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. Average shoreline changes 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 change 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 Post-construction (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 in 2017.

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 shoreline change measured between September 2013 (baseline survey) and June 2024 (Year-1 Post-construction) represent the cumulative changes that have been measured since the initial baseline survey and the most recent monitoring event, which occurred approximately one year after the immediate post-construction survey in May 2023. The changes measured between December 2017 (Post-construction) and January 2023 (Pre-construction) represent changes that occurred within the Central Reach Project Area within the nourishment interval between the 2017 initial construction and before the 2023 renourishment. Short-term measured shoreline changes of the +6.0 ft. NAVD88 contour that occurred in the first monitoring period between May 2023 and June 2024 are also provided in Table 3. All values in Table 3 represent actual changes and not rates. Table 4 shows rates of change determined using a linear regression method that considers each of the data sets available for the short- and long-term periods between September 2013 (baseline survey) and June 2024 (Year-1 Post-construction), December 2017 (Post-construction) and January 2023 (Pre-construction), and May 2023 (Post-construction) to June 2024 (Year-1 Post-construction).

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

MONITORING STATION		Sept. 2013 (Baseline) to June 2024 (Year-1 Post-Con)	Dec. 2017 (2017 Post-Con) to Jan. 2023 (2023 Pre-Con)	May 2023 (2023 Post-Con) to June 2024 (Year-1 Post-Con)
North Monitoring Area	D-01	-15.6		14.7
	D-02	-36.6		-15.9
	D-03	-8.2		9.0
	D-04	4.3		13.5
	D-05	-16.3		11.9
	D-06	-45.2		-43.0
	D-07	-33.4		-6.8
	D-08	-4.2		3.4
	D-09	11.0		1.3
Central Reach Project Area	D-10	22.3	-6.1	-22.3
	D-10.5	38.5	-45.1	-32.3
	D-11	54.7	-72.4	-55.2
	D-12	47.7	-85.5	-70.9
	D-13	68.1	-115.1	-96.9
	D-14	98.3	-113.5	-71.1
	D-15	84.5	-146.8	-84.3
	D-16	68.1	-121.2	-84.1
	D-17	55.7	-69.7	-129.7
	D-18	91.4	-46.1	-60.7
	D-19	105.1	-13.5	98.0
South Monitoring Area	D-20	140.1		119.7
	D-21	61.5		30.9
	D-22	-34.0		-11.3
	D-23	-19.3		-0.4
	D-24	25.3		45.2
	D-25	12.4		13.8
	D-26	-17.2		-6.6
	D-27	8.0		33.8
	D-28	-13.4		7.9
	D-29	-5.2		27.2
	D-30	-30.9		-10.6
	D-31	3.5		5.8
	D-32	-16.2		-3.4
	D-33	7.9		8.4
	D-34	-9.7		-30.2
NORTH MONITORING AREA (D-01 TO D-10)		-14.4	---	-3.1
CENTRAL REACH PROJECT AREA (D-10 TO D-19)		68.6	-88.3	-71.5
SOUTH MONITORING AREA (D-19 TO D-34)		8.3	---	17.2

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

	MONITORING STATION	Sept. 2013 (Baseline) to June 2024 (1-Year Post-Con)	Dec. 2017 (2017 Post-Con) to Jan. 2023 (2023 Pre-Con)	May 2023 (2023 Post-Con) to June 2024 (Year-1 Post-Con)
North Monitoring Area	D-01	-2.2		12.8
	D-02	-3.5		-13.8
	D-03	1.0		7.8
	D-04	0.3		11.7
	D-05	0.7		10.4
	D-06	-2.4		-37.4
	D-07	-2.9		-5.9
	D-08	-0.8		2.9
	D-09	-0.8		1.1
Central Reach Project Area	D-10	3.5	-5.1	-19.4
	D-10.5	4.0	-10.3	-28.1
	D-11	5.3	-13.8	-48.0
	D-12	3.0	-17.4	-61.6
	D-13	4.4	-20.5	-84.2
	D-14	7.2	-18.7	-61.8
	D-15	5.0	-22.2	-73.2
	D-16	6.8	-19.0	-73.1
	D-17	7.0	-13.7	-112.7
	D-18	7.9	-9.6	-52.8
	D-19	4.5	-2.8	85.2
South Monitoring Area	D-20	8.1		104.0
	D-21	3.9		26.9
	D-22	-1.6		-9.8
	D-23	-2.4		-0.3
	D-24	-0.5		39.3
	D-25	-0.1		12.0
	D-26	0.1		-5.7
	D-27	1.0		29.4
	D-28	-1.7		6.9
	D-29	-1.7		23.7
	D-30	-5.1		-9.2
	D-31	0.2		5.0
	D-32	-1.6		-3.0
	D-33	0.7		7.3
	D-34	0.7		-26.2
NORTH MONITORING AREA (D-01 TO D-10)		-0.9	---	-2.7
CENTRAL REACH PROJECT AREA (D-10 TO D-19)		5.6	-15.7	-62.1
SOUTH MONITORING AREA (D-19 TO D-34)		0.0	---	14.9

Figure 3 graphically displays the position of +6.0 ft. NAVD88 contour for the December 2017, January 2023 (Pre-construction), May 2023 (Post-construction), and June 2024 (Year-1 Post-construction) surveys along the entire monitoring area relative to the September 2013 +6.0 ft. NAVD88 contour position.

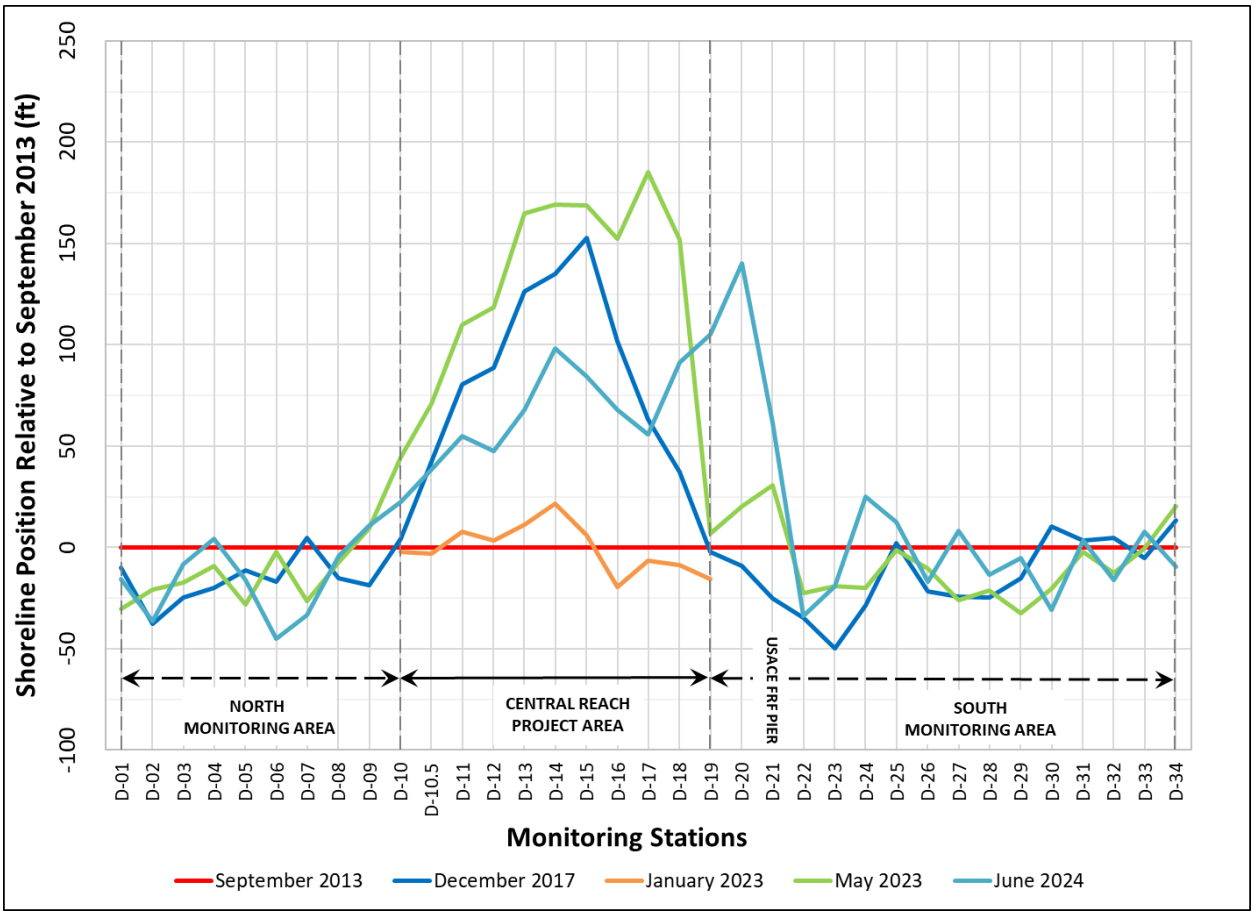

Figure 3. Historical Shoreline Positions (+6.0 ft. NAVD88) Relative to September 2013

A review of Figure 3 illustrates several notable trends throughout the different years and monitoring areas. In the Central Reach Project Area, the shoreline positions in December 2017 and May 2023 are significantly seaward of the shoreline position in September 2013 due to the beach nourishment projects constructed in 2017 and 2023. 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. In the year following the 2023 project, the Central Reach Project Area shows recession which is primarily attributed to equilibration of the beach fill that typically occurs within 6 to 12 months following construction along the Outer Banks. The June 2024 shoreline position relative to May 2023 shows the shoreline throughout the Central Reach Project Area receded, with notable recession between stations D-13 and D-17. However, the majority of the North and South Monitoring Area shorelines remain consistently landward of the 2013 position. Within the North and South Monitoring Areas, the June 2024 monitoring data shows the most seaward shoreline position was located in the South Monitoring Area at station D-20 (approx. 1,000 ft. north of USACE FRF pier), whereas the landward most shoreline position was located in the North Monitoring Area at station D-06.

Another noteworthy observation from Figure 3 is the seaward advance of the June 2024 shoreline in the South Monitoring Area along the 1,500 ft. of shoreline immediately south of the Central Reach Project Area and within the USACE FRF property. The data clearly indicates notable seaward advance of the shoreline between stations D-19 and D-21 in contrast to shoreline recession observed to the south within the remainder of the South Monitoring Area. 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 between stations D-19 and D-21 moved seaward by an average 99.6 ft. between September 2013 and June 2024, which likely associated with the beach fill placed along the Central Reach Project Area. In contrast, during the same time period the average shoreline change measured along the remainder of the South Monitoring Area from station D-22 to station D-34 (Town boundary with Southern Shores) was -6.2 ft. 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 overall 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 2023 beach renourishment project extended the +6 ft. NAVD88 contour seaward an average of 139.3 ft. This number reflects the change in the position of the +6 ft. NAVD88 contour based on the placement of mostly unequilibrated fill within the construction beach fill template. The project average includes D-10 through D-19.

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. The average shoreline change measured at stations D-13 through D-16 was -124.1 ft. The average shoreline changes between December 2017 and January 2023, in the northern portion of the Central Reach Project Area at stations D-10 (Skimmer Way) through D-12 (Sound Sea Ave.) was -52.3 ft.; whereas the average shoreline change in the southern part of the Central Reach Project Area measured at stations D-17 (located at the south end of Buffell Head Rd.) through D-19 (northern USACE FRF boundary) was -43.1 ft.

In the most recent monitoring period between May 2023 and June 2024, beach profile data indicates that the average shoreline change of the +6 ft. NAVD88 contour within the Central Reach Project Area moved 71.5 ft. landward in the first year following completion of the 2023 project. The greatest shoreline change rates were experienced between D-12 (Sound Sea Ave.) and D-17 (located at the south end of Buffell Head Rd.), average of -78.2 ft./yr. The northern portion of the Project Area between D-10 (Skimmer Way) and D-11 experienced less recession at an average shoreline change of -35.1 ft./yr., whereas the changes along the southern portion of the Project Area (D-18 to D-19) were the least recessional at -15.8 ft./yr.

The long-term shoreline changes within the Central Reach Project Area calculated from Sept. 2013 to June 2024, which are provided in Table 3 and Table 4 are influenced by both the 2017 and 2023 projects. In the Central Reach Project Area, the shoreline experienced an average positive shoreline change rate of 5.6 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 June 2024, identified by the blue line. 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. The variation in the location of the average +6 ft. NAVD88 contour between December 2017 and January 2023 reflects the changes in the average shoreline position that occurred between the 2017 and 2023 projects. The large seaward advance between January 2023 and May 2023 reflects the seaward advance associated with the 2023 project. For the most recent period, Figure 4 depicts the Project Area shoreline experienced an average negative cumulative shoreline change between

May 2023 and June 2024. As previously stated, this relatively dramatic decrease in width is associated with the equilibration process.

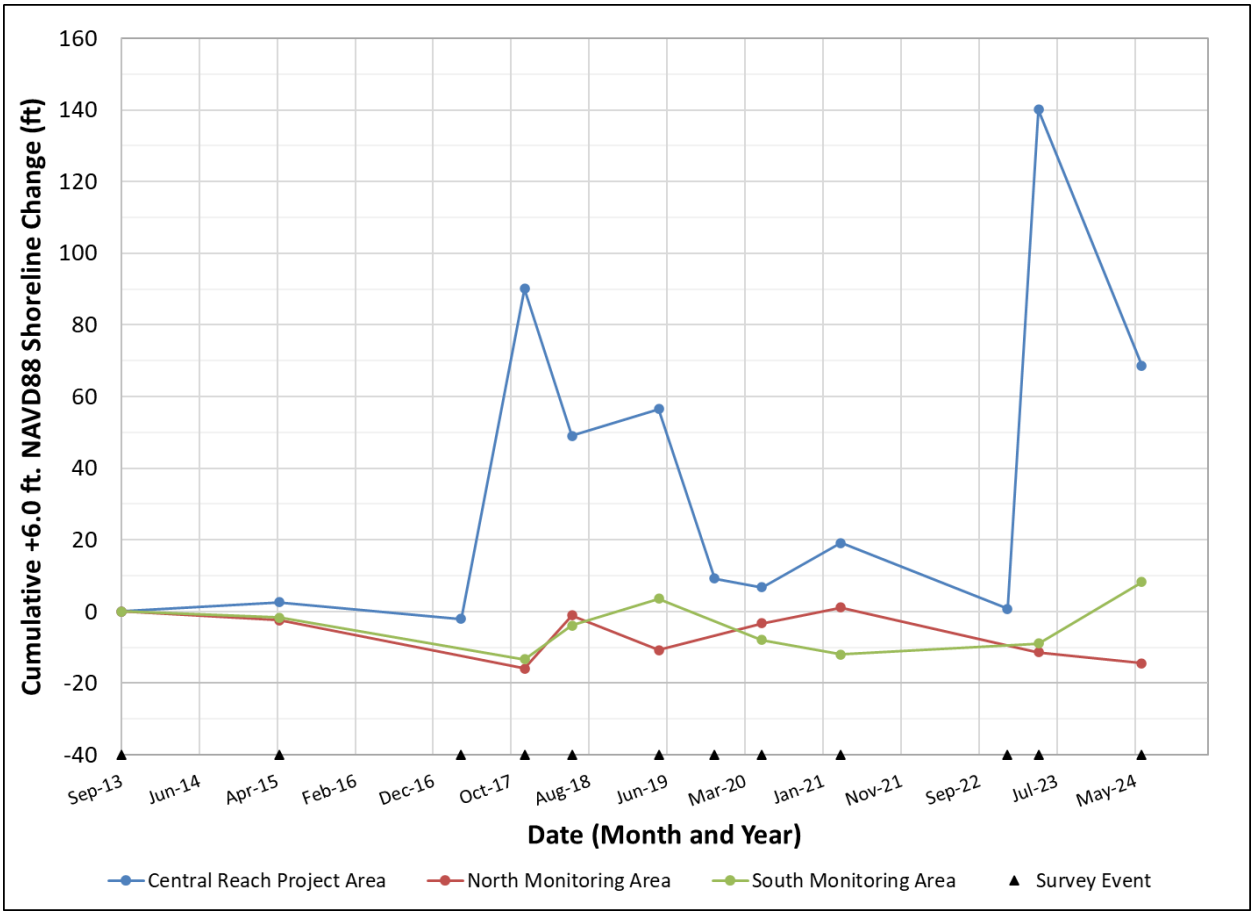

Figure 4. Cumulative Average Shoreline Changes in the +6.0 ft. NAVD88 Contour Position since September 2013 in the Central Reach Project Area and North and South Monitoring Areas

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

From the baseline survey in September 2013 to the recent monitoring in June 2024, the average position of the +6.0 ft. NAVD88 contour along the North Monitoring Area moved landward 14.4 feet (Table 3). This equates to a rate of -0.9 ft./yr. (Table 4). This trend is also illustrated in Figure 4. The North Monitoring Area experienced negative shoreline change between September 2013 and December 2017. 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. Between April 2021 and May 2023, the average position of the +6.0 ft. NAVD88 contour retreated. Similarly, from May 2023 to June 2024, the trend continued with average shoreline change of the +6.0 ft. NAVD88 contour of -3.1 ft., equivalent to an annualized rate of -2.7 ft./yr. As a result of the negative change measured between May 2023 and June 2024, the June 2024 cumulative shoreline position was similar to the average position of the +6.0 ft. NAVD88 contour to what was measured in December 2017.

While Figure 4 depicts the average shoreline change, Table 3 shows variability at each profile in the short and long term. For example, between September 2013 and June 2024, the shoreline change rate at station D-10 (Skimmer Way) has experienced the greatest positive trend advancing at 3.5 ft./yr. whereas the greatest negative trend of -3.5 ft./yr. was measured at station D-02 (N. Baum Trail). On the other hand, from May 2023 to June 2024, station D-01, the northern boundary of the North Monitoring Area, experienced the greatest positive (seaward) shoreline change rate (12.8 ft./yr.). Station D-06 experienced the greatest negative (landward) shoreline change rate of -37.4 ft./yr.

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

Since the initial baseline survey of the Duck shoreline in September 2013 to June 2024, the average position of the +6.0 ft. NAVD88 contour along the South Monitoring Area (D-19 to D-34) moved seaward 8.3 ft. (Table 3). This is equivalent to a rate of 0.0 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 followed by a general trend of shoreline recession between May 2019 and May 2023. Between May 2023 and June 2024, the shoreline change was positive.

Table 3 and Table 4 demonstrate the variability in shoreline change on a profile-to-profile basis. Between September 2013 and June 2024, 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 -5.1 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 an annualized rate of +8.1 ft./yr. over the 10.75-year period.

During the recent monitoring period from May 2023 to June 2024 the average shoreline change in the South Monitoring Area was +17.2 ft. Between May 2023 to June 2024, the greatest negative change in the position of the +6.0 ft. NAVD88 contour was observed at station D-34 (southern Town boundary) of -30.2 ft. (landward movement) over the approximate 1-year period. Over the same time, the greatest positive shoreline change was observed at station D-20 (1,000 ft. north of FRF pier), which experienced +119.7 ft. of change in the position of 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-21 (130 ft. north of FRF pier) was +76.9 ft. (seaward movement) between May 2023 to June 2024. During this same 13-month period, the average shoreline change between stations D-22 (630 ft. south of FRF pier) and D-34 (southern Town boundary), was +7.7 ft.

V. VOLUMETRIC CHANGE RESULTS

Volumetric changes measured over the entire monitoring area for various time periods are provided in Table 5. The volume change rates 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 June 2024, December 2017 to January 2023, and May 2023 to June 2024. 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 June 2024 surveys present the long-term 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. The May 2023 to June 2024 surveys present the most recent volume changes. 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. 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