

**TOWN OF DUCK NORTH CAROLINA
2021 SHORELINE & VOLUME CHANGE
MONITORING REPORT**



**SUBMITTED TO:
TOWN OF DUCK**

SUBMITTED BY:



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

ADAM T. PRIEST, PE NO. 048852

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EXECUTIVE SUMMARY

The Town of Duck is located on the Outer Banks of North Carolina, roughly 27 miles south-southeast of the North Carolina and Virginia border. The Town extends along 5.9 miles of Atlantic Ocean shoreline from the Dare County and Currituck County line south to the Town of Southern Shores.

The Town of Duck has implemented a long-term beach management program to sustain the beaches that support a significant portion of their local economy and maintains the tax base of the Town. In May and June 2017, the Town constructed a beach nourishment project along 1.6 miles of its oceanfront that was shown to be the most vulnerable portion of the Town's oceanfront. Approximately 1.26 million cubic yards of fill was distributed between Skimmer Way (station D-10) and the northern USACE Field Research Facility (FRF) property boundary (station D-19).

As part of its long-term beach management program, the Town has implemented an annual monitoring program to assess both the performance of the beach nourishment project and to track the overall health of the beach along the entire Town. The annual monitoring focuses on analyzing shoreline and volume changes. The beach is divided into three areas designated as the Project Area (station D-10 to D-19); the area North of the Beach Project (D-01 to D-10), which extends south from the Town limit to Skimmer Way; and the area South of the Beach Project (D-19 to D-34), which extends from the northern boundary of the FRF property south to the Town boundary with Southern Shores.

A shoreline change analysis was completed to assess shoreline advance and recession along the study area. The contour used to monitor shoreline change throughout the Town of Duck is the +6.0 ft. NAVD88 contour. The shoreline change analysis compared the position of the +6.0 ft. NAVD88 contour in September 2013, December 2017, June 2020, and April 2021. The following table summarizes the average shoreline changes (ft.) measured between September 2013 and April 2021 (Long-term), December 2017 and April 2021 (Post-Project), and June 2020 and April 2021 (Short-term), for the Project Area and Areas North and South of the Project.

Table ES-1
Summary of Average Shoreline Changes (ft.) within the Project Area and North and South Monitoring Areas

PROFILE	September 2013 (Baseline) to April 2021 (Year-4)	Dec. 2017 (Post-Con to April 2021 (Year-4)	June 2020 (Year-3) to April 2021 (Year-4)
AREA NORTH OF PROJECT (D-01 TO D-10)	1.1	15.7	7.5
PROJECT AREA (D-10 TO D-19)	19.6	-59.1	15.7
AREA SOUTH OF PROJECT (D-19 TO D-34)	-12.0	0.9	-3.7

Similar to the shoreline change analysis, the tracking of long-term volumetric changes within the project area as well as north and south of the project area, are measured by comparing the September 2013 data with the most recent annual monitoring. Volumetric changes that have occurred Post-Project are determined by comparing the December 2017 data with the most recent annual monitoring data. The monitoring report also provides short-term volumetric changes that occurred over the past annual

monitoring cycle (June 2020 to April 2021). Average volumetric change rates above the -24-foot NAVD88 contour (cubic yards/ft./year) for the Project Area and areas North and South of the Project are provided in Table ES-2.


Table ES-2
Summary of Average Volume Change Rates (cy/ft./yr.) within the Project Area and North and South Monitoring Areas

MONITORING AREAS	September 2013 (Baseline) to April 2021 (Year-4)	December 2017 (Post-Con) to April 2021 (Year-4)	June 2020 (Year-3) to April 2021 (Year-4)
AREA NORTH OF PROJECT (D-01 TO D-10)	0.7	5.5	-2.9
PROJECT AREA (D-10 TO D-19)	8.7	-14.2	-19.4
AREA SOUTH OF PROJECT (D-19 TO D-34)	-0.1	-3.6	-24.9

The long-term average volumetric change rates indicate a positive trend throughout the Town; however, the Project Area rate is clearly being influenced by the beach nourishment project constructed in 2017. Since the project was completed, the area north of the project experienced a higher rate of positive volumetric change than the long-term rates since 2013. North of the project, the increase in the positive volumetric change rate is nearly 8 times greater than the long-term rate. Since the project was completed, the area south of the project experienced a higher rate of negative volumetric change than the long-term rates since 2013. .

With regards to the Project Area, comparison of profile surveys conducted in April 2017 (Pre-Construction) and December 2017 (Post-Construction) suggests the effective volumetric gain to the Project Area due to the 2017 beach nourishment project was 963,100 cubic yards. Monitoring data collected in April 2021 indicate a negative volumetric change within the Project Area of approximately -450,000 cubic yards since December 2017 (Post-construction). This equates to a rate of -14.2 cy/ft./yr. when annualized. As of April 2021, the analysis indicates that approximately 53% of the initial volume placed along the Town of Duck in 2017 remained in the project area above the -24-foot NAVD88 contour.

Monitoring of the project over the first 4 years following construction indicates a volumetric change rate higher than estimated in the initial project design, which may be related to a number of factors. The Town's maintenance plan calls for an estimated renourishment fill density of approximately 30 cy/ft., every 5 years, which translates to an annual average loss of approximately 6 cy/ft./yr. The actual rate of volumetric change measured since 2017, in the first four years post-construction, has been an annual average loss of 14.2 cy/ft./yr., which is more than twice the rate programed in the beach maintenance plan. Given the 2017 project was the initial construction of the Town's project and beach profile data along the Project Area was limited prior to the construction of the 2017 project, the monitoring program is revealing the true erosion rate. The true erosion rate is influenced by the construction of the project itself, recent impacts of storms, alongshore variability, and other factors that may be contributing to the erosion rate beyond the initial estimate. The monitoring data has been used in the design of the 2022 project, both to plan for erosion rates higher than initially anticipated, and through modification of the fill configuration aimed at slowing the volume losses over the next 5-year nourishment interval.



CPE recommends the Town continue to monitor the beach along the entire Town oceanfront in order to assess long-term shoreline and volumetric changes. In that regard, with the re-nourishment scheduled for 2022, pre-construction surveys will be collected by the contractor in 2022, which can serve as the year 5 monitoring surveys for the project area. Furthermore, as part of the construction contract, the dredge contractor will conduct a post-construction survey within 2 weeks following completion of beach fill placement. This survey will serve as the new baseline conditions for the Duck beach nourishment project. Following construction of the beach project in 2022, the continued annual monitoring of the project provides not only a pre-storm condition survey that can be used to estimate storm damages, but also the continued assessment of volume trends, which will be used in the planning of future maintenance events.

Outside the Project Area, continued monitoring is instrumental for the Town to evaluate future areas of concerns and longshore transport trends, and to develop successful shoreline management strategies to deal with issues as they arise. In that regard, post-construction surveys, which will be conducted by the dredge contractor within 2-weeks following the 2022 project, will include the Area North and Area South of the Project. Continued monitoring of the areas outside the Project Area is vital to achieving the Town's goal of providing a reasonable level of storm damage reduction to public and private development. In that regard, CPE recommends that given the observed trend of erosion along the Area South of the Project, that the storm vulnerability analysis, last conducted in 2019, be updated using the 2022 monitoring data to be collected following construction of the beach nourishment project. The results of the analysis will be important as the Town transitions from preparation and construction of the 2022 project to planning for the 2027 project.

**TOWN OF DUCK
2021 SHORELINE & VOLUME CHANGE
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A 2021 Town of Duck Topographic and Hydrographic Data Acquisition Report



TOWN OF DUCK 2021 SHORELINE & VOLUME CHANGE MONITORING REPORT

I. INTRODUCTION

The Town of Duck is focused on a long-term shoreline management program that will serve to sustain the beaches that support a significant portion of their local economy, maintain the tax base of the Town, retain existing recreational resources, and protect existing natural resources. In order to accomplish these stated goals, the Town is taking steps to maintain and monitor its oceanfront beach and dune to a configuration that provides a reasonable level of storm damage reduction to public and private development and mitigates long-term erosion impacts.

As part of the long-term shoreline management program, the Town of Duck, in cooperation with Dare County, constructed a large beach nourishment project in 2017 that placed approximately 1.26 million cy of sand along approximately 1.6 miles of the Town's shoreline. The project extends from profile station D-10 in the north, which is located near 140 Skimmer Way, to station D-19 in the south, which is located at the south property line of 137 Spindrift Lane (northern boundary of the USACE FRF property). The beach fill design for the Town of Duck included a 20-foot wide dune at elevation +20.0 feet NAVD88 fronted by a variable width berm at elevation +6.0 feet NAVD88.

The Town has implemented a beach monitoring program to track both the performance of the beach fill project constructed in 2017 and the overall health of the beach along the entire Town. This monitoring report describes shoreline changes and volume changes measured along the Town's oceanfront shoreline.

The shoreline change analysis evaluated changes between profile surveys conducted by Coastal Protection Engineering of North Carolina, Inc. (CPE) (formerly Aptim Coastal Planning & Engineering of North Carolina, Inc.) in September 2013, May 2015, December 2017, June 2020, and April 2021. Volumetric changes were evaluated by comparing beach profile surveys collected in September 2013, May 2015, December 2017, June 2020, and April 2021.

II. PROJECT LOCATION

The Town of Duck is located on the Outer Banks of North Carolina roughly 27 miles south-southeast of the North Carolina and Virginia border. The Town encompasses 5.5 square miles extending along 5.9 miles of Atlantic Ocean shoreline from the Dare County and Currituck County line south-southeast to the Town of Southern Shores. The USACE FRF is located within the Town limits near profile station D-21 and is approximately 2.3 miles north of the southern limit and 3.6 miles south of the northern limit. A Location Map is provided in Figure 1. This location map also shows the limits of the nourishment project built along a 1.6-mile section of the Town's oceanfront shoreline between May 23 and June 29, 2017.

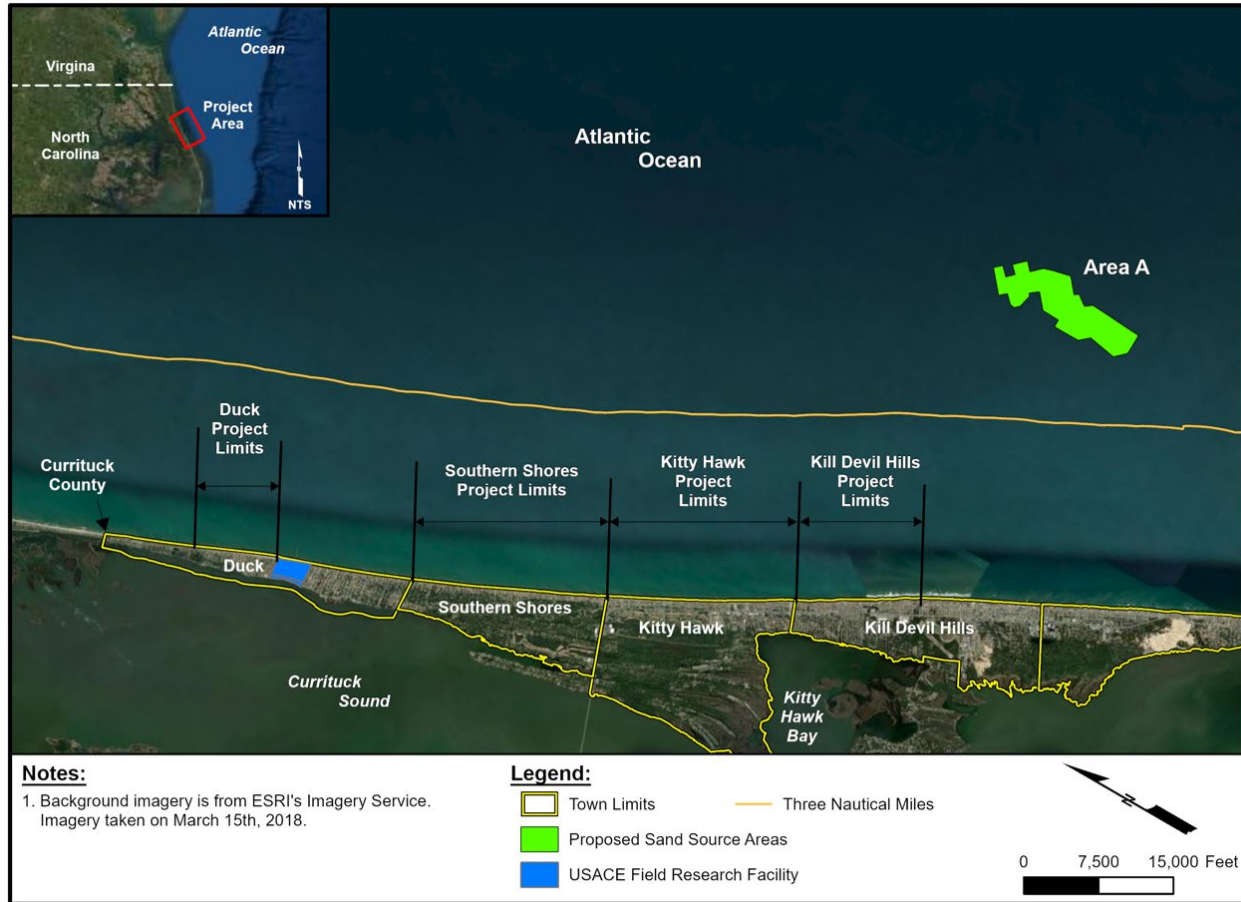
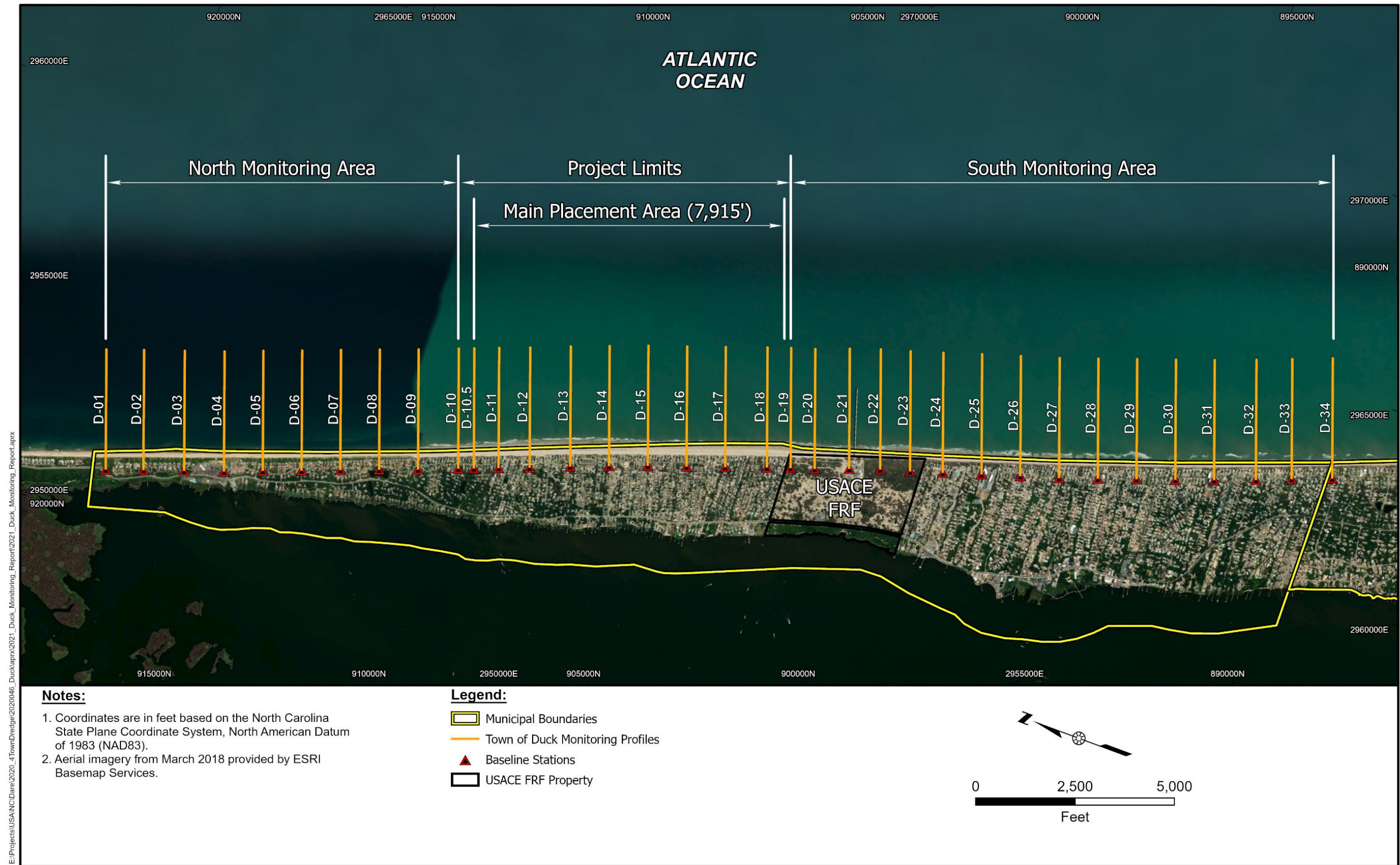


Figure 1. Project Location Map

For the purpose of monitoring, this report has separated the oceanfront beach of Duck into three areas: namely, the Project Area and the areas North of the Project and South of the Project. These areas are depicted on Figure 2. The Project Area includes the beach between the northern FRF property line, located near station D-19, through station D-10, which is near the northern end of Skimmer Way. The section referred to as North of the Project extends from station D-10 (northern end of Skimmer Way) north to the Duck town limits (station D-01). The area designated South of the Project extends from station D-19 south to D-34 and includes the shoreline along the USACE FRF property. Profile D-34 is located near the Duck town boundary with the Town of Southern Shores. Figure 2 also depicts the stations at which beach profile surveys were conducted.



III. SURVEY DATA COLLECTION

As previously stated, beach profile surveys were conducted along the Town's shoreline by CPE in September 2013, May 2015, December 2017, June 2018, May 2019, June 2020, and April 2021. Each of these surveys include the 34 profile transects shown in Figure 2. In April 2021, CPE surveyed one additional transect (D-10.5) than had not been surveyed in previous years. The profile transects are spaced 1,000 feet along the Town's oceanfront beach. CPE also conducted an additional survey in December 2019 following Hurricane Dorian. The December 2019 survey included only the profiles within the project area (D-10 to D-19). Beach profile data was collected along transects listed in Table 1. Coordinates shown in Table 1 are referenced to the North Carolina State Plane coordinate system in feet NAD83 and the profile azimuth refers to degrees referenced to true north. Transects listed in Table 1 are shown graphically in Appendix A – 2021 Town of Duck Topographic and Hydrographic Data Acquisition Report. Appendix A also includes detailed survey methodology, monument information, profile plots, profile digital photography, and field book notes.

Beach profile surveys extended landward until a structure was encountered or to a range 50 feet beyond the landward toe of dune, whichever was more seaward. Elevation measurements were also taken seaward along the profile to at least the -30-foot NAVD88 contour. 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 records along individual profiles was 25 feet. The upland survey extended into wading depths sufficiently to allow the offshore portion to overlap the upland portion by a minimum of 50 feet.


Data along profiles D-19, D-20, D-21, D-22, and D-23 were only be collected by CPE for the upland portion of the profiles due the USACE FRF request not to approach the shoreline with survey vessels. Offshore data was obtained from the USACE FRF who regularly surveys the offshore portions of those profiles. The USACE FRF data was collected on April 28, 2021.

IV. SHORELINE CHANGE RESULTS

A shoreline change analysis was completed to assess shoreline advance and recession along the study area. The shoreline is typically defined as a specified elevation contour. For this study, the shoreline was defined as the +6.0 ft. NAVD88 contour, which represents the beach nourishment project design berm elevation (CPE-NC, 2015A). Shoreline change is calculated by comparing shoreline position along shore perpendicular transects or profiles. Typically, shoreline change is then annualized to describe recession and advance rates. Annualized shoreline change rates are calculated by dividing the shoreline change by the time period (number of years) between survey events (i.e. feet per year). These changes are described in terms of positive (“+”) or advance (shoreline moving seaward) and negative (“-”) or recession (shoreline moving landward).

Table 1. Profile Survey Baseline and Azimuth

Profile	Easting	Northing	Azimuth
D-01	2951387.5	918267.7	70
D-02	2951733.8	917384.4	70
D-03	2952103.0	916429.4	70
D-04	2952464.0	915495.3	70
D-05	2952849.3	914598.0	70
D-06	2953224.4	913696.9	70
D-07	2953607.3	912798.8	70
D-08	2953983.0	911897.9	70
D-09	2954356.7	910994.8	70
D-10	2954759.1	910066.7	70
D-10.5	2954914.2	909703.5	70
D-11	2955158.1	909133.1	70
D-12	2955461.4	908412.5	70
D-13	2955874.3	907478.4	70
D-14	2956252.1	906578.3	70
D-15	2956628.6	905677.8	70
D-16	2956978.7	904767.7	70
D-17	2957333.7	903863.9	70
D-18	2957718.8	902886.5	70
D-19	2957932.5	902331.0	70
D-20	2958139.7	901760.7	70
D-21	2958472.1	900958.7	70
D-22	2958754.0	900228.8	70
D-23	2958992.7	899515.6	70
D-24	2959267.2	898739.8	70
D-25	2959601.7	897824.3	70
D-26	2959928.6	896902.3	70
D-27	2960250.6	895981.9	70
D-28	2960604.1	895073.0	70
D-29	2960963.6	894166.2	70
D-30	2961317.7	893257.6	70
D-31	2961676.7	892350.7	70
D-32	2962078.1	891379.4	70
D-33	2962439.4	890553.2	70
D-34	2962839.6	889616.1	70



The analysis discussed in this report for the Town of Duck evaluated the +6.0 ft. NAVD88 contour positions measured during the September 2013, May 2015, December 2017, June 2020, and April 2021 beach profiles surveys. Even though the 2017 beach nourishment project was completed in June 2017, the December 2017 survey has been adopted to represent the post-construction conditions within the project area due to large-scale profile adjustments that normally occur immediately following the placement of beach fill. This and future annual monitoring reports will reference shoreline changes and volume changes in the project area relative to the December 2017 condition. This report also includes a shoreline comparison of what are referred to as baseline surveys, which represent the initial surveys conducted by CPE during the planning process for the projects. The first survey of the Duck shoreline by CPE, was conducted in September 2013. The September 2013 data were used as the existing condition in the design of the berm and dune design for the Town's first beach nourishment project. The last survey conducted prior to the 2017 beach nourishment operation by CPE was conducted in May 2015. The +6.0 ft. NAVD88 contour position for each survey was identified along shore perpendicular transects spaced at approximately 1,000-foot intervals at the profiles along the monitoring area identified in Table 1.

The changes in the position of the +6.0 ft. NAVD88 contour measured between the September 2013 baseline survey and April 2021 are provided in Table 2. Short-term measured changes of the +6.0 ft. NAVD88 contour that occurred between June 2020 and April 2021 are also provided in Table 2. These values represent actual changes and not rates.

Table 3 shows rates of change for the +6.0 ft. NAVD88 contour between September 2013 (baseline survey) and April 2021, December 2017 (Post-Construction) to April 2021, and June 2020 to April 2021. The September 2013 to April 2021 time period represents long-term rates since CPE began monitoring the Town's Shoreline.

Figure 3 graphically displays the position of +6.0 ft. NAVD88 contours for May 2015, December 2017 (Post-Construction), June 2020, and April 2021 along the entire monitoring area relative to the position of the +6.0 ft. NAVD88 contour in September 2013. A review of Figure 3 shows the +6.0 ft. contour along the Project Area moved seaward between June 2020 and April 2021. During the same time period from June 2020 to April 2021 the shoreline north of the Project Area (stations D-01 and D-10) alternated between landward and seaward shoreline movements. South of the Project Area, the shoreline between stations D-20 and D-22 moved seaward, while the shoreline between stations D-23 and D-26 moved landward and the shoreline between stations D-27 and D-34 fluctuated between landward and seaward movements. In this regard, the characterization of shoreline changes within the monitoring areas is best represented by averaging shoreline trends for multiple profile lines within certain sections. As discussed below, average shoreline trends were computed for the three subareas within the monitoring area, namely, North of the Project, the Project Area, and South of the Project.

Table 2. +6.0 ft. NAVD88 Shoreline Changes (ft.)

PROFILE		September 2013 (Baseline) to April 2021 (Year-4)	June 2020 (Year-3) to April 2021 (Year-4)
Area North of Project	D-01	12.3	57.9
	D-02	-37.8	5.3
	D-03	11.1	20.7
	D-04	6.9	22.9
	D-05	29.2	-16.3
	D-06	-9.1	-13.4
	D-07	-4.7	3.8
	D-08	15.9	20.9
	D-09	-3.9	-39.7
Project Area	D-10	-8.8	12.4
	D-11	12.7	9.4
	D-12	4.3	0.5
	D-13	15.2	8.8
	D-14	22.8	-0.4
	D-15	46.7	25.6
	D-16	16.9	16.6
	D-17	13.0	5.6
	D-18	32.2	21.6
	D-19	41.1	56.6
Area South of Project	D-20	39.1	38.8
	D-21	4.0	30.2
	D-22	-16.3	13.0
	D-23	-64.3	-71.3
	D-24	-41.6	-18.0
	D-25	-14.0	-24.5
	D-26	-19.2	-4.8
	D-27	-10.3	8.3
	D-28	-37.6	-19.4
	D-29	-23.0	-3.5
	D-30	12.7	27.5
	D-31	-20.7	-38.6
	D-32	-22.4	-23.9
	D-33	-18.2	-30.1
	D-34	-1.8	0.5
AREA NORTH OF PROJECT (D-01 TO D-10)		1.1	7.5
PROJECT AREA (D-10 TO D-19)		19.6	15.7
AREA SOUTH OF PROJECT (D-19 TO D-34)		-12.0	-3.7

Table 3. +6.0 ft. NAVD88 Shoreline Change Rates (ft./yr.)

PROFILE		September 2013 (Baseline) to April 2021 (Year-4)	December 2017 (Post-Con) to April 2021 (Year-4)	June 2020 (Year-3) to April 2021 (Year-4)
Area North of Project	D-01	1.6	6.8	69.5
	D-02	-5.0	0.0	6.4
	D-03	1.5	10.8	24.9
	D-04	0.9	8.1	27.4
	D-05	3.9	12.1	-19.6
	D-06	-1.2	2.3	-16.0
	D-07	-0.6	-2.8	4.6
	D-08	2.1	9.3	25.1
	D-09	-0.5	4.4	-47.6
Project Area	D-10	-1.2	-3.9	14.9
	D-11	1.7	-20.3	11.3
	D-12	0.6	-25.4	0.6
	D-13	2.0	-33.3	10.5
	D-14	3.0	-33.7	-0.5
	D-15	6.2	-31.9	30.7
	D-16	2.2	-25.4	20.0
	D-17	1.7	-15.0	6.7
	D-18	4.2	-1.5	25.9
	D-19	5.4	13.0	67.9
Area South of Project	D-20	5.2	14.4	46.5
	D-21	0.5	8.8	36.2
	D-22	-2.1	5.6	15.6
	D-23	-8.5	-4.4	-85.5
	D-24	-5.5	-3.9	-21.6
	D-25	-1.8	-4.8	-29.5
	D-26	-2.5	0.8	-5.7
	D-27	-1.4	4.2	9.9
	D-28	-5.0	-3.9	-23.3
	D-29	-3.0	-2.4	-4.2
	D-30	1.7	0.7	33.0
	D-31	-2.7	-7.2	-46.3
	D-32	-3.0	-8.1	-28.7
	D-33	-2.4	-3.9	-36.2
	D-34	-0.2	-4.6	0.7
AREA NORTH OF PROJECT (D-01 TO D-10)		0.1	4.7	8.9
PROJECT AREA (D-10 TO D-19)		2.6	-17.7	18.8
AREA SOUTH OF PROJECT (D-19 TO D-34)		-1.6	0.3	-4.4

* Average MHW shoreline change rates provided as a reference only.

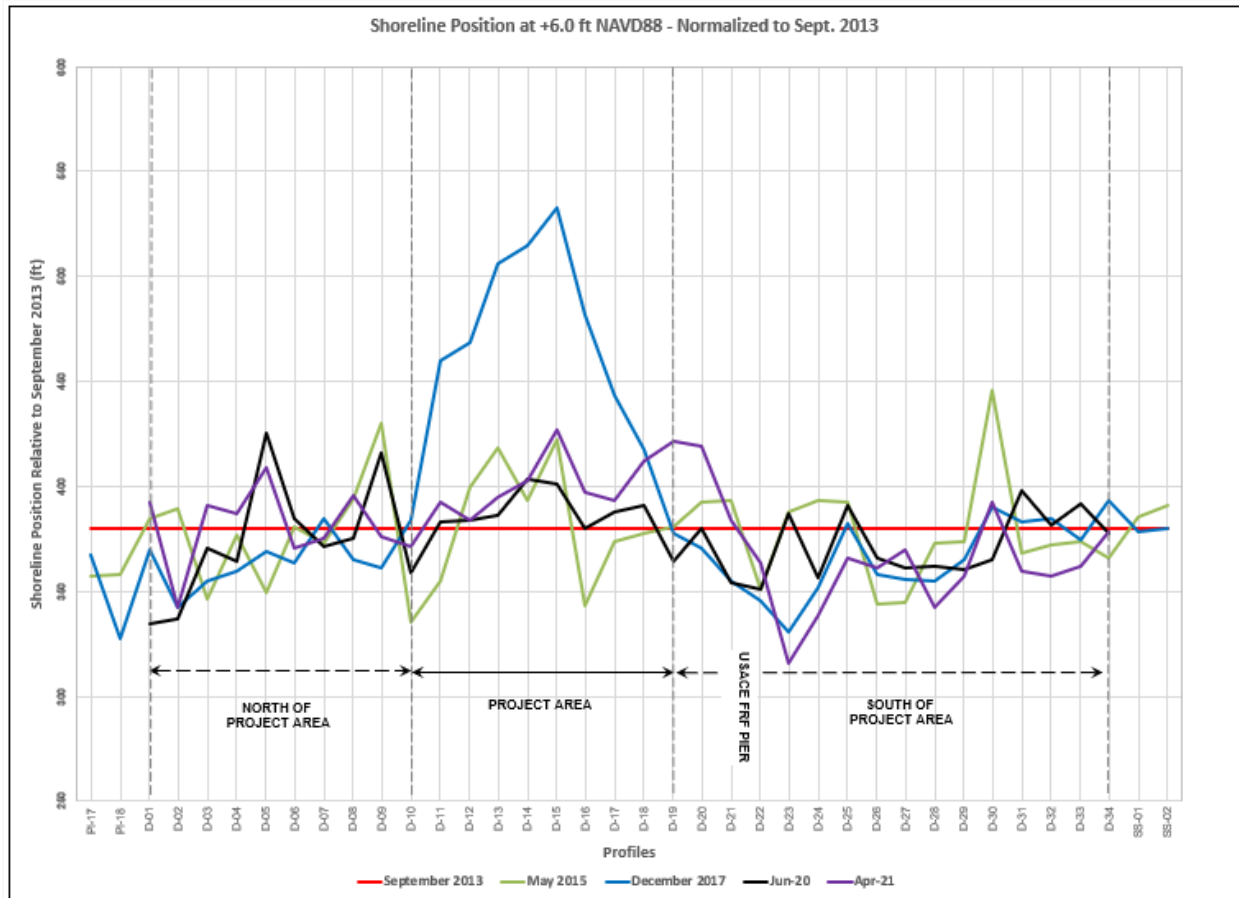


Figure 3. Historical +6.0 ft. NAVD88 Position Relative to the September 2013 +6.0 ft. NAVD88 Position

Project Area (D-10 to D-19)

With the construction of the beach nourishment project in 2017, the +6 ft. NAVD88 contour was extended seaward +183 ft. based on comparisons of the before dredge (BD) and after dredge (AD) surveys. However, these numbers reflect the change based on the placement of the unequibrated beach fill construction template. Between April 2017 and December 2017, the beach fill underwent immediate post-fill adjustments which reduced the initial advancement of the +6.0 ft. NAVD88 contour to an average of +89.5 feet. Note, this average does not include D-19 as this profile was not surveyed during the April 2017 pre-construction survey. The project average includes D-10 through D-18. This seaward advance of the +6.0 ft. NAVD88 contour is more reflective of the effective advance as a result of the project.

Beach profile data indicated that between December 2017 and April 2021, the average shoreline change of the +6 ft. NAVD88 contour within the Project Area was -59.1 ft., which is equivalent to a rate of change of -17.7 ft./yr. A profile-by-profile comparison shows a wide range of rates of change in the position of the +6.0 ft. NAVD88 contour (Table 3). The greatest shoreline changes measured appear to be taking place in the central portion of the project between Station D-13 (Sea Tern Dr.) and D-16 (Pintail Dr.). The average shoreline change along those 4 profiles was -103.6 ft. The average shoreline change between December 2017 and April 2021, in the northern portion of the Project Area from D-12 (Sound Sea Ave.) to D-10 (Skimmer Way) was -55.0 ft.; whereas, the average shoreline change in the southern part of the Project Area from D-17 (located at the south end of Buffell Head Rd.) to D-19 (northern USACE FRF boundary) was -3.9 ft. Table 2 includes measured shoreline change for each profile as well as the average shoreline

change for the beach nourishment project and the monitored areas outside the project. Table 3 includes rates of change of the +6.0 ft. NAVD88 contour for each profile as well as the average rate of change along the Project Area and the Areas to the North and South.

Figure 4 depicts the average cumulative change in the position of the +6.0 ft. NAVD88 contour within the Project Area (i.e. average change of stations D-10 to D-19) between September 2013 and April 2021. The large increase in the cumulative average shoreline change in the Project Area between May 2015 and December 2017 reflects the 89-foot seaward advance of the average shoreline position associated with the beach fill project completed in June 2017. After an initial shoreline recession measured between December 2017 and June 2018, the shoreline change appeared to stabilize somewhat and even advance seaward on average, between June 2018 and May 2019. Between May 2019 and December 2019, a significant shoreline recession was observed associated with Hurricane Dorian. Recession continued at a lower rate between December 2019 and June 2020. Between June 2020 and April 2021, the position of the +6.0 ft. NAVD88 contour moved an average 15.7 ft. seaward along the Project Area.

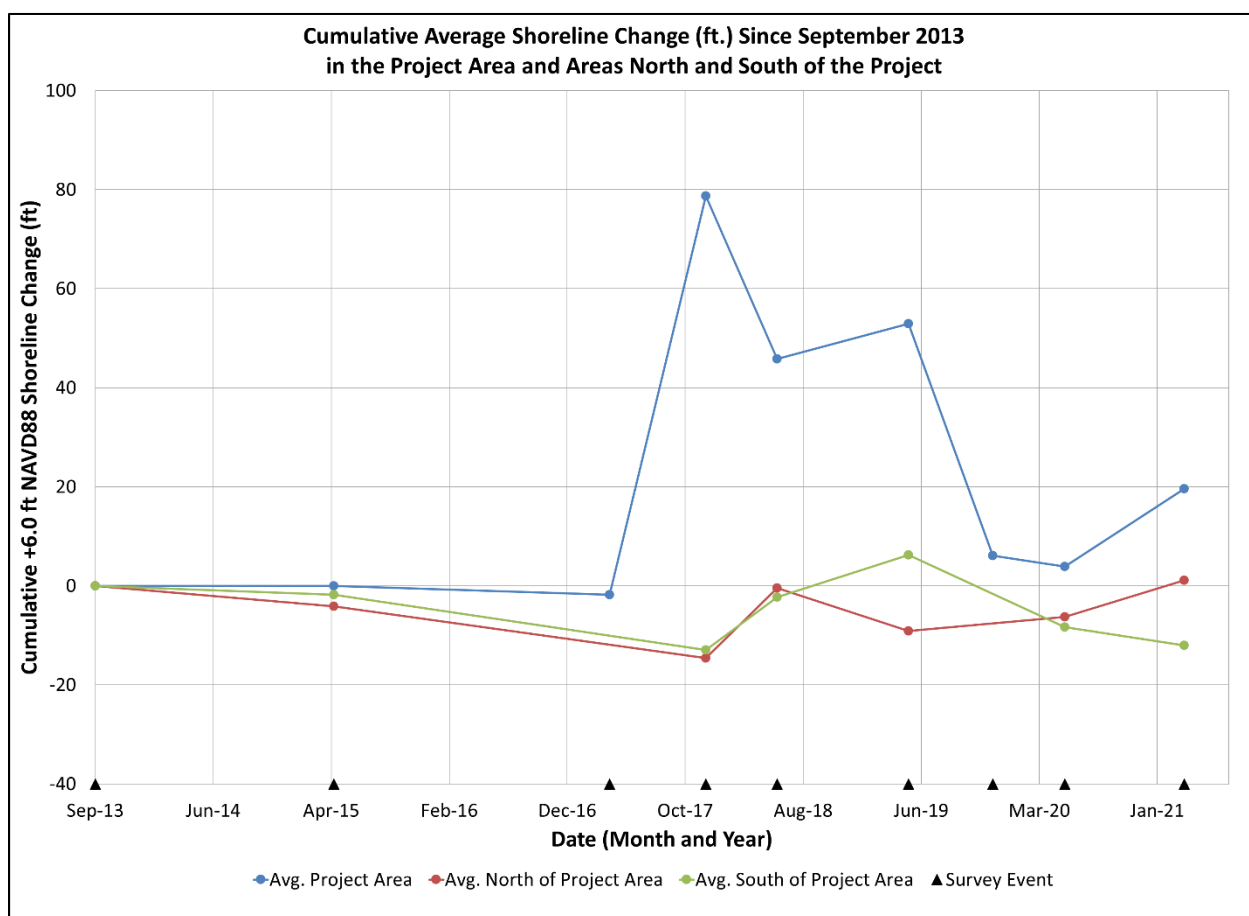


Figure 4. Cumulative Average Changes in the +6.0 ft. NAVD88 Contour Position since September 2013 in the Project Area and in the Areas North and South of the Project Area

Area North of Project (D-01 to D-10)

The average position of the +6.0 ft. NAVD88 contour north of the beach nourishment project (stations D-01 to D-10) is nearly the same as the average position measured in September 2013. As shown in Figure 4, between September 2013 and December 2017, the Area North of the Project experienced negative shoreline change. Between December 2017 and June 2018, the shoreline position experienced a positive change resulting in a similar average position of what was measured in September 2013. Though moderate recession was observed between June 2018 and May 2019, an average shoreline advance was observed between May 2019 and April 2021 resulting in a similar average position as was measured in September 2013 and June 2018.

As seen in Table 2, the individual measurements from profile to profile vary considerably. Between September 2013 and April 2021, the shoreline change at station D-05 (S. Station Bay Dr) has experienced the greatest positive change of +29.2 ft. whereas the greatest negative change of -37.8 ft. was measured at station D-02 (N Baum Trail).

During the recent survey interval, from June 2020 to April 2021, the shoreline moved seaward an average 7.5 ft. Although the average change was positive, the measured shoreline change varied throughout the area. In general, the northernmost profiles at stations D-01 and D-04 had an average shoreline change of 26.7 ft. (seaward). The average shoreline change measured from station D-05 to D-09 (south end of S. Baum Trail to Pelican Way) was -8.9 feet (landward movement). Station D-01, located at Station 1 Ln, which is considered the northern boundary of the Area North of Project, experienced the greatest positive (seaward) shoreline change between June 2020 and April 2021 (57.9 ft.) Station D-09, located at Pelican Way, which is considered the first profile north of the Project Area, experienced the greatest negative (landward) shoreline change between June 2020 and April 2021 (-39.7 ft.)

Area South of Project (D-19 to D-34)

The average shoreline change of the +6.0 ft. NAVD88 contour south of the Project Area between September 2013 and April 2021 was -12.0 ft. (landward movement). This is equivalent to a rate of -1.6 ft./yr. when annualized. As shown in Figure 4, between September 2013 and December 2017, the Area South of the Project experienced negative shoreline change. As shown in Figure 4, between December 2017 and May 2019, the area experienced an average positive shoreline change. However, between May 2019 and April 2021, the average shoreline change has been negative, resulting in little overall change in the average shoreline position between December 2017 and April 2021.

As seen in Table 2 and Table 3, the individual measurements from profile to profile vary considerably. The average shoreline change measured from D-19 (northern boundary of FRF property) and D-22 (200 ft. north of FRF pier) was 34.6 ft. (seaward movement) between June 2020 and April 2021. All of these stations fall within the FRF property, including D-19 which showed shoreline change of +56.6 feet. Between stations D-23 (800 ft. south of FRF pier) and D-33 (Bias Ln E), the average shoreline change was -18.0 ft. between June 2020 and April 2021. All of these stations fall south of the FRF pier, including D-23 which showed shoreline change of -71.3 feet.

V. VOLUMETRIC CHANGE RESULTS

Volumetric changes measured over the entire monitoring area for various time periods are provided in Table 4. The volume changes are given in terms of cubic yards/foot of shoreline/year (cy/ft./yr.). Volume change rates were evaluated for the periods from September 2013 to April 2021 (long-term), December 2017 (Post-construction) to April 2021, and June 2020 to April 2021. Volume change rates for the period from September 2013 to May 2015 area also included in Table 4 and represent trends occurring prior to construction of the project. The December 2017 to April 2021 surveys show changes occurring since the beach nourishment project was completed whereas the June 2020 to April 2021 surveys present the recent volume changes measured between the last two monitoring events.

The discussion of volume changes focuses on changes occurring within the beach nourishment Project Area (stations D-10 to D-19) as well as changes that are occurring north and south of the Project Area. Figure 5 graphically depicts the volumetric changes calculated above -24 ft. NAVD88 between September 2013 and April 2021 as well as changes measured from June 2020 to April 2021 and between December 2017 and April 2021.

Initial Beach Fill Volumes

Between May and June 2017, the 2017 beach nourishment project placed a total of 1.26 million cubic yards of fill along the Duck shoreline between stations D-10 and D-19 (APTIM, 2020). However, the performance of the 2017 project along the Town of Duck is based on changes that have occurred relative to the conditional monitoring survey conducted in December 2017. For purposes of monitoring the performance of the beach fill, the initial volume of material within the limits of the Project Area is defined as the volume change measured between April 2017 and December 2017 (APTIM, 2018). Based on volume changes computed between the April 2017 and December 2017, a volume change of approximately 963,100 cubic yards were measured on the active profile (above the -24-foot NAVD88 contour) from station D-10 to station D-19 (APTIM, 2020). For more information on why this method of assessing volume is used, please refer to the 2018 Shoreline and Volume Change Monitoring Report (APTIM, 2018).

Project Area (D-10 to D-19)

Beach profile monitoring surveys indicate a volume change within the Project Area of approximately -450,000 cubic yards between December 2017 (Post-construction) and April 2021. This equates to a rate of -14.2 cy/ft./yr. when annualized. **As of April 2021, the analysis indicates that the Town of Duck beach nourishment project had approximately 53% of the initial fill volume remaining as measured above the -24-foot NAVD88 contour in December 2017.** Figure 6 shows the cumulative volumetric changes for the Town of Duck measured since the baseline survey was conducted in September 2013. Cumulative volumetric changes are displayed for the Project Area, North of Project Area, and South of Project Area. The large increase in the Project Area curve (blue line) between April 2017 and December 2017 reflects the addition of volume due to the project construction. Since then, a relatively linear trend in erosion has been measured from December 2017 to April 2021.

Table 4. Volumetric Change Rates (cy/ft./yr.) along Duck above -24 ft. NAVD88

PROFILE		September 2013 to May 2015 (Baseline Surveys)	September 2013 to April 2021 (Long-Term)	December 2017 (Post- Con) to April 2021 (Year-4)	June 2020 (Year-3) to April 2021 (Year-4)
Area North of Project	D-01	-10.5	-0.2	3.5	0.7
	D-02	0.3	-2.7	0.5	-16.4
	D-03	-33.2	3.1	4.7	-0.6
	D-04	-16.0	-0.5	5.2	-7.7
	D-05	-52.4	3.8	14.2	4.6
	D-06	-18.3	-1.3	8.5	7.4
	D-07	-28.4	0.4	3.5	-11.3
	D-08	-37.2	-0.9	0.6	-11.9
	D-09	25.1	2.3	8.3	-12.2
	D-10	-44.6	3.6	6.1	18.1
Project Area	D-11	-69.9	7.7	-8.6	-13.7
	D-12	30.3	9.3	-8.6	-18.1
	D-13	33.1	11.7	-15.6	-21.9
	D-14	1.5	9.7	-32.8	-92.7
	D-15	12.3	7.8	-28.9	-41.0
	D-16	-19.5	9.2	-22.9	-39.3
	D-17	19.5	11.7	-8.9	-4.0
	D-18	5.2	8.5	-17.2	-10.7
	D-19	-4.4	7.5	-4.7	29.0
	D-20	3.9	7.8	-1.4	5.5
Area South of Project	D-21	27.1	7.7	3.7	-9.5
	D-22	-9.4	4.3	3.3	-28.5
	D-23	67.1	2.6	4.5	-9.5
	D-24	38.0	-5.4	-11.7	-32.0
	D-25	-1.1	-6.3	-15.5	-68.0
	D-26	-28.2	-4.5	-17.7	-55.9
	D-27	-30.6	-3.3	-4.0	-19.3
	D-28	-10.9	-3.8	2.0	-12.2
	D-29	-55.3	-3.2	-1.1	-10.3
	D-30	80.2	0.9	0.9	5.7
	D-31	-7.1	-1.7	-9.3	-75.9
	D-32	-2.8	-1.8	-8.0	-54.1
	D-33	-12.9	-1.1	4.0	-50.1
	D-34	-35.1	-0.8	-2.6	-12.7
AREA NORTH OF PROJECT (D-01 TO D-10)		-21.5	0.7	5.5	-2.9
PROJECT AREA (D-10 TO D-19)		-3.7	8.7	-14.2	-19.4
AREA SOUTH OF PROJECT (D-19 TO D-34)		1.1	-0.1	-3.6	-24.9

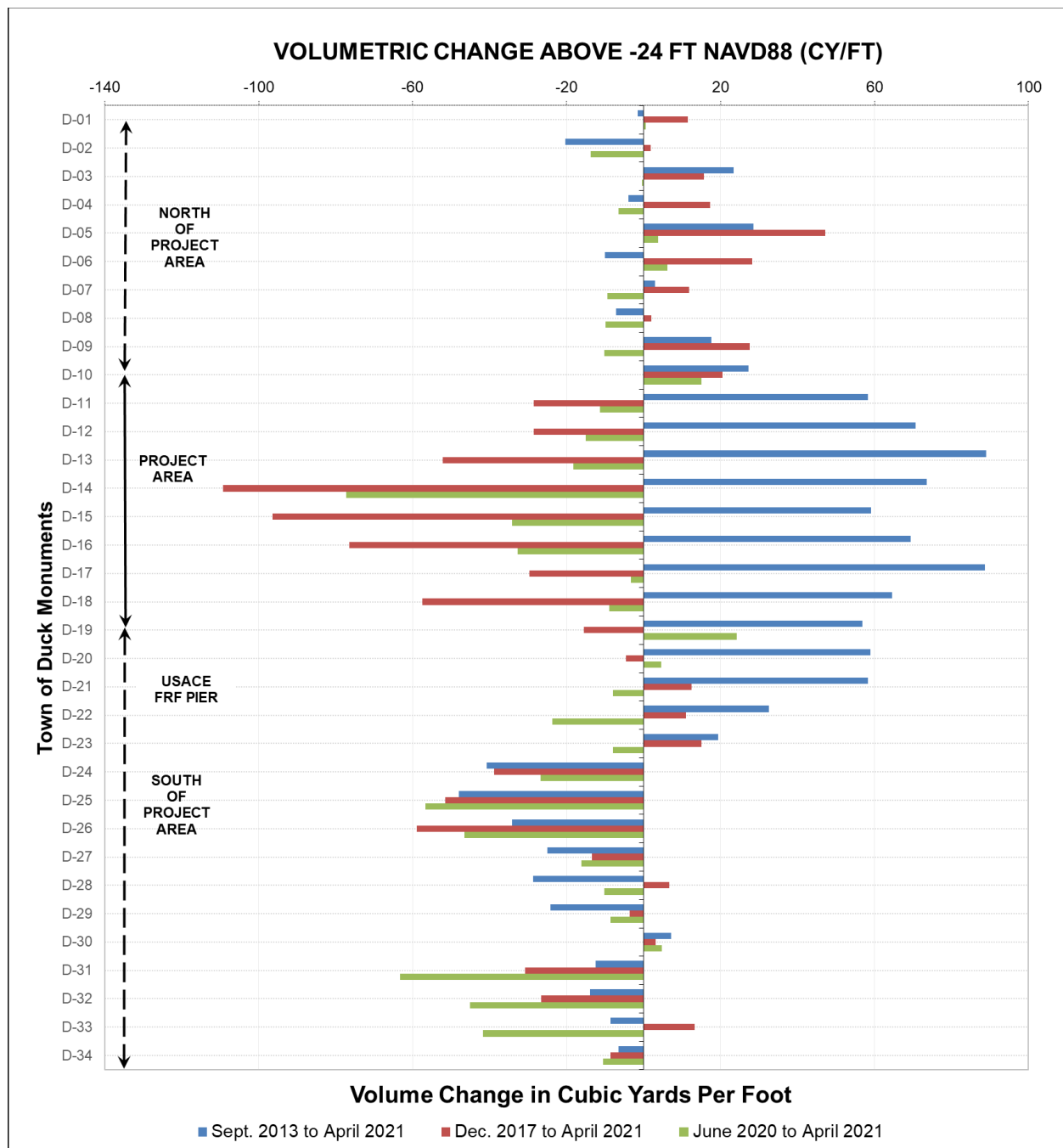


Figure 5. Volume Changes (cubic yards/foot) measured between Sept. 2013 to April 2021, Dec. 2017 to April 2021, and June 2020 to April 2021

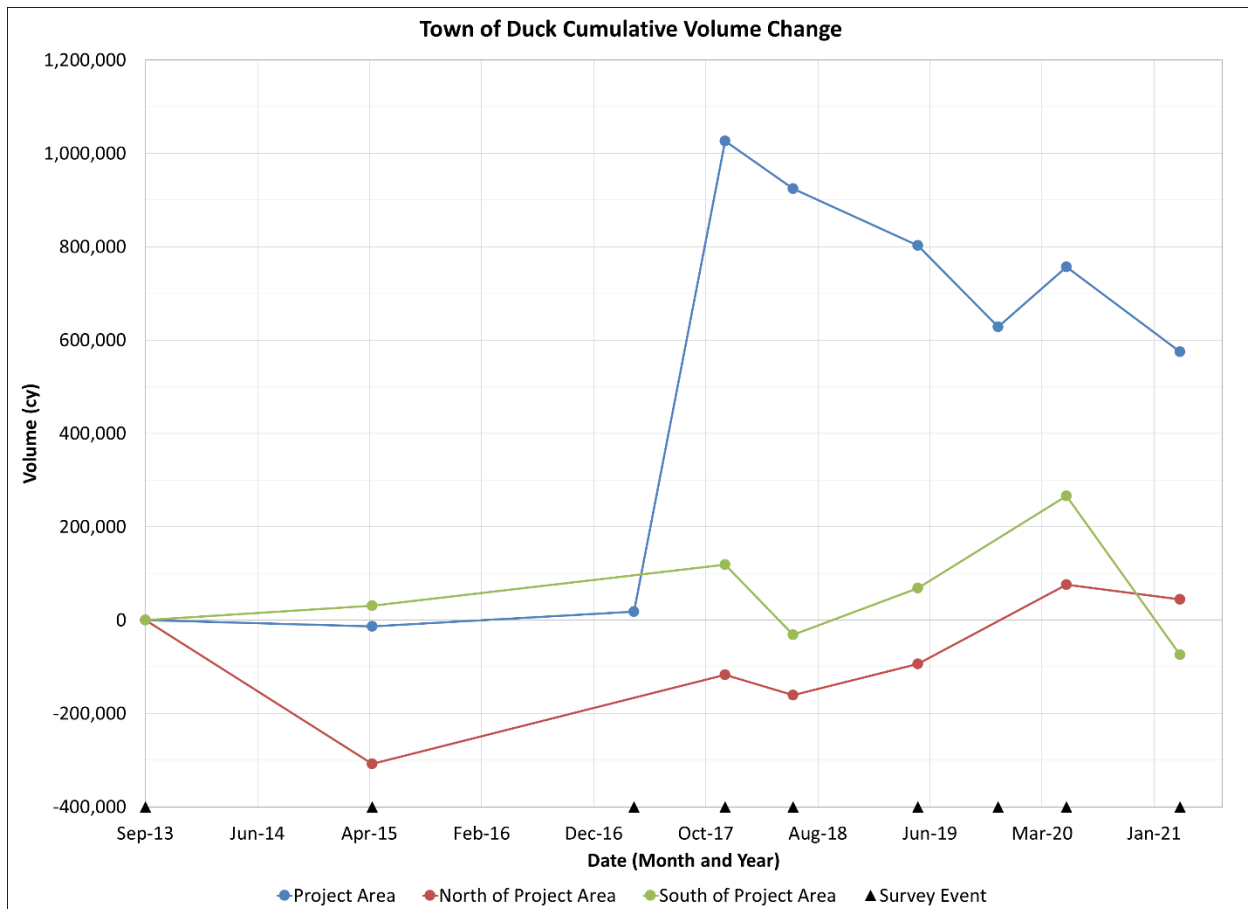



Figure 6. Average Cumulative Volumetric Changes above the -24 ft. NAVD88 contour since September 2013 in the Project Area and in the Areas North and South of the Project Area

The net volumetric change measured from June 2020 to April 2021, was a negative volumetric change of approximately 178,000 cubic yards. This is equivalent to an average loss of approximately -19.4 cy/ft./yr. and equates to approximately 40% of the total volumetric change measured between December 2017 and April 2021. The greatest negative volumetric change was measured along station D-14 (-77.3 cy/ft.), located at Sea Tern Drive E. The largest positive volumetric change was measured at station D-19 (+24.1 cy/ft.), located at the northern border of the USACE FRF property. Only the northernmost and southernmost profiles within the Project Area (stations D-10 and D-19) measured a positive volumetric change over the 10-month period. Figure 5 illustrates both the individual short-term volumetric change trends along each profile as well as changes that have occurred since September 2013 and December 2017.

Area North of Project (D-01 to D-10)

Volumetric changes in the monitoring Area North of the Project, prior to the construction of the beach nourishment project (September 2013 to May 2015), indicated an average volume change rate of -21.5 cy/ft./yr. Since the project was constructed (December 2017 to April 2021), the average volumetric change rate measured within the Area North of the Project was +5.5 cy/ft./yr. The recent period between June 2020 to April 2021 (10-months) measured an average loss of -2.9 cy/ft./yr. within the area. In Figure 6, the curve representing the cumulative volumetric changes north of the Project Area (red) shows the relatively steep erosional trend observed between September 2013 and May 2015, prior to the construction of the project. The next data point for the Area North of the Project is the cumulative volume measured in December 2017, which shows an increase in volume between May 2015 and December 2017. It is noteworthy to report that



even after the project, the cumulative volumetric change curve shows less volume in the Area North of the Project in December 2017 than what was present in September 2013. Between December 2017 and June 2018, the Area North of the Project experienced a modest reduction in volume followed by a 2-year period (June 2018 to June 2020) of volumetric increase. This was followed by a 10-month period (June 2020 to April 2021) of volume decrease. As of April 2021, the Area North of the Project has a net positive volumetric change of approximately 44,000 cy compared to the area in September 2013. Since the project was constructed in 2017, the Area North of the Project has experienced a positive volumetric change of approximately 165,000 cy.

In the previous monitoring report (CPE, 2020), the analysis of the changes along the shoreline immediately north of the Project Area between Station 1 Ln. and Skimmer Way (stations D-01 and D-10) measured a positive volumetric change of 18.2 cy/ft. between May 2019 and June 2020. The more recent volumetric change trend measured between June 2020 and April 2021 show this Area North of the Project lost an average -2.4 cy/ft., equivalent to approximately 32,000 cy.

Area South of Project (D-19 to D-34)

Volumetric changes in the monitoring Area South of the Project, prior to the construction of the beach nourishment project (September 2013 to May 2015), were relatively stable indicating modest positive volumetric changes at a rate of 1.1 cy/ft./yr. However, a review of the changes from station to station indicates the behavior of the shoreline was highly variable. Within this area, volume changes between profile stations varied from an accretion rate of 80.2 cy/ft./yr. at station D-30 to an erosion rate of -35.1 cy/ft./yr. at station D-34. During the 40-month period from December 2017 to April 2021, since the construction of the beach nourishment project, this area lost an average of 3.6 cy/ft./yr. During the recent 10-month period, from June 2020 to April 2021, this area eroded at an average rate of -24.9 cy/ft./yr. In Figure 6, the curve representing the cumulative volumetric changes south of the Project Area (green) illustrates the relatively modest accretional trend observed between September 2013 and May 2015, prior to the construction of the project. The next data point for the Area South of the Project is the cumulative volume measured in December 2017, which shows an increase in volume between May 2015 and December 2017. Between December 2017 and June 2018, the Area South of the Project experienced negative volumetric changes followed by a 2-year period (June 2018 to June 2020) of volumetric increase. This was followed by a 10-month period (June 2020 to April 2021) of volume decrease. This trend was similar to the trend observed in the Area North of the Project over the same period of time. As of April 2021, the Area South of the Project has experienced a net volumetric loss of approximately 75,000 cy compared to the area in September 2013. Since the project was constructed in 2017, the Area South of the Project experienced a net volume loss of approximately 176,000 cy.

During the recent survey interval from June 2020 to April 2021, only three profiles south of the Project experienced a positive volumetric change: D-19 (located 55 feet south of the northern boundary of the USACE FRF), D-20 (1600 ft north of USACE FRF pier) and D-30 (Four Seasons Ln). An examination of volume changes measured station to station shows the highest volumetric losses of 68.0 cy/ft./yr. and 75.9 cy/ft./yr. occurred at stations D-25 and D-31, respectively (Table 4). Figure 5 illustrates both the individual short-term volumetric change trends along each profile as well as changes that have occurred since September 2013 and December 2017.

VI. DISCUSSION


This monitoring report evaluated shoreline and volumetric changes along the portions of shoreline nourished in 2017 within the Town of Duck as well as portions of the adjacent shorelines to the north and south. The monitoring area extends south from station D-01, located at the northern limits of the Town of Duck, to station D-34, located near the Town of Duck town limits with the Town of Southern Shores. With the construction of the beach nourishment project in June 2017, the monitoring area was divided into three sections, namely, the Project Area (D-10 to D-19), the Area North of the Project (D-01 to D-10), and the Area South of the Project (D-19 to D-34). Data collected in April 2021 was used to evaluate shoreline and volumetric changes that have occurred since the baseline survey was conducted in September 2013, since the construction of the 2017 beach nourishment project, and over the past year between the 2020 and 2021 monitoring surveys.

Shoreline Change Analysis

Project Area. Surveys conducted in April 2017 and December 2017 indicated that the beach fill effectively relocated the +6.0 ft. NAVD88 contour an average of +89.5 feet seaward (from D-10 to D-18). D-19 was not surveyed during the April 2017 pre-construction survey and therefore, is not included in the project average. The construction of the project resulted in a seaward movement of the +6.0 ft. NAVD88 contour of 183 feet on average; however, between the project completion in June 2017 and the post-construction survey conducted in December 2017, the project experienced considerable equilibration and therefore the December 2017 +6.0 ft. NAVD88 design contour is assumed to be equilibrated. The average shoreline change measured within the Project Area from December 2017 to April 2021 from D-10 to D-18 was -70.5 ft.

Figure 7 shows that in some areas, particularly along the northern part of the project from 140 Skimmer Way (D-10) to Sound Sea Ave. (D-12) the current +6.0 ft. NAVD88 contour is landward of the pre-project (April 2017) location of the +6.0 ft. NAVD88 contour. Along the southern portion of the project, where the pre-project condition was most severely eroded, the +6.0 ft. NAVD88 contour is still seaward of the pre-project condition. The average shoreline change rate along the Project Area measured between December 2017 and April 2021 was -17.7 ft./yr. However, over the 10-month period between June 2020 and April 2021 the rate was +18.8 ft./yr. (seaward movement).

The average position of the +6.0 ft. NAVD88 contour is 19.6 ft. seaward of the September 2013 baseline survey as of April 2021. In comparison, the average MHW shoreline position is 22.8 ft. seaward of the September 2013 baseline position suggesting the beach slope is almost the same as it was in September 2013. In the 2020 monitoring report, a similar comparison of the +6.0 ft. NAVD88 and MHW contour indicated a much less steep profile than the baseline condition (CPE, 2020). The steepness of the beach is influenced by wave conditions preceding the observations and the grain size of the sand. In the 2020 monitoring report, the discrepancy between the average slope measured in 2013 and the average slope observed in June 2020 was suggested to be associated with grain size. When the beach fill project was constructed, the material used to construct the southern 2,500 feet of the project (south of approximately D-16) came from a combination of sand from Borrow Area A and C at a ratio of 2 loads from Borrow Area A for every 1 load from Borrow Area C; whereas the material used to construct the rest of the project to the north all came from Borrow Area C. The mean grain sizes of the sand in Borrow Areas A and C were determined to have an average mean grain size of 0.36 mm and 0.26 mm, respectively (CPE-NC, 2015B). The fact that Borrow Area C was known to be finer than Borrow Area A and finer than the native beach led to the directive that additional sand was required to be placed along sections constructed with sand from Borrow Area C alone. Samples taken along the beach following construction of the project showed the average mean grain size of the samples collected in areas constructed with material from Borrow Area A had a mean grain size of approximately 0.39 mm, compared to the mean grain size of samples collected



along the portion of the project constructed with material from Borrow Area C, which had a mean grain size of 0.29 mm.

While placement of finer material may have contributed to a shallower beach slope, the fact that the 2021 beach profile data indicates an average beach slope similar to the September 2013 baseline conditions may be indicative of sediment mixing to form a similar average grain size over time and/or the result of coincidental wave conditions preceding the observations. The fill for the 2022 project will all be dredged from Borrow Area A only. Future monitoring of the project following the 2022 project should evaluate whether the slope along the beach is more consistent than what has been observed between the construction of the 2017 project and the April 2021 monitoring.

Area North of Project. The average long-term shoreline changes computed along the Area North of the Project (D-01 to D-10), was 1.1 ft (seaward movement), between September 2013 and April 2021. This time period includes the construction of the beach nourishment project. This is equivalent to a rate of +0.1 ft./yr. The average rate between D-01, located near the northern Town Boundary and D-05, located at S Station Bay Dr, was 0.6 ft./yr. (seaward movement); whereas the average long-term shoreline change from S Station Bar Dr south to the Project Area (D-05 to D-10) was a negative -0.3 ft./yr. (landward movement). In summary, the shoreline has remained essentially stable along the portion of the Town north of the project since September 2013.

Recent surveys (June 2020 and April 2021) indicate an overall average change in the +6.0 ft. NAVD88 contour of +7.5 ft. (seaward movement). However, there is a clear distinction between the trend directly north of the project from D-10 to D-04, located at the Sanderling Resort, and the portion of the Town's beach north of the Sanderling Resort. The average change in the +6.0 ft. NAVD88 contour position from D-10 to D-04 was -1.3 ft. (landward movement), whereas, from D-04 to D-01 the average change was +26.7 ft. (seaward movement).

Area South of Project. Long-term shoreline changes computed along the Area South of the Project (D-19 to D-34), was -12.0 ft (landward movement), between September 2013 and April 2021. This time period includes the construction of the beach nourishment project. This is equivalent to a rate of -1.6 ft./yr. It should be noted that the portion of the beach located between the northern boundary of the USACE FRF and 1,000 ft. north of the USACE FRF pier (stations D-19 and D-21) experienced a positive trend of seaward movement, with an average shoreline change of +28.1 ft., or a rate of +3.7 ft./yr.. Between stations D-23 (approximately 500 feet north of the southern boundary of the FRF property) and D-29 (located along Ocean Way), the average shoreline change rate was approximately -4.0 ft./yr. between September 2013 and April 2021. South of D-29 to D-34 (southern Town boundary), the average shoreline change rate over the same time period was -1.6 ft./yr.

Recent surveys (June 2020 and April 2021) indicate an overall average change in the +6.0 ft. NAVD88 contour of -3.7 ft. However, there is a clear distinction between the trend directly south of the project from the northern boundary of the USACE FRF property (D-19) to approximately 600 ft. south of USACE FRF pier (D-22), and the trend from approximately 600 ft. south of USACE FRF pier (D-22) south to the Town southern boundary (D-34). In the area directly south of the project, the average change was +34.6 ft. over the approximate 10-month period from June 2020 to April 2021. In contrast, the average shoreline change measured from 600 ft. south of USACE FRF pier to the Town southern boundary was -14.2 ft. Within this area, the +6.0 ft. NAVD88 contour between the end of Plover Dr (D-31) and Bias Ln. E. (D-33) experienced a landward movement of -30.9 ft. on average.

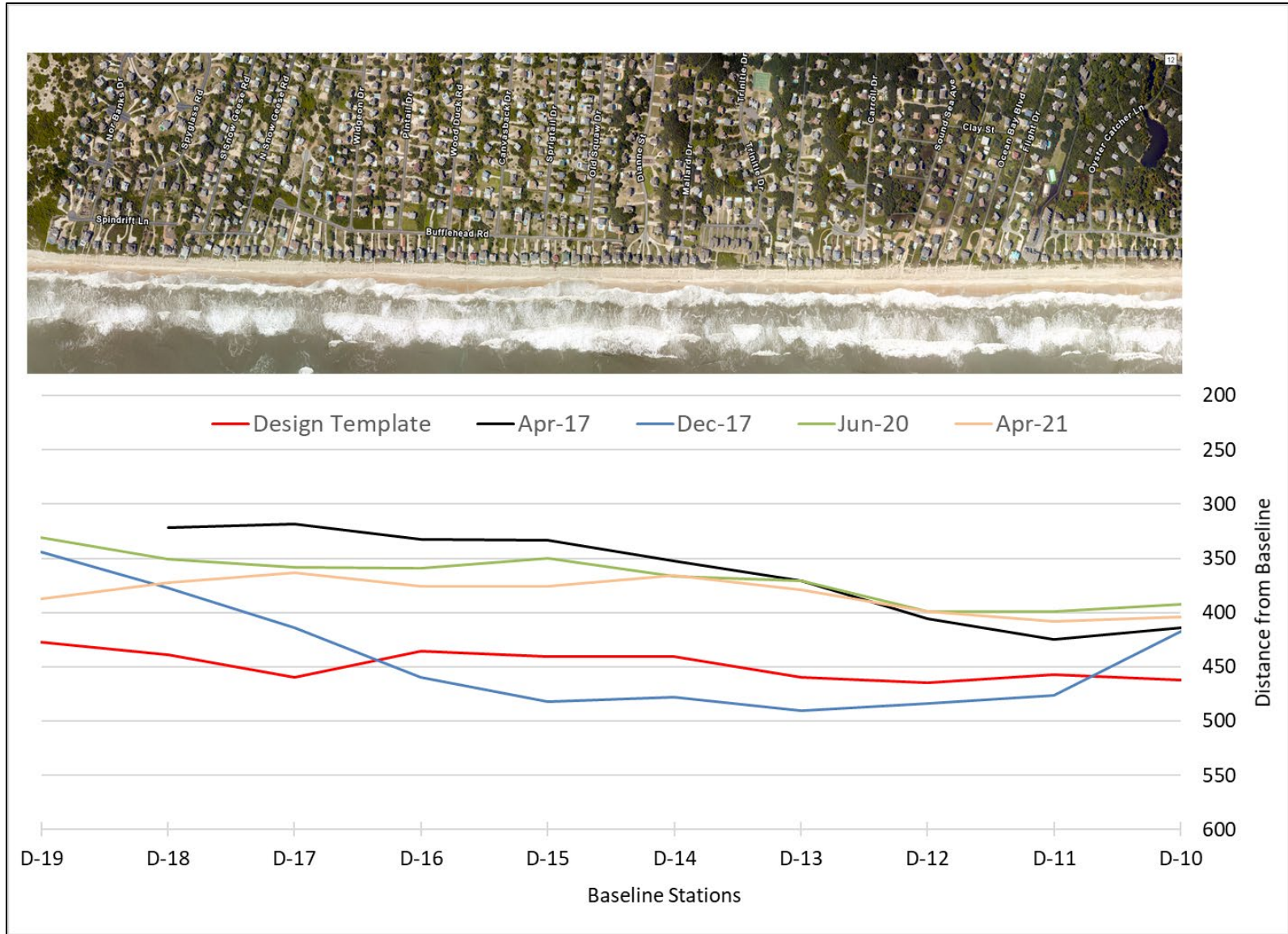


Figure 7. +6.0 ft. NAVD88 Contour Position throughout the Project Area compared to the +6.0 ft. NAVD88 Contour for the Project Design

Volumetric Change Analysis

Project Area. Beach profile surveys indicate that during the most recent survey interval (June 2020 to April 2021), a volumetric loss of approximately 178,000 cubic yards was measured. The highest losses occurred between Sound Sea Ave. and Pintail Dr. (D-13 to D-16). Since the completion of Town of Duck beach nourishment project, the Project Area has lost a total of approximately 450,000 cubic yards (December 2017 to April 2021). This equates to approximately 47% of the fill measured in the Project Area in December 2017. As of April 2021, the analysis indicates that the Town of Duck beach nourishment project had 53% of the initial fill volume remaining as measured above the -24-foot NAVD88 contour in December 2017.

As discussed in the Shoreline Change portion of this Section, the +6.0 ft. NAVD88 contour position at every profile within the project area is landward of the designed berm position. In other words, in terms of the design berm, the project has eroded back into the project design at the berm elevation. In fact, on average, the +6.0 ft. NAVD88 contour is approximately 65.4 ft. landward of where it was designed to be between D-10 and D-19. That said, as mentioned above, approximately 53% of the material placed along the Project Area as measured in December 2017 is still located within the Project Area. This suggests that a considerable amount of sand is being stored in the offshore portion of the profile.

Area North of Project. Since the project was constructed, the average volumetric change in the Area North of the Project was +5.5 cy/ft./yr. The long-term average volumetric change rate measured between September 2013 and April 2021, was +0.7 cy/ft./yr. The trend observed since the project was constructed is higher than the long-term average of +0.7 cy/ft./yr. This may be in part due to the spreading of material from the project to the Area North of the Project. However, the volumetric change rate North of the Project is slightly lower than the rate documented in the 2020 Monitoring report due to recent negative volumetric change measured between June 2020 to April 2021. The average volumetric change along this area over that 10-month period was -2.4 cy/ft. or -2.9 cy/ft./yr.

Area South of Project. Since the project was constructed (Dec. 2017 to April 2021), the average volumetric change south of the Project Area was -3.6 cy/ft./yr. The long-term average volumetric change rate in the area south of the project, measured between September 2013 and April 2021, was -0.1 cy/ft./yr. The negative volumetric trend observed since the project was constructed is greater than the long-term average of -0.1 cy/ft./yr. However, this is a reversal of the post-project volumetric change rate reported along the Area South of the Project between December 2017 and June 2020 (+3.5 cy/ft./yr.) (CPE, 2020). The reversal in the post-project trend is due to significant negative volumetric changes measured between June 2020 and April 2021, which can be seen in Figure 5. The average volumetric change along this area over that 10-month period was -20.7 cy/ft. or -24.9 cy/ft./yr.

In June 2018, an anomalous wide and deep trough was identified just offshore at station D-21. The volumetric change measured at station D-21 between December 2017 and June 2018 was a negative 55.4 cy/ft. Between June 2018 and May 2019, a positive volumetric change of 36.9 cy/ft. was measured along D-21; however, the net volumetric change that occurred between December 2017 and May 2019 was still negative. Most recently, between June 2020 and April 2021, a negative volumetric change of -7.9 cy/ft. was measured along D-21, bringing the net volumetric change measured since December 2017 at station D-21 to a +12.5 cy/ft. This is significant, because the development of the anomalous trough offshore of D-21 shortly after the construction of the project may have obscured the volumetric gains experienced along the area directly south of the project related to the spreading of the beach fill.



VII. RECOMMENDATIONS

CPE recommends the Town continue to monitor the beach along the entire Town oceanfront in order to assess long-term shoreline and volumetric changes. That said, with the re-nourishment scheduled for 2022, pre-construction surveys will be collected by the dredge contractor, which can serve as the year 5 monitoring surveys for the Project Area. Furthermore, as part of the construction contract, the dredge contractor will conduct a post-construction survey within 2 weeks of completion of beach fill placement, which will serve as the new baseline conditions for the Duck beach nourishment project. As part of the project completion report for the construction project, CPE will provide updated volumetric changes within the project area based on a comparison of the December 2017 and Pre-Construction surveys conducted by the dredge contractor. These rates will be used in the planning of the 2027 maintenance event. Following construction of the beach project in 2022, the continued annual monitoring of the project provides not only a pre-storm condition survey that can be used to estimate storm damages, as was the case following the impact of Hurricane Dorian, but also the continued assessment of volume trends, which will also be used in the planning of future maintenance events.

Outside the Project Area, continued monitoring is instrumental for the Town to evaluate future areas of concerns and longshore transport trends, and to develop successful shoreline management strategies to deal with issues as they arise. In that regard, post-construction surveys, which will be conducted by the dredge contractor within 2-weeks following the 2022 project, will include the Area North and Area South of the Project. Data collected in April 2021 indicate that since construction of the project in 2017, the volumetric trend along the Town's beaches in the Area North of the Project has been positive change (accretion). It is not uncommon to see positive volumetric changes adjacent to a beach nourishment project due to the spreading of material that serves to feed the adjacent beaches.

In contrast, the Area South of the Project has experienced a negative volumetric change trend (erosion) since December 2017. Continued monitoring of the areas outside the Project Area is vital to achieving the Town's goal of providing a reasonable level of storm damage reduction to public and private development. In that regard, CPE recommends that given the continued trend of erosion along the Area South of the Project, that the storm vulnerability analysis, last conducted in 2019, be updated using the 2022 monitoring data to be collected following construction of the beach nourishment project. The results of the analysis will be important as the Town transitions from preparation and construction of the 2022 project to planning for the 2027 project.



VIII. REFERENCES

APTIM, 2018. Aptim Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina 2018 Shoreline & Volume Change Monitoring Report*. Prepared for Town of Duck. Wilmington, NC.

APTIM, 2020. Aptim Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck Shore Protection Project Beach Maintenance Plan*. Prepared for Town of Duck. Wilmington, NC.

CPE, 2020. Coastal Protection Engineering of North Carolina, Inc. Post-Storm Design Report: Hurricane Dorian Town of Duck Shore Protection Project Repair Dare County, NC. Prepared for Town of Duck. Wilmington, NC.

CPE, 2020. Coastal Protection Engineering of North Carolina, Inc., *Town of Duck North Carolina 2020 Shoreline & Volume Change Monitoring Report*. Prepared for Town of Duck. Wilmington, NC.

CPE-NC, 2015A. Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina Erosion & Shoreline Management Design Report*. Prepared for Town of Duck. Wilmington, NC.

CPE-NC, 2015B. Coastal Planning & Engineering of North Carolina, Inc., *Comprehensive Marine Sand Search and Borrow Areas Design Report*. Prepared for the Towns of Duck, Kitty Hawk, and Kill Devil Hills. Wilmington, NC.