

VI. DISCUSSION

This monitoring report evaluated shoreline and volumetric changes along the portions of shoreline nourished in 2017 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 at 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 beach nourishment project in June 2017, the monitoring area was divided into three sections, namely; the Project Area (D-10 to D-19), the Area North of the Project (D-01 to D-10), and the Area South of the Project (D-19 to D-34). Data collected in June 2020 was used to evaluate shoreline and volumetric changes that have occurred since the baseline survey was conducted in 2013, since the construction of the 2017 beach nourishment project, and over the past year between the 2019 and 2020 monitoring surveys.

Shoreline Change Analysis:

Project Area. Surveys conducted in April 2017 and December 2017 indicated that the beach fill effectively relocated the +6.0 ft NAVD88 contour an average of +89.5 feet seaward (from D-10 to D-18). D-19 was not surveyed during the April 2017 pre-construction survey and therefore, is not included in the project average. The construction of the project widened the beach considerably more; however, since the project was completed in June 2020 and the post-construction survey was conducted in 2017, the project experienced considerable equilibration over that time and therefore the December 2017 +6.0 ft. design contour is assumed to be equilibrated. The average shoreline change measured within the Project Area from December 2017 to June 2020 along the same section of the project from D-10 to D18 was -81.6. As shown in Figure 7, in some areas, particularly along the northern part of the project from 140 Skimmer Way (D-10) to Sound Sea Ave. (D-12) the current +6.0 ft. contour is landward of the pre-project (April 2017) +6.0 ft. NAVD88 contour. Along the southern portion of the project, where the pre-project condition was most severely eroded, the +6.0 ft. NAVD88 contour is still seaward of the pre-project condition. The average shoreline change rate along the project area measured between December 2017 and June 2020 was -29.9 ft./yr. However, over the 13-month period between May 2019 and June 2020 the rate was -45.2 ft/yr.

Much of the negative change in the +6.0 ft. contour is attributed to the impacts of Hurricane Dorian, which impacted the project in September 2019. Between May 2019 and December 2019 (Post-Storm Survey) the +6.0 ft. contour retreated an average of 46.8 ft. Between December 2019 (Post-Storm Survey) and the June 2020 survey, the +6.0 ft. NAVD88 Contour moved an average of -2.2 ft. (landward). In comparison, the MHW contour, which is at +1.18 ft. NAVD88 experienced negative shoreline change on average in the project area of -13.1 ft., between May 2019 and December 2019; whereas over the next 6 months from December 2019 to June 2020 the average shoreline change for the MHW contour advanced seaward 10.5 ft., indicating some recovery. This pattern is typical of beach response to storms. The migration of sand from the MHW contour offshore during a storm followed by recovery of the MHW contour following a storm is well documented. If the storm is large enough to impact the upper part of the profile, in this case the +6.0 ft. contour, it is more difficult for the upper beach to recover quickly as the processes that move sand from the nearshore up the foreshore and allow for recovery along the MHW line, do not move sediments so far up the profile to allow for recovery of the +6.0 ft. contour.

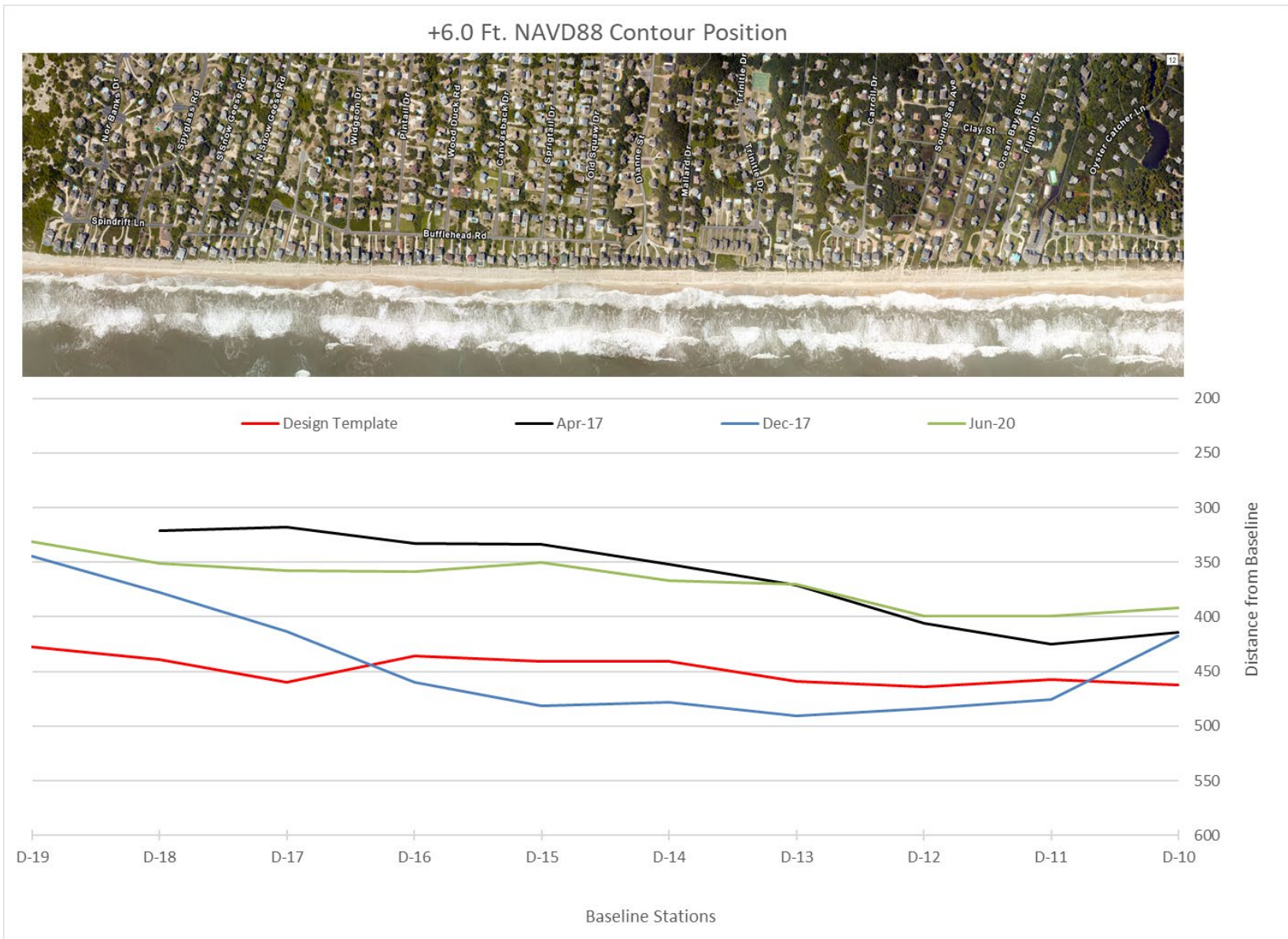


Figure 7. +6.0 ft. NAVD88 contour position throughout the Project Area compared to the +6.0 ft. NAVD88 contour for the project design.

The average position of the +6.0 ft. NAVD88 shoreline is only 3.9 ft. seaward of the September 2013 baseline survey as of June 2020. In comparison, the average MHW shoreline position is 51.0 ft. seaward of the September 2013 baseline position suggesting the beach slope is considerably less steep than it was in September 2013. As discussed in the previous paragraphs, the steepness of the beach is influenced by storm events, but it is also influenced by the grain size of the sand. When the beach fill project was constructed, the material used to construct the southern 2,500 feet of the project came from a combination of sand from Borrow Area A and C at a ratio of 2 loads from A for every 1 load from C; whereas, the material used to construct the rest of the project to the north all came from Borrow Area C. The mean grain sizes of the sand in Borrow Areas A and C were determined to have an average mean grain size of 0.36 mm and 0.26 mm, respectively (CPE-NC, 2015B). The fact that Borrow Area C was known to be finer than Borrow Area A and finer than the native beach led to the directive that additional sand was required to be placed along sections constructed with sand from Borrow Area C alone. Samples taken along the beach following construction of the project showed the average mean grain size of the samples collected in areas constructed with material from Borrow Area A had a mean grain size of approximately 0.39 mm, compared to the mean grain size of samples collected along the portion of the project constructed with material from Borrow Area C, which had a mean grain size of 0.29 mm. This data may help explain some of the beach fill performance and should be evaluated in the design of the next renourishment project.

Area North of the Project. The average long-term shoreline changes computed along the Area North of the Project (D-01 to D-10), was -6.3 ft (landward movement), between September 2013 and June 2020. This time period includes the construction of the beach nourishment project. This is equivalent to a rate of -0.9 ft./yr. The average rate between D-01, located near the northern Town Boundary and D-04, located at the Sanderling Resort, was -4.2 ft./yr. (landward movement); whereas the average long-term shoreline change from the Sanderling south to the Project Area (D-04 to D-10) was a positive 0.7 ft./yr. (seaward movement).

Recent surveys (May 2019 and June 2020) indicate an overall average change in the +6.0 ft. NAVD88 contour of +2.8 ft. (Seaward). However, there is a clear distinction between the trend directly north of the project from the Project Area (D-10) to D-04, located at the Sanderling Resort, and the portion of the Town's beach north of the Sanderling Resort. The average change in the +6.0 ft. contour position from D-10 to D-04 was +12.2 ft. (seaward), and from D-04 to D-01 the average change was -16.1 ft. (landward).

Area South of the Project. Long-term shoreline changes computed between September 2013 and June 2020, which includes the construction of the beach nourishment project, averaged -8.3 ft. (landward movement), equivalent to a rate of -1.2 ft./yr. However, one section of the shoreline located between Plover Dr. and Bias Ln E. (stations D-31 and D-33) has experienced a positive trend of seaward movement, with an average shoreline change of +10.5 ft., or a rate of +1.6 ft./yr. when annualized.

Recent surveys (May 2019 and June 2020) indicate an overall average change in the +6.0 ft. NAVD88 contour of -14.5 ft. However, there is a clear distinction between the trend directly south of the project from the northern boundary of the FRF property (D-19) to Sea Colony Drive (D-25), and the trend from Sea Colony Drive (D-25) south to the Town southern boundary (D-34). In the area directly south of the project, the average change was -35.7 ft. over the approximate 13-month period from May 2019 to June 2020. In contrast, the average shoreline change measured from Sea Colony Drive south was +3.0 ft. Within this area, the +6.0 ft. NAVD88 contour between the end of Christopher Dr. (D-29) and Bias Ln. E. (D-33) experienced a seaward movement of +12.1 ft. on average.

Volumetric Change Analysis:

Project Area Beach profile surveys indicate that during the most recent survey interval (May 2019 to June 2020), a volumetric loss of approximately 45,000 cubic yards was measured. The highest losses occurred between Ocean Pines Dr. and Dianne St. (D-12 to D-15). Since the completion of Town of Duck beach nourishment project, the Project Area has lost a total of 271,000 cubic yards (December 2017 to June 2020). This equates to approximately 28% of the fill measured in the Project Area in December 2017. As of June 2020, the analysis indicates that the Town of Duck beach nourishment project had 72% of the initial fill volume remaining as measured above the -24-foot NAVD88 contour.

As discussed in the Shoreline Change portion of this Section, survey data suggests the slope of the beach between the design berm contour of +6.0 ft. NAVD88 and the MHW contour has flattened over the life to the project. This appears to be more pronounced in the northern portion of the project constructed with sand from Borrow Area C. This flattening of the beach appears to have occurred as the +6.0 ft. contour retreated landward while the MHW line moved slightly seaward. The +6.0 ft. contour position at every profile within the project area is landward of the designed berm position. In other words, in terms of the design berm, the project has eroded back into the project design at the berm elevation. In fact, on average, the +6.0 ft. contour is approximately 81.0 ft. landward of where it was designed to be between D-10 and D-19. That said, as mentioned above, approximately 72% of the material placed along the project area as measured in December 2017 is still located within the project area. This suggests that a considerable amount of sand is being stored in the offshore portion of the profile. This may be a function of the mean grain size of the material used to build the northern 5,700 feet of the project being of relatively finer grain size than the pre-project beach mean grain size. This is something that is being evaluated as part of the design of the proposed 2022 renourishment project.

The portion of the project remaining in place continues to provide vital storm protection to the Town as well as recreational benefits. CPE is continuing to evaluate project performance and adapt to conditions that are better understood through the evaluation of the project monitoring data. More information on this topic is provided in the Recommendations Section.

Area North of the Project The long-term average volumetric change rate in the area North of the Project, measured between September 2013 and June 2020, was +1.2 cy/ft./yr. Individual rates range from -2.4 cy/ft./yr. at station D-06 near Martin Lane to +4.1 cy/ft./yr. at station D-09 located at the south end of Pelican Way.

Since the project was constructed, the average volumetric change in the Area North of the Project was +8.3 cy/ft./yr. This is significantly higher than the long-term average of +1.2 cy/ft./yr. This rate is also significantly higher than the rate documented in the 2019 Monitoring report for the period from December 2017 to May 2019, which was +1.7 cy/ft./yr. (APTIM, 2019). This is reflective of the recent positive volumetric change measured between May 2019 and June 2020. The average volumetric change along this area over that 13-month period was 18.2 cy/ft. or 16.8 cy/ft./yr. Some of these gains to the area North of the Project over this 13-month period may be related to volumetric losses to the project attributed to Hurricane Dorian (CPE, 2020). For instance, the 4,000-foot area immediately north of the Project Area between Martin Ln. and Skimmer Way had a positive volumetric change of +11.1 cy/ft., equivalent to approximately 60,000 cy. However, some of the highest volumetric gains measured on individual profiles occurred over a mile north of the project area, which may be associated with other coastal processes.

Area South of the Project The long-term average volumetric change rate in the area south of the project, measured between September 2013 and June 2020, was +3.1 cy/ft./yr. Individual rates range from -2.8 cy/ft./yr. at station D-28 at the end of Duck Landing Lane to +9.8 cy/ft./yr. at station D-21 located directly north of the Field Research Facility Pier (Figure 5).

Since the project was constructed (Dec. 2017 to June 2020), the average volumetric change south of the project area was +3.5 cy/ft./yr. This is comparable to the long-term average of +3.1 cy/ft./yr. calculated from Sept. 2013 to June 2020. However, this is a reversal of the post-project volumetric change rate reported along the area South of the Project between December 2017 and May 2019 (-2.8 cy/ft./yr.) (APTIM, 2019). The reversal in the post-project trend is due to significant positive volumetric changes measured between May 2019 and June 2020, which can be seen in Figure 5. The average volumetric change along this area over that 13-month period was 12.8 cy/ft. or 11.8 cy/ft./yr. Some of these gains to the Area South of the Project over this 13-month period may be related to volumetric losses to the project attributed to Hurricane Dorian (CPE, 2020). For instance, the 3,000-foot area immediately south of the Project Area along the FRF property (D-19 to D-23) had a positive volumetric change of +10.9 cy/ft., equivalent to approximately 38,000 cy. However, some of the highest volumetric gains measured on individual profiles occurred over a mile south of the project area, which may be associated with other coastal processes.

When comparing the December 2017 survey to June 2020, there does not appear to be a significant increase of volume to the area directly south of the project as is typically observed adjacent to beach nourishment projects. With the relatively short beach fill project constructed along the Town of Duck, combined with the fact that the project did not include a typical taper section to the South, due to restrictions on placing material along the FRF, one might expect end losses and volumetric gains to the area south of the project to be even more obvious along this project.

In June 2018, an anomalous wide and deep trough was identified just offshore at station D-21. The volumetric change measured at station D-21 between December 2017 and June 2018 was a negative 55.4 cy/ft. Between June 2018 and May 2019, a positive volumetric change of 36.9 cy/ft. was measured along D-21; however, the net volumetric change that occurred between December 2017 and May 2019 was still negative. Most recently, between May 2019 and June 2020, a positive volumetric change of 38.8 cy/ft was measured along D-21, bringing the net volumetric change measured since December 2017 at station D-21 to a +20.4 cy/ft. This is significant, because. The development of the anomalous trough offshore of D-21 shortly after the construction of the project may have obscured the volumetric gains experienced along the area directly south of the project related to the spreading of the beach fill.

VII. RECOMMENDATIONS

CPE recommends the Town continue to monitor the beach along the entire Town oceanfront in order to assess long-term shoreline and volumetric changes. Within the Project Area, the continued annual monitoring not only provides a pre-storm condition survey that can be used to estimate storm damages as was the case following the impact of Hurricane Dorian, but it also allows for the continued assessment of volume trends, which are being used to design the renourishment project, currently proposed for 2022. Outside the Project Area, continued monitoring 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.

Since construction of the project in 2017, the volumetric trend along the Town's beaches has been positive change (accretion) both north of and south of the Project Area. It is not uncommon to see positive volumetric changes adjacent to a beach nourishment project due to the spreading of material that serves to feed the adjacent beaches. However, some of the volumetric changes appear to be occurring outside the expected influence of the project and may be caused by other coastal processes. Continued monitoring of the areas outside the project will detect any changes in this trend, which may render other portions of the Town vulnerable.

The monitoring program serves as the basis for determining how frequently additional nourishment is needed and how much volume is required to maintain the project design over the long term. In this regard, initial monitoring of the project over the first 3 years following construction indicates a volumetric change rate higher than estimated in the initial project design, which may be related to a number of factors. The Town's maintenance plan calls for an estimated nourishment fill density of approximately 30 cy/ft., every 5 years, which translates to an annual average loss of approximately 6 cy/ft. The actual rate of volumetric change measured since 2017, in the first three years post-construction, has been 12.4 cy/ft., which is twice the rate programmed in the beach management plan. It must be considered, however, that the loss of material from a beach nourishment project typically does not occur in a linear pattern; rather the trend is to observe higher losses immediately following construction of the project followed by a tapering off of rates over time as the project equilibrates with the surroundings and fill diffusion losses decrease. Given the 2017 project was the initial construction of the Town's project and beach profile data along the Project Area was limited prior to the construction of the 2017 project, the monitoring program is revealing the true erosion rate. The true erosion rate is influenced by the construction of the project itself, recent impacts of storms, alongshore variability, and other factors that may be contributing to the erosion rate beyond the initial estimate.

While the post-project volumetric change rate may decrease over the next two years, prior to the 2022 project, the Town may need to place additional material on the project in excess of the 30 cy/ft. fill density prescribed in the beach maintenance plan to re-establish and maintain the present design objectives. CPE is currently working on updating these numbers as part of the design of the 2022 project, which can be re-evaluated as additional monitoring data become available.

Following the impact of Hurricane Dorian on the project, the Town contracted with CPE to conduct post-storm surveys to determine storm impacts. CPE completed a volume analysis and design report stating that Hurricane Dorian caused the loss of approximately 170,800 cy of sand (~20 cy/ft.) that should be eligible for FEMA Public Assistance funding. While CPE is working on updating the design for the 2022 project to account for the higher observed erosion rates as discussed previously, it is recommended that the Town plan to at least replace the 170,800 cy of material lost as a result of Hurricane Dorian in addition to the programmed placement of 254,000 cy of sand. In the report prepared for FEMA, CPE estimated the additional cost to replace the 170,800 cy of sand to be approximately \$2,972,000 (CPE. 2020).