

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
	D-19	7.0	-13.5	-34.1
South Monitoring Area	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	
Central Reach Project Area	D-10	3.4	-5.1
	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	---

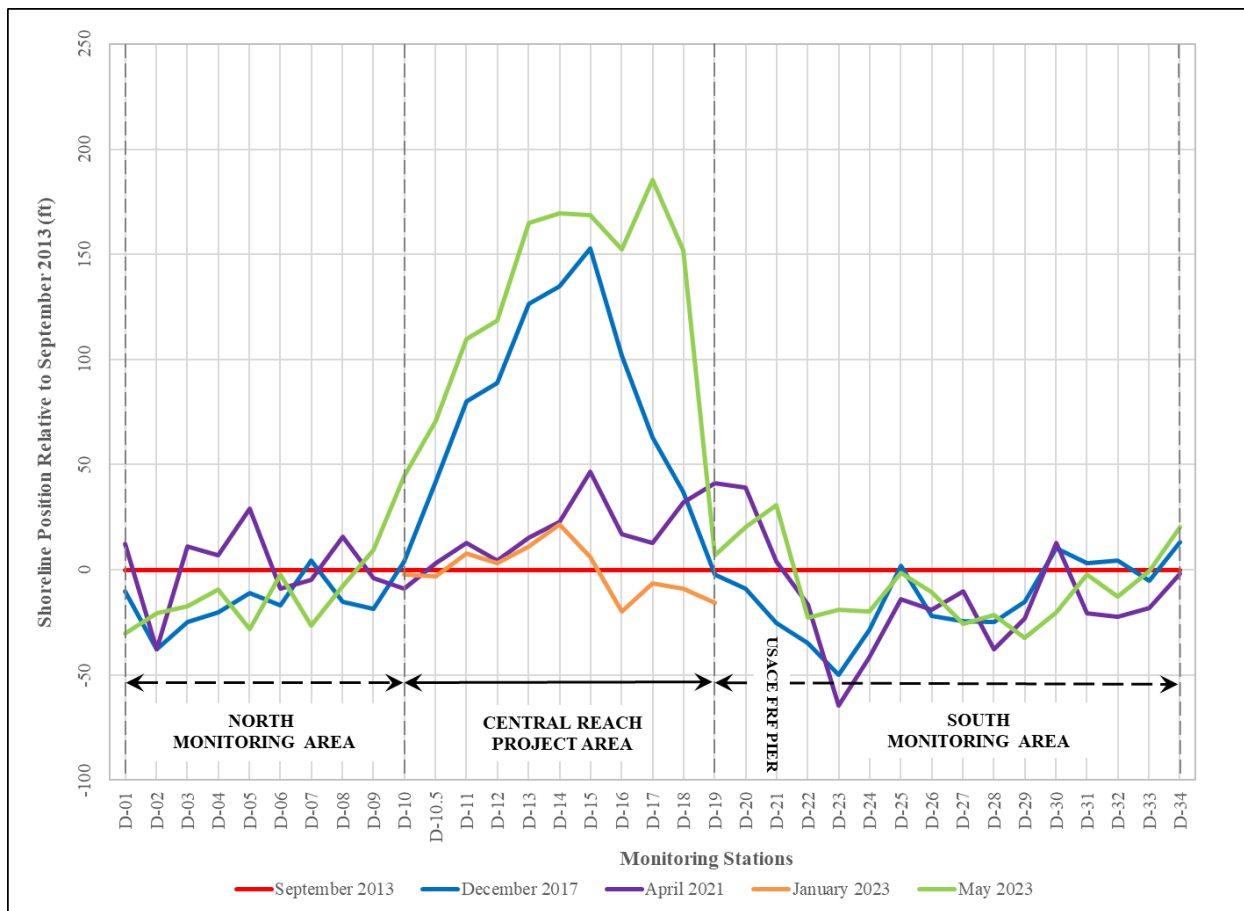



Figure 3. Historical Shoreline Positions (+6.0 ft. NAVD88) Relative to the September 2013

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 unequibrated 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.

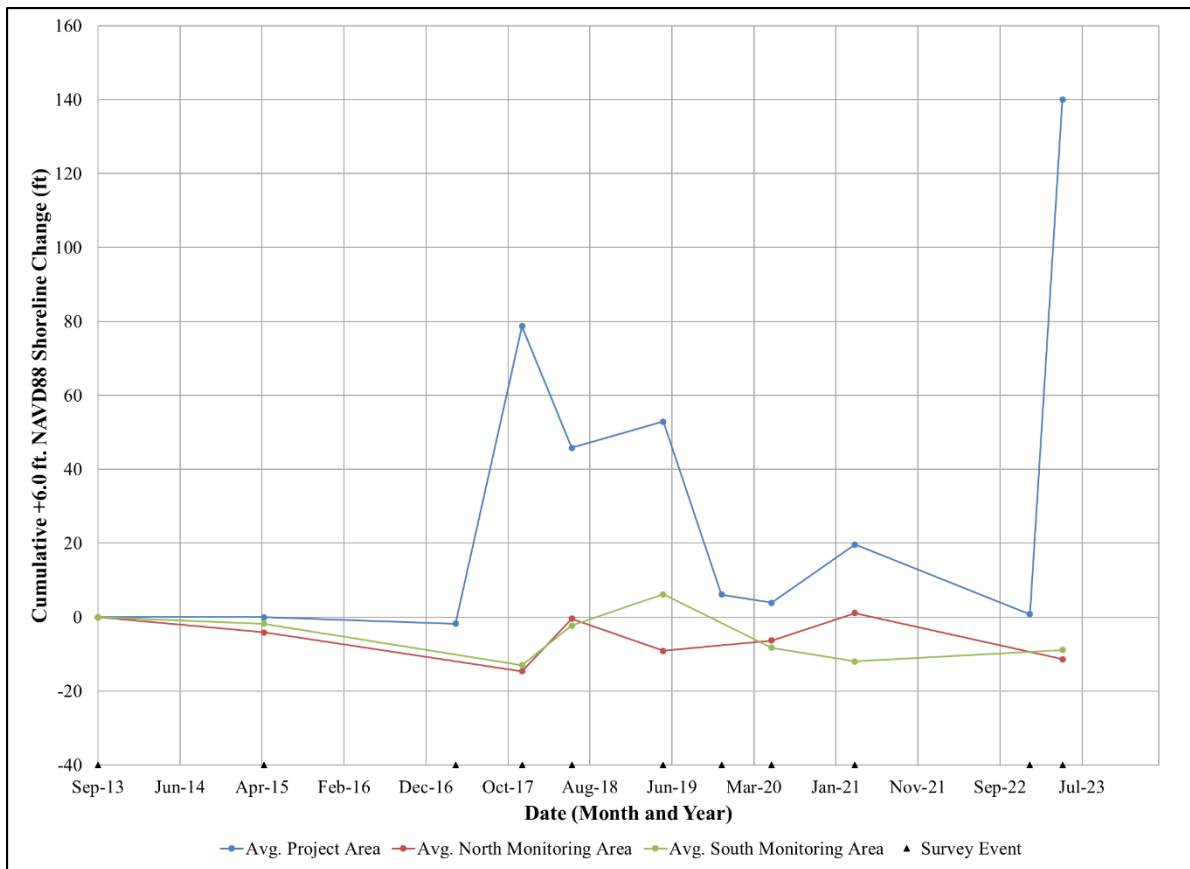


Figure 4. Cumulative Average Shoreline Changes in the +6.0 ft. NAVD88 Contour Position since September 2013 in the Central Reach Project Area and North and South Monitoring Areas

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.