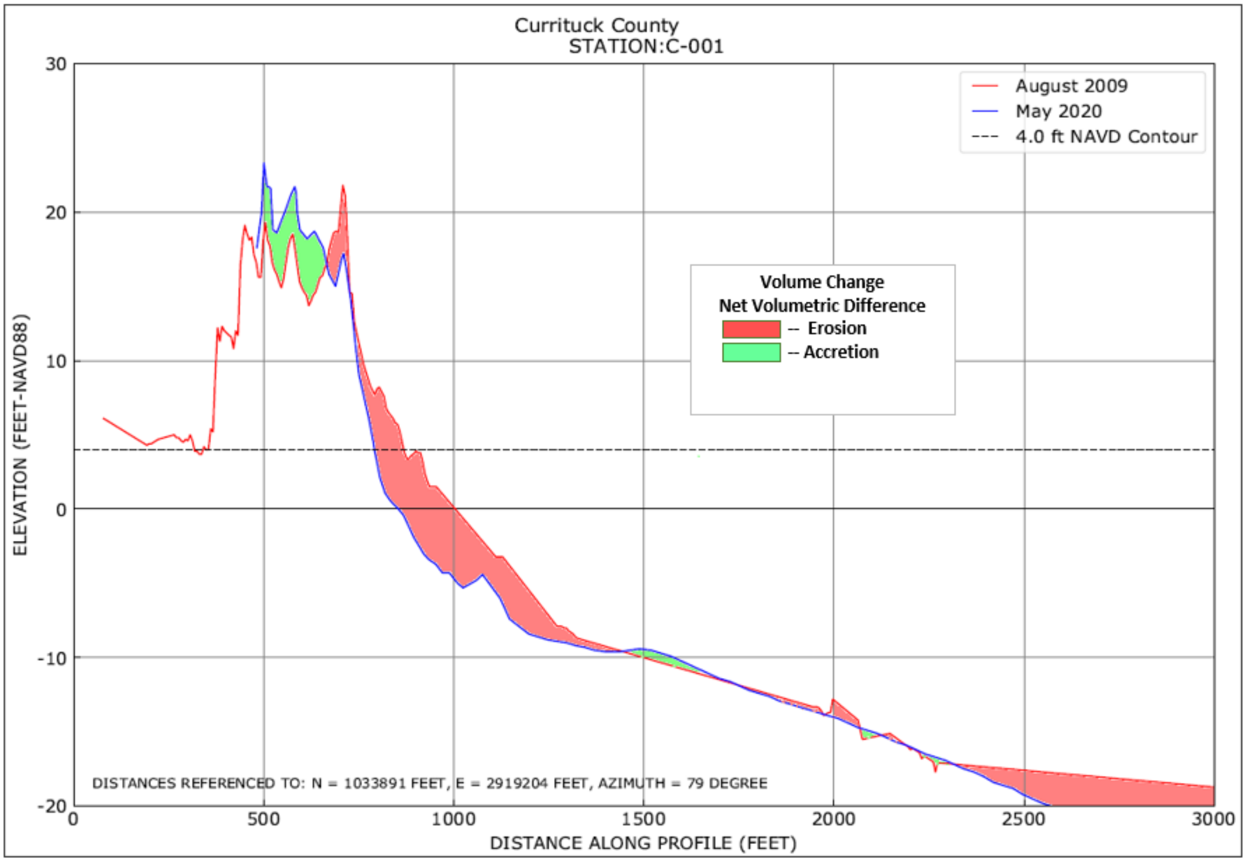


Figure 15. Beach Profile Cross Section Illustrating Volume Change

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 based on 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 following section discusses the depth of closure concept and how this depth was determined for this study.

## 5.1 Depth of Closure Determination

The active profile is defined as the portion of a beach profile along which sediment movement occurs. Typically, the active profile extends from the berm crest to the depth of closure. The depth of closure (DOC) is a theoretical depth along a beach profile where sediment transport is very small or non-existent.

Multiple methods and sources were used to evaluate the DOC and the results are summarized in Table 11. A volume check method was used in the Pine Island Section, comparing CPE's 2020 data and CSE's 2015 and 2017 data, to evaluate closure depths. Profile inspection was another method that was used to estimate the upper and lower limits of the active profile. The profile inspection revealed the DOC to be around -18 ft. NAVD88. The CSE report uses a DOC of -19 ft. NAVD88. A check of the volume change between the 2017 and 2020 surveys show the DOC to be around -18 ft. NAVD88.

**Table 11. Depth of Closure Elevations (relative to NAVD88)**

| Method | DOC (ft) |
|---|---|
| CSE DOC | -19 |
| Profile Inspection | -18.2 |
| Volume Check 2017 to 2020 | -18 |
| Volume Check 2015 to 2020 | -15 |
| Volume Check 2015 to 2017 | -23 |

As this is the first countywide beach monitoring event for Currituck County, the selection of a DOC aimed to capture all significant offshore changes, with the expectation that there will be opportunities for refinement as the monitoring program develops. Considering the results of the profile inspection, volume check, and CSE's published value on the limited survey data currently available, this Year-1 Beach Monitoring and Beach Stability Study uses a DOC of -19 feet NAVD88. This depth may be adjusted in the future due to more data being available.

## 5.2 Volume Envelope Comparison

Given the Year-1 beach profile data are the first County-wide surveys to extend seaward to the DOC, the volumetric change analyses that can be conducted are limited. In the absence of comparative data sets, a metric that can be evaluated to provide a relative comparison of beach volume is to compare the total volume along a profile contained in the "volume envelope".

For this study, the volume envelope is 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. The landward limit of the volume envelope, in this case the landward +18 ft. NAVD88 contour on the primary dune, 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 six (6) 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 16 provides a graphical depiction of the volume envelope concept.

Figure 17 and Figure 18 show a comparison of the volume measured within the volume envelope along the portion of the Project Area north of the Horse Gate (C-001 to C-059) and south of the Horse Gate (C-059 to 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. Of the four Sections the Project Area is split into, the Corolla Section had the lowest average density, which is shown in Table 12.

Comparing the volume measured in the volume envelope along the County's oceanfront allows for the relative comparison of each profile and may provide an indicator of areas that are more vulnerable than others. The results of the volume envelope analysis are discussed further in the Beach Vulnerability Analysis section of this report.

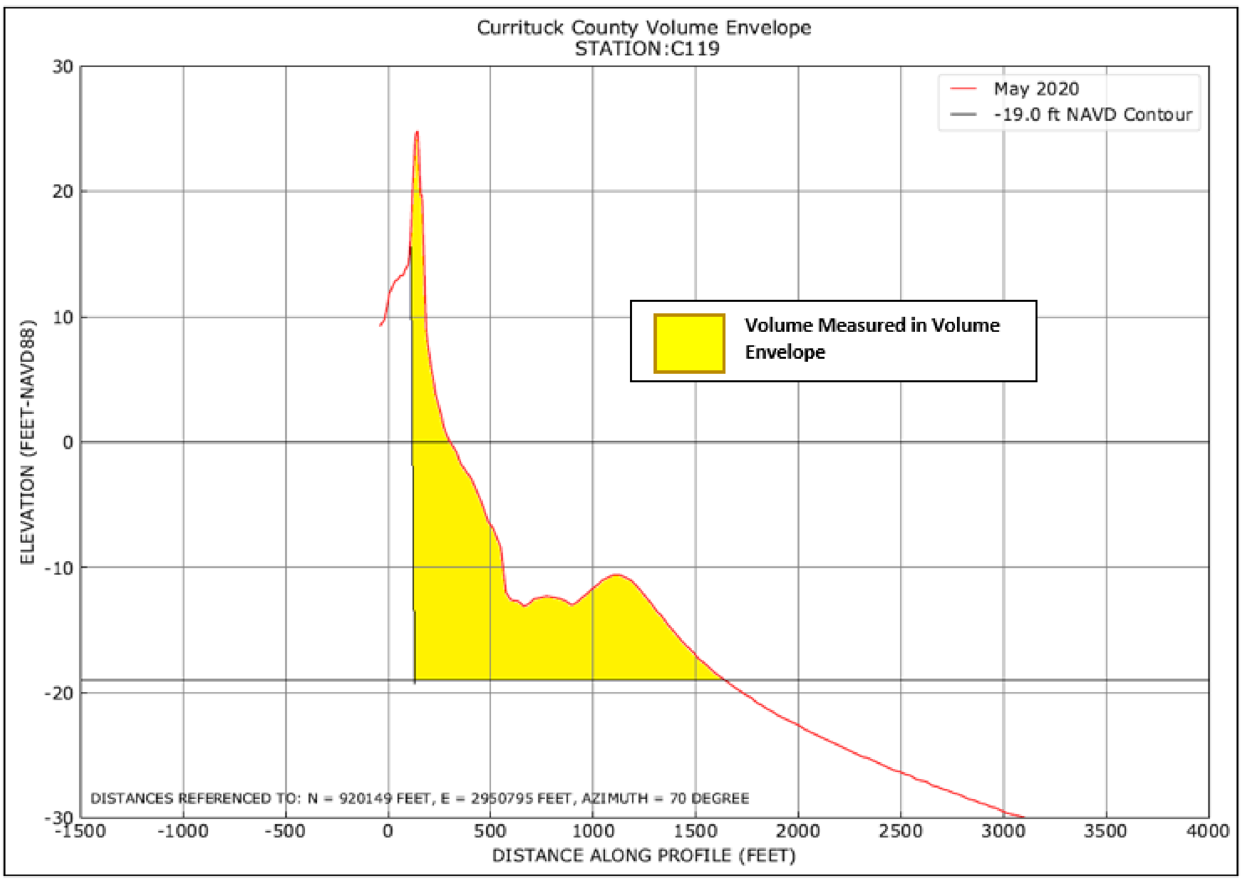


Figure 16. Beach Profile Cross Section Illustrating the Volume Envelope

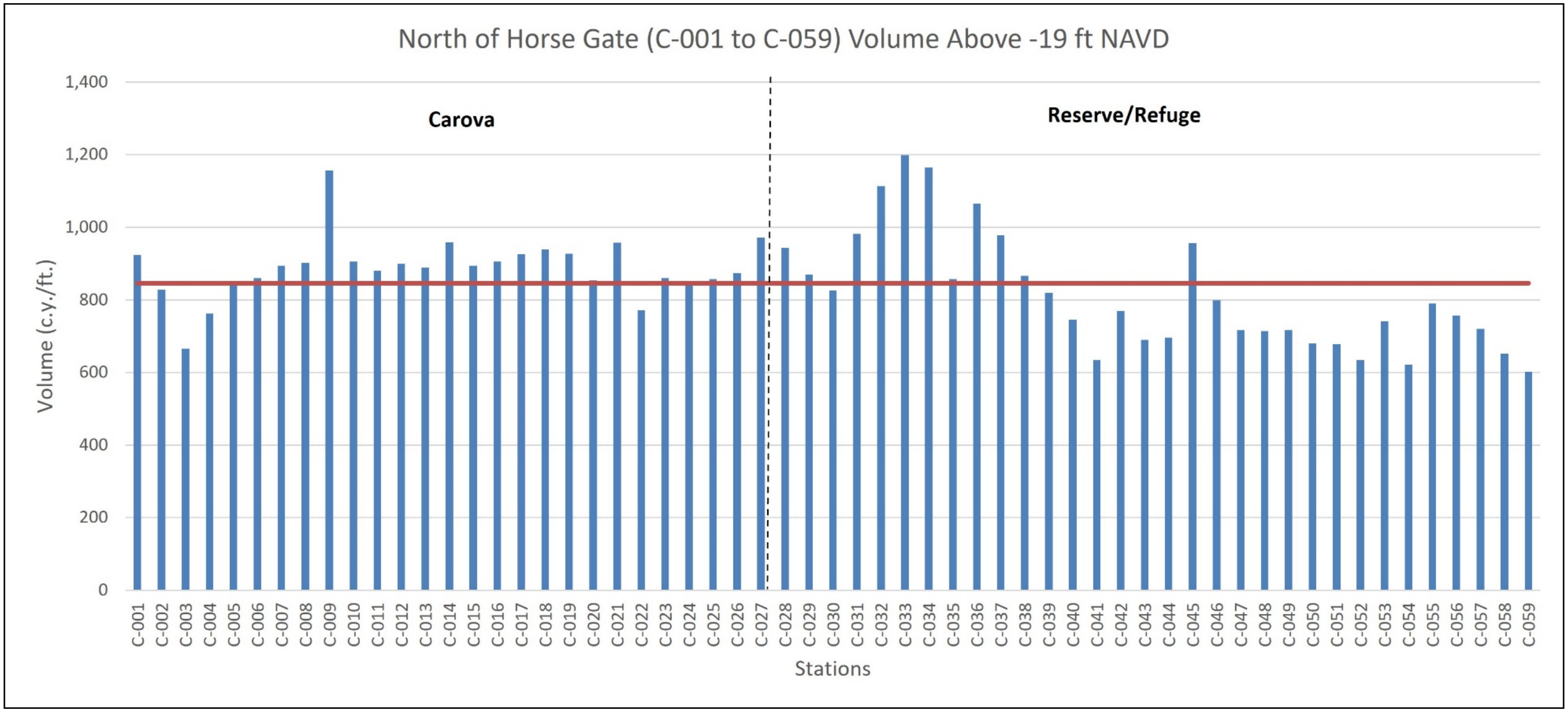


Figure 17. Volume Envelope values along profiles North of the Horse Gate (C-001 through C-059)

(The red line indicates the average volume envelope density north of the Horse Gate.)

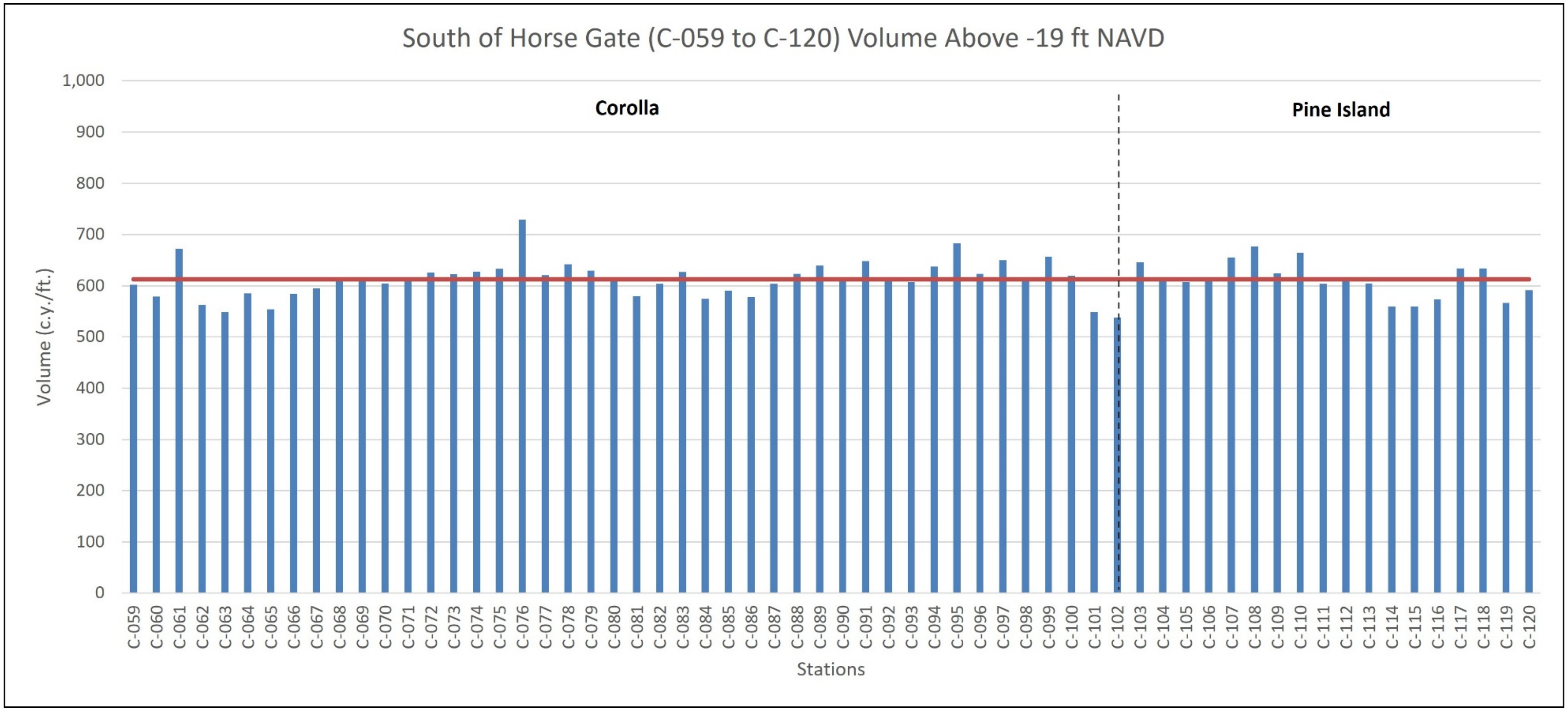


Figure 18. Volume Envelope values along profiles South of the Horse Gate (C-059 through C-120)
(The red line indicates the average volume envelope density south of the Horse Gate.)

Table 12. Average Density within the Volume Envelope

| Section | Average Volume Envelope Density (CY/FT) |
|---|---|
| Carova (C-001 to C-027) | 886.7 |
| Reserve/Refuge (C-027 to C-059) | 817.0 |
| Corolla (C-059 to C-102) | 612.3 |
| Pine Island (C-102 to C-120) | 609.2 |
| Area North of Horse Gate (C-001 to C-059) | 846.3 |
| Area South of Horse Gate (C-059 to C-120) | 612.5 |
| Total Project Area (C-001 to C-120) | 727.6 |

## 5.3 CSE to CPE 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. Utilizing data provided by the Pine Island Property Owners Association (PIPOA), volumetric change rates were computed for the period between September 2015 and October 2017, represented by the CSE data. Furthermore, volumetric change rates were also computed for the period between October 2017 (CSE) and May 2020 (CPE). The average volumetric change rate was positive between September 2015 and October 2017 (+4.0 cy/ft./yr.), with a cumulative positive volumetric change of approximately 200,600 cubic yards. In contrast, the average volumetric change rate measured between October 2017 and May 2020 was -10.2 cy/ft./yr., resulting in a cumulative negative volumetric change of approximately -626,200 cubic yards.

Table 13 lists the individual volumetric rates computed for each profile between September 2015 and October 2017 as well as between October 2017 and May 2020. Table 14 lists the total volume change computed between the three beach profile data sets collected in the vicinity of the Pine Island Section.

Figure 19 shows a graphical comparison of the 2015 to 2017 rates and the 2017 to 2020 rates. The red bars, which reflect volumetric changes measured between 2017 and 2020 are primarily negative, with the exception of moderate positive rates measured at station C-107 and C-120. In comparison, the blue bars, which reflect rates measured between 2015 and 2017 are more varied with some rates negative and some positive. Most of the transects that showed the highest positive changes between 2015 and 2017 are the same profiles that show some of the greatest negative change between 2017 and 2020. It is unclear as to the reason for this reversal in the trend. Wave data collected from the USACE Field Research Facility between September 2015 and May 2020 was reviewed to determine whether considerable differences in wave energy were observed during this period that may explain the differences in the volumetric change trends. This review of the wave energy during these two periods proved inconclusive in terms of explaining the discrepancies in volumetric changes computed for the two different monitoring periods.

Table 13. Pine Island CSE and CPE Density Change Rate Comparison (cy/ft/yr.)

| Stations | September 2015 to October 2017 | October 2017 to May 2020 |
|---|---|---|
| C-097 | 14.3 | -8.2 |
| C-098 | 19.1 | -15.4 |
| C-099 | 13.0 | -9.9 |
| C-100 | 12.2 | -13.0 |
| C-101 | 0.3 | -12.5 |
| C-102 | -12.1 | -14.8 |
| C-103 | -7.4 | -4.5 |
| C-104 | 2.9 | -11.8 |
| C-105 | 5.3 | -9.9 |
| C-106 | -17.7 | -6.0 |
| C-107 | 2.0 | 1.5 |
| C-108 | 14.9 | -15.8 |
| C-109 | 10.1 | -16.4 |
| C-110 | -6.2 | -0.4 |
| C-111 | 0.9 | -8.2 |
| C-112 | -4.0 | -7.3 |
| C-113 | 9.7 | -11.0 |
| C-114 | 6.0 | -17.8 |
| C-115 | 8.1 | -11.6 |
| C-116 | 0.1 | -8.4 |
| C-117 | -1.4 | -5.5 |
| C-118 | 18.5 | -17.5 |
| C-119 | 23.2 | -22.6 |
| C-120 | -17.0 | 1.0 |
| Average | 4.0 | -10.2 |
| Max | 23.2 | 1.5 |
| Min | -17.7 | -22.6 |

Table 14. Pine Island (C-097 to C-120) Volume Change Above -19.0 ft NAVD88 for September 2015 to October 2017 and October 2017 to May 2020 (cy)

| Stations | September 2015 to October 2017 | October 2017 to May 2020 |
|---|---|---|
| C-097 to C-098 | 34,800 | -30,400 |
| C-098 to C-099 | 33,400 | -32,700 |
| C-099 to C-100 | 26,300 | -29,600 |
| C-100 to C-101 | 13,100 | -32,900 |
| C-101 to C-102 | -12,300 | -35,200 |
| C-102 to C-103 | -20,400 | -24,800 |
| C-103 to C-104 | -4,700 | -20,900 |
| C-104 to C-105 | 8,600 | -28,000 |
| C-105 to C-106 | -13,000 | -20,700 |
| C-106 to C-107 | -16,400 | -5,900 |
| C-107 to C-108 | 17,600 | -18,500 |
| C-108 to C-109 | 26,000 | -41,600 |
| C-109 to C-110 | 4,000 | -21,700 |
| C-110 to C-111 | -5,500 | -11,100 |
| C-111 to C-112 | -3,200 | -20,000 |
| C-112 to C-113 | 6,000 | -23,700 |
| C-113 to C-114 | 16,400 | -37,300 |
| C-114 to C-115 | 14,800 | -38,000 |
| C-115 to C-116 | 8,600 | -25,800 |
| C-116 to C-117 | -1,400 | -18,000 |
| C-117 to C-118 | 17,800 | -29,700 |
| C-118 to C-119 | 43,700 | -52,000 |
| C-119 to C-120 | 6,500 | -27,700 |
| Total Volume Change (cy) | 200,700 | -626,200 |

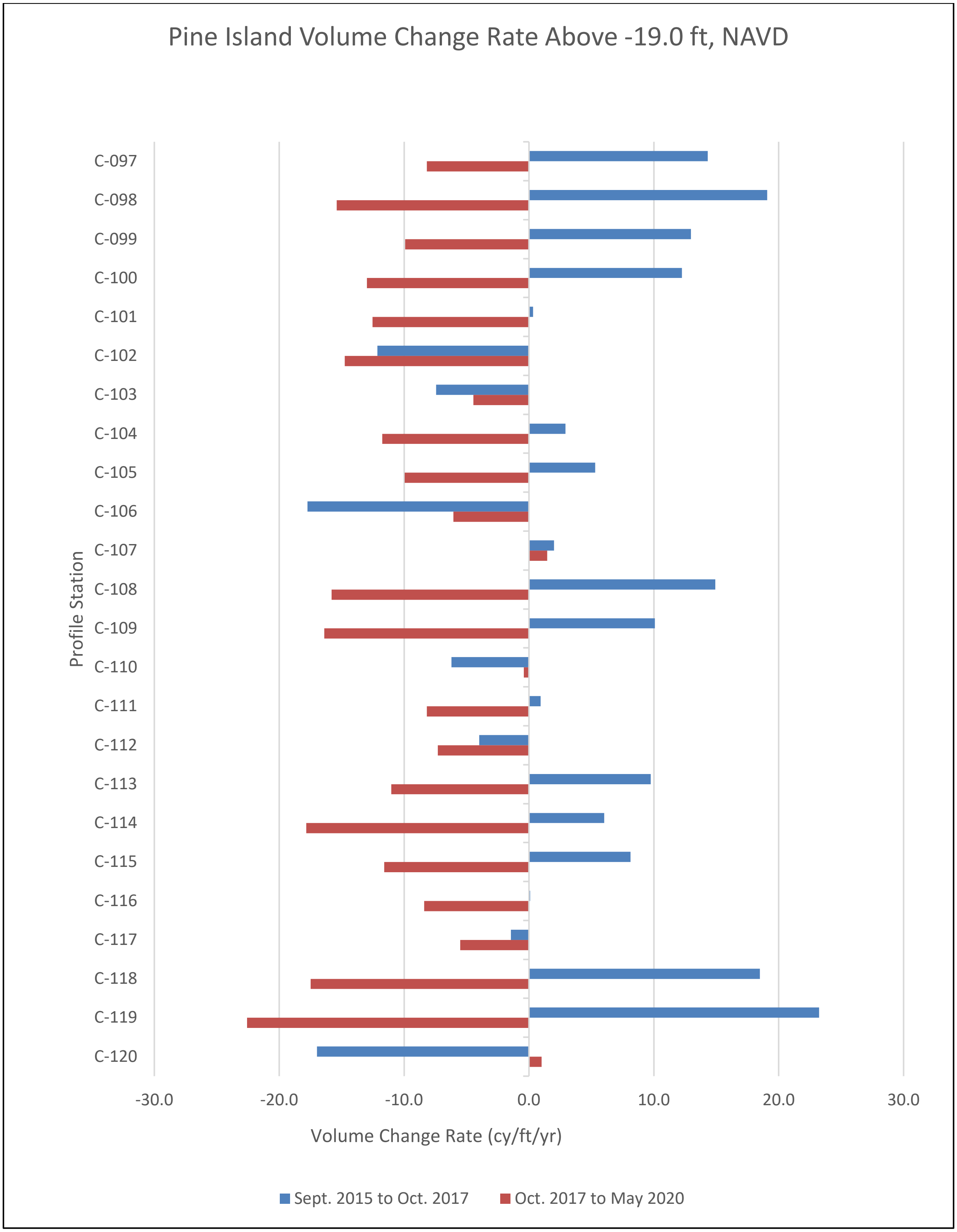


Figure 19. Pine Island (C-097 to C-120) Volume Change Rate Above -19.0 ft NAVD88 for September 2015 to October 2017 and October 2017 to May 2020 Period

# 6 BEACH VULNERABILITY ANALYSIS

## 6.1 Introduction

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

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

The SBEACH model previously calibrated for similar studies for the Towns of Duck, Southern Shores and Kill Devil was used for this study. A sensitivity analysis was conducted using sediment data from samples collected along the Currituck County Project Area as part of the overall project. The sensitivity analysis allowed for the adjustment of calibration parameters as needed to account for major differences in the sediment characteristics between Duck and the Currituck County Project Area.

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

## 6.2 Methods

The design storm used in the vulnerability assessment was based off Hurricane Isabel which impacted the Outer Banks in early September 2003. The SBEACH simulation was used to identify the most landward point of the profile that the elevation dropped one or more feet in elevation. The results provided insight to structures that are vulnerable to these specific design storm conditions.

## 6.3 Application

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

The following basic assumptions underlie the SBEACH model:

- Breaking waves and variations in water level are the major causes of sand transport and profile response.
- The median sediment grain diameter along the profile is reasonably uniform across the shore.
- The shoreline is straight (i.e. the longshore effects are negligible during simulation period).
- Linear wave theory is applicable throughout the beach profile.

The analysis does not include specific evaluations of damages to individual 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.

## 6.4 Data

Data sets employed in this analysis include oceanographic, meteorological, and bathymetric /topographical. Oceanographic and meteorological data collected during Hurricane Isabel were used to define the storm event simulated in the modeling analysis; storm data were obtained between August 30 and September 22, 2003. The April/May 2020 beach profile data collected as part of this study are the primary source of bathymetric/topographical data. Regarding wave, water level, and meteorological data, this study was limited to available data. Details regarding each data set used in this analysis are discussed in the following sections. Where applicable, the location of the measurement devices (wave gauges, tide gauges, etc.) are referenced to the North Carolina State Plane Coordinate System.

### 6.4.1 Wave Data

Wave data such as wave height and wave period were taken from USACE Wave Information Studies (WIS) Station 63216. The WIS station is located offshore Currituck County (Easting: 2979699.565, Northing: 988235.374, feet NAD83) in 72 ft of water. Even though the data is collected by means of hindcast, the historical projections were compared to known values taken from USACE FRF wave buoy (FRF630) and determined accurate by comparing the two sets of data for similarities. When plotted the pattern is visible and the $r^2$ value is equivalent to 0.92; see Figure 20.

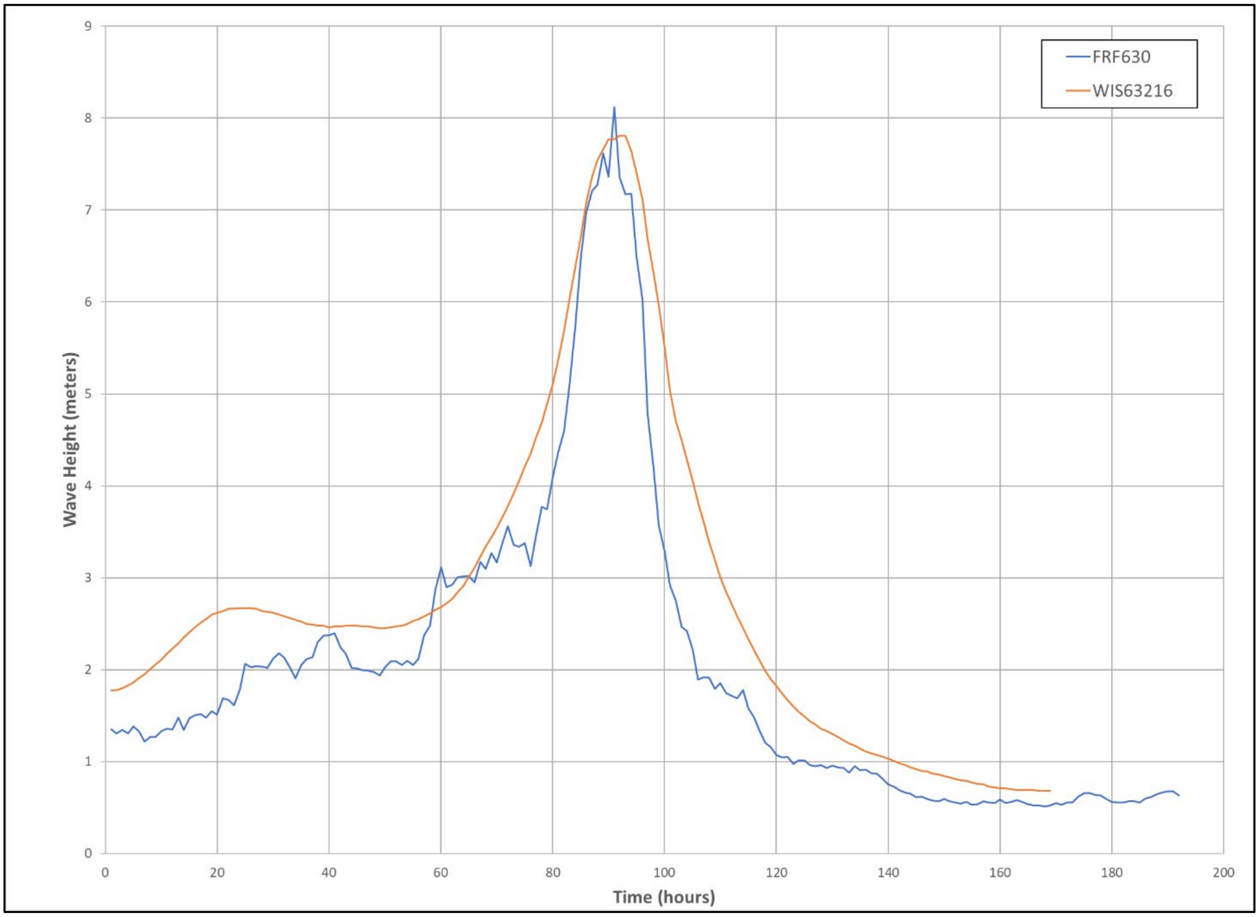


Figure 20. Wave Height Comparison of WIS Station and FRF Station

### 6.4.2 Meteorological Data

Meteorological data such as wind speed and direction were also taken from WIS station 63216 and compared with the results from the Duck NOAA tide gauge (station 8651370). Similar to the wave height data, since the meteorological data was formulated using hindcast it was compared to verified data. When plotted together the data shows the same pattern with an $r^2$ value equivalent to 0.93 and determined accurate for this simulation. The meteorological data was hindcast at an elevation 10 m about the surface of the water.

### *6.4.3 Topographic/Bathymetric Data*

In order to define current conditions along the shore in Currituck County, beach profile data collected as part of this study were used as the primary topographic and bathymetric data input to run the model. Collection of these data are described in the *Data Collection* Section. These data were acquired in April and May of 2020, along each of the transect referred to in Table 4.

The modeled profiles were further developed using supplemental survey datasets to extend the profile from the landward extent of expected overwash to an offshore location beyond the depth of closure. Extending the profiles beyond the extent of the 2020 beach profile data was necessary to ensure model stability. The supplemental data used to extend the profiles landward included publicly available LiDAR data collected in 2019 by the USACE. Supplemental data used to extend the profiles seaward included historic bathymetric data dating from 1939 to present, which is available within the NOAA Bathymetric Data Viewer (NOAA, 2020). Effectively, the 2020 CPE data were extended approximately 1,000 ft landward of the baseline and approximately 18,000 ft seaward. Figure 21 is an example of a modified profile used in the SBEACH model.

## 6.5 Model Configuration

### *6.5.1 Set-up*

SBEACH is a two-dimensional model which simulates beach profile changes that result from varying storm waves and water levels. These profile changes include the formation and movement of morphological features such as longshore bars, troughs, berms, and dunes. SBEACH assumes that the simulated profile changes are produced only by cross-shore processes, while longshore sediment transport processes are neglected. Input data required by SBEACH includes beach cross-sections, the median sediment grain size, several calibration parameters, and a temporally varying storm hydrograph (wave height, wave direction, wave period, and water surface elevation) and wind field (wind speed and direction). Simulated profile changes are driven by the cross-shore variation in wave height and wave setup calculated at discrete points along the profile from the offshore zone to the landward survey limit.

The acquired data previously mentioned was imported into the program and ready to be defined by beach and sediment transport parameters. Considering that profiles are gridded within the SBEACH model, a variable grid was used to provide fine resolution to adequately detail topographic and nearshore features in the model simulation while less variable offshore bathymetry was gridded using a coarser resolution to improve model efficiency. Table 15 details the grid spacing and associated limits used within the SBEACH model.

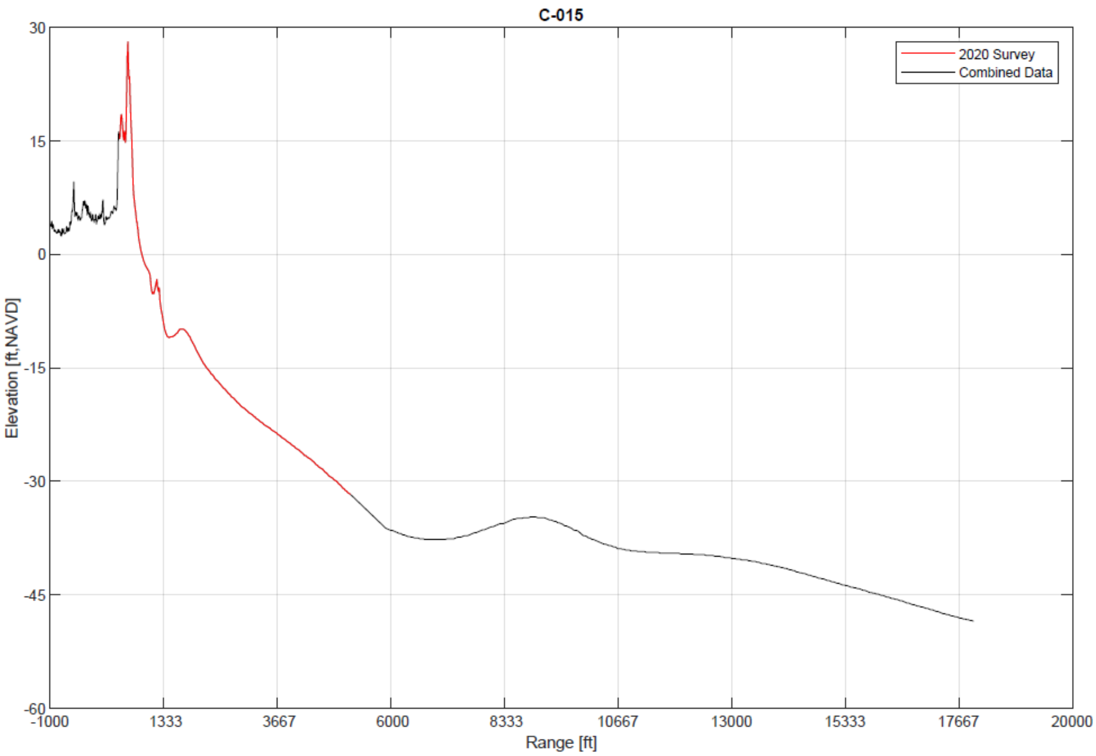

Figure 21. Typical SBEACH Profile

Table 15. SBEACH Grid

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

### *6.5.2 Model Calibration*

The beach and sediment transport parameters must be defined by the user. To define these parameters, the model was calibrated using surveys collected at the nearby USACE Field Research Facility prior to and following Hurricane Isabel. Model calibration was completed by adjusting the beach and sediment transport parameters until the post-storm beach profiles generated by SBEACH were similar to surveyed post-storm profiles. The calibrated model was then validated using surveys collected at the nearby USACE FRF prior to and following the 1991 Perfect Storm. Calibration and verification details are provided in the Duck Erosion and Shoreline Management Feasibility Study (CPE, 2013). Parameters initially used to calibrate the SBEACH model for the Town of Duck were evaluated to determine applicability for use in the Currituck County Project Area.

### 6.5.3 Sensitivity Analysis

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

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

### 6.5.4 Model Parameters

The beach and sediment transport parameters used in the SBEACH production runs are summarized in Table 16.

**Table 16. SBEACH Model Parameters**

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

*Variable factor between simulations

### 6.5.5 Results

The SBEACH analysis simulated how the beach profiles are affected by a significant storm event such as one modeled after Hurricane Isabel. As previously described, this analysis identified a structure as “impacted” if any part of the structure was seaward of the landward most location where the profile was lowered by 1 foot in the storm simulation. The landward most location where the profile was lowered by 1 foot was extracted from model results along profiles to identify impact points. These impact points were then connected to create an impact line that was used to identify structures damaged between profiles. Considering the inexact nature of the SBEACH analysis, structures located within 15 feet of the impact lines shown on the maps included in Appendix C were considered vulnerable. This is consistent with the analysis performed for the Towns of Duck (CPE-NC, 2015) and Southern Shores (APTIM, 2018).

Using the 1-foot erosion criteria and the 15-foot buffer, the selected model simulation indicates 40 oceanfront structures that are at risk of damage due to a storm similar to Hurricane Isabel. The largest section is comprised of 22 structures spanning between Stations C-061 (located on the north end of Atlantic Ave) and C-066 (located approximately 300 ft. south of Corolla Village Rd.). Following that cluster of structures is another 3 structures that are impacted between Stations C-069 (located approximately 550 ft. north of Tuna St.) and C-071 (located approximately 100 ft. south of Sturgeon St.). The next largest impact area is between Stations C-101 (700 ft. north of Spindrift Tr.) and C-103 (located approximately 90 ft. north of N Cove Rd.) where the impact line directly intersects 9 structures. There is also a group of 4 structures that are directly impacted between Stations C-040 (located approximately 500 feet south of Canary Lane) and C-044 (located approximately 600 feet south of Seagull Lane). In addition to these 38 structures, there are 2 other structures identified as vulnerable along the Project Area. There is 1 in between Station C-083 (located approximately 500 feet south of Dolphin St.) and Station C-084 (located approximately 170 feet south of Albacore St.), and 1 just south of Station C-115 (located approximately 120 ft. north of Ogein Dr.). The structures identified as vulnerable according to the criteria established, are highlighted on the maps included in Appendix C. The number of vulnerable structures identified in each of the four Sections of the Project area are provided in Table 17.

**Table 17. Number of Vulnerable Structures by Project Section**

| Section | Number of Structures Impacted |
|---|---|
| Carova: (C-001 to C-027) | 0 |
| Reserve/Refuge: (C-027 to C-059) | 4 |
| Corolla: (C-059 to C-102) | 31 |
| Pine Island: (C-102 to C-120) | 5 |
| TOTAL | **40** |

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

Table 18. Percent chance of the modeled storm reoccurring

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

# 7 CONCLUSIONS

An evaluation of long-term shoreline change, beach volume density, and storm vulnerability were conducted as part of a 3-year Beach Monitoring and Beach Stability Assessment of the Currituck County oceanfront beaches. The stated goals of the 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.

In reviewing these conclusions, it is important for the reader to understand that these conclusions were only based on data collected in Year-1 of a 3-year study. As data are acquired in Years 2 and 3, additional analyses will be conducted to better assess the Currituck County oceanfront beaches. 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 2020 were used to project future shoreline changes throughout the Project Area over a 10, 20, and 30-year time horizon. The projections show that in general, the Carova Section and the Pine Island Section of the Project Area would experience very little impacts to a consistent shoreline change rate over a 30-year horizon. In the Carova Section, only the northernmost five (5) oceanfront homes appeared to be impacted by the projected shoreline over the 30-year horizon. No impacts were indicated over the 20-year horizon. In the Pine Island Section, the only structures shown to be impacted by the shoreline change projections over the 30-year horizon are actually homes located north of Yaupon Lane. The reason these houses are included in the Pine Island numbers is because the boundary line between the Corolla and Pine Island Sections is approximately 500 feet north of Yaupon Lane.

Within the Reserve/Refuge Section, in which the average long-term shoreline change was greatest, projected shoreline change indicates five (5) houses in total that could be impacted by shoreline change over the 30-year horizon. One house is located just south of Albatross Ln nears station C-037. The other four (4) houses are those located seaward of Sand Fiddler Road between Canary Ln. and La Mer Ln. (between C-040 and C-044). All four of the houses could be impacted by the 30-year projected shoreline. Two (2) of the houses could be impacted by the 10-year projected shoreline. While the number of houses 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. One other consideration in terms of projected shoreline changes along the Reserve/Refuge Section is that the relatively high shoreline change rates measured between C-051 C-058, along the Currituck Banks Estuarine Reserve, show that the 30-year shoreline projection may begin to impact maritime shrub and maritime forest habitat. This may be something for the County to share with the managers of the Estuarine Reserve.

The greatest number of impacts from projected shoreline changes were observed within the Corolla Section of the Project Area. More specifically, most of those projected impacts were observed in the northern half of the Section, north of Albacore St. (north of station C-084). The only area in which no shoreline change projections over the 30-year horizon impact oceanfront structures is along the Corolla Light development between Corolla Village Road and Shad St. (in the vicinity of C-066 to C-068). Several oceanfront houses along Lighthouse Drive in Whalehead Beach were also shown to have no impact from the shoreline change projection over the 30-year horizon, however, most of the homes appear to be impacted. Not only did the projected shoreline over the 30-year horizon impact many of the houses in this portion of the Project Area, but portions of Sandcastle Drive (C-059 to C-061), Atlantic Avenue (C-061 to C-063), and Lighthouse Drive (C-080 to C-081) were also impacted. While projected shoreline retreat over a 10-year horizon appear to impact less than 5 houses north of Albacore St., 20-years of projected shoreline retreat appears to impact most of the oceanfront houses between the Ocean Hills clubhouse and Corolla Village Road (between C-060 and C-066) and most of the oceanfront houses between Bonito St. and Albacore St. (between C-078 and C-084).

South of Albacore St. in the Corolla Section, oceanfront structures impacted by the projected shoreline changes over the 30-year horizon are primarily located within the Buck Island (In the vicinity of C-084 and C-085), Crown Point (between C-085 and C-086), along the northern portion of Ocean Sands (between C-087 and C-089), and within the Spindrift developments (between C-101 and C-103). The projected impacts from shoreline retreat between Albacore St. and Seabird Way in Ocean Sands, only appear to be impacted between the 20- and 3-year horizon. Only the oceanfront structures within the Spindrift development between C-101 and C-102 appear to be impacted by the projected shoreline change over the 20-year horizon. No impacts were indicated from projected shoreline changes over the 10-year horizon along the southern half of the Corolla Section.

The results of the Year-1 Shoreline Change 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, from the horse gate to Seabird Way. The majority of the oceanfront homes as well as certain portions of roads may be impacted by long-term shoreline recession between the 20- and 30-year time horizon. Several sub sections in this vicinity indicate projected impacts between the 10- and 20-year horizon. The nine (9) oceanfront structures along the Spindrift community at the boundary between the Corolla and Pine Island Sections are also shown to be impacted by projected shoreline changes between the 10- and 30-year horizon. North of the Horse Gate, nine (9) oceanfront structures appear to be impacted by the projected shoreline retreat. Five (5) of those houses are at the extreme north end of the County directly adjacent to the County line. The other four (4) houses located in the Reserve/Refuge Section, seaward of Sandfiddler Road, 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 June 2019 and May 2020 indicate much different rates than those measured long-term between 2009 and 2020. 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 SBEACH Vulnerability

The Vulnerability Analysis conducted through the use of the SBEACH model, also provides useful information to determine future vulnerability of public and private development along the County's oceanfront beach. In total, 40 oceanfront homes were determined to be vulnerable from a storm similar in characteristics to Hurricane Isabel, which impacted the County in 2003. These houses were spread throughout the Project Area, and primarily located in areas where shoreline change projections also indicated potential impacts.

No structures were identified as impacted by the SBEACH vulnerability analysis in the Carova Section of the Project Area, however four (4) houses along the Reserve/Refuge Section were identified. These houses are the same four (4) houses located between Canary Lane and La Mer Lane (between stations C-040 and C-044), that were previously described in regard to projected shoreline recession. These four houses are located seaward of Sandfiddler Road along this stretch of beach. This section of beach has a lower volume of sand within the volume envelope, discussed in Section 5.2, than the surrounding areas (Figure 17). These structures could impact traffic through this section of beach should a storm or continued shoreline recession result in the homes being situated on the dry or wet sand beach.

The remaining 36 homes identified as impacted by the SBEACH Vulnerability analysis are located in the Corolla and Pine Island Sections of the Project Area; however, the majority (31) are located within the Corolla Section. The largest stretch of impacted homes is located between the Ocean Hills clubhouse (C-060) and Corolla Village Road (C-066). Twenty-two (22) oceanfront houses identified as vulnerable and several other oceanfront pools are located within this portion of the Project Area. This is the same stretch of beach in which projected shoreline recession impacts were indicated at both the 10- and 20- year horizon. Figure 18 indicates that beach profile transects along this same stretch of beach have markedly lower volume envelope density values than the overall average south of the horse gate.

Within the Whalehead Beach community, four oceanfront homes and several other oceanfront pools were indicated as impacted along Lighthouse Drive (C-069 to C-084). This is the same stretch of beach in which projected shoreline recession was shown to impact some oceanfront homes over the 20-year horizon. All nine (9) oceanfront homes located along the Spindrift community were determined to be vulnerable based on the established criteria. As previously stated, the Spindrift Community was split between the Pine Island and Corolla Section. These 9 homes were also shown to be impacted by projected shoreline recession between the 10- and 30-year horizon. Furthermore, Figure 18 indicates that beach profiles C-101 and C-102 located just north and within the Spindrift community, have markedly lower volume envelope density values than the overall average south of the horse gate.

Although no projected shoreline recession impacts were identified along the Pine Island Section south of Yaupon Lane, one oceanfront home was identified as vulnerable through the SBEACH analysis. That home is located near Ogein Drive, just south of C-115. C-115 and the beach profiles directly to the north (C-114) and south (C-116) have volume envelope densities markedly lower than the overall average for transects located south of the horse gate as shown in Figure 18.

# 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-2 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 to Year 2. The data will allow better evaluation of short-term shoreline change trends.

2. Consider Future Shore Parallel Surveys: As discussed within this 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 does not believe that repeating the shore parallel survey in Year 2 will provide tangible value in terms of the goals of this 3-year study. However, it is recommended that a repeat survey be considered for Year-3 after reviewing results of the Year-2 analysis. It may also be of value to have a second dataset comparable to the robust data coverage acquired during Year-1 in the event that numerical modeling is required to evaluate future shoreline management alternatives.

3. Coordinate results of Year-1 Analysis with Currituck Banks Reserve Management Staff: One of the findings of the Shoreline Change Projections was that over the 30-year horizon, long-term shoreline change rates may result in transitions of some of the maritime forest and maritime shrub habitat to more of an active dune environment. It may not be of concern to them but may be of interest.

4. Consider an Evaluation to determine the 5-Year Stillwater and Wave Runup Elevation: Following the impacts of federally declared disasters such as Hurricanes, oceanfront communities are eligible for emergency flood protection measures through FEMA's Public Assistance Program. FEMA describes the public funding eligibility as follows: *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 stillwater level or the berm's pre-incident profile, whichever is less. In some cases, placing sand below the 5-year stillwater level may be necessary to provide a base for the berm. The placement of that sand is also eligible as part of the emergency protective measure.* Based on current conditions of the dune along the Project Area, and the potential impacts of storms, it may serve the County to determine the 5-Year maximum storm-induced water-surface elevation along the Project Area. Having this elevation at hand following a storm may allow rapid evaluation of whether the County may be eligible for Public Assistance funding to provide emergency Berms and Beaches.

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