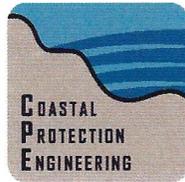


**TOWN OF DUCK NORTH CAROLINA
2023 SHORELINE & VOLUME CHANGE
MONITORING REPORT**

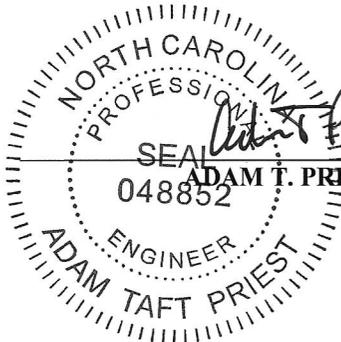


**SUBMITTED TO:
TOWN OF DUCK**

SUBMITTED BY:



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



ADAM T. PRIEST, PE NO. 048852

**11/22/23
DATE**

November 2023

EXECUTIVE SUMMARY

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 its initial beach nourishment project that placed approximately 1.26 million cubic yards of fill along 1.6 miles of shoreline that was shown to be the most vulnerable portion of the Town’s oceanfront. Between April and May 2023, the Town constructed its first beach renourishment project along the same area that was nourished in 2017, placing approximately 576,800 cubic yards of fill between Skimmer Way (station D-10) and the northern boundary of the USACE Field Research Facility (FRF) property (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 renourishment 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 Central Reach Project Area (station D-10 to D-19); the North Monitoring Area (D-01 to D-10), which extends south from the Town limit to Skimmer Way; and the South Monitoring Area (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 monitoring 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 for three different timeframes to update the changes within the Project Area and assess the recent and long-term changes in the North and South Monitoring Areas. Table ES-1 below summarizes the average shoreline changes (ft.) measured from Sept. 2013 to May 2023 (Long-Term Shoreline Change), Dec. 2017 to Jan. 2023, and April 2021 to May 2023 (Post-construction) (Short-term), for the North Monitoring Area, Central Reach Project Area and South Monitoring Area.

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

MONITORING AREAS	Sept. 2013 (Baseline) to May 2023 (2023 Post-Con)	Dec. 2017 (2017 Post-Con) to Jan. 2023 (2023 Pre-Con)	April 2021 to May 2023 (2023 Post-Con)
NORTH MONITORING AREA (D-01 TO D-10)	-11.4	---	-12.5
CENTRAL REACH PROJECT AREA (D-10 TO D-19)	140.1	-88.3	121.0
SOUTH MONITORING AREA (D-19 TO D-34)	-8.9	---	6.2

Similar to the shoreline change analysis, the tracking of long-term volumetric changes within the Central Reach Project Area as well as the North and South Monitoring Areas, are measured by comparing the September 2013 baseline data with the most recent annual monitoring (May 2023 post-construction). Volumetric changes that have occurred subsequent to the 2017 Project are determined by comparing the December 2017 data with the last dataset before the 2023 project (Jan. 2023 pre-construction). The monitoring report also provides short-term volumetric changes that occurred between the most recent

townwide surveys (April 2021 to May 2023). Average volumetric change rates calculated above the -24-foot NAVD88 contour (cubic yards/ft./year) for the Central Reach Project Area and North and South Monitoring Areas are provided in Table ES-2.

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

MONITORING AREAS	Sept. 2013 (Baseline) to May 2023 (2023 Post-Con)	Dec. 2017 (2017 Post-Con) to Jan. 2023 (2023 Pre-Con)	April 2021 to May 2023 (2023 Post-Con)
NORTH MONITORING AREA (D-01 TO D-10)	0.7	---	-0.1
CENTRAL REACH PROJECT AREA (D-10 TO D-19)	12.3	-10.8	24.3
SOUTH MONITORING AREA (D-19 TO D-34)	3.0	---	13.3

The long-term average volumetric change rates indicate a positive trend throughout the Town; however, the Central Reach Project Area rate is clearly being influenced by the beach nourishment projects constructed in 2017 and 2023. Since 2013, the North Monitoring Area has maintained a relatively stable rate of volumetric change (+0.7 cy/ft./yr.), while the South Monitoring Area has experienced a positive trend at a rate of +3.0 cy/ft./yr. over the 9.7-year period.

With the completion of the 2023 beach renourishment project, the entirety of the 2017 project's performance can be analyzed. A comparison of profile surveys conducted in April 2017 (pre-construction) and December 2017 (post-construction) measured the effective volumetric gain to the Project Area was 963,100 cubic yards, due to the 2017 beach nourishment project. Monitoring of the 2017 project over the approximate 5 years between December 2017 and January 2023, indicates a volumetric change rate of -10.8 cy/ft./yr. This rate is considered the most representative rate of volumetric change observed within the Central Reach Project Area between the 2017 initial construction and the 2023 renourishment projects. The volumetric change during this period is equivalent to a loss of approximately 521,800 cubic yards and indicates that approximately 46% of the initial volume placed along the Town of Duck in 2017 remained in the Project Area above the -24-foot NAVD88 contour.

The short-term (April 2021 to May 2023) average volumetric change rates indicate a positive trend throughout the Town; however, the Central Reach Project Area rate is clearly being influenced by the beach nourishment project constructed in 2023. It should also be noted that two surveys were conducted between April 2021 and May 2023, including surveys in October 2022 and January 2023 (Pre-construction). When comparing April 2021 survey to these two surveys the results indicate that the trend along the Project Area, prior to the 2023 project was erosional. In fact, between April 2021 and January 2023 there was an erosional trend and a loss of approximately 107,900 cubic yards. Since April 2021, the North Monitoring Area has maintained a relatively stable rate of volumetric change (-0.1 cy/ft./yr.), while the South Monitoring Area has experienced a positive trend at a rate of +13.3 cy/ft./yr. over the 25-month period.

Using the previously calibrated SBEACH model and the May 2023 beach profile survey data, an updated storm vulnerability analysis was conducted of the oceanfront beach and dune system along the Town of Duck. The updated SBEACH analysis based on May 2023 conditions indicated that within the South Monitoring Area, no structures and 9 pools were identified as vulnerable. This is a decrease in the number



of structures and pools identified as vulnerable based on the 2019 conditions, which was 29 structures and 40 pools. There were no structures or pools identified to be vulnerable within the Central Reach Project Area. Along the North Monitoring Area, within the Town of Duck (stations D-01 to D-10), there were 0 structures or pools identified as vulnerable.

CPE recommends the Town continue to monitor the beach along the entire Town oceanfront in order to assess if shoreline and volume change trends identified in this report persist. For the Central Reach Project Area, the May 2023 survey has been adopted to represent the post-construction conditions. Future annual monitoring reports will reference shoreline and volume changes in the Central Reach Project Area relative to the May 2023 condition to track the performance of the 2023 project and aid in the determination as to when additional nourishment is needed in the Central Reach Project Area. In that regard, data collected in January 2023 indicated that the 2017 project eroded at a rate of -10.8 cy/ft./yr. when compared to the Dec. 2017 Post-construction survey. This erosion rate and rates computed through the continued monitoring of the 2023 project will be used to design the next renourishment event. The continued annual monitoring of the project also provides a pre-storm condition survey that can be used to estimate damages if the project is impacted by a significant storm.

Continued monitoring of the North and South Monitoring Areas 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. The May 2023 post-construction survey indicates that since 2013, the volumetric trend along the Town's beaches in the North Monitoring Area has been stable. Data collected in May 2023 also indicates a stable volumetric change in the recent period since April 2021. The South Monitoring Area has experienced a positive volumetric change trend (accretion) since 2013. This may be due in part to sand placed during the 2017 project migrating south of the Project Area. Continued monitoring of the areas outside the Central Reach Project Area is vital to achieving the Town's goal of providing a reasonable level of storm damage reduction to public and private development along the entire Town oceanfront.

**2023 SHORELINE & VOLUME CHANGE
MONITORING REPORT
TOWN OF DUCK, NORTH CAROLINA**

TABLE OF CONTENTS

I.	INTRODUCTION.....	1
II.	PROJECT LOCATION.....	1
III.	SURVEY DATA COLLECTION.....	4
IV.	SHORELINE CHANGE RESULTS.....	6
V.	VOLUMETRIC CHANGE RESULTS.....	12
VI.	STORM DAMAGE VULNERABILITY ANALYSIS UPDATE.....	18
VII.	DISCUSSION	21
VIII.	RECOMMENDATIONS	23
IX.	REFERENCES.....	24

LIST OF FIGURES

Figure No.

Figure 1.	Project Location Map	2
Figure 2.	Detailed Project Area Map showing the North Monitoring Area, Central Reach Project Area, South Monitoring Area, and the location of the Monitoring Stations.....	3
Figure 3.	Historical Shoreline Positions (+6.0 ft. NAVD88) Relative to the September 2013.....	9
Figure 4.	Cumulative Average Shoreline Changes in the +6.0 ft. NAVD88 Contour Position since September 2013 in the Central Reach Project Area and North and South Monitoring Areas	11
Figure 5.	Volume Changes (cubic yards/foot) measured between Sept. 2013 to May 2023 and April 2021 to May 2023.....	14
Figure 6.	Average Cumulative Volumetric Changes above the -24 ft. NAVD88 contour since September 2013 in the Central Reach Project Area and the North and South Monitoring Areas	16

LIST OF TABLES

Table No.

Table 1.	Dataset Descriptions	4
Table 2.	Monitoring Survey Baseline and Azimuth	5
Table 3.	Summary of Recent and Long-Term Shoreline Changes (ft.).....	7
Table 4.	Summary of Recent and Long-Term Shoreline Change Rates (ft./yr.).....	8
Table 5.	Volumetric Change Rates (cy/ft./yr.) along Duck above -24 ft. NAVD88	13
Table 6.	Storm Damage Vulnerability – Existing Conditions	20



LIST OF APPENDICES

Appendix No.

- A 2023 Town of Duck Beach Profile Cross Section Plots
- B 2023 Town of Duck Survey Data
- C 2023 Town of Duck Storm Vulnerability Maps



**TOWN OF DUCK
2023 SHORELINE & VOLUME CHANGE
MONITORING REPORT**

I. INTRODUCTION

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, 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. This area, referred to as the Central Reach project, extends from near station D-10 in the north, which is located near 128 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 2017 project in 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. In 2023, the Town completed its first renourishment project of the Central Reach project. Approximately 576,800 cy were placed along the same area as the 2017 project. The beach fill design for the 2023 Central Reach project included a variable width berm at elevation +6.0 feet NAVD88 and a 10-foot wide dune that varied in elevation between +14.0 and +19.0 feet NAVD88 along the southern 1 mile of the Project Area.

The Town has implemented a beach monitoring program to track both the performance of the Central Reach beach fill project 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 monitoring report also includes the results of an updated storm damage vulnerability analysis using the latest May 2023 beach profile conditions.

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 Field Research Facility (FRF) is located within the Town limits between station D-19 and D-23 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 Duck nourishment project (Central Reach), built along a 1.6-mile section of the Town’s oceanfront shoreline.

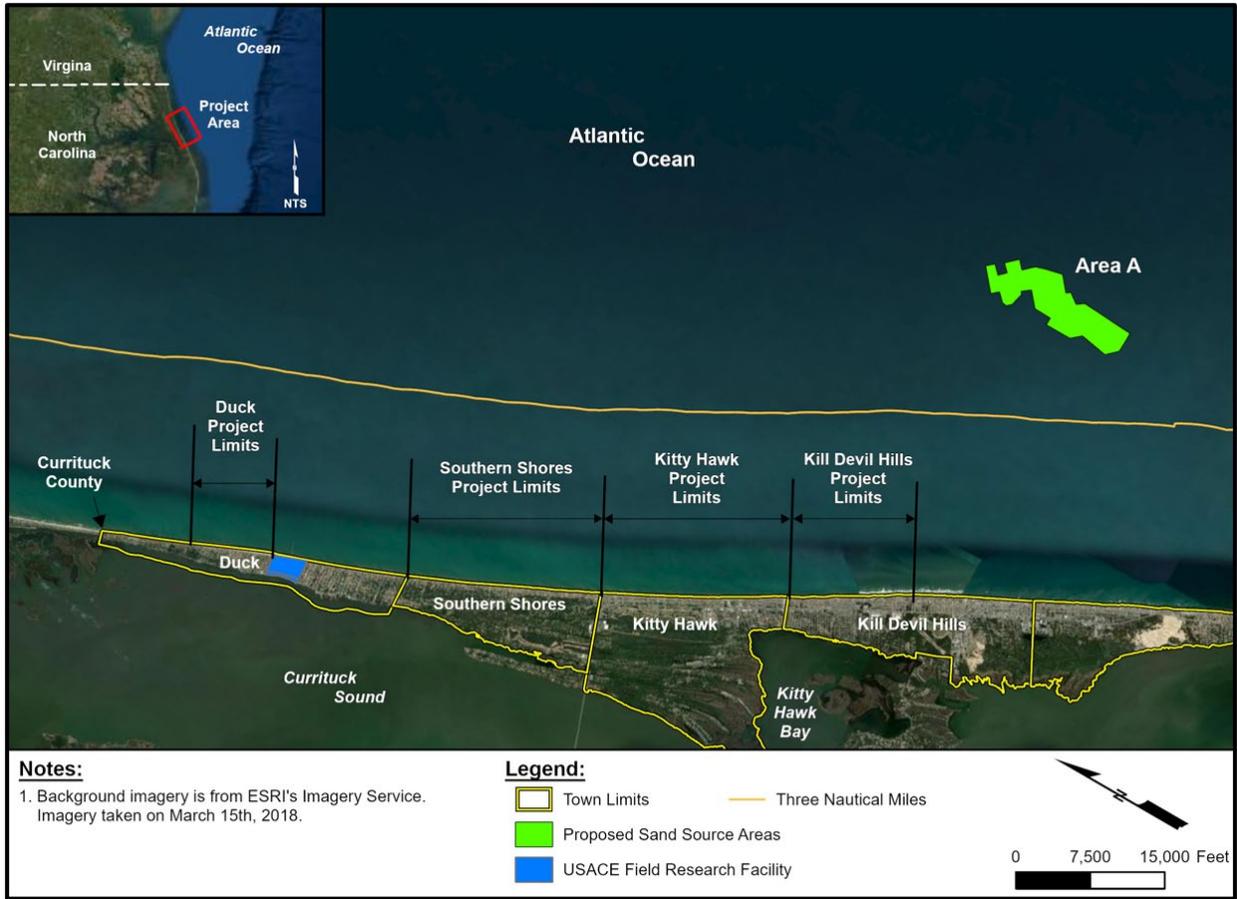


Figure 1. Project Location Map

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

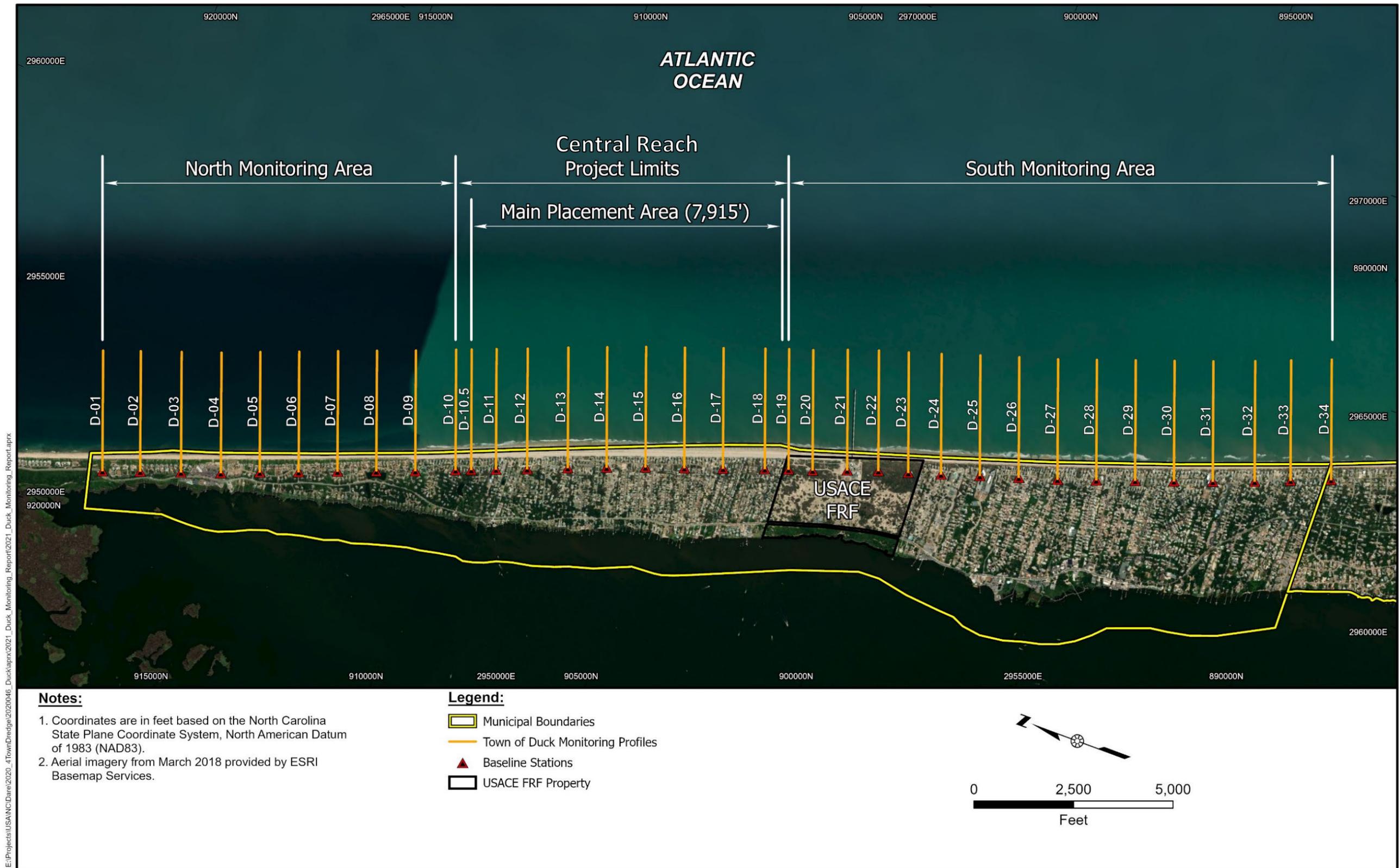


Figure 2. Detailed Project Area Map showing the North Monitoring Area, Central Reach Project Area, South Monitoring Area, and the location of the Monitoring Stations

III. SURVEY DATA COLLECTION

Data used in this study included eleven (11) different data sets including the most recent beach profile data acquired by Weeks Marine’s survey sub-contractor TI Coastal in May 2023. See Table 1 below for dates and description of the datasets that were used.

Table 1. Dataset Descriptions

Agency/Firm	Survey Type	Date	Transects
CPE (APTIM)	Profile Survey	September 2013	D-01 to D-34
CPE (APTIM)	Profile Survey	May 2015	D-01 to D-34
CPE (APTIM)	Profile Survey	December 2017	D-01 to D-34
CPE (APTIM)	Profile Survey	June 2018	D-01 to D-34
CPE (APTIM)	Profile Survey/Offshore Bathymetry	May 2019	D-01 to D-34
CPE (APTIM)	Profile Survey	December 2019	D-10 to D-19
CPE	Profile Survey	June 2020	D-01 to D-34
CPE	Profile Survey	April 2021	D-01 to D-34
TI Coastal	Profile Survey	October 2022	D-10 to D-19
TI Coastal	Profile Survey	January 2023	D-10 to D-19
TI Coastal	Profile Survey	May 2023	D-01 to D-34

In April 2021, CPE surveyed one additional station (D-10.5) that had not been surveyed in previous years; this station has been surveyed during each subsequent monitoring event. The monitoring stations are spaced approximately 1,000 feet apart along the Town’s oceanfront beach. CPE also conducted an additional survey in December 2019 following Hurricane Dorian that included only the profiles within the Central Reach Project Area (stations D-10 to D-19); however, this survey data was not used in the analysis but is included in the cumulative shoreline and volume change plots. CPE collected survey data only along the upland portion of the profiles located at stations D-19, D-20, D-21, D-22, and D-23 due to the USACE FRF request not to approach the shoreline in this area 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 May 16, 2023.

Beach profile data were collected along monitoring stations listed in Table 2. Coordinates shown in Table 2 are referenced to the North Carolina State Plane coordinate system in feet NAD83 and the profile azimuth refers to degrees referenced to true north. Cross section plots of the beach profiles surveyed in May 2023 at each station are included in Appendix A – 2023 Town of Duck Beach Profile Cross Section Plots. The survey data from the May 2023 survey is provided in Appendix B – 2023 Town of Duck Survey Data.

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 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.

Table 2. Monitoring Survey Baseline and Azimuth

Monitoring Station	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

IV. SHORELINE CHANGE RESULTS

A shoreline change analysis was completed to assess shoreline advance and recession along the monitoring 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 stations or profiles. Typically, shoreline change is then annualized to describe recession and advance rates per year. Averages for the monitoring areas were determined by computing a weighted average based on distance between the monitoring stations relative to the overall distance of the area. Annualized rates computed for the monitoring were calculated using a linear regression method. The rate is calculated by determining the slope of the linear trendline for a certain shoreline position (+6 ft. NAVD88) for all available survey events. However, it should be noted that the October 2022 survey data was not used in the analysis but is included in the cumulative volume change plots. These changes are described in terms of positive (“+”) or advance (shoreline moving seaward) and negative (“-”) or recession (shoreline moving landward).

The May 2023 survey has been adopted to represent the post-construction conditions within the Central Reach Project Area. Future annual monitoring reports will reference shoreline changes in the Central Reach Project Area relative to the May 2023 condition to track the performance of the 2023 project. This report also includes a shoreline comparison of what is referred to as a baseline survey, which represents the initial survey 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 initial construction of the Central Reach Project.

Table 3 provides the measured shoreline changes between various surveys for each station where data exists and provides averages for the various areas monitored. The changes in the position of the +6.0 ft. NAVD88 contour measured between September 2013 (baseline survey) to May 2023 (Post-construction) represent the cumulative changes that have been measured since the initial baseline survey and the most recent monitoring event. The changes measured between December 2017 (Post-Construction) and January 2023 (Pre-construction) represent the changes that occurred within the Central Reach Project Area within the nourishment interval between the 2017 initial construction and the 2023 renourishment. Short-term measured changes of the +6.0 ft. NAVD88 contour that occurred between April 2021 and May 2023 are also provided in Table 3. All values in Table 3 represent actual changes and not rates. Table 4 shows rates of change for the +6.0 ft. NAVD88 contour determined using a linear regression method that considers each of the data sets available for the periods between September 2013 (baseline survey) and May 2023 (Post-construction) and December 2017 (Post-Construction) and January 2023 (Pre-construction).

Figure 3 graphically displays the position of +6.0 ft. NAVD88 contour for the December 2017, April 2021, January 2023 (Pre-construction), and May 2023 (Post-construction) surveys along the entire monitoring area relative to the September 2013 +6.0 ft. NAVD88 contour position. A review of Figure 3 illustrates several noteworthy trends. First, the shoreline positions in December 2017 and May 2023 are noticeably seaward of the shoreline position in September 2013. This is primarily attributed to the construction of the 2017 and 2023 Central Reach beach nourishment projects. The shoreline position observed in May 2023 is actually seaward of the shoreline position in December 2017. However, this is primarily due to the timing of when the post-construction surveys were completed following construction. In 2017, the Central Reach Project was completed in June 2017 with post-construction surveys completed 6-months later in December. In 2023, the post-construction surveys were conducted within 2 weeks following beach fill placement.

Table 3. Summary of Recent and Long-Term Shoreline Changes (ft.)

MONITORING STATION		Sept. 2013 (Baseline) to May 2023 (2023 Post-Con)	Dec. 2017 (2017 Post-Con) to Jan. 2023 (2023 Pre-Con)	April 2021 to May 2023 (2023 Post-Con)
North Monitoring Area	D-01	-30.3		-42.6
	D-02	-20.7		17.0
	D-03	-17.2		-28.3
	D-04	-9.1		-16.0
	D-05	-28.2		-57.4
	D-06	-2.2		6.9
	D-07	-26.6		-21.9
	D-08	-7.6		-23.5
	D-09	9.7		13.6
Central Reach Project Area	D-10	44.7	-6.1	53.5
	D-10.5	70.8	-45.1	67.8
	D-11	110.0	-72.4	97.2
	D-12	118.6	-85.5	114.4
	D-13	165.0	-115.1	149.8
	D-14	169.4	-113.5	146.6
	D-15	168.8	-146.8	122.1
	D-16	152.2	-121.2	135.3
	D-17	185.4	-69.7	172.4
	D-18	152.1	-46.1	119.9
South Monitoring Area	D-19	7.0	-13.5	-34.1
	D-20	20.3		-18.7
	D-21	30.6		26.6
	D-22	-22.7		-6.4
	D-23	-18.9		45.4
	D-24	-19.9		21.7
	D-25	-1.3		12.7
	D-26	-10.6		8.6
	D-27	-25.8		-15.5
	D-28	-21.3		16.3
	D-29	-32.4		-9.4
	D-30	-20.3		-33.0
	D-31	-2.2		18.4
	D-32	-12.7		9.7
	D-33	-0.4		17.7
D-34	20.5		22.3	
NORTH MONITORING AREA (D-01 TO D-10)		-11.4	---	-12.5
CENTRAL REACH PROJECT AREA (D-10 TO D-19)		140.1	-88.3	121.0
SOUTH MONITORING AREA (D-19 TO D-34)		-8.9	---	6.2

Table 4. Summary of Recent and Long-Term Shoreline Change Rates (ft./yr.)

MONITORING STATION		Sept. 2013 (Baseline) to May 2023 (Post-Con)	Dec. 2017 (2017 Post-Con) to Jan. 2023 (2023 Pre-Con)
North Monitoring Area	D-01	-3.0	
	D-02	-3.7	
	D-03	0.9	
	D-04	-0.4	
	D-05	1.7	
	D-06	-0.3	
	D-07	-2.1	
	D-08	-0.6	
	D-09	-1.1	
	D-10	3.4	-5.1
Central Reach Project Area	D-10.5	4.0	-10.3
	D-11	5.7	-13.8
	D-12	3.4	-17.4
	D-13	5.0	-20.5
	D-14	7.1	-18.7
	D-15	5.4	-22.2
	D-16	6.8	-19.0
	D-17	8.1	-13.7
	D-18	7.1	-9.6
	D-19	0.3	-2.8
South Monitoring Area	D-20	2.5	
	D-21	1.6	
	D-22	-0.7	
	D-23	-3.2	
	D-24	-3.6	
	D-25	-1.0	
	D-26	0.5	
	D-27	-0.7	
	D-28	-2.7	
	D-29	-3.2	
	D-30	-4.8	
	D-31	0.0	
	D-32	-1.4	
	D-33	-0.2	
	D-34	1.9	
NORTH MONITORING AREA (D-01 TO D-10)		-0.7	---
CENTRAL REACH PROJECT AREA (D-10 TO D-19)		5.7	-15.7
SOUTH MONITORING AREA (D-19 TO D-34)		-1.1	---

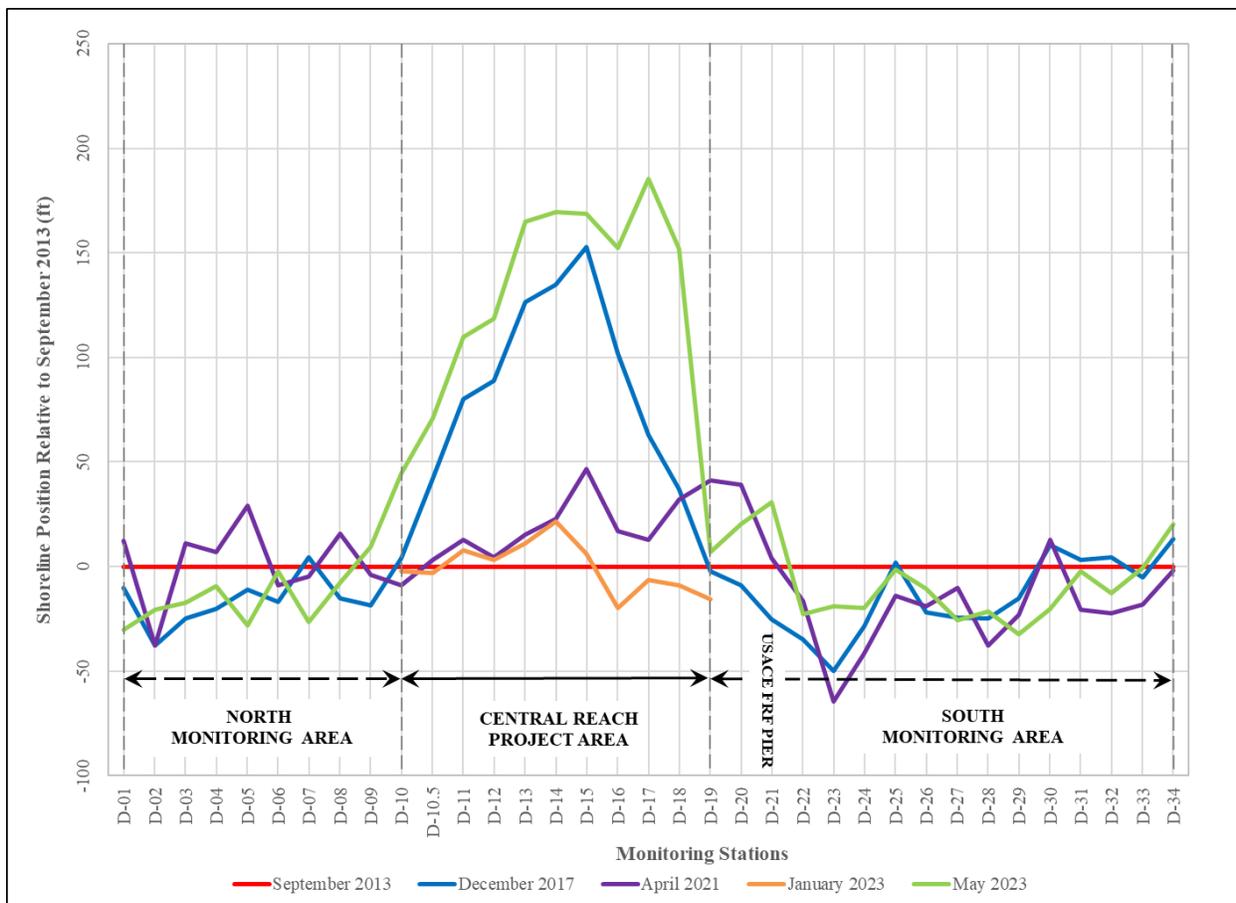


Figure 3. Historical Shoreline Positions (+6.0 ft. NAVD88) Relative to the September 2013

Also apparent through an examination of Figure 3 is that while the May 2023 position of the +6 ft. NAVD88 contour immediately adjacent to the Central Reach Project Area is slightly seaward of the 2013 position, most areas outside of the Project Area are landward of the 2013 position. This is also apparent in the average shoreline change values shown in Table 3. Table 3 shows the position of the +6.0 ft. contour along the Central Reach Project Area moved seaward between January 2023 and May 2023, which is primarily attributed to the beach fill project that was constructed between April and May 2023. During the same time period from April 2021 and May 2023 the North Monitoring Area shoreline (stations D-01 and D-10) experienced a landward shoreline movement on average. In the South Monitoring Area, the shoreline experienced a seaward movement on average; however, the shoreline between stations D-19 and D-22 moved landward, while the shoreline between stations D-23 and D-26 moved seaward 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 stations within certain sections. As discussed below, average shoreline trends were computed for the three subareas within the monitoring area, namely, North Monitoring Area, the Central Reach Project Area, and South Monitoring Area.

Central Reach Project Area (D-10 to D-19)

The construction of the beach nourishment project in 2017 resulted in an average seaward movement of the +6 ft. NAVD88 contour of +183 ft. based on comparisons of the Before Dredge (BD) and After Dredge (AD) surveys. Consideration should be given to the fact that these numbers reflect the change based on the placement of the unequilibrated beach fill construction template. Between April 2017 (2017 Pre-



construction) and December 2017 (2017 Post-construction), the beach fill underwent post-fill adjustments which reduced the initial advancement of the +6.0 ft. NAVD88 contour to an average of +89.5 feet. Note, the project average includes stations D-10 through D-18, station D-19 was not surveyed during the April 2017 Pre-construction survey. 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 January 2023, the average shoreline change of the +6 ft. NAVD88 contour within the Central Reach Project Area was -88.3 ft., which is equivalent to a rate of change of -15.7 ft./yr. A profile-by-profile comparison shows the rate of change in the position of the +6.0 ft. NAVD88 contour varied across the Central Reach Project Area as shown in Table 4. The greatest shoreline changes were measured in the central portion of the Central Reach Project Area between station D-13 (Sea Tern Dr.) and D-16 (Pintail Dr.). The average shoreline change along those 4 profiles was -124.1 ft. The average shoreline changes between December 2017 and January 2023, in the northern portion of the Central Reach Project Area from station D-10 (Skimmer Way) to D-12 (Sound Sea Ave.) was -52.3 ft.; whereas the average shoreline change in the southern part of the Central Reach Project Area from D-17 (located at the south end of Buffell Head Rd.) to D-19 (northern USACE FRF boundary) was -43.1 ft.

With the construction of the 2023 beach renourishment project, the +6 ft. NAVD88 contour was extended seaward an average of 140.9 ft. based on comparisons of the Before Dredge (BD) and After Dredge (AD) surveys. This number reflects the change in the position of the +6 ft. NAVD88 contour based on the placement of unequilibrated fill within the construction beach fill template. The project average includes D-10 through D-19.

The long-term shoreline changes within the Central Reach Project Area calculated from Sept. 2013 to May 2023, which are provided in Table 3 and Table 4, are influenced by both the 2017 and 2023 projects. While both the North and South Monitoring Areas saw small negative long-term shoreline change rates between Sept. 2013 and May 2023 (-0.7 ft./yr. and -1.1 ft./yr., respectively), the Central Reach Project Area saw an average positive shoreline change rate of 5.7 ft./yr.

Figure 4 depicts the average cumulative change in the position of the +6.0 ft. NAVD88 contour within the Central Reach Project Area (i.e. average change of stations D-10 to D-19) between September 2013 and May 2023. The large increase in the cumulative average shoreline change in the Central Reach Project Area between April 2017 and December 2017 reflects the average shoreline seaward advance associated with the 2017 project. 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 Central Reach Project Area. Between April 2021 and January 2023, the position of the +6.0 ft. NAVD88 contour again moved landward prior to the construction of the 2023 project. The large seaward advance between January 2023 and May 2023 reflects the seaward advance associated with the 2023 project. As previously mentioned with regards to Figure 3, the fact that the cumulative shoreline change reflected in May 2023 is further seaward than what is reflected by the data point for December 2017, is not an indication that the beach was wider after the 2023 project than after the 2017 project but rather that the 2017 data was collected approximately 6 months after the project was constructed and represents an equilibrated beach.

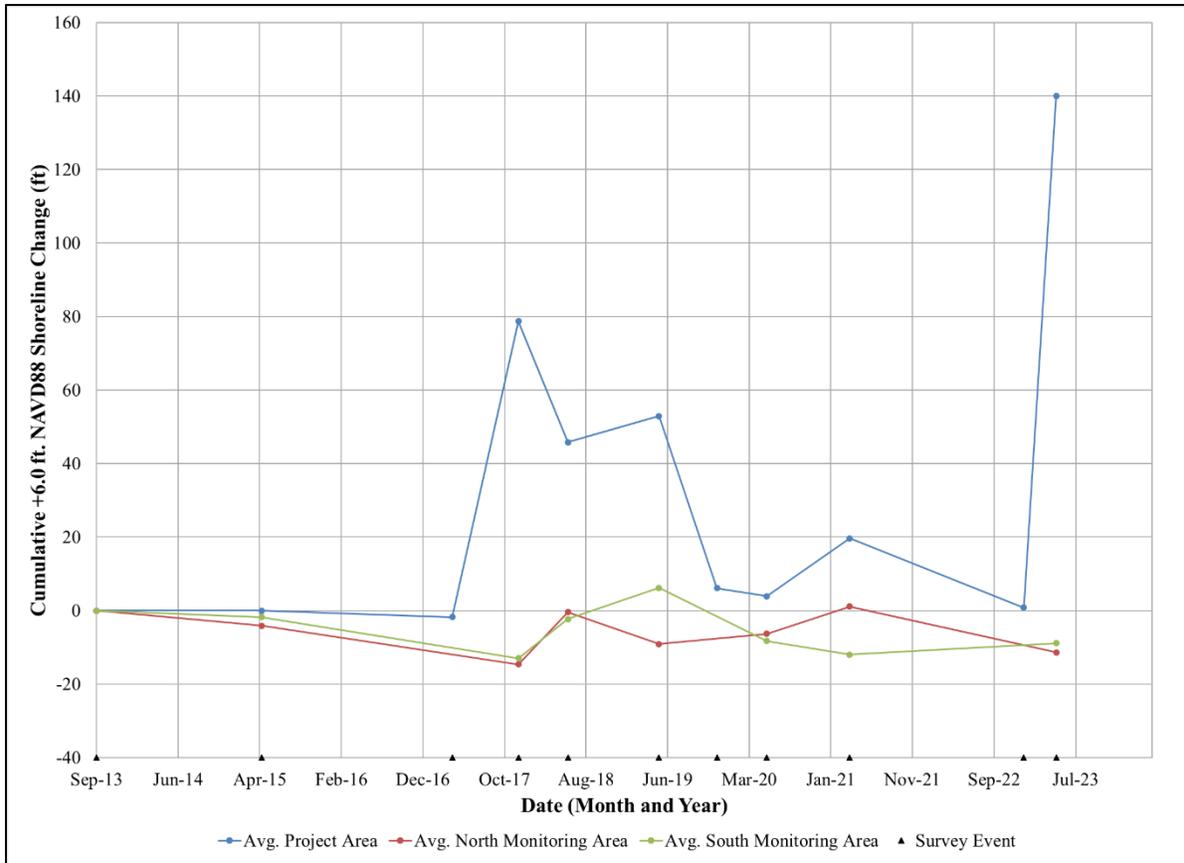


Figure 4. Cumulative Average Shoreline Changes in the +6.0 ft. NAVD88 Contour Position since September 2013 in the Central Reach Project Area and North and South Monitoring Areas

North Monitoring Area (D-01 to D-10)

Since monitoring of the Duck shoreline began in September 2013 to May 2023, the average position of the +6.0 ft. NAVD88 contour along the North Monitoring Area (D-01 to D-10) moved landward 11.4 feet (Table 3). This equates to a rate of -0.7 ft./yr. (Table 4). This trend is also illustrated in Figure 4. Between September 2013 and December 2017, the North Monitoring Area experienced negative shoreline change. Between December 2017 and June 2018, the shoreline position experienced a positive change resulting in a similar average position of the 6.0 ft. NAVD88 contour to 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. From April 2021 to May 2023, the average shoreline change of the +6.0 ft. NAVD88 contour was -12.5 ft., which is greater than the cumulative shoreline change measured between Sept. 2013 and May 2023. This is equivalent to a rate of -6.3 ft./yr., when annualized.

While Figure 4 reflects the average shoreline change, there is a considerable amount of variability in shoreline trends from profile to profile as seen in Table 3. Between September 2013 and May 2023, the shoreline change rate at station D-10 (Skimmer Way) has experienced the greatest positive trend advancing at 3.4 ft./yr. whereas the greatest negative trend of -3.7 ft./yr. was measured at station D-02 (N. Baum Trail). During the recent survey interval, from April 2021 to May 2023, station D-10, located at Skimmer Way, which is considered the southern boundary of the North Monitoring Area, experienced the greatest positive (seaward) shoreline change rate (18.4 ft./yr.). Station D-05, located at S Station Bay Dr., experienced the

greatest negative (landward) shoreline change rate, when annualized between April 2021 and May 2023 (-27.6 ft./yr.).

South Monitoring Area (D-19 to D-34)

Since monitoring of the Duck shoreline began in September 2013 to May 2023, the average position of the +6.0 ft. NAVD88 contour along the South Monitoring Area (D-19 to D-34) moved landward -8.9 ft. (Table 3). This is equivalent to a rate of -1.1 ft./yr. when annualized. As shown in Figure 4, between September 2013 and December 2017, the South Monitoring Area experienced negative shoreline change. Between December 2017 and May 2019, the area experienced an average positive shoreline change. However, between May 2019 and May 2023, the average shoreline change has been negative.

While Figure 4 reflects the average shoreline change, there is considerable amount of variability in shoreline change trends from profile to profile as seen in Table 3 and Table 4. Between September 2013 and May 2023, the greatest negative change in the position of the +6.0 ft. NAVD88 contour was observed at station D-30 (approximately 100 ft. north of LaLa Ct. beach access) which experienced shoreline recession at a rate of -4.8 ft./yr. Over the same time, the greatest positive shoreline change was observed at station D-20 (approximately 1,000 ft. north of the FRF pier), which experienced shoreline advance at +2.5 ft./yr. over the 9.7-year period.

During the recent survey interval from April 2021 to May 2023 the average shoreline change in the South Monitoring Area was +6.2 ft. Between April 2021 and May 2023, the greatest negative change in the position of the +6.0 ft. NAVD88 contour was observed at station D-19 (northern boundary of FRF property) of 34.1 ft. (landward movement) over the 2.1-year period. Over the same time, the greatest positive shoreline change was observed at station D-23 (800 ft. south of FRF pier), which experienced 45.4 ft. of change in the 6.0 ft. NAVD88 contour. The average shoreline change measured within the FRF property between station D-19 (northern boundary of FRF property) and D-22 (650 ft. south of FRF pier) was -8.2 ft. (landward movement) between April 2021 and May 2023. Between stations D-23 (800 ft. south of FRF pier) and D-34 (13th Ave), the average shoreline change was +9.6 ft. between April 2021 and May 2023.

V. VOLUMETRIC CHANGE RESULTS

Volumetric changes measured over the entire monitoring area for various time periods are provided in Table 5. 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 May 2023, December 2017 to January 2023, and April 2021 to May 2023. The December 2017 to January 2023 surveys show changes occurring between the 2017 and 2023 beach nourishment projects and provide the most comprehensive indication of the 2017 project's performance. The September 2013 to May 2023 and April 2021 to May 2023 surveys present the long-term and recent volume changes. These changes are mainly focused on evaluating the changes outside of the Central Reach Project Area since the volumes in the Central Reach Project Area are heavily influenced by the construction of the 2017 and 2023 projects. Future annual monitoring reports will reference volume changes in the Central Reach Project Area relative to the May 2023 condition to track the performance of the 2023 project. This report also includes a volume change relative to the September 2013 survey, which is referred to as the baseline survey, which represents the initial survey conducted by CPE during the planning process for the project. Table 5 provides the volume change rates at each monitoring station along the Town of Duck for each of the monitoring periods. Figure 5 graphically depicts the volumetric changes calculated above -24 ft. NAVD88 between September 2013 and May 2023 as well as changes measured from April 2021 and May 2023.

Table 5. Volumetric Change Rates (cy/ft./yr.) along Duck above -24 ft. NAVD88

PROFILE		Sept. 2013 (Baseline) to May 2023 (2023 Post-Con)	Dec. 2017 (2017 Post- Con) to Jan. 2023 (2023 Pre-Con)	April 2021 to May 2023 (2023 Post-Con)
North Monitoring Area	D-01	-2.3		-10.6
	D-02	2.4		20.2
	D-03	2.8		1.2
	D-04	0.0		2.4
	D-05	0.1		-14.9
	D-06	-0.4		2.1
	D-07	0.6		0.5
	D-08	-2.0		-5.7
	D-09	1.7		-2.4
Central Reach Project Area	D-10	4.1	0.8	5.6
	D-10.5	-	-	8.0
	D-11	8.8	-12.3	12.8
	D-12	10.4	-15.1	15.0
	D-13	17.1	-4.9	38.9
	D-14	14.4	-28.2	34.5
	D-15	14.4	-19.1	38.5
	D-16	17.2	-13.7	47.1
	D-17	15.0	-6.5	27.3
	D-18	13.2	-9.0	30.1
D-19	8.3	-0.1	9.6	
South Monitoring Area	D-20	8.6		11.9
	D-21	7.9		8.8
	D-22	4.1		2.9
	D-23	2.3		0.9
	D-24	4.0		36.5
	D-25	2.6		29.5
	D-26	3.3		29.5
	D-27	0.2		11.3
	D-28	-2.4		2.6
	D-29	-1.8		3.5
	D-30	0.2		-2.2
	D-31	5.6		32.7
	D-32	2.8		20.4
	D-33	-0.3		2.9
	D-34	1.8		11.3
NORTH MONITORING AREA (D-01 TO D-10)		0.7		-0.1
CENTRAL REACH PROJECT AREA (D-10 TO D-19)		12.3	-10.8	24.3
SOUTH MONITORING AREA (D-19 TO D-34)		3.0		13.3

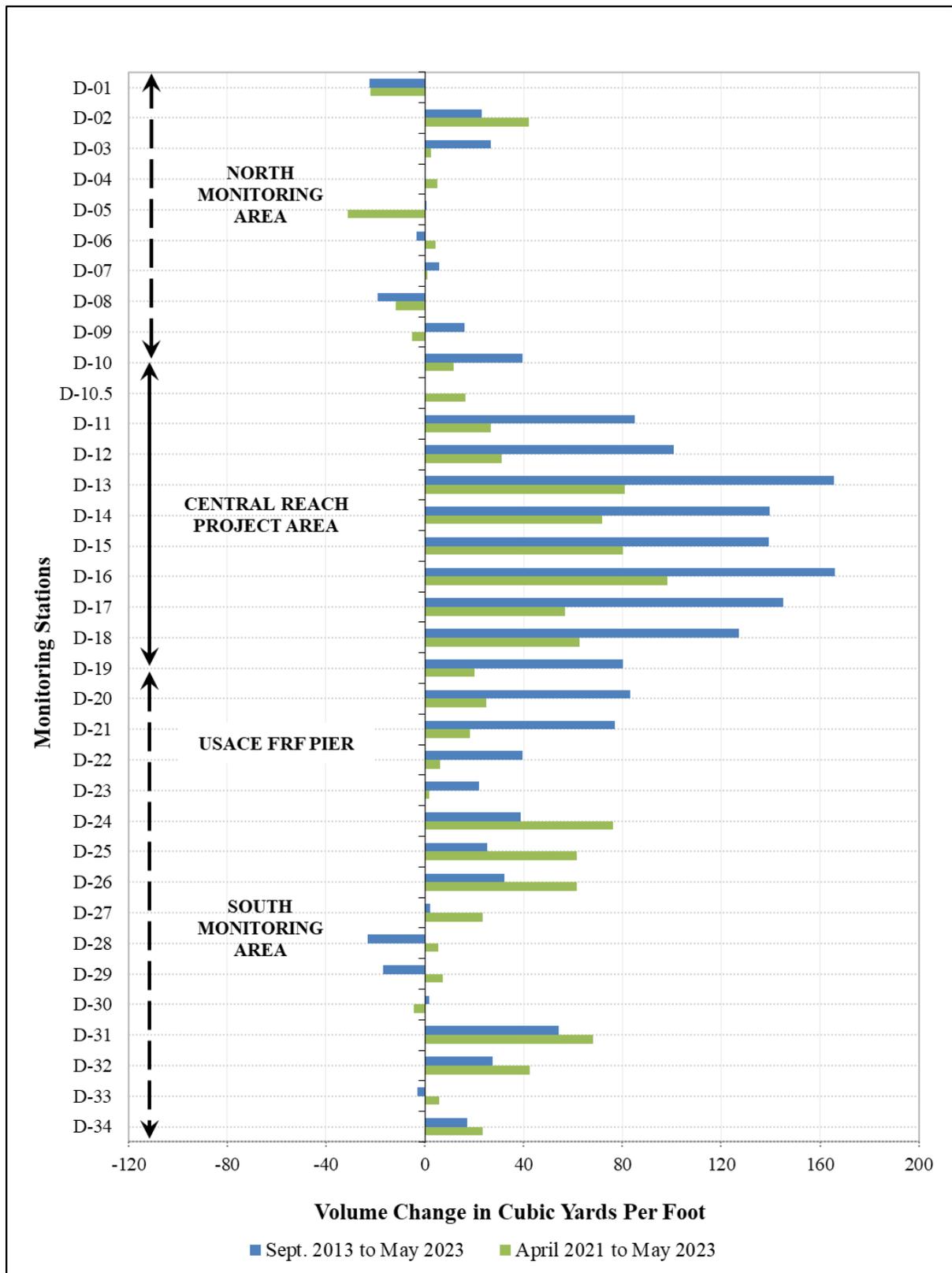


Figure 5. Volume Changes (cubic yards/foot) measured between Sept. 2013 to May 2023 and April 2021 to May 2023.

2017 Beach Fill Volumes

Between May and June 2017, a total of 1.26 million cubic yards of fill were placed along the Duck shoreline between stations D-10 and D-19 (Central Reach Project) (APTIM, 2020). The performance of the 2017 Central Reach Project is based on changes that occurred relative to the conditional monitoring survey conducted in December 2017. Based on volume changes computed between 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 was used, please refer to the 2018 Shoreline and Volume Change Monitoring Report (APTIM, 2018).

2023 Beach Fill Volumes

Between April and May 2023, the 2023 beach renourishment project placed a total of 576,800 cubic yards of fill along the Duck shoreline between stations D-10 and D-19 (Central Reach Project). The May 2023 survey has been adopted to represent the post-construction conditions within the Central Reach Project Area. Future annual monitoring reports will reference shoreline and volume changes in the Central Reach Project Area relative to the May 2023 condition to track the performance of the 2023 project.

Central Reach Project Area (D-10 to D-19)

From September 2013 to May 2023 the Central Reach Project Area experienced a net positive volumetric change of approximately 1,061,000 cy, which equates to an annual average density change rate of +12.3 cy/ft./yr. This positive trend is reflective of both the 2017 and 2023 beach nourishment projects.

With regards to the performance of the beach fill placed along the Central Reach Project in 2017, beach profile monitoring surveys indicate a volume change of approximately -521,800 cubic yards between December 2017 and January 2023. This equates to a rate of -10.8 cy/ft./yr. when annualized. **As of January 2023, the analysis indicated that the Town of Duck beach nourishment project had approximately 46% of the initial fill volume remaining as measured in December 2017 above the -24-foot NAVD88 contour.**

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 Central Reach Project Area, North Monitoring Area, and South Monitoring Area. The large increase in the Central Reach Project Area (blue line) between April 2017 and December 2017 reflects the volume gain associated with the 2017 project construction. A relatively linear trend in erosion was measured from December 2017 to January 2023. The large increase in the Central Reach Project Area (blue line) between January 2023 and May 2023 is reflective of the volume added associated with the construction of the 2023 project.

The net volumetric change measured from April 2021 to May 2023, was a positive volumetric change of approximately 496,900 cubic yards. This is equivalent to an average annual rate of approximately +24.3 cy/ft./yr. The majority of that positive volumetric change is associated with the construction of the 2023 Project that placed approximately 576,800 cy within the Central Reach Project Area. Figure 6 illustrates the erosional trend that occurred along the Central Reach Project Area between April 2021 and Jan. 2023. During this time, a negative volumetric change of approximately 108,000 cy was measured, which is equivalent to an average change rate of -7.3 cy/ft./yr. this approximately 21-month period was followed by a significant positive volumetric change between January and May 2023, associated with the 2023 beach nourishment project.

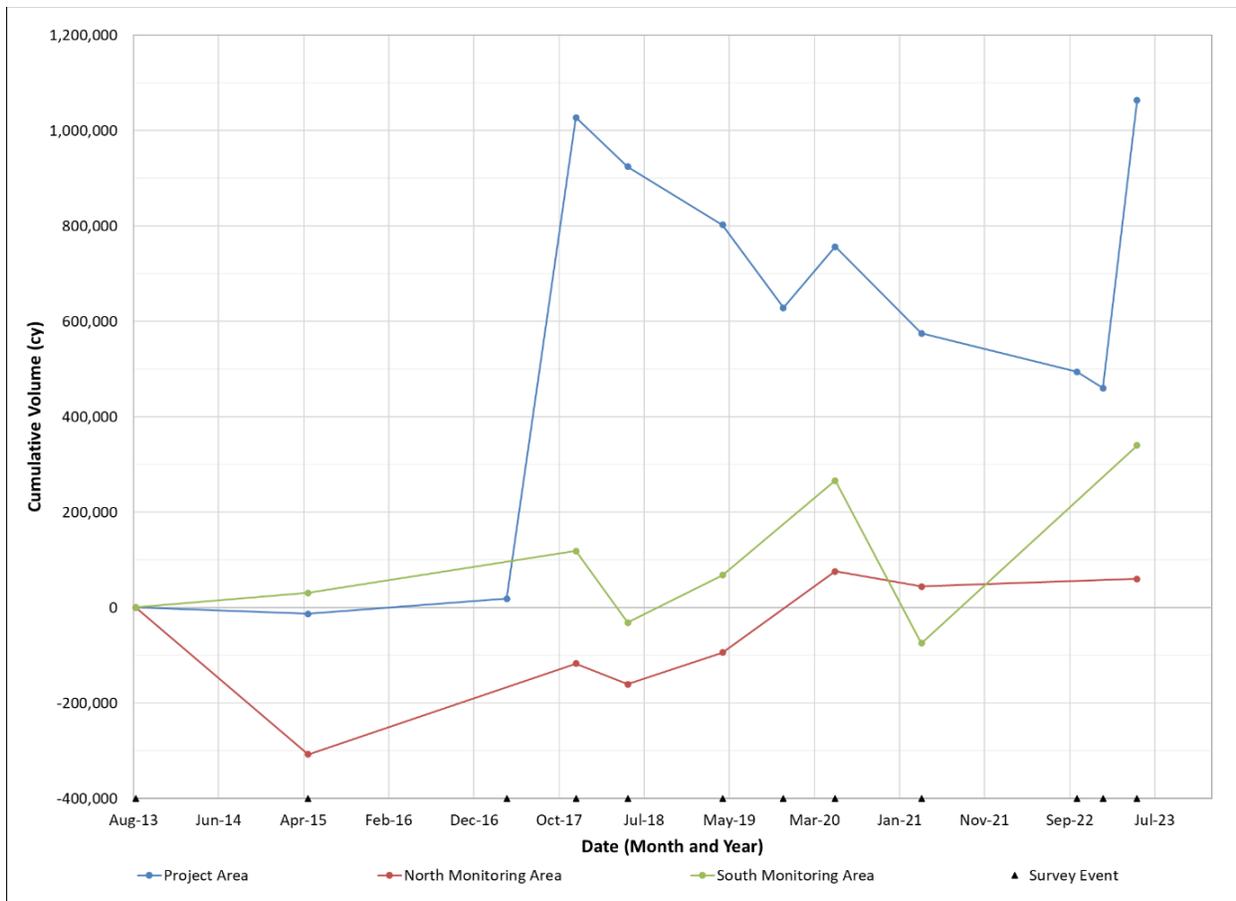


Figure 6. Average Cumulative Volumetric Changes above the -24 ft. NAVD88 contour since September 2013 in the Central Reach Project Area and the North and South Monitoring Areas

North Monitoring Area (D-01 to D-10)

From September 2013 to May 2015 the North Monitoring Area experienced a net positive volumetric change of approximately 60,100 cy. This equates to an annual average density change rate of +0.7 cy/ft./yr. and is reflective of relative stability within the area over the 9.7-year period. As shown in Table 5, the rates of change varied from profile to profile within the North Monitoring Area ranging from positive rate of 2.8 cy/ft./yr. at station D-03 (south end of S. Baum Trail) to a negative rate of -2.3 at station D-01 (approximately 300 feet south of northern Town boundary).

In Figure 6, the cumulative volumetric changes in the North Monitoring Area (red line) indicates a relatively steep erosional trend between September 2013 and May 2015, prior to the 2017 Central Reach Project. This erosional trend resulted in a negative volumetric change of approximately 308,000 cy. A positive volumetric trend was measured between May 2015 and December 2017. Between December 2017 and June 2020, positive volumetric change occurred in the North Monitoring Area. It is noteworthy to report that although approximately 308,000 cy of negative volumetric change was measured between September 2013 and May 2015, the volumetric changes that occurred between May 2015 and June 2020 more than offset those previous losses and resulted in a cumulative positive volumetric change of approximately 76,000 cy, relative to the September 2013 condition. Between June 2020 and May 2023, the North Monitoring Area has remained relatively stable with regards to volumetric changes.



Between June 2020 and April 2021, the volumetric change rate along the North Monitoring Area between station D-01 (Station 1 Ln.) and station D-10 (Skimmer Way) was -2.9 cy/ft./yr. (CPE, 2021). The more recent volumetric change rate measured between April 2021 and May 2023 shows that the North Monitoring Area remained stable on average with a modest change of -0.1 cy/ft./yr.

South Monitoring Area (D-19 to D-34)

From September 2013 to May 2023 the South Monitoring Area experienced a net positive volumetric change of approximately 339,900 cy. This equates to an annual average density change rate of +3.0 cy/ft./yr. over the 9.7-year period since September 2013. As shown in Table 5, the rates of change varied from profile to profile within the South Monitoring Area ranging from a positive rate of 8.6 cy/ft./yr. at station D-20 (approximately 1,000 feet north of the FRF pier) to a negative rate of -2.4 cy/ft./yr. at station D-28 (located at the east end of Duck Landing Lane). Of the 16 profiles included in the South Monitoring Area, 4 of the 5 stations where the greatest positive density change rates were measured are located directly to the south of the Central Reach Area (D-19 through D-22), which is likely reflective of the positive impact the beach fill placement in the Central Reach Area has had along this section.

During the recent 25-month period, from April 2021 to May 2023, this area accreted at an average rate of +13.3 cy/ft./yr. Only one profile in the South Monitoring Area, located at station D-30 (Four Seasons Ln), experienced a negative volumetric change during this period. An examination of volume changes measured station to station shows the three of the four highest volumetric gains occurred at stations D-24, D-25, and D-26, respectively, as shown in Table 5. These three adjacent profiles are all just south of the USACE FRF property. The large gain in volume at these stations appears to be due to the filling in of a trough that was present in April 2021.

In Figure 6, the cumulative volumetric changes in the South Monitoring Area (green line) illustrates a relatively modest accretional trend between September 2013 and May 2015, prior to the construction of the project. This accretional trend resulted in a positive volumetric change of approximately 31,000 cy. A negative volumetric change was measured between December 2017 and June 2018, to the degree that in June 2018, the net volumetric change from the baseline survey in September 2013 to June 2018 was negative. From June 2018 to June 2020, the South Monitoring Area experienced a positive volumetric change of approximately 298,000 cy. The South Monitoring Area experienced a considerable negative volumetric change between June 2020 and April 2021. However, between April 2021 and May 2023, the Area experienced a positive volumetric change to the degree that in May 2023 the cumulative volumetric change was greater in May 2023 than had been measured at any other time since September 2013.

VI. STORM DAMAGE VULNERABILITY ANALYSIS UPDATE

The May 2023 beach profile survey data was used to update the previously completed storm damage vulnerability analysis for the Town of Duck. The analysis utilized the Storm Induced Beach Change Model, SBEACH, developed by Larson and Kraus (Larson and Kraus, 1989) for the US Army Corps of Engineers (USACE). SBEACH is a two-dimensional model, that 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. Input data required by SBEACH includes beach cross-sections, the median sediment grain size, several calibration parameters, a temporally varying storm hydrograph (wave height, wave direction, wave period, and water surface elevation) and wind field (wind speed and direction).

The simulated beach profile changes that result from varying storm waves and water levels 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. This empirically based numerical model was formulated using both field data and the results of large-scale physical model tests. 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 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-shore.
- The shoreline is straight (i.e., longshore effects are negligible during the simulation term).
- Linear wave theory is applicable everywhere along the beach profile.

The SBEACH model was applied in the original Erosion and Shoreline Management Feasibility Study (CPE-NC, 2013) and the Town of Duck Erosion and Shoreline Management Engineering Design Report (CPE-NC, 2015). Detailed model setup and calibration information can be found in the original feasibility report (CPE-NC, 2015). The original feasibility study used beach profile data from 2013, and an update was conducted in 2016 (CPE-NC, 2016) using beach profile data from 2015. Another update was conducted in 2019 (APTIM, 2019), using beach profile data from May 2019. This report describes the latest update to assess storm vulnerability with SBEACH using the May 2023 survey as the initial condition.

During the design analysis for the initial Central Reach Beach Nourishment Project, an extensive analysis was completed to determine whether a scaled hurricane or nor'easter should be used for design purposes (CPE-NC, 2015). A review of historical data indicated that scaling all storm parameters to create synthetic storms results in conditions that do not represent natural occurrences. Using a method such as this may be appropriate for a quick study to investigate project feasibility but could ultimately result in over- or underestimation of project need and performance. As a result, actual storm characteristics were reviewed to select storms that best matched extreme event characteristics. Considering that the storm hydrograph is the primary model driver, the top wave height and storm surge events were compared with the calculated return period descriptors. The Perfect Storm best represented a 3-year event, Hurricane Sandy resembled a 5-year event, and Hurricane Isabel may best describe a 25-year event. Considering the project's goal was to provide a reasonable level of storm damage reduction, Hurricane Isabel was adopted as the design storm.

To ensure consistency with the previous SBEACH studies conducted in the Central Reach Project Area, the 2023 analysis used the same Hurricane Isabel storm characteristics as used in the previous vulnerability assessments conducted for the Town of Duck. The only modification was to update the water level to 2023



to account for the relative sea level rise. The increase in water level was calculated based on the relative sea level rise rate measured at the NOAA Tide Gauge (Station ID 8651370) located at the USACE FRF Pier in Duck, NC and multiplying that rate by 20 years (the time elapsed since Hurricane Isabel's landfall in North Carolina), to represent the water level if the hurricane impacted the area in 2023.

The results of the SBEACH simulations were used to identify structures that could be impacted during the design storm events. A 1-foot change in profile elevation is a reasonable threshold for estimating when structures become vulnerable to wave damage, including undermining and/or inundation (USACE, 1985). Therefore, a structure was considered vulnerable if any part of the structure was seaward of the landward most location where the profile was lowered by 1 foot. For this study, the landward most location where the profile was lowered by 1-foot was extracted from model results along profiles to identify the impact points. These impact points were then connected to create an impact line that was used to identify structures damaged between profiles. The resulting May 2023 impact lines are shown on the maps included in Appendix C. For comparison purposes, the impact lines developed during the May 2019 vulnerability analysis are also shown on the maps.

As summarized in Table 6, the updated May 2023 analysis showed that no structures and only 9 pools were shown to be vulnerable as defined herein. Compared to the results of the May 2019 vulnerability analysis, this represents a reduction of 29 structures and 32 pools that were shown as vulnerable during the previous vulnerability analysis. In May 2019, the analysis of the area north of the USACE FRF property identified 1 structure and no pools as vulnerable within the North Monitoring Area (D-1 to D-10), while 0 structures or pools were identified as vulnerable within the Central Reach Project Area (D-10 to D-19). According to the updated analysis of the May 2023 conditions, no structures or pools were identified as vulnerable within the North Monitoring Area or within the Central Reach Project Area as shown in Table 6.

The volume change between the May 2019 and May 2023 monitoring events for the North Monitoring Area (D-01 to D-10) indicated that this area experienced a volumetric gain over the 4-year period. The results indicated that between May 2019 and May 2023, the North Monitoring Area gained an average 15.6 cy/ft., or approximately 143,800 cubic yards, over the 4-year period.

The 2023 analysis of the Town of Duck shoreline south of the USACE FRF property (D-23 to D-34) indicated a significant reduction in the number of identified vulnerable structures compared to the results of the 2019 analysis. While 28 structures were identified as vulnerable in the 2019 analysis, 0 structures were identified based on 2023 conditions. Similarly, the total number of pools identified as vulnerable south of the USACE FRF in 2023 was 9, a reduction of 78% compared to the 40 pools identified as vulnerable based on 2019 conditions.

The volume change between the May 2019 and May 2023 monitoring events for the South Monitoring (D-19 to D-34) areas indicated that this area also experienced volumetric gains over the 4-year period. Between May 2019 and May 2023, the South Monitoring Area gained, on average, 19.7 cy/ft., or approximately 268,000 cy. Most of those structures identified as impacted in the 2019 analysis were located at the south end of Duck, between stations D-25 (100 ft. south of Old Duck Rd) and D-34 (southern Town boundary), a total distance of approximately 8,820 feet. Between May 2019 and May 2023, a positive volumetric change of approximately 139,000 cy was measured, or an average 15.5 cy/ft, across the active profile (above -24 ft NAVD88).

Table 6. Storm Damage Vulnerability – Existing Conditions

Monitoring Stations		May 2019 Conditions		May 2023 Conditions	
From	To	Structure	Pool	Structure	Pool
D-01	D-02	0	0	0	0
D-02	D-03	0	0	0	0
D-03	D-04	0	0	0	0
D-04	D-05	1	0	0	0
D-05	D-06	0	0	0	0
D-06	D-07	0	0	0	0
D-07	D-08	0	0	0	0
D-08	D-09	0	0	0	0
D-09	D-10	0	0	0	0
D-10	D-11	0	0	0	0
D-11	D-12	0	0	0	0
D-12	D-13	0	0	0	0
D-13	D-14	0	0	0	0
D-14	D-15	0	0	0	0
D-15	D-16	0	0	0	0
D-16	D-17	0	0	0	0
D-17	D-18	0	0	0	0
D-18	D-19	0	0	0	0
D-19	D-20	0	0	0	0
D-20	D-21	0	0	0	0
D-21	D-22	0	0	0	0
D-22	D-23	0	0	0	0
D-23	D-24	0	1	0	0
D-24	D-25	0	0	0	0
D-25	D-26	1	0	0	0
D-26	D-27	0	3	0	0
D-27	D-28	1	6	0	0
D-28	D-29	13	7	0	0
D-29	D-30	4	7	0	0
D-30	D-31	0	3	0	0
D-31	D-32	3	7	0	3
D-32	D-33	5	4	0	3
D-33	D-34	1	2	0	3
D-01	D-34	29	40	0	9

Note that this analysis only identified which structures could experience damage due to storm-induced erosion caused by a storm with predetermined storm characteristics that mimic those measured during Hurricane Isabel. The analysis did not include an evaluation of damages due to flooding, wave impacts, or wind nor does it quantify the economic impacts resulting from the damage or loss of such structures.

VII. DISCUSSION

This monitoring report evaluated shoreline and volumetric changes along the portions of shoreline renourished in 2023 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 near 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 Central Reach beach nourishment project, the monitoring area was divided into three sections, namely, the North Monitoring Area (D-01 to D-10), the Central Reach Project Area (D-10 to D-19), and the South Monitoring Area (D-19 to D-34). Beach profile data collected in May 2023 were used to evaluate long-term shoreline and volumetric changes that have occurred relative to the baseline survey conducted in September 2013. Beach profile data collected in January 2023 (pre-construction) were compared with December 2017 data to evaluate shoreline and volumetric changes that occurred within the Central Reach Project Area between the 2017 and 2023 beach nourishment projects. Recent changes were also evaluated over the past two years based on the April 2021 and May 2023 monitoring surveys.

Shoreline Change Analysis

Central Reach Project Area. During the period following the completion of the 2017 Central Reach Project in Duck (June 2017) and after approximately 6-months of the project equilibrating and prior to the initiation of the 2023 project, the position of the +6 ft. NAVD88 contour receded landward by an average of 88.3 ft. within the Central Reach Project Area (December 2017 to January 2023). The 2023 beach renourishment project extended the position of the +6 ft. NAVD88 contour seaward an average of 140.9 ft. based on comparisons of the Before Dredge (BD) and After Dredge (AD) surveys. This number reflects the change in the position of the +6 ft. NAVD88 contour based on the placement of unequilibrated fill within the construction beach fill template. Typically, a beach nourishment project experiences dramatic decrease in width in the months following construction as the profile equilibrates (Willson et al., 2017). This equilibration process often results in a relatively high level of negative shoreline change. Monitoring surveys conducted in 2024 may reflect this equilibration process.

North Monitoring Area. The average long-term shoreline change rate computed along the North Monitoring Area (stations D-01 to D-10), was -0.7 ft./yr. (landward movement), between September 2013 and May 2023. This period includes the construction of the two beach nourishment projects (2017 and 2023). While the shoreline has remained essentially stable along the North Monitoring Area since September 2013, the average rate between station D-01, located near the northern Town Boundary and station D-04, located at Sanderling Resort, was -1.6 ft./yr. (landward movement); whereas the average long-term shoreline change from Sanderling Resort south to the Central Reach Project Area (stations D-04 to D-10) was a positive 0.1 ft./yr. (seaward movement). This suggests the Central Reach Project may be having more of a positive impact on shoreline change directly adjacent to the Project Area.

Recent surveys, conducted between April 2021 and May 2023, indicate an overall average change in the position of the +6.0 ft. NAVD88 contour of -6.3 ft./yr. (landward movement). However, directly north of the Central Reach Project Area from station D-06 (Martin Lane) to D-10 (Skimmer Way) the average shoreline change trend was +1.3 ft./yr. (seaward movement), whereas, from station D-01 (approximately 300 feet south of the northern Town boundary) to D-06 (Martin Lane) the average rate of change was -9.6 ft./yr., (landward movement). Again, this suggests the Central Reach Project may have a more positive impact on shoreline change directly adjacent to the Project Area.

South Monitoring Area. The long-term average shoreline change computed along the South Monitoring Area (stations D-19 to D-34), was -1.1 ft./yr. (landward movement), between September 2013 and May 2023. This time period includes the construction of both the 2017 and 2023 beach nourishment projects. While the shoreline has remained essentially stable along the North Monitoring Area since September 2013,

in the area directly south of the project (stations D-19 to D-22) the average rate was +0.9 ft./yr. (seaward movement). In contrast, from station D-22 (650 ft. south of the FRF Pier) to D-31 (Plover Dr.) the average long-term shoreline trend was -1.9 ft./yr. (landward movement). The +6.0 ft. NAVD88 contour between the end of Plover Dr (station D-31) and 13th Ave. (station D-34) experienced a seaward movement of 0.1 ft./yr. on average. This suggests the Central Reach Project may be having more of a positive impact on shoreline change directly adjacent to the Project Area.

Recent surveys (April 2021 to May 2023) indicate an overall average change in the +6.0 ft. NAVD88 contour of +2.9 ft./yr. The shoreline change rates measured throughout the South Monitoring Area are relatively variable. In the area directly south of the project (stations D-19 to D-26), the average shoreline change rate was +2.7 ft./yr. over the approximate 25-month period from April 2021 to May 2023. In contrast, the average shoreline change measured from station D-26 (Cook Dr.) to station D-31 (Plover Dr.) was -1.2 ft./yr. The +6.0 ft. NAVD88 contour between the end of Plover Dr (station D-31) and 13th Ave. (station D-34) experienced a seaward movement of 8.2 ft./yr. on average. Again, this suggests the Central Reach Project may have a more positive impact on shoreline change directly adjacent to the Project Area.

Volumetric Change Analysis

Central Reach Project Area. The 2023 beach renourishment project placed a total of 576,800 cubic yards of fill along the Duck shoreline between stations D-10 and D-19 between April and May 2023. The performance of the 2023 project along the Town of Duck will be based on changes that have occurred relative to the post-construction monitoring survey conducted in May 2023.

Rates of change that characterize the performance of the 2017 project were computed from the December 2017 (post-construction) and January 2023 (pre-construction) surveys. The results of this analysis indicated that the 2017 Central Reach Project Area lost approximately 521,800 cy, which equates to an average volumetric change rate of -10.8 cy/ft./yr. when annualized over the 5-year period. As of January 2023, the analysis indicated that the 2017 beach nourishment project had approximately 46% of the initial fill volume placed along the Town of Duck in 2017.

A positive volumetric change of approximately 1,061,000 cubic yards was measured between September 2013 and May 2023. This equates to a positive rate of 12.3 cy/ft./yr. over the 9.7-year period. The changes over this period are obviously driven by the construction of the 2017 and 2023 projects. However, this rate is higher than the negative volumetric change measured between the 2017 and 2023 projects, which suggests that the Central Reach project is more than keeping up with the rate of loss occurring as a result of natural processes and spreading losses from the projects.

North Monitoring Area. The long-term average volumetric change rate in the area north of the project measured between September 2013 and May 2023 was +0.7 cy/ft./yr. This rate is essentially the same rate as reported in the 2021 monitoring report (CPE, 2021) given the recent minimal volumetric change measured between April 2021 to May 2023. The average volumetric change along this area over that 25-month period was -0.3 cy/ft. or -0.1 cy/ft./yr.

South Monitoring Area. The long-term average volumetric change rate in the area south of the project, measured between September 2013 and May 2023, was +3.0 cy/ft./yr. This positive rate of volumetric change is greater than reported in the 2021 monitoring report (-1.0 cy/ft./yr.) (CPE, 2021), due to recent positive volumetric change measured between April 2021 and May 2023. The average volumetric change along the South Monitoring Area over that 25-month period was +27.6 cy/ft. or +13.3 cy/ft./yr. Although the changes varied from profile to profile, the predominant trend was positive and only one profile in the South Monitoring Area, located at station D-30 (Four Seasons Ln), experienced a negative volumetric change during this period. The positive volumetric changes may be due in part by the construction of the



2022/2023 beach fill project in Southern Shores and due to the onshore migration of offshore sand from beyond the depth of closure. This phenomenon has been observed by CPE in recent surveys along Currituck County.

Storm Damage Vulnerability Analysis Update:

Using the previously calibrated SBEACH model and the May 2023 beach profile survey data, an updated storm vulnerability analysis was conducted of the oceanfront beach and dune system along the Town of Duck. The updated SBEACH analysis indicated that 0 structures and 9 pools were identified as vulnerable based on May 2023 conditions. These numbers represent a 100% reduction in the number of structures identified as vulnerable based on 2019 conditions (29 structures) and a 78% reduction in the number of pools identified as vulnerable based on 2019 conditions (40 pools). The significant reduction in the number of vulnerable structures and pools correlates with the positive volumetric changes observed between May 2019 and May 2023.

VIII. RECOMMENDATIONS

CPE recommends the Town continue to monitor the beach along the entire Town oceanfront in order to assess if shoreline and volume change trends identified in this report persist. Future monitoring will be instrumental for the Town to evaluate future areas of concerns and to develop successful shoreline management strategies to deal with issues as they arise. The monitoring program will continue to provide valuable information on the performance of the 2023 beach nourishment project and aid in the determination as to when additional nourishment is needed in the Central Reach Project Area. Data collected in January 2023 indicates that the 2017 project eroded at a rate of -10.8 cy/ft./yr. when compared to the Dec. 2017 Post-construction survey. This erosion rate and rates computed through the continued monitoring of the 2023 project, will be used to design the next renourishment event.

Outside the Central Reach Project Area, continued monitoring of the North and South Monitoring Areas 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. Data collected in May 2023 indicates that since 2013, the volumetric trend along the Town's beaches in the North Monitoring Area has been stable. Data collected in May 2023 also indicates a stable volumetric change in the recent period since April 2021.

The South Monitoring Area has experienced a positive volumetric change trend (accretion) since 2013. This is most likely due to sand placed during the 2017 project migrating south of the Project Area. Continued monitoring of the areas outside the Central Reach Project Area is vital to achieving the Town's goal of providing a reasonable level of storm damage reduction to public and private development.

IX. 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, 2019. Aptim Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina 2019 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, 2021a. Coastal Protection Engineering of North Carolina, Inc., *Town of Duck North Carolina 2021 Shoreline & Volume Change Monitoring Report*. Prepared for Town of Duck. Wilmington, NC.

CPE, 2021b. Coastal Protection Engineering of North Carolina, Inc., *Town of Duck, North Carolina Erosion and Shoreline Management Design Report*. Prepared for the Town of Duck. Wilmington, NC.

CPE-NC, 2016. Coastal Planning & Engineering of North Carolina, Inc., *Town of Duck North Carolina Shoreline & Volume Change Monitoring Report*, 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.

CPE-NC, 2013. Coastal Planning & Engineering of North Carolina, Inc., *Erosion and Shoreline Management Feasibility Study*, Wilmington, NC.

Willson, K.; Thomson, G.; Roberts Briggs, T.; Elko, N; and Miller, J. *Beach Nourishment Profile Equilibration: What to Expect After Sand is Placed on a Beach*. Shore & Beach Vol. 85, No. 2, Spring 2017.

APPENDIX A

2023 TOWN OF DUCK BEACH PROFILE CROSS SECTION PLOTS

APPENDIX B

2023 TOWN OF DUCK SURVEY DATA

APPENDIX C

2023 TOWN OF DUCK STORM VULNERABILITY MAPS