

V. VOLUMETRIC CHANGES

Volumetric changes measured over the entire monitoring area for various time periods are provided in Table 4. The volume changes are given in terms of cubic yards/foot of shoreline/year (cy/ft./yr.). Volume change rates were evaluated for the periods from September 2013 to May 2015, December 2017 (Post-construction) to May 2019, and June 2018 to May 2019. The September 2013 to May 2015 rates represent trends occurring prior to construction of the project. The December 2017 to May 2019 surveys show changes occurring since the beach nourishment project was completed whereas the June 2018 to May 2019 surveys present the recent volume changes measured between the last two monitoring events.

Table 4. Volumetric Changes (CY/FT./YR) along Duck above -24 FT NAVD88.

PROFILE	September 2013 to May 2015 (Baseline Surveys)	Dec. 2017 (Post-Con) to May 2019 (Year-2)	June 2018 (Year-1) to May 2019 (Year-2)
PI-17	-14.6	4.8	43.1
PI-18	-33.2	30.6	24.0
D-01	-10.5	-9.4	-1.3
D-02	0.3	24.8	51.7
D-03	-33.2	-14.5	8.1
D-04	-16.0	-0.6	8.1
D-05	-52.4	-12.6	-5.4
D-06	-18.3	18.4	16.1
D-07	-28.4	-7.4	-18.4
D-08	-37.2	7.8	-4.8
D-09	25.1	2.7	14.3
D-10	-44.6	8.3	12.1
D-11	-69.9	-11.4	-8.6
D-12	30.3	-5.8	-28.0
D-13	33.1	0.4	-1.0
D-14	1.5	-35.0	-24.1
D-15	12.3	-23.4	1.8
D-16	-19.5	-37.1	-22.2
D-17	19.5	-22.0	-26.7
D-18	5.2	-31.4	-28.6
D-19	-4.4	-25.2	-53.7
D-20	3.9	-4.0	-9.3
D-21	27.1	-13.0	40.3
D-22	-9.4	25.6	37.9
D-23	67.1	-4.4	-6.9
D-24	38.0	-3.4	10.5
D-25	-1.1	-17.9	-1.8
D-26	-28.2	3.7	41.7
D-27	-30.6	-21.8	1.4
D-28	-10.9	7.6	16.4
D-29	-55.3	-3.7	-3.7
D-30	80.2	-9.7	8.2
D-31	-7.1	9.0	-2.6
D-32	-2.8	-3.6	-7.3
D-33	-12.9	-0.7	3.4
D-34	-35.1	16.7	34.5
SS-01	-4.8	-9.5	-
SS-02	6.3	22.8	-
AREA NORTH OF PROJECT (D-01 to D-10)	-21.5	1.7	8.0
PROJECT AREA (D-10 to D-19)	-3.7	-18.3	-17.9
AREA SOUTH OF PROJECT (D-19 to D-34)	-1.1	-2.8	6.8

The discussion of volume changes focuses on changes occurring within the beach nourishment Project Area (stations D-10 to D-19) as well as changes that are occurring north and south of the Project Area. Figure 5 graphically depicts the volume changes calculated above -24 ft. NAVD88 measured between September 2013 and May 2019 as well as changes measured from June 2018 to May 2019 and between December 2017 and May 2019.

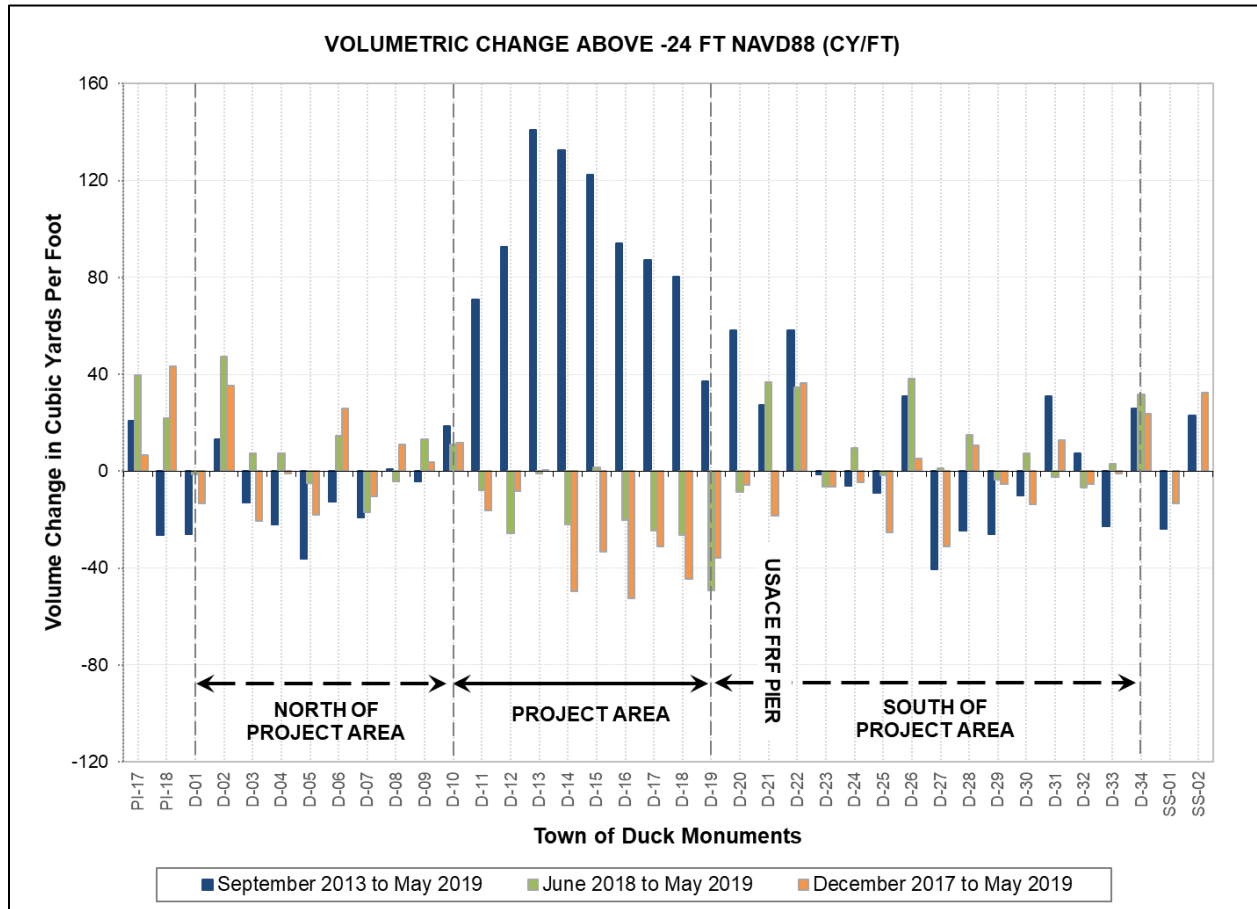


Figure 5. Volume Changes (cubic yards/foot) measured between Sept. 2013 to May 2019, June 2018 to May 2019, and Dec. 2017 to May 2019.

Initial Beach Fill Volumes

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

method of assessing volume is used, please refer to the 2018 Shoreline and Volume Change Monitoring Report (APTIM, 2018).

Project Area (D-10 to D-19)

Beach profile monitoring surveys indicate a volume change within the project area of -225,900 cubic yards between December 2017 (Post-construction) and May 2019. This equates to a rate of -18.3 cy/ft./yr. when annualized. This average rate is heavily influenced by the negative volume changes experienced on the southern 4,500 ft. of the beach fill project between stations D-14 and D-19 as seen in Figure 5. The average volume change from D-14 south to D-19 was calculated to be a loss of -29 cy/ft./yr., equivalent to 186,300 cubic yards, or 82% of the total volume lost since December 2017. **As of May 2019, the analysis indicates that the Town of Duck beach nourishment project had approximately 77% of the initial fill volume remaining as measured above the -24-foot NAVD88 contour.**

Over the recent survey interval (June 2018 and May 2019), a volumetric loss of 126,200 cubic yards of material was measured from within the Project Area. This is equivalent to an average loss of approximately -17.9 cy/ft./yr. Based on these calculations for volume change, approximately 56% of the negative volume change measured between December 2017 and May 2019 occurred during the recent 11-month period. Figure 5 shows that the volume changes measured along the northern portion of the Project Area, from D-10 to D-15 varied, while the changes at stations D-16 to D-19 experienced relatively consistent high losses that increased from north to south. The volume change at station D-10, the northernmost profile, experienced the greatest positive volume change of 11.1 cy/ft.; whereas the greatest negative volume change was measured along station D-19 (-49.3 cy/ft.), located just north of the USACE FRF facility. The four southern profiles within the Project Area (D-16 to D-19) measured an average volume change of approximately -30.1 cy/ft. over the 11-month period. The volume changes occurring along these four profiles are a result of significant erosion of the beach slope between elevation 0 and -6 ft. NAVD88 due to the formation of a well-defined nearshore trough as well as the deflation of the offshore portion of the profiles generally between a depth of 10 to 18 feet of water. In comparison, the average volume change measured along the northern 6 profiles within the Project Area had an average volume change of -7.3 cy/ft. over the same period.

The relatively high losses along the southern portion of the project area between stations D-16 and D-19 occurred at the same time there were large gains on the profiles at stations D-21 and D-22, south of the project area. The analysis shows a significant buildup of sand on profiles at stations D-21 and D-22, located immediately north and south of the pier, compared to the changes measured between December 2017 and June 2018. In that regard, during the period from June 2018 to May 2019, a check of the wave conditions measured by Gage 630 operated by the USACE FRF indicates there was a predominance of wave energy out of the southern quadrants that would have tended to move littoral sediment to the north. During this time, the waves out of the southern quadrants accounted for 72.7% of the wave energy with 27.3% coming from the northern quadrants. More discussion is included regarding the sediment transport to the south of the project in the subsequent section of this report under the heading Area South of Project (D-19 to D-34).

The overall shoreline changes measured in the project area show a moderate trend of volume loss along the northern portion of the project between D-10 and D-15, whereas the southern portion of

the project between D-16 and D-19 exhibited higher trends during the recent 11-month period. The higher trend of erosion in the southern portion of the project may be influenced by the continued profile adjustments occurring as a result of additional material that was placed in that area during beach nourishment project in order to allow wave action to naturally form the southern transition. As discussed below, some of the material lost out of the Project Area may have been transported to the north and south.

Area North of Project (D-01 to D-10). Volumetric changes in the monitoring area North of the Project prior to the construction of the beach nourishment project (September 2013 to May 2015) indicated an average volume change rate of -21.5 cy/ft./yr. The recent period between June 2018 and May 2019 (11-months) measured an average gain of 8.0 cy/ft./yr. within the area. Consequently, the volume change measured within the area North of the Project from December 2017 (Post-construction) to May 2019 was a positive average volume change rate of 1.7 cy/ft./yr.

In the previous monitoring report (APTIM, 2018), the analysis of the changes along the 4,000 ft. of shoreline immediately north of the Project Area between Martin Ln. and Skimmer Way (stations D-06 and D-10) from December 2017 to June 2018 measured a gain of 4.7 cy/ft. (9.3 cy/ft./yr.) or approximately 17,000 cubic yards. However, the recent trends measured between June 2018 and May 2019 show this 4,000 ft. section gained an average 3.5 cy/ft., equivalent to approximately 5,100 cubic yards during the 11-month period. Although this section continued to show a gain, the rate of the trend has slowed. Some of the gains may still be associated with the northward spreading of the nourishment material during the recent 11-month period and attributed to the predominance of wave energy out of the southern quadrants (72.7%) that would have tended to move littoral sediment to the north for the time period between June 2018 and May 2019.

The area along the northern approximately 5,000-foot section of the monitoring area from D-06 through D-01, also accreted an average of 11.8 cy/ft. during the same 11-month period, which equates to a gain of approximately 63,300 cubic yards. However, the majority of the accretion within the 5,000-ft section is the result of an anomalous accretion of 47.7 cy/ft. that occurred on the profile at station D-02. Not considering the gain at station D-02, the section still exhibited an average gain of 4.7 cy/ft. The northernmost monitoring profiles at stations, PI-17 and PI-18, also experienced accretion during the 11-month period, gaining an average 30.8 cy/ft.

Area South of Project (D-19 to D-34). The monitoring area south of the Project Area during the 1.7-year period from September 2013 to May 2015, prior to the construction of the beach nourishment project, was relatively stable with an average accretion rate of 1.1 cy/ft./yr. However, a review of the changes from station to station indicates the behavior of the shoreline was highly variable. Within this area, volume changes between profile stations varied from an accretion rate of 80.2 cy/ft./yr. at station D-30 to an erosion rate of -35.1 cy/ft./yr. at station D-34. During the 17-month period from December 2017 to May 2019, since the construction of the beach nourishment project, this area lost an average of 2.8 cy/ft./yr. During the recent 11-month period from June 2018 to May 2019 this area accreted at an average rate of 6.8 cy/ft./yr.

During the recent survey interval from June 2018 to May 2019, the 3,000-foot section south of the Project, between stations D-20 and D-23, gained an average of 15.5 cy/ft./yr. In contrast, the adjacent profile to the north at station D-19 measured a loss of -53.7 cy/ft./yr. The loss at station

D-19 were due to erosion of the nearshore slope below the 0 ft. NAVD88 contour and the deflation of the offshore bar. An examination of volume changes measured station to station shows anomalous volume gains at 40.3 cy/ft./yr. and 37.9 cy/ft./yr. at stations D-21 and D-22, respectively while stations D-20 and D-23 to the north and south exhibited losses of 9.3 cy/ft./yr. and 6.9 cy/ft./yr., respectively (Table 4). The anomalous changes at D-21 and D-22 appear to be influenced by an increase of material on the berm and by the formation of a bar that was not present on the profile at station D-21 in June 2018 as shown on Figure 6.

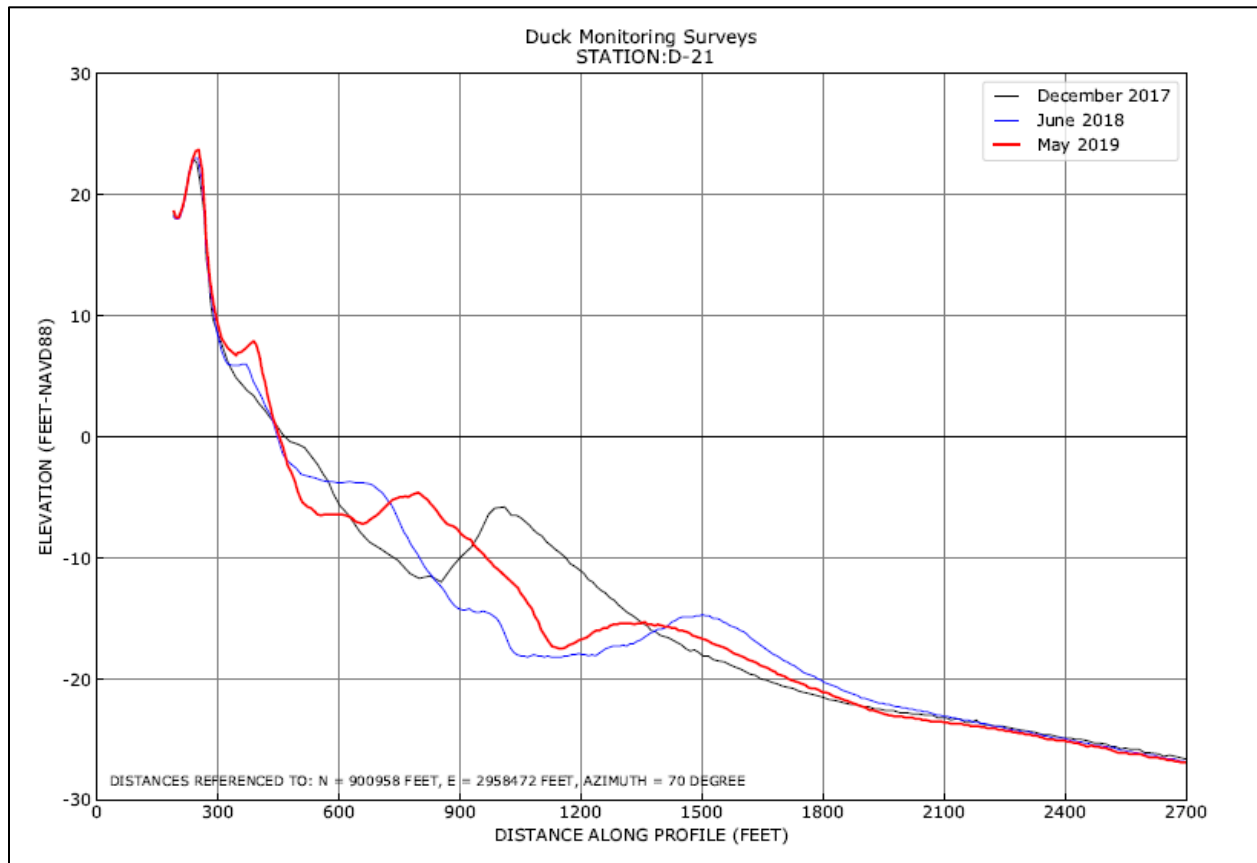


Figure 6. Profile at station D-21 showing progression of nearshore changes measured during the December 2017, June 2018, and May 2019 surveys.

The anomalous behavior of D-21 and D-22 will be reexamined during the next monitoring survey to see if this trend persists or if it was just an ephemeral change that resulted from the wind and wave conditions experienced between the survey events. In any event, the behavior of D-21 and D-22 prevents any definitive assessment as to possible southward spreading of the fill material.

The area from stations D-24 and D-30 (Shipwatch to Four Seasons Ln), exhibited predominantly positive volume changes. In this approximately 6,000-foot long span of beach, the average volume change measured over the 11-month period was a gain of 9.5 cy/ft. This is a reversal from the previous monitoring period (December 2017 to June 2018), as this area had the highest concentration of negative volume change south of the project area averaging a loss of -17.4 cy/ft. However, these changes could be representative of the differences when comparing surveys that were performed at different times of the year due to the seasonal variation in the shape of the beach

profile. The southern 3,000 ft. of the area between stations D-31 and D-34 (Plover Dr. and 13th Ave) measured an average gain of 7.0 cy/ft./yr.

During the 17-month period from December 2017 (Post-construction) to May 2019 the area South of the Project measured an average volume change of -2.8 cy/ft./yr. (Table 4). This equates to a volume loss of approximately 50,500 cubic yards. However, an analysis of calculated volumetric changes along the area between D-23 and D-34 indicates the changes were highly variable from profile to profile. In the 2,000-foot section of shoreline immediately south of the southern terminus of the beach fill project (stations D-19 to D-22), survey data indicated negative volume change rates along profiles D-19 (-25.2 cy/ft./yr.), D-20 (-4 cy/ft./yr.) and D-21 (-13 cy/ft./yr.), which are located north of the pier. South of the pier, the same surveys indicate an accretion along profile D-22 of 25.6 cy/ft./yr. The USACE FRF Pier may play a part in the sediment transport patterns that have been observed along the southern portion of the Town's project. A previous analysis completed by APTIM in 2013 found that based on the results of an Even-Odd Analysis, the USACE FRF pier had a limited longshore transport barrier effect; however, the limits of this effect did not extend beyond the FRF property. The area located further south along the area between stations D-23 to D-27 (southern end of the FRF property and Wampum Dr.) had an average volume loss of -8.8 cy/ft./yr. over the December 2017 to May 2019 time period. In contrast, the southernmost 6,000 ft. of the area between Duck Landing Rd and 13th Ave (stations D-28 and D-34) experienced more moderate and positive changes with a measured average gain of 2.2 cy/ft./yr.