

## V. VOLUMETRIC CHANGES

### General

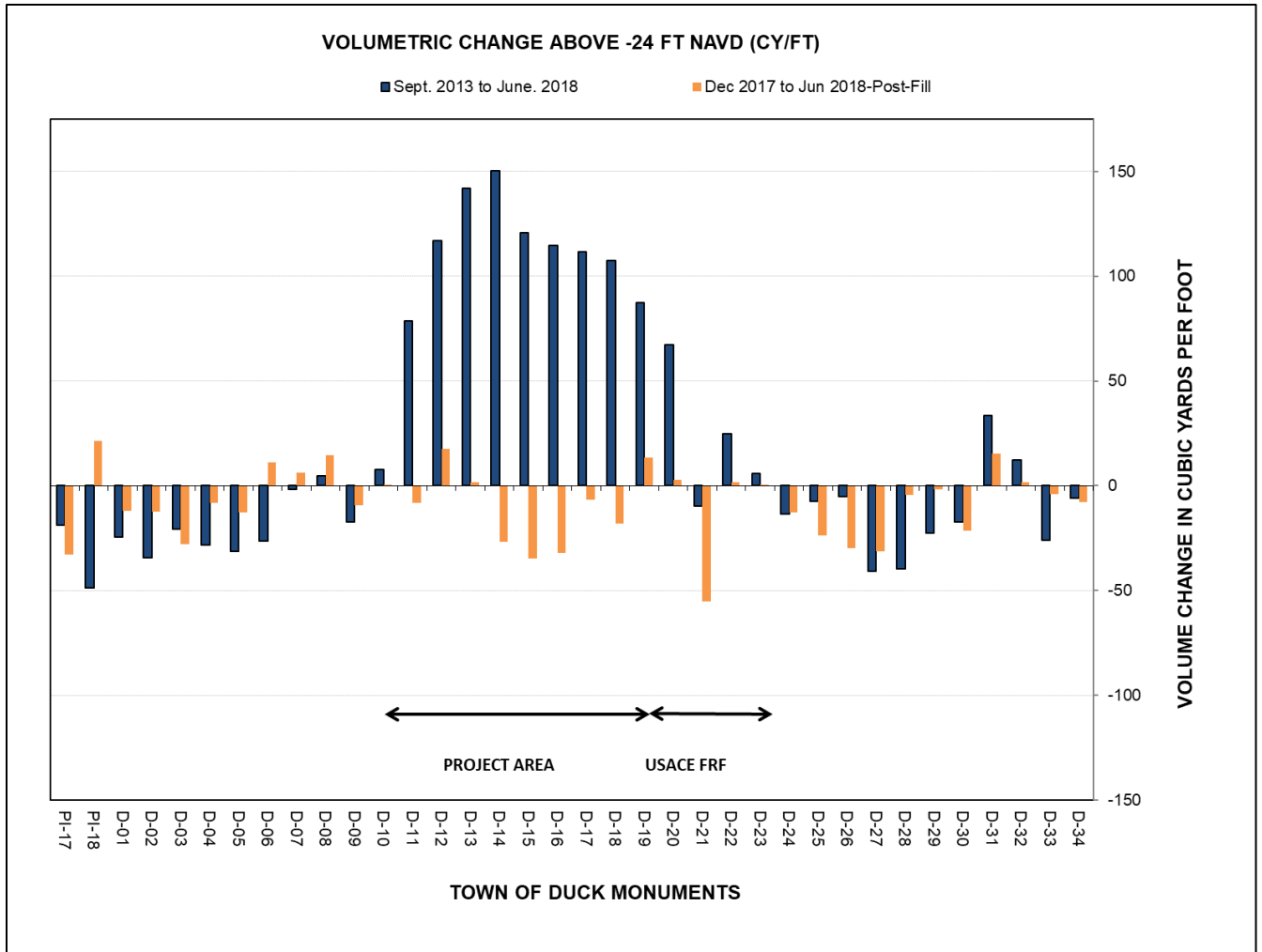
Volumetric changes measured over the entire monitoring area for various time periods are provided in Table 4. The volume changes are given in terms of cubic yards/foot of shoreline/year (cy/ft./yr.). Both within the beach nourishment project (stations D-10 through D-19), and outside the beach nourishment project, volume change rates were evaluated for the period from September 2013 to May 2015 and December 2017 to June 2018. The September 2013 to May 2015 rates represent trends occurring prior to construction of the project. The December 2017 to June 2018 surveys show short-term changes occurring after the beach nourishment project.

**Table 4. Volumetric Change Rates Pre-Project and Post-Project for the Town of Duck**

PROFILE	VOLUMETRIC CHANGES (CY/FT/YR)	
	SEPT. 2013 to May 2015	DEC 2017 TO JUNE 2018
PI-17	-14.6	-65.4
PI-18	-33.3	42.8
D-01	-10.5	-24.1
D-02	0.3	-24.4
D-03	-33.2	-55.7
D-04	-16.0	-16.5
D-05	-52.4	-25.8
D-06	-18.3	22.5
D-07	-28.4	12.8
D-08	-37.2	29.1
D-09	25.1	-18.7
D-10	-44.6	1.0
D-11	-69.9	-16.5
D-12	30.3	35.2
D-13	33.1	3.0
D-14	1.5	-53.3
D-15	12.3	-69.6
D-16	-19.5	-63.8
D-17	19.5	-13.7
D-18	5.2	-36.4
D-19	-4.4	27.2
D-20	3.9	5.4
D-21	27.1	-110.7
D-22	-9.4	3.3
D-23	67.1	0.2
D-24	38.0	-25.2
D-25	-1.1	-47.4
D-26	-28.2	-59.2
D-27	-30.6	-62.7

D-28	-10.9	-8.6
D-29	-55.3	-3.8
D-30	80.2	-42.5
D-31	-7.1	30.4
D-32	-2.8	3.1
D-33	-12.9	-7.7
D-34	-35.1	-15.9
<b>NORTH OF PROJECT</b> (PI-17 TO D-10)	-21.9	-10.2
<b>PROJECT AREA</b> (D-10 TO D-19)	-3.7	-18.7
<b>SOUTH OF PROJECT</b> (D-19 TO D-34)	1.2	-19.6

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 7 graphically depicts the volume changes measured between September 2013 and June 2018 as well as changes measured between December 2017 and June 2018.



**Figure 7. Volume Changes (cubic yards/foot) measured between September 2013 and June 2018 and December 2017 and June 2018.**

**PROJECT AREA (D-10 TO D-19)**

The Town of Duck Erosion & Shoreline Management Feasibility Study (CPE-NC, 2013), determined that between 1996 and 2011, the shoreline between the USACE FRF northern boundary and Diane St. had receded approximately 73 ft. It was not known if this change occurred gradually over the approximately 15 year period, or if it occurred more abruptly prior to the 2011 survey. In any event, the feasibility study determined that because of the shoreline changes that occurred during that period, a portion of the Town was vulnerable to storm impacts from a storm with similar characteristics as Hurricane Isabel. For that reason, the Town initiated the efforts that lead to the construction of the beach nourishment project in 2017.

During the design phase of the beach nourishment project, the advanced fill required for a 5 year renourishment period was estimated to be 234,000 cubic yards (CPE-NC, 2015). These estimates

were based on shoreline and volume changes measured prior to 2013 as well as estimates of diffusion losses.

In May 2015, beach profile surveys were conducted to update shoreline and volume change rates throughout the Town limits and to update the beach nourishment design during the development of project plans and specifications. Within the proposed project area (D-10 to D-19), a volumetric loss of approximately -13,300 cy was measured in the 1.7 years between September 2013 and May 2015. This translated into a rate of -3.7 cy/ft./yr.

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 profile stations D-10 and D-19. However, the performance of the 2017 beach fill project along the Town of Duck is based on changes that occur relative to the conditions depicted by the December 2017 monitoring survey. While the beach fill project was completed in June 2017, beach fill projects typically undergo an initial period of profile adjustment in which material placed on the upper portion of the profile is redistributed to lower portions of the profile in response to tide and wave conditions. In addition to the onshore-offshore profile adjustments, some of the beach fill material is removed from the ends of the fill and distributed to the adjacent shorelines. Once these initial adjustments occur, the performance of the beach fill typically begins to mimic the behavior of a natural beach. Therefore, for purposes of monitoring the performance of the beach fill, the volume of the beach fill material on the active profile determined from comparison of the Pre-Construction survey obtained in April 2017 with the December 2017 monitoring survey is used to represent the initial volume of material in the beach fill project. In this regard, the volume of beach fill material remaining on the active beach profile as of December 2017 was 963,100 cubic yards.

Over the 6-month period between December 2017 and June 2018, the volume of material within the Project Area decreased by 98,500 cubic yards. The average volume change measured along the profiles from D-10 to D-19 was approximately -9.3 cy/ft. However, as illustrated in Figure 7, there is considerable variation in the volume changes measured along the project area. The greatest positive volume change was measured along Profile D-12 (17.6 cy/ft.); whereas the greatest negative volume change was measured along Profile D-15 (-34.8 cy/ft.). Relatively high negative volume changes were measured along profiles D-14, D-15, and D-16. These three profiles had an average volume change of approximately -31.1 cy/ft. over the 6-month period. The volume changes occurring along these profiles are a result of losses that occurred from the berm as well as the truncation of a large bar that was present in December 2017 offshore of the beach in 6 to 12 feet of water. Excluding these three profiles, the remainder of the project had an average volume change of essentially 0 over the same period.

While the overall shoreline changes measured in the project area, and more specifically between D-14 and D-16, were higher than trends measured prior to the construction of the project, the changes may be influenced by the relatively short time period between surveys and the continued profile adjustments occurring as a result of the beach nourishment project. Also, a review of wave data recorded by Gage 630 operated by the FRF indicated there was a total of 11 nor'easters between December 2017 and June 2018 that generated wave heights in excess of 2 meters (6.6 ft.). Each of these nor'easters lasted several days and could have had significant impacts on the onshore-offshore movement of the beach fill material. Included in these 11 storms was Winter

Storm Riley which impacted the area from March 1 to March 4 and produced a maximum wave height at Gage 630 of 3.5 meters (11.5 ft.). In general, as the beach fill adjusts, the volume rate of change is expected to moderate.

As discussed below, some of the material lost out of the Project Area may have been transported to the north and south.

### OUTSIDE OF BEACH NOURISHMENT PROJECT AREA

**North of Project Area (PI-17 to D-10).** The monitoring area north of the Project Area, was eroding at an average rate of -21.9 cy/ft./yr. during the 1.7-year period from September 2013 to May 2015, prior to the construction of the beach nourishment project. During the 2.6-year period from May 2015 to December 2017, which included the construction of the beach nourishment project, this area accreted at an average rate of 8.3 cy/ft./yr. During the ensuing 6-month period from December 2017 to June 2018, the area lost an average of -10.2 cy/ft./yr. Table 5 includes pre-construction volume change rates for the area north of the Project Area, measured between September 2013 and May 2015 as well as volume change rates between May 2015 and December 2017, which includes the period of time in which the beach project was constructed.

**Table 5. Volumetric Change Rates North of Project Area**

PROFILE	VOLUMETRIC CHANGES (CY/FT/YR)		
	SEPT. 2013 to May 2015	SEPT. 2013 to JUNE 2018	MAY 2015 to DEC 2017
PI-17	-14.6	-3.9	12.6
PI-18	-33.3	-10.2	-5.6
D-01	-10.5	-5.2	2.3
D-02	0.3	-7.2	-8.7
D-03	-33.2	-4.3	24.4
D-04	-16.0	-5.9	2.1
D-05	-52.4	-6.6	28.1
D-06	-18.3	-5.6	-2.9
D-07	-28.4	-0.3	15.3
D-08	-37.2	1.0	20.3
D-09	25.1	-3.6	-19.3
D-10	-44.6	1.6	30.6
<b>NORTH OF PROJECT (PI-17 TO D-10)</b>	-21.9	-4.2	8.3

Upon closer examination of the recent trends measured between December 2017 and January 2018, the portion of the area directly north of the Project Area lying between profile stations D-06 and D-10, which covers the approximate 4,000 feet of shoreline immediately to the north of the

Project Area, gained 4.7 cy/ft., or approximately 17,000 cubic yards. The accretion along the 4,000-foot section of shoreline immediately north of the project may be associated with the northward spreading of the nourishment material during this 6-month period. In contrast, the approximately 7,000-foot section of the monitoring area north of D-06, from D-05 through PI-17, eroded an average of -12.1 cy/ft. during the same 6-month period, which equates to approximately -62,000 cy.

A check of the wave conditions measured by Gauge 630 operated by the US Army Field Research Facility (FRF) for the time period between December 2017 and June 2018 indicates there was a predominance of wave energy out of the northern quadrants that would have tended to move littoral sediment to the south. During this time, the waves out of the northern quadrants accounted for 56.3% of the wave energy with 43.7% coming from the southern quadrants. Although the predominant wave energy was directed to the southwest, it is still possible that material was transported to the north off the end of the fill. This is because the taper section would have changed the angle waves broke relative to the shoreline to such a degree that even waves coming from northern quadrants could have resulted in northward directed littoral transport along the taper section. In any event, documented performance of beach fills in other areas has shown beach fill material tends to migrate out of the nourishment area in both directions as the bulge in the shoreline created by the fill tends to flatten as the shoreline within the nourished area returns to its pre-fill position.

Over the long-term from September 2013 to June 2018 (Table 5), volumetric changes north of the Project Area averaged -4.2 cy/ft./yr. The extreme northern sections of the area between profile stations D-06 and PI-17 continued to experience higher erosion rates compared to the section between D-07 and D-09 on the southern end of the area. Between profile stations D-06 and PI-17, the long-term average rate of volume change was -6.1 cy/ft./yr. while the southern end of the area only lost an average of -1.0 cy/ft./yr. The performance of the southern end of the area is again an indication of the positive impacts the beach nourishment project is having in this area.

**South of Project Area (D-20 to D-34).** Prior to the construction of the nourishment project (September 2013 to May 2015), the area south of the project between profiles D-19 and D-34 was relatively stable with an average accretion rate of 1.6 cy/ft./yr. Although the average volume change was relatively small, the behavior of the shoreline from profile station to profile station 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. Table 6 includes pre-construction volume change rates measured south of the Project Area, between September 2013 and May 2015 as well as volume change rates between May 2015 and December 2017, which includes the period of time in which the beach project was constructed.

**Table 6. Volumetric Change Rates South of Project Area**

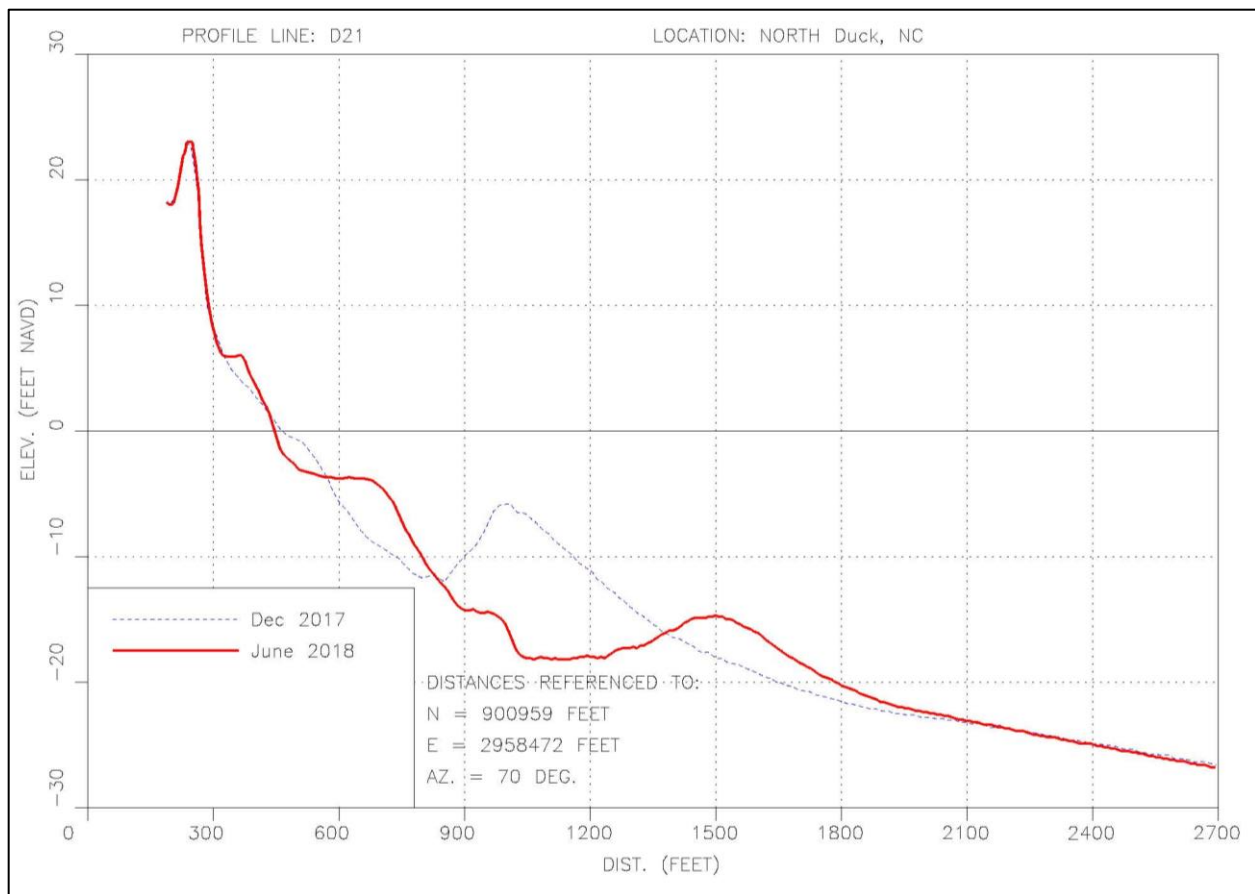
PROFILE	VOLUMETRIC CHANGES (CY/FT/YR)		
	SEPT. 2013 to May 2015	SEPT. 2013 to JUNE 2018	MAY 2015 to DEC 2017
D-19	-4.4	18.4	31.8
D-20	3.9	14.2	22.4
D-21	27.1	-2.0	0.2
D-22	-9.4	5.2	15.0
D-23	67.1	1.3	-41.3
D-24	38.0	-2.8	-24.8
D-25	-1.1	-1.5	7.0
D-26	-28.2	-1.1	27.5
D-27	-30.6	-8.6	16.1
D-28	-10.9	-8.3	-6.6
D-29	-55.3	-4.8	27.6
D-30	80.2	-3.7	-50.2
D-31	-7.1	7.1	11.5
D-32	-2.8	2.6	6.7
D-33	-12.9	-5.5	0.0
D-34	-35.1	-1.2	23.5
<b>SOUTH OF PROJECT (D-19 TO D-34)</b>	1.2	0.6	4.2

During the period from May 2015 to December 2017, which included construction of the beach fill project, the average accretion of the area increased to 4.2 cy/ft./yr., however, volumetric changes were still highly variable from profile to profile particularly along the area between D-23 and D-34. In the 4,000-foot section of shoreline immediately south of the southern terminus of the beach fill project (stations D-19 to D-23), the shoreline gained an average of 17.4 cy/ft./yr. between May 2015 and December 2017, which equates to approximately 122,300 cy. The remainder of the area (D-24 to D-34) had an average volume loss of -0.3 cy/ft./yr. over the same time period. Even so, the volume changes continued to be highly variable from profile to profile with volume changes ranging from accretion of 27.6 cy/ft./yr. at station D-26 to erosion of 50.2 cy/ft./yr. at station D-30. Some of the accretion in the 4,000-foot segment just south of the Project Area can be attributed to spreading of the fill material to the south. However, the variable nature of the volume changes throughout the area makes generalizations difficult.

During the 6-month period from December 2017 to June 2018, the 4,000-foot section immediately south of the Project Area (D-19 through D-23) lost an average of -14.9 cy/ft./yr. An examination of volume changes measured station to station for this time period (Table 4) shows an anomalous volume loss of -110.7 cy/ft./yr. at station D-21 while stations D-19 and D-20 to the north and D-22 and D-23 to the south exhibited an average accretion of 9.0 cy/ft./yr. The anomalous changes

at D-21 appear to be influenced by the truncation of the bar that was present in depths of 6 to 10 feet of water at the time of the December 2017 survey and the formation of a rather deep and wide trough in the same location as shown on Figure 8. While a similar truncation of the bar and formation of a trough occurred along most of the profiles along the Town of Duck between December 2017 and June 2018, the trough that formed along profile D-21 appears to be 4 to 6 feet deeper than those observed along adjacent profiles (see Appendix A). With profile D-21 located immediately north of the FRF pier, some of the profile changes at D-21 could have been influenced by the piles supporting the pier. The anomalous behavior of D-21 will be reexamined during the next monitoring survey to see if this feature persists or if it was just an ephemeral change that eventually disappeared over time. In any event, the behavior of D-21 prevents any definitive assessment as to possible southward spreading of the fill material.

The area south of D-23, between profile stations D-24 and D-30 (Shipwatch to Four Seasons Lane), exhibited the highest concentration of negative volume change in the area south of the project. In this approximately 6,000-foot long span of beach, the average volume change measured over the 6-month period between December 2017 and June 2018 was -17.4 cy/ft. That equates to a volume loss of approximately 121,000 cy over the 6-month period.



**Figure 8. Profile D-21 showing deep and wide trough measured during the June 2018 compared to December 2017 survey.**



The long-term volume changes south of the Project Area measured between September 2013 and June 2018 (Table 6) was a gain of 0.6 cy/ft./yr. This is a slight decrease in the positive volume change as measured between September 2013 and December 2017 (+2.9 cy/ft./yr.). The major difference in the shoreline response for these two periods occurred between profile stations D-24 and D-30 (Shipwatch to Four Seasons Lane), in the area where the highest volume losses occurred over the 6-month period between December 2017 and June 2018. For the previous long-term period between September 2013 and December 2017, this section of the shoreline lost an average of -0.7 cy/ft./yr., whereas the updated long-term rate in this section measured between September 2013 and June 2018 was a loss of -4.4 cy/ft./yr. The area should be closely monitored to see if the risk of damage to development in the area increases.