

**TOWN OF KITTY HAWK & KILL DEVIL HILLS,  
NORTH CAROLINA  
2021 SHORELINE & VOLUME CHANGE  
MONITORING REPORT**



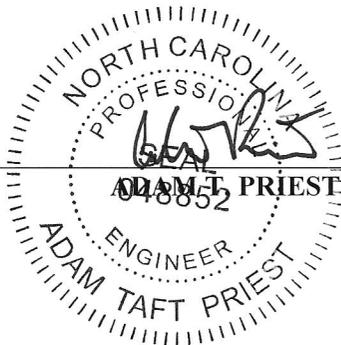
**SUBMITTED TO:**

**TOWN OF KITTY HAWK  
&  
TOWN OF KILL DEVIL HILLS**

**SUBMITTED BY:**



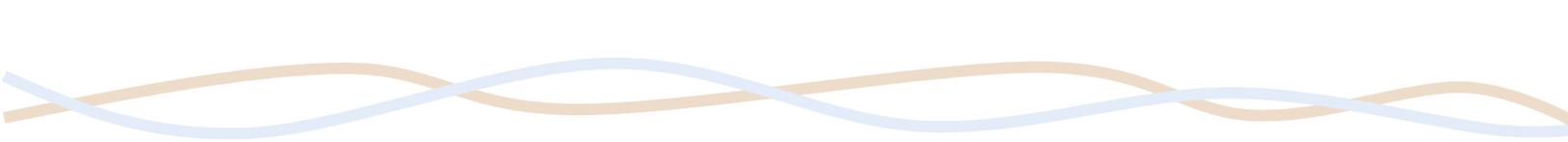
**COASTAL PROTECTION & ENGINEERING OF NORTH CAROLINA, INC.  
ENGINEERING LICENCE CERTIFICATE #: C-2331**



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**3/28/2022  
DATE**

**March 2022**



**TOWN OF KITTY HAWK & KILL DEVIL HILLS  
2021 SHORELINE & VOLUME CHANGE  
MONITORING REPORT**

**EXECUTIVE SUMMARY**

The Towns of Kitty Hawk and Kill Devil Hills are located on the Outer Banks of North Carolina roughly 37 and 40 miles south-southeast of the North Carolina and Virginia border, respectively. The Town of Kitty Hawk extends 3.6 miles along Dare County’s oceanfront beach, while Kill Devil Hills, located immediately south of Kitty Hawk, includes 4.7 miles of oceanfront beach. Kitty Hawk is bordered to the north by the Town of Southern Shores, whereas Kill Devil Hills is bordered to the south by the Town of Nags Head.

The Towns of Kitty Hawk and Kill Devil Hills, in cooperation with Dare County, completed a beach nourishment project in October 2017. During the latter stages of the design for the Kitty Hawk and Kill Devil Hills projects, the Town of Southern Shores experienced a severe erosion episode that negatively impacted the southern 1,500 feet of its shoreline. In response, the Kitty Hawk project was modified to include the southern 1,500 feet of beach in Southern Shores.

While construction of the projects was completed in October 2017, the conditions of the projects as measured by the December 2017 post-construction survey were used to represent post-construction conditions. During the period between actual placement of beach fill and December 2017, the projects were undergoing initial adjustments by natural coastal processes that included migration of fill material from the upper portion of the beach to offshore portions of the active beach profile to achieve a more natural equilibrated condition.

The portion of the project located within the Town of Southern Shores extends from station 0+00, which is located approximately 120 feet north of the pier at the Hilton Garden Inn, north to station -25+00, which is located approximately 400 feet north of Skyline Rd. The project includes a 1,500-foot main fill section and a 1,000-foot taper on the north end. The portion of the project located within the Town of Kitty Hawk extends from station 0+00 south to station 189+87, which is located between East Sibbern Drive and East Arch Street. The project in the Town of Kill Devil Hills extends from station 189+87, which is located at the north Town limit, south to approximately station 325+66, which is located at the Prospect Avenue Public Access.

Comparison of the June 2017 (Pre-construction) and December 2017 (Post-construction) profile surveys indicated an increase of approximately 3,174,900 cubic yards of sand fill within the limits of the beach nourishment projects, which is assumed to be directly attributed to the beach fill project. The relative volumes of fill within each project area included: 211,700 cubic yards for Southern Shores, 2,119,700 cubic yards for Kitty Hawk, and 843,600 cubic yards for Kill Devil Hills. These volumes are used as the basis of tracking the performance of the projects.

Data collected in April 2021 (4-year monitoring survey) was compared to beach profile survey data collected in December 2017 (Post-construction survey) and June 2020 (3-year monitoring survey) to assess project performance. Comparison of beach profile data from December 2017 and April 2021 indicated the volume of beach fill remaining within the Southern Shores project

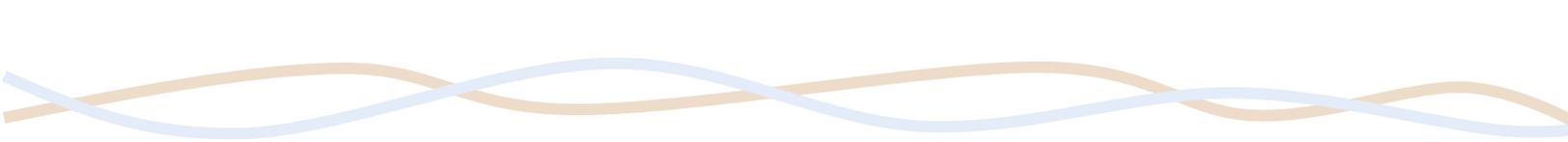
area as of April 2021 was 61.8%. Profile-based volumetric analyses indicated that between December 2017 and April 2021, the Kitty Hawk and Kill Devil Hills project areas lost approximately 444,400 cubic yards and 105,800 cubic yards, respectively. The volumetric losses indicate the volume of beach fill remaining within both projects as of April 2021 was 79.0% for Kitty Hawk and 87.5% for Kill Devil Hills. Table ES-1 summarizes the profile-based volumetric changes measured between December 2017 and April 2021, and June 2020 and April 2021, as well as volumetric changes calculated using the hybrid method comparing June 2020 and April 2021 surveys.

**Table ES-1**  
**Summary of Volumetric Changes (cy) within the Southern Shores, Kitty Hawk, and Kill Devil Hills Project Areas**

Project Area	Beach Profile-Based Volume Change Dec. 2017 to April 2021 (Cubic Yards)	Beach Profile-Based Volume Change June 2020 to April 2021 (Cubic Yards)	Hybrid Based Volume Change Year-3 (June 2020) to Year-4 (April 2021) (Cubic Yards)		
			Landward Portion (Profiles)	Seaward Portion (Bathymetric Surface)	Total
<b>North of Project</b> (-50+00 to -25+00)	-24,000	66,700	72,900	-2,000	70,900
<b>Southern Shores</b> (-25+00 to 0+00)	-80,800	30,300	55,100	-14,700	40,400
<b>Kitty Hawk</b> (0+00 to 189+87)	-444,400	456,900	463,300	-48,700	414,600
<b>Kill Devil Hills</b> (189+87 to 325+66)	-105,800	250,800	177,000	67,300	244,300
<b>South of Project</b> (325+66 to 369+89)	-156,000	-20,300	22,000	--	--

In Kitty Hawk, the rate in which volumetric changes have occurred based on profile-based analysis, does not appear to be linear over the 3.3-year monitoring period. For example, profile-based volumetric change analysis showed that approximately 28% of the initial fill along the Kitty Hawk portion of the project was lost over the 6-month period between December 2017 and June 2018; however, the rate of volume loss tapered off between June 2018 and May 2019. Between May 2019 and February 2020, the analysis indicated volumetric gains occurred along the Kitty Hawk Project Area and losses between February 2020 and June 2020. The most recent data indicated a volume gain from June 2020 to April 2021 of 456,900 cubic yards that represents more than a 50% recovery of the net losses measured over the rest of the post-construction monitoring period from December 2017 to June 2020.

Furthermore, the profile-based volumetric changes varied throughout the length of the Kitty Hawk project. Volumetric changes measured along the Northern Section of the project from the northern Town limit (station 0+00) to approximately 400 feet south of Eckner St. (station 60+50) indicated the project volume has remained relatively stable between December 2017 and April 2021. In fact, the average volumetric density change rate along this portion of the project between December 2017 and April 2021 was less than -1 cy/ft./yr. In the Central and Southern Sections of the project from approximately 400 feet south of Eckner St. to the southern town limit, the April 2021 beach profile surveys indicated losses of approximately 24.5% and 32%, of the volume of



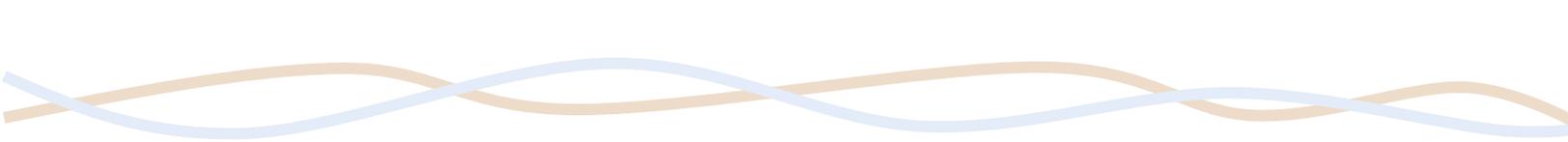
beach fill measured in place in December 2017, respectively. However, the analysis indicated that both the Central and Southern Sections experienced positive volumetric changes between June 2020 and April 2021.

In Kill Devil Hills, following initial negative volumetric losses between December 2017 and June 2018, the Kill Devil Hills project experienced a net positive volumetric change between June 2018 and May 2019. Hurricane Dorian resulted in a significant loss of sand from the project area based on beach profile and shore parallel surveys conducted in May 2019 and February 2020; however, analysis of June 2020 data indicated a slight recovery of material between February 2020 and June 2020. The most recent data indicated a gain from June 2020 to April 2021 of 250,800 cy that represents more than a 72% recovery of the net losses measured over the rest of the post-construction monitoring period (December 2017 to June 2020).

Volumetric changes not only varied temporally, but also spatially throughout the length of the Kill Devil Hills project. Both the Northern (northern town boundary to Random St.) and Southern Section (approximately 300 feet north of East 1<sup>st</sup> St. to Prospect Ave) of the project initially experienced relatively high losses between December 2017 and June 2018, followed by modest increases in volume between June 2018 and May 2019. Both Sections of the project experienced considerable losses associated with Hurricane Dorian; however, in the 14 months from February 2020 to April 2021, the Northern Section experienced a modest negative volumetric change, whereas the Southern Section showed some recovery of volume. Between June 2020 and April 2021, both the Northern and Southern Sections experienced considerable gains. The Central Section of the project, has performed very well, having initially gained volume between December 2017 and May 2019, and remaining relatively consistent between May 2019 and April 2021. Overall, the profile-based volumetric change analysis indicated approximately 87.5% of the beach fill measured in December 2017 remained in place as of April 2021.

As reported in the *2018 Shoreline & Volume Change Monitoring Report*, certain areas offshore of the Kitty Hawk and Kill Devil Hills projects are characterized by nearshore depressions or troughs and shore oblique sandbars. In order to resolve changes in the beach volumes occurring in the offshore portions of the project area, a second method of assessing volumetric changes was used in this study. This method, referred to as the hybrid method, involved the use of more densely spaced offshore bathymetric data to help resolve irregularities that occur offshore Kitty Hawk and Kill Devil Hills.

Table ES-1 shows a comparison between the volumetric changes calculated using beach profile-based method and the hybrid method. The hybrid method showed positive volumetric changes occurring along the Kitty Hawk and Kill Devil Hills project areas between June 2020 and April 2021. The volumetric change calculated between June 2020 and April 2021 using the hybrid method were 9% and 5% less than those computed using the profile-based method for Kitty Hawk and Kill Devil Hills, respectively. Since implementing the hybrid method in 2018, differences between the profile-based method and hybrid method have ranged from the hybrid showing greater volumetric changes, less volumetric changes, and even different trends for Kitty Hawk than Kill Devil Hills in the same year. The discrepancies are believed to be a result of the fact that changes occurring on a particular profile are more heavily weighted over the distance between beach profiles (approximately 1,000 feet), as opposed to the way the offshore volumes are computed



using the hybrid method, which compute the volume using a higher density of data points between individual profiles. Therefore, CPE continues to assert that the volumetric changes computed using the hybrid method more accurately represent changes along the beach fill project.

**TOWN OF KITTY HAWK & KILL DEVIL HILLS  
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A 2021 Town of Kitty Hawk, Town of Kill Devil Hills Topographic and Hydrographic Data Acquisition Report

**TOWN OF KITTY HAWK & KILL DEVIL HILLS  
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MONITORING REPORT**

**I. INTRODUCTION**

The Town of Kitty Hawk has initiated a shore protection project aimed at: 1) reducing the vulnerability of public infrastructure including NC 12, town roads between NC 12 and U.S. Highway 158, as well as utilities to storm-induced erosion; 2) reducing flooding in many non-oceanfront areas throughout the Town during ocean over wash conditions, including portions of NC 12 and U.S. Highway 158; and 3) reducing the vulnerability of homes within the Town that front the Atlantic Ocean and are exposed to wave events during nor'easters and other large storm events. In order to accomplish these goals, the Town of Kitty Hawk is taking steps to maintain its oceanfront beach and dune to a configuration that: provides a reasonable level of storm damage reduction; provides a reasonable level of flood reduction; and mitigates long-term erosion that could threaten public infrastructure and private property as well as recreational opportunities and biological resources.

Likewise, the Town of Kill Devil Hills is focused on a long-term shoreline management program that will serve to sustain the beaches that support a significant portion of their local economy, maintain the tax base of the Town, retain existing recreational resources, and protect existing natural resources. In order to accomplish these stated goals, the Town of Kill Devil Hills has taken steps to maintain its oceanfront beach and dune to a configuration that provides a reasonable level of storm damage reduction to public and private development and mitigates long-term erosion impacts.

The Town of Southern Shores, through coordination with the Town of Kitty Hawk and Dare County, initiated beach nourishment to respond to an erosion episode that manifested along the southern 1,500 feet of its shoreline between 2015 and 2017. The Southern Shores portion of the project was added during the latter stages of the final design for the Kitty Hawk and Kill Devil Hills projects.

The Towns, in cooperation with Dare County and neighboring Town of Duck, successfully completed the initial construction of their shore protection projects in October 2017. The Southern Shores portion of the project consisted of the construction of an approximately 77-foot wide berm at elevation +6.0 feet NAVD88 along the southern 1,500 feet of its shoreline with a 1,000-foot taper on the north end. The Kitty Hawk portion of the shore protection project was designed to create a 60-foot wide berm at elevation +6.0 feet NAVD88 to provide a reduction in wave runup elevation. The design also included the construction of a 10-foot wide dune at elevation +12.0 feet NAVD88 to serve as a "Starter Dune" that could grow through the installation of sand fencing and dune vegetation. A main fill section was constructed along approximately 18,987 feet of oceanfront beginning in the north at station 0+00, which is located approximately 120 feet north of the pier at the Hilton Garden Inn, and ending at the southernmost profile near station 189+87, which is located between East Sibbern Drive and East Arch Street. Since the Kitty Hawk project

was constructed in conjunction with Kill Devil Hills, a taper at the southern Town boundary was not necessary.

Initially, the design of the Kitty Hawk project included a 1,000 ft. taper at the northern town boundary, which would have extended the fill north of its town limits into the southern portion of the Town of Southern Shores. However, after the erosion hot-spot developed along the southern 1,500 feet of Southern Shores in early 2017, the subsequent addition of this 1,500-foot section of the shoreline resulted in the shifting of the 1,000-foot northern taper of the overall project to the north of the Southern Shores erosion hot spot. Figure 1 shows a map depicting the extent of the Kitty Hawk main fill section, the Southern Shores fill, and the taper.

The design for the Kill Devil Hills shore protection project included the construction of a 20-foot wide dune at elevation +15.0 feet NAVD88 fronted by a 40-foot wide berm at elevation +6.0 feet NAVD88 along the northern 12,505 feet of the Town's oceanfront beach. No dune construction was required between stations 240+42 and 269+49 and south of station 304+82 to achieve the design level of storm damage reduction. In addition to the 12,505 ft. design fill section, the project also included a 1,074-foot long taper on the south end. Since the Kill Devil Hills project was constructed in conjunction with Kitty Hawk, a taper north of the Town boundary was not necessary. In total, the Kill Devil Hills project placed sand from baseline station 189+87 (near the northern Town boundary) to station 325+66 (Prospect Ave. Public Access). Figure 2 shows the extent of the project including the main fill construction template, the southern taper, and the construction baseline.

Construction of the Kitty Hawk and Southern Shores projects was accomplished between June 26 and October 21, 2017, while construction of the Kill Devil Hills project occurred between June 22 and August 18, 2017. To account for post-construction changes that immediately follow the placement of a beach fill, a profile survey taken in December 2017 along the entire Project Area was selected to represent post-construction conditions. Based on a comparison of the June 2017 pre-construction survey and the December 2017 post-construction survey, the volume of fill material residing within the Southern Shores Project Area (stations 0+00 to -25+00) as of December 2017 was approximately 211,700 cubic yards. The volume of fill material residing within the Kitty Hawk Project (stations 0+00 to 189+87) and Kill Devil Hills Project (stations 189+87 to 325+66) were approximately 2,119,700 cubic yards and approximately 843,600 cubic yards, respectively. The equivalent density of the beach fill as of December 2017 was approximately 85 cy/ft. for Southern Shores and 112 cy/ft. for Kitty Hawk while the density along Kill Devil Hills was equivalent to 62 cy/ft.

The analysis described in this report focuses on assessing the performance of the beach fill projects constructed in 2017 and providing guidance on planning for future maintenance events.

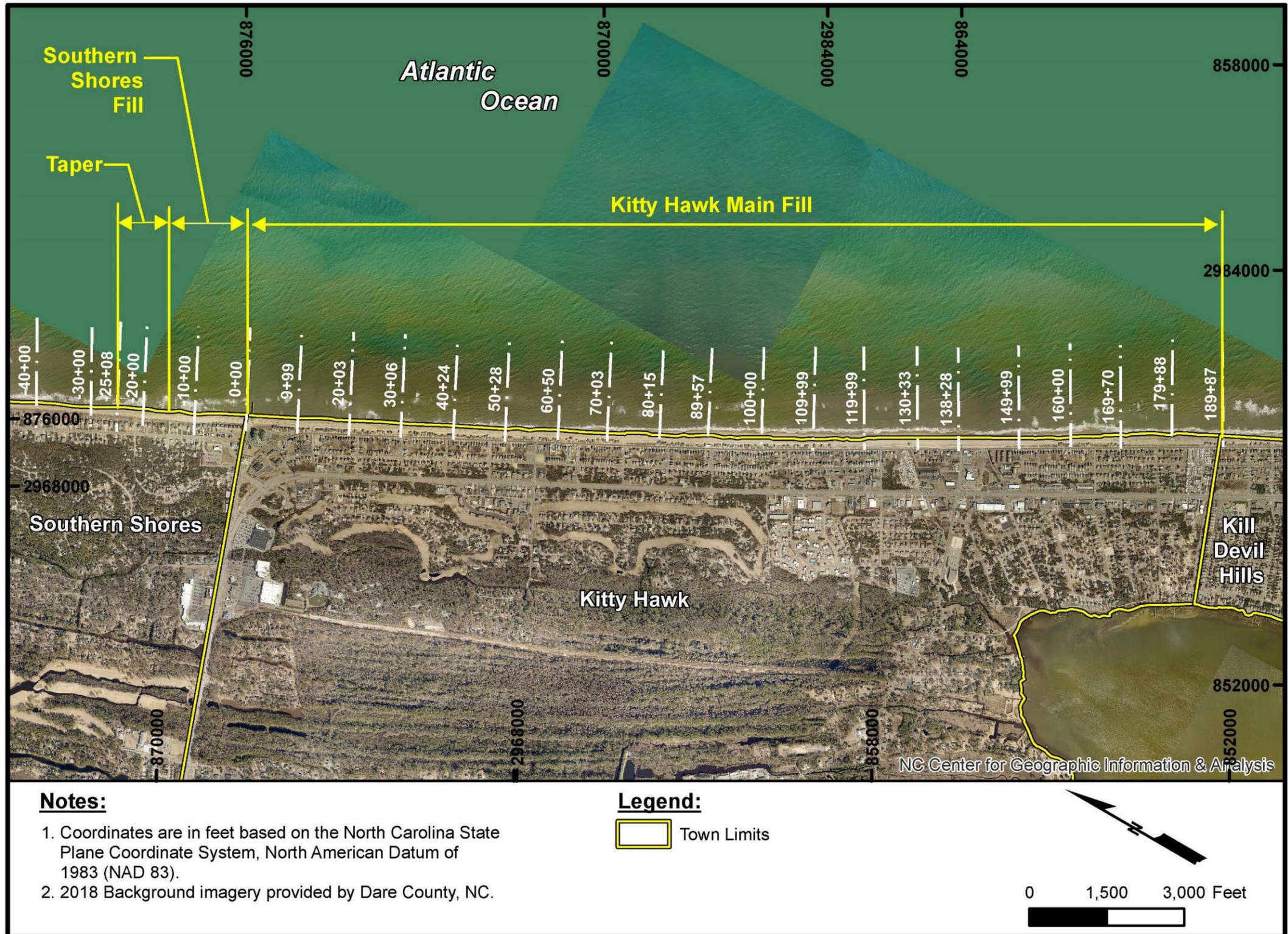


Figure 1. Map showing the Extent of the Project including the Kitty Hawk Main Fill Area, the Southern Shores Fill Area, the Northern Taper, and the Construction Baseline

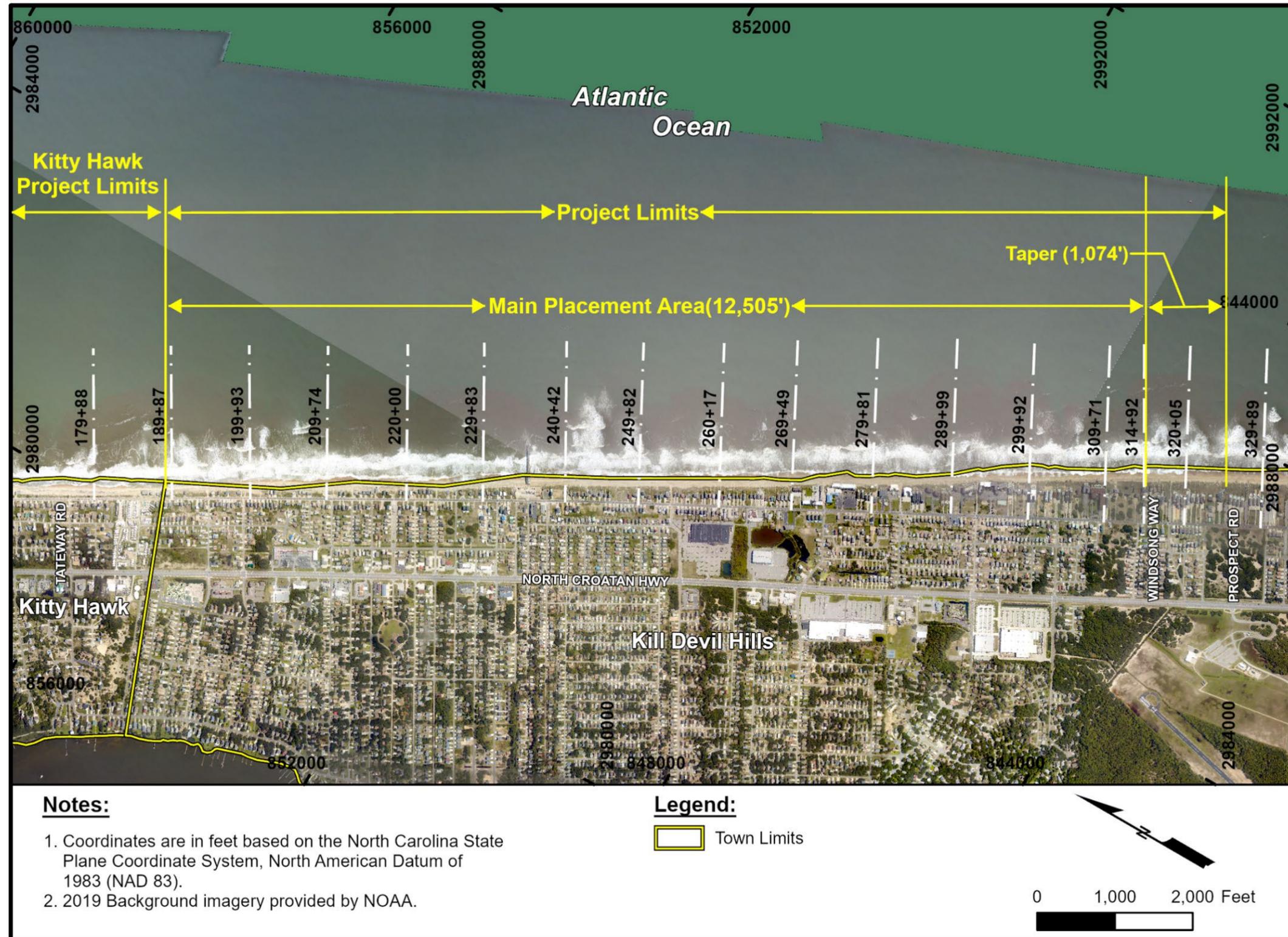
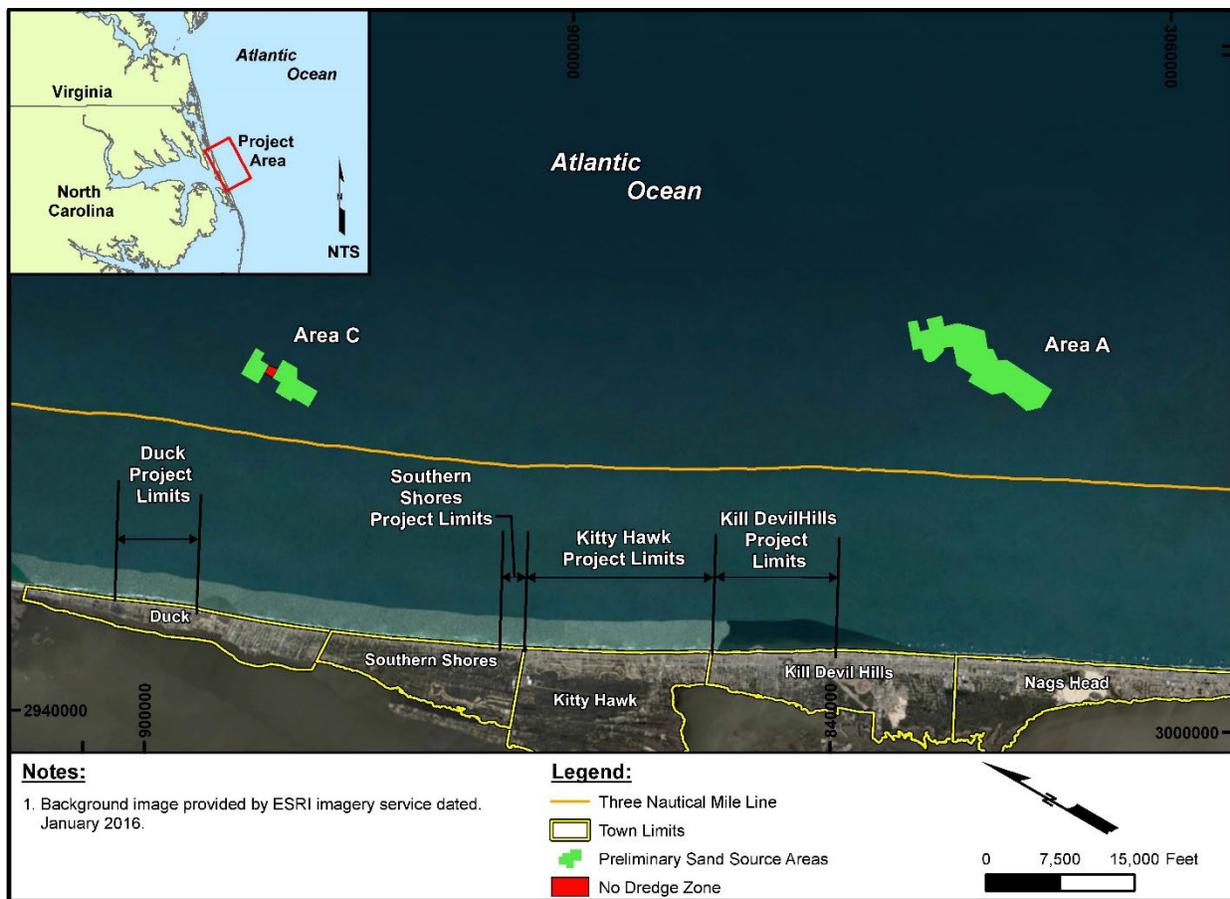


Figure 2. Map showing the Extent of the Project including the Kill Devil Hills Main Fill Area, the Southern Taper, and the Construction Baseline

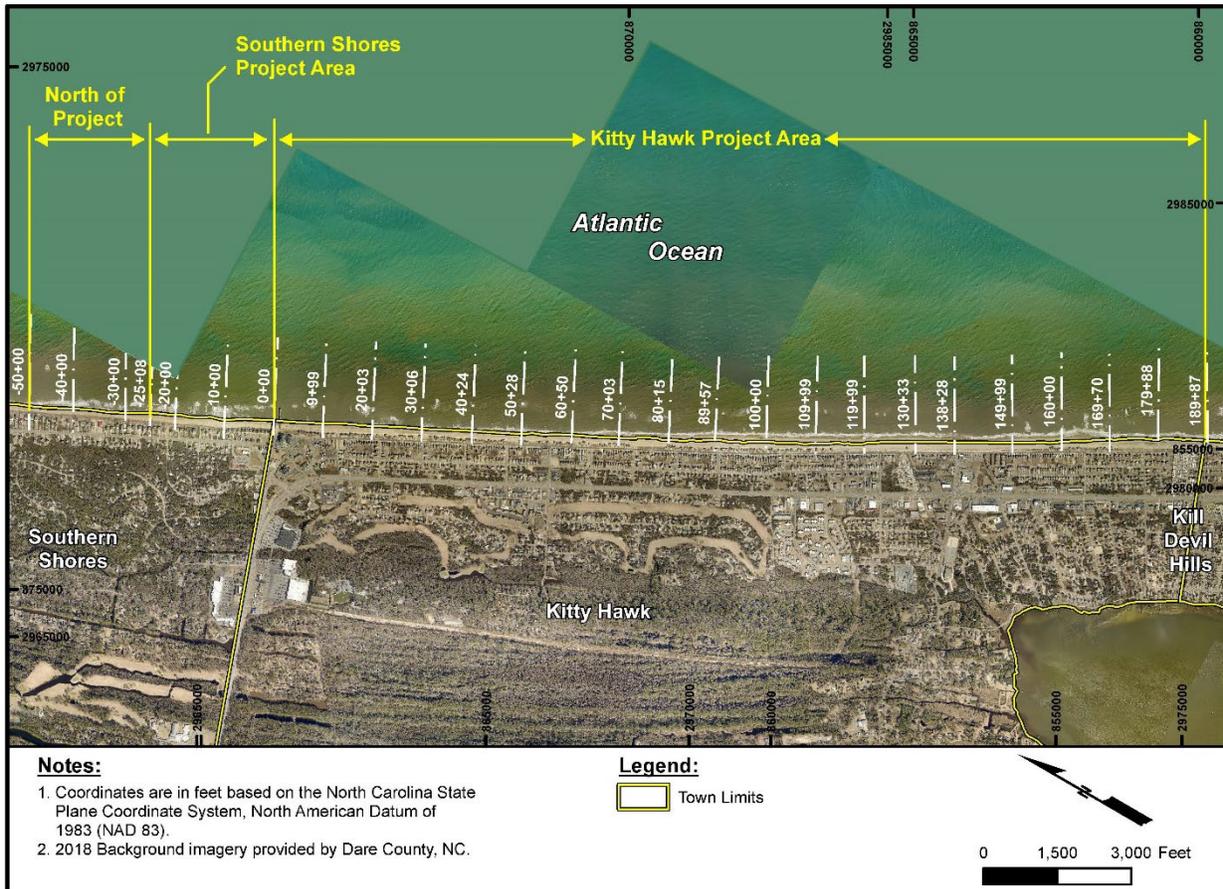
## II. PROJECT LOCATION

The Towns of Kitty Hawk and Kill Devil Hills are located on the Outer Banks of North Carolina roughly 37 and 40 miles south-southeast of the North Carolina and Virginia border, respectively. The Town of Kitty Hawk extends 3.6 miles along Dare County’s oceanfront beach, while Kill Devil Hills, located immediately south of Kitty Hawk, includes 4.7 miles of oceanfront beach. Kitty Hawk is bordered to the north by the Town of Southern Shores; whereas Kill Devil Hills is bordered to the South by the Town of Nags Head. A regional location map is provided in Figure 3. This location map highlights the nourishment projects along the Town’s oceanfront beach and the two Outer Continental Shelf (OCS) borrow areas used to construct the beach nourishment project in 2017. All sand placed along Southern Shores, Kitty Hawk, and Kill Devil Hills was dredged from Borrow Area A.



**Figure 3. Project Location Map**

For the purpose of monitoring, this report has separated the oceanfront beaches of Southern Shores, Kitty Hawk, and Kill Devil Hills into the “Southern Shores Project Area”, the “Kitty Hawk Project Area” and the “Kill Devil Hills Project Area”. The areas north and south of the project areas have been designated as “North of Project” and “South of Project”. The additional profile lines north and south of the project areas are intended to show longshore sediment transport along the beachfront. The entire monitoring area is referred to as the “Study Area”. These distinct areas are depicted in Figure 4 and Figure 5. The Southern Shores Project Area extends from stations -25+00 to 0+00, the Kitty Hawk Project Area includes the beach between the southern boundary of the Town of Southern Shores (station 0+00) to the northern boundary of Kill Devil Hills (approximately station 189+87). The Kill Devil Hills Project Area spans from the southern boundary of the Town of Kitty Hawk to the southern terminus of the beach nourishment project (station 325+66). The “North of Project” area includes the beach from stations -25+00 to -50+00, which lies within the town limits of Southern Shores. The “South of Project” area includes an additional 4,425 ft. of beachfront (from station 325+66 to station 369+89) located within Kill Devil Hills, but outside of the Kill Devil Hills Project Area.



**Figure 4. Project Map showing Northern Half of Monitoring Area**

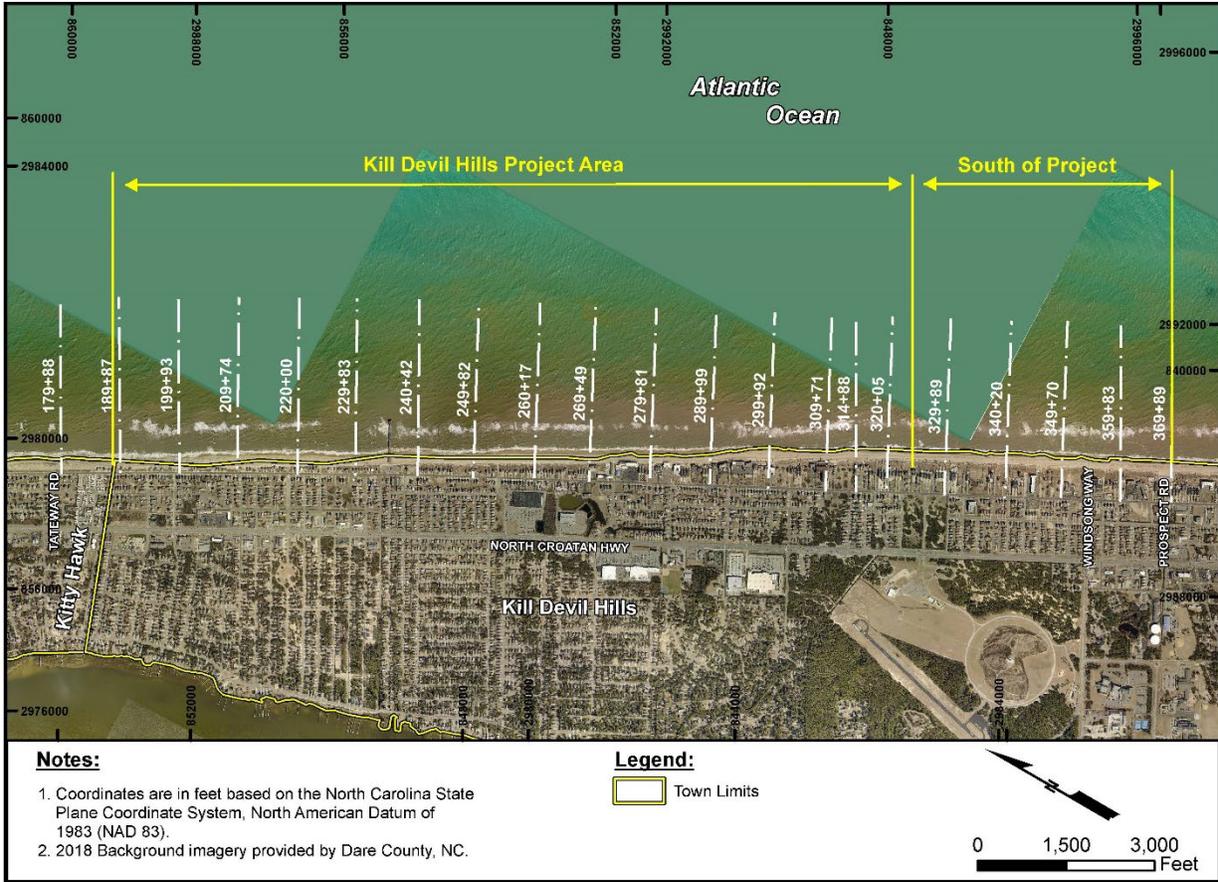


Figure 5. Project Map showing Southern Half of Monitoring Area

### III. DATA COLLECTION

Beach profile data were collected along the oceanfront beaches in Southern Shores, Kitty Hawk, and Kill Devil Hills in June 2017 and December 2017 in the areas where sand was placed during the 2017 project. The area includes 35 beach profiles from stations -20+00 to 320+05 (Figure 4 and Figure 5). All beach profile data collected after the 2017 beach fill project, included three (3) additional profiles north of the Project Area in Southern Shores (stations -50+00 to -30+00) and five (5) additional profiles south of the Project Area in Kill Devil Hills (stations 329+89 to 369+89).

Beginning in June 2018, a profile was added to the annual monitoring at station 314+88. The most recent data set collected in April 2021 included an additional profile at station 325+66, where the taper ended in the 2017 nourishment project. The coordinates of each profile line, referenced to the North Carolina State Plane coordinate system in feet NAD83 and the azimuth of the profile relative to true north are provided in Table 1. Detailed information on the survey conducted in April 2021 is provided in Appendix A – 2021 Town of Kitty Hawk, Kill Devil Hills Topographic and Hydrographic Data Acquisition Report. Appendix A also includes detailed survey methodology, monument information, profile plots, ground digital photography, and field book notes.

**Table 1. Beach Profile Survey Baseline and Azimuth**

Town	Station	Easting	Northing	Azimuth
So. Shores	-50+00	2968838.0	876228.0	62.6
	-40+00	2969249.0	875440.0	62.6
	-30+00	2969731.6	874496.1	62.6
	-20+00	2970189.7	873607.2	62.6
	-10+00	2970653.0	872721.0	62.6
	0+00	2971224.2	871890.8	62.6
	9+99	2971685.8	871003.3	62.6
	20+03	2972153.2	870116.7	62.2
	30+06	2972621.7	869230.0	62.2
	40+24	2973097.5	868329.7	62.2
Kitty Hawk	50+28	2973566.7	867441.7	62.2
	60+50	2974044.0	866538.4	62.2
	70+03	2974489.1	865695.8	62.2
	80+15	2974962.0	864800.8	62.2
	89+57	2975401.9	863968.2	62.2
	100+00	2975900.2	863052.2	61.5
	109+99	2976406.1	862189.9	59.6
	119+99	2976911.9	861327.7	59.6
	130+33	2977435.1	860436.0	59.6
	138+28	2977811.3	859735.5	59.6
	149+99	2978430.3	858740.1	59.6
	160+00	2978966.6	857895.3	59.6
	169+70	2979427.7	857040.4	59.6
	179+88	2979942.7	856163.1	59.6
	189+87	2980448.6	855301.2	59.6
	199+93	2980957.8	854433.7	59.6
	209+74	2981440.4	853579.1	60.5
	220+00	2981944.6	852686.2	60.5
	229+83	2982428.6	851830.2	60.5
	240+42	2982949.5	850908.8	60.5
249+82	2983384.8	850076.1	61.9	
Kill Devil Hills	260+17	2983879.6	849166.0	61.9
	269+49	2984314.0	848341.7	62.2
	279+81	2984795.0	847429.1	62.2
	289+99	2985305.3	846547.0	62.2
	299+92	2985733.2	845649.7	62.2
	309+71	2986193.1	844785.8	62.0
	314+88	2986436.0	844329.4	62.0
	320+05	2986679.0	843873.0	62.0
	325+66	2986919.6	843418.4	62.0
	329+89	2987139.0	843003.8	62.1
	340+20	2987621.2	842092.3	62.1
	349+70	2988097.3	841269.6	62.1
	359+83	2988539.2	840357.5	62.1
	369+89	2989042.4	839485.5	62.1

Beach profile data used in this analysis were collected by Coastal Protection Engineering of North Carolina, Inc. (CPE), with the exception of the pre-construction data (June 2017), which were collected by the dredge contractor's surveyor, TI Coastal. Data collection 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 all 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 data collection extended seaward into wading depths sufficiently to allow the offshore portion to overlap the upland portion by a minimum of 50 feet. More detailed information on data acquisition is available in Appendix A.

During the evaluation of volumetric changes that occurred between December 2017 and June 2018, relatively large volume changes, particularly seaward of the -6 ft. NAVD88 contour, were indicated between stations 119+99 and 138+28 as well as between stations 179+88 and 189+87. Upon closer examination, the ocean floor in this portion of the Kitty Hawk and Kill Devil Hills Project Areas are characterized by near shore depressions or troughs.

The presence of these nearshore depressions was evident based on data plotted from a 2009 multibeam survey conducted by the US Army Corps of Engineers Field Research Facility (USACE FRF). The features were also present on a plot of the data collected by CPE (formerly Aptim Coastal Planning & Engineering of North Carolina, Inc., formerly Coastal Planning & Engineering of North Carolina, Inc.) during a single-beam bathymetric survey conducted in December 2017/February 2018. Comparison of the 2009 USACE FRF survey with the 2017/2018 CPE survey indicated the nearshore depressions were mobile, i.e., they appeared to migrate north to south along the coast. Given the potential influence of the nearshore depressions on the results of beach profile-based analysis, CPE requested and obtained approval from the Town of Kitty Hawk and the Town of Kill Devil Hills to conduct a shore parallel bathymetric survey of the entire project area from station -50+00 in Southern Shores to station 329+89 in Kill Devil Hills. A survey was completed in October 2018 and generally covered the offshore bottom from approximately the -10-foot NAVD88 contour seaward for a distance of approximately 3,000 feet. The survey consisted of track lines spaced 200-feet apart running parallel to the shoreline. CPE used the October 2018 survey data to evaluate changes in the volume of material within the area surveyed during both the October 2018 survey and the December 2017/February 2018 survey.

Based on the initial evaluation of volume changes computed using the higher density shore parallel bathymetric survey data, CPE recommended this methodology of collecting a combination of beach profile and shore parallel bathymetric data to conduct annual monitoring. Beginning in May 2019, CPE has included shore parallel bathymetric data acquisition, along the same track lines surveyed in October 2018, as part of the annual monitoring. Based on numerous verifications of both the hybrid and profile based volumetric change methods, it is the position of CPE that the hybrid method better represents volumetric changes occurring along the project areas. This position aligns with other published literature including Bernstein, et al. (2003).

#### IV. SHORELINE CHANGES

A shoreline change analysis was completed to assess shoreline advance and recession along the study 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. Both the Kitty Hawk and Kill Devil Hills beach nourishment project design used a +6.0 ft. NAVD88 contour for the design berm elevation as described in the project engineering reports (CPE-NC, 2015a and CPE-NC, 2015b). Shoreline change is calculated by comparing shoreline position along shore perpendicular transects. Shoreline changes are described in terms of positive (“+”) or advance (shoreline moving seaward) and negative (“-”) or recession (shoreline moving landward).

The analysis discussed in this report evaluated the +6.0 ft. NAVD88 contour positions measured during the December 2017, June 2020, and April 2021 beach profiles surveys. This report also includes a shoreline comparison of what are referred to as baseline surveys, which represent the initial surveys conducted by CPE during the planning process for the projects. The first survey conducted along Kill Devil Hills by CPE, was conducted in July 2012, and extended from stations 138+28 through 329+88. The first survey conducted along Kitty Hawk by CPE was conducted in April 2014. The +6.0 ft. NAVD88 contour position for each survey was identified at each shore perpendicular transect spaced at approximately 1,000-foot intervals.

**Southern Shores.** Pre-construction surveys performed by Great Lakes Dredge and Dock surveyor in June 2017 and post-construction surveys conducted by CPE in December 2017, indicated the +6.0 ft. NAVD88 contour along the southern 2,000 feet of Southern Shores (stations -20+00 to 0+00) experienced an average seaward shift of +62.7 ft. as a result of the beach fill project. Between December 2017 and April 2021, the profile surveys indicated that the Southern Shores Project Area receded an average of -36.4 ft. landward. The individual measurements from profile to profile vary considerably. The shoreline change measured at station -20+00 shows a modest seaward advancement (+2.8 ft.); whereas shoreline change of -53.6 ft. and -58.5 ft., were measured at stations -10+00 and 0+00 respectively, indicating landward movement over the 3.3-year period between December 2017 and April 2021. Between the most recent survey interval, from June 2020 to April 2021, the +6.0 ft. NAVD88 contour at station -20+00 moved seaward 3.3 feet, whereas landward changes were measured at stations -10+00 and 0+00. Table 2 includes measured shoreline change at each profile as well as the average shoreline change for both the Southern Shores portion of the project and the Kitty Hawk portion of the project.

**Kitty Hawk.** With the construction of the beach nourishment project, the +6.0 ft. NAVD88 contour in Kitty Hawk was moved seaward an average of 104.8 feet between June 2017 and December 2017. The Kitty Hawk +6.0 ft. NAVD88 contour receded landward an average of 42.7 feet between December 2017 and April 2021, which equates to a shoreline change rate of -12.8 ft./yr. During the 3.3-year period, recession (landward movement) of the +6.0 ft. NAVD88 contour was measured along each profile along the Kitty Hawk Project Area with the exception of station 40+24, which saw a +19.2 ft. shoreline change. Between June 2020 and April 2021, the average +6.0 ft. NAVD88 contour moved landward 2.8 feet (Table 2), which equates to an annualized shoreline change rate of -3.4 ft./yr.

**Table 2. +6 ft. NAVD88 Shoreline Changes (ft.) for Southern Shores and Kitty Hawk**

STATION		Baseline (April 2014) to Year-4 Monitoring (April 2021)	Post-Con (December 2017) to Year-4 Monitoring (April 2021)	Year-3 Monitoring (June 2020) to Year-4 Monitoring (April 2021)
North of Project	-50+00	---	-7.7	-2.2
	-40+00	---	3.6	-7.9
	-30+00	---	7.5	26.6
	-20+00	---	2.8	3.3
So. Shores	-10+00	---	-53.6	-7.4
	0+00	-8.5	-58.5	-28.7
Kitty Hawk Project Area	9+99	41.3	-14.5	20.4
	20+03	41.5	-9.8	7.3
	30+06	93.1	-29.0	-44.3
	40+24	108.4	19.2	20.4
	50+28	101.4	-0.4	-6.0
	60+50	78.1	-10.6	-28.8
	70+03	72.2	-33.6	-17.5
	80+15	102.5	-57.1	-22.3
	89+57	87.6	-57.7	24.1
	100+00	67.2	-66.5	1.8
	109+99	59.2	-35.1	18.2
	119+99	54.4	-87.1	-0.9
	130+33	57.6	-92.6	12.1
	138+28	28.0	-98.5	-22.3
	149+99	12.5	-111.2	21.0
	160+00	-3.8	-23.2	-26.6
	169+70	55.4	-35.3	-9.8
179+88	107.0	-5.8	42.9	
189+87	-1.8	-47.0	-17.4	
<b>NORTH OF PROJECT</b> (-50+00 TO -20+00)		---	1.6	4.9
<b>SOUTHERN SHORES</b> (-20+00 TO -0+00)		---	-36.4	-10.9
<b>KITTY HAWK</b> (0+00 TO 189+87)		57.7	-42.7	-2.8

Although the average shoreline change measured along the Kitty Hawk Project Area between December 2017 and April 2021 showed recession (landward movement of the shoreline), a profile-by-profile comparison shows a wide range of changes in the position of the +6.0 ft. NAVD88 contour (Table 2). Over the 3.3-year monitoring period, the shoreline changes measured along the Kitty Hawk Project Area ranged from an advance of +19.2 ft. at station 40+24 (approximately 120 feet south of Bennett St.) to a recession of -111.2 ft. at station 149+99 (located approximately 150 feet south of the Sea Dunes townhomes). On average, shoreline change trends in the Northern

Section tended to be lower than those in the Central and Southern Sections. The average shoreline change from station 0+00 (northern Town boundary) to 60+50 (located approximately 400 feet south of Eckner St.) was -14.8 ft. between December 2017 and April 2021. This equates to an average shoreline change rate of approximately -4.4 ft./yr. The average shoreline change measured between December 2017 and April 2021 in the Central Section of the project (station 60+50 to 119+99 or approximately 400 feet south of Eckner St. to approximately 300 feet north of Lillian St.) was -49.7 ft. This equates to an average shoreline change rate of approximately -14.9 ft./yr. The highest shoreline changes were measured along the Southern Section of the project from station 119+99 (approximately 300 feet north of Lillian St.) to 189+87 (southern Town boundary). The average shoreline change measured along this stretch over the 3.3-year monitoring period was -62.6 ft., which equates to an average rate of -18.8 ft./yr. The higher average in the Southern Section was primarily driven by shoreline changes measured along the section from station 119+99 (located approximately 300 feet north of Lillian St.) and 149+99 (located approximately 150 feet south of the Sea Dunes townhomes).

The shoreline change measured at station 149+99, located approximately 150 feet south of the Sea Dunes townhomes, is associated with the hot spot erosion which is shown in Figure 6. This hot spot appears to be approximately 800 feet long and is believed to be heavily influenced by the irregular bathymetry offshore of this portion of the project. This is discussed in greater detail in the volumetric section of the report.

Analysis of shoreline changes measured between June 2020 and April 2021, shows a different trend from those measured over the longer 3.3-year period from December 2017 to April 2021. An average shoreline change of -8.5 ft. was measured along the Northern Section of the Project Area (north of station -60+50 located approximately 400 feet south of Eckner St.). This equates to an average annualized rate of approximately -10.2 ft./yr. In the Central Section of the project between stations 60+50 and 119+99, the average shoreline change measured over the 10-month period was -3.6 ft., or an annualized average rate of -4.3 ft./yr. The average volumetric change along the Southern Section of the Kitty Hawk Project Area was essentially 0 ft.

The data provided in Table 2 also shows that in comparison to the original baseline survey conducted in Kitty Hawk in April 2014, the average position of the +6.0 ft. NAVD88 contour in April 2021, was approximately 57.7 feet seaward of the baseline position. The most significant seaward movement of the +6.0 ft. NAVD88 contour has occurred between stations 30+06 (near Maynard St.) and 89+57 (approximately 100 feet north of Balchen St.), along which the average shoreline change measured a seaward advance of 91.9 ft. All stations surveyed in April 2021 show an advance of the shoreline position compared to the baseline surveys with the exception of stations 160+00 and 189+87 (located at the southern Town boundary), which showed the April 2021 shoreline landward of where they were in April 2014 by distances of 3.8 ft. and 1.8 ft., respectively.



**Figure 6. Drone Image of Erosional Hot Spot at Station 149+99 from July 16, 2020**

**Kill Devil Hills.** With the construction of the 2017 beach nourishment project, the +6.0 ft. NAVD88 contour in Kill Devil Hills was moved seaward an average of 31.8 ft. between June 2017 and December 2017. Between December 2017 and April 2021, the +6.0 ft. NAVD88 contour position along the Kill Devil Hills Project Area (stations 189+87 to 320+05) receded an average of -5.8 ft. During the most recent survey interval from June 2020 to April 2021, the average +6.0 ft. NAVD88 contour remained essentially stable (+0.7 ft.). Table 3 shows the measured change at each profile location.

A profile-by-profile analysis of the Kill Devil Hills Project Area showed a wide range of shoreline changes measured between December 2017 and April 2021, ranging from an advance of 63.4 ft. at station 249+82 to a recession of -56.9 ft. at station 199+93 (Table 3). The average +6.0 ft. NAVD88 contour position along the Northern Section of the project from station 189+87 (northern Town boundary) to 229+83 (approximately 600 ft. north of the Avalon Pier) moved -28.6 feet (landward) over the 3.3-year period. Along the Central Section that extends from station 229+83 to 289+99, the average position of the +6.0 ft. NAVD88 contour moved +11.2 feet (seaward) over the 3.3-year period. Along the Southern Section that extends from station 289+99 (approximately 320 ft. north of East First St.) to 320+05 (approximately 200 feet south of the Asheville St. Beach Access), the average +6.0 ft. NAVD88 contour moved +1.9 feet (seaward) over the 3.3-year period.

From June 2020 to April 2021, the shoreline change varies from -30.8 ft. at station 240+42 (approximately 500 ft. south of the Avalon Pier) to 33.9 ft. at station 220+00 (E. Archdale St.). Over the recent period between June 2020 and April 2021, positive average shoreline change was measured along the Northern and Southern Sections (+4.2 ft. and +2.0 ft., respectively), while on average negative shoreline change was measured along the Central Section (-3.1 ft.).

The data provided in Table 3 also shows that in comparison to the original baseline survey conducted in Kill Devil Hills in July 2012, the average position of the +6.0 ft. NAVD88 contour in April 2021, was approximately 38.3 feet seaward of the baseline position. The most significant seaward movement of the +6.0 ft. NAVD88 contour has occurred between stations 209+74 (near E. Wilkinson St.) and 260+17 (approximately 360 feet north of 4<sup>th</sup> St.), along which the average shoreline change measured a seaward advance of 73.3 ft. All stations surveyed in April 2021 show an advance of the +6.0 ft. NAVD88 contour compared to the baseline surveys with the exception of stations 189+87 (located at the southern Town boundary), 199+93 (approximately 300 feet north of Lillian St.), and 320+05 (approximately 200 ft south of the Asheville St. beach access), which showed the April 2021 +6.0 ft. NAVD88 contour landward of where they were in July 2012 by distances of 36.2 ft. and 10.5 ft., and 5.7 ft., respectively.

**Table 3. +6.0 ft. NAVD88 Shoreline Changes (ft.) for Kill Devil Hills**

STATION		Baseline (July 2012) to Year-4 Monitoring (April 2021)	Post-Con (December 2017) to Year-4 Monitoring (April 2021)	Year-3 Monitoring (June 2020) to Year-4 Monitoring (April 2021)
Kill Devil Hills Project Area	189+87	-36.2	-47.0	-17.4
	199+93	-10.5	-56.9	0.2
	209+74	59.6	-50.9	-4.2
	220+00	109.7	-6.1	33.9
	229+83	47.8	18.1	8.3
	240+42	27.9	-26.6	-30.8
	249+82	109.3	63.4	32.7
	260+17	85.7	36.3	3.9
	269+49	14.9	-22.4	-20.6
	279+81	39.9	2.6	-5.2
	289+99	40.0	7.0	-10.0
	299+92	21.8	4.1	28.7
	309+71	32.4	-10.2	26.1
	314+88	-	-	-25.9
320+05	-5.7	6.9	-9.0	
South of Project	325+66	---	-	-
	329+89	---	-30.3	-45.5
	340+20	---	2.1	-23.9
	349+70	---	29.1	46.3
	359+83	---	-43.6	-40.8
	369+89	---	-27.3	-8.4
<b>KILL DEVIL HILLS (189+87 TO 320+05)</b>		38.3	-5.8	0.7
<b>SOUTH OF PROJECT (329+89 TO 369+89)</b>		---	-14.0	-14.5

**North of Project.** The average shoreline change between December 2017 and April 2021 north of the beach nourishment project in Southern Shores (stations -50+00 to -20+00) was +1.6 ft. The April 2021 data indicates that since December 2017, the shoreline change has been positive (seaward) from stations -40+00 (72 Ocean Blvd.) to -20+00 (approximately 130 feet south of Skyline Rd.); whereas a negative (landward) shoreline change occurred at station -50+00 (located approximately 450 feet south of Chicahawk Trail). As shown in Table 2, between June 2020 and April 2021, the shoreline receded (landward) at stations -50+00 and -40+00 and advanced (seaward) at stations -30+00 and -20+00.

**South of Project.** The average shoreline change between December 2017 and April 2021 south of the project in Kill Devil Hills (between stations 329+88 and 369+89) was -14.0 ft. (landward). The negative shoreline change trend along the South of Project area, is being driven by relatively high shoreline changes measured between June 2020 and April 2021. The average shoreline change measured along the South of Project area during this interval was -14.5 feet, as shown in Table 3.

## V. VOLUMETRIC CHANGES

In this study, two (2) different methods were used to assess volumetric changes throughout the Project Area. The first method used beach profile surveys collected in June 2017, December 2017, June 2020, and April 2021. The comparison of these profiles and the use of the average end area method, allows for the calculation of volumetric changes associated with the initial construction of the project, as well as changes that have occurred since December 2017. Comparison of beach profile data is a standard method for assessing volumetric changes for a beach.

The second method used in this study to assess volume changes, which is referred to as the hybrid method, involved the combination of beach profile data and a more densely spaced offshore bathymetric data set to help resolve irregularities that occur offshore of Kitty Hawk and Kill Devil Hills. As reported in the *2018 Shoreline & Volume Change Monitoring Report*, certain areas offshore of the Kitty Hawk and Kill Devil Hills projects are characterized by nearshore depressions or troughs and shore oblique sandbars (APTIM, 2019).

The initial assessment of volume change based on beach profiles collected in December 2017 and June 2018, indicated a strong correlation between the location of the nearshore depressions and locations along the beach in which high volume losses were measured. This initial observation prompted the collection of additional bathymetric data by CPE, in October 2018. The data acquisition consisted of shore-parallel lines spaced approximately 200-feet apart, extending from approximately the -10 ft. NAVD88 contour out to a depth of at least -30 ft. NAVD88, along which bathymetric data were collected. Data were collected alongshore from station -50+00 in Southern Shores to station 329+89 in Kill Devil Hills.

The data collected in October 2018 served two (2) purposes. The first was to create a project wide baseline to compare to future data. The second was to assess the potential influence that the nearshore troughs or depressions may have had on the calculations of volume change using

standard beach profile data. In order to assess this influence, data collected in October 2018 was compared to bathymetric data obtained by CPE between December 2017 and February 2018 along a portion of the Project Area between stations 75+79 and 216+07. This analysis found a considerable difference in the volume change measured using beach profile data and the volume change measured using the hybrid method, which uses both beach profile data and more densely spaced shore-parallel bathymetry (APTIM, 2019). The differences in the volumetric change results obtained from the profile-based analysis and the hybrid method was primarily attributed to the three-dimensional changes in the offshore bottom that are occurring as a result of the mobile nature of the nearshore depressions whereas the profile lines are only capable of identifying two-dimensional changes. In this regard, elevations obtained along a given profile located in proximity to the nearshore depressions can exhibit significant changes from one survey to the next as these features migrate along the given profile. Since the profiles used in the monitoring program are spaced approximately 1,000 feet apart, any change measured along a given profile has a significant influence on volumes measured using the average end area method. Conversely changes in the offshore topography between the profile lines due to the movement of the depressions would not be captured by surveys conducted along the two-dimensional profiles. Cross-shore profiles spaced more closely together (i.e. 500-feet) may resolve some of these changes; however, CPE recommended the collection of bathymetric data in the offshore areas in question, using closely spaced shore parallel transects, as a better option.

The hybrid method of computing volumetric changes uses beach profile data to compute upland and nearshore volume change (out to approximately -16 ft. NAVD88) and bathymetric data collected along more densely spaced shore-parallel track lines to calculate the offshore portion of the Project Area between approximately -16 ft. NAVD88 and the depth of closure (-24 ft. NAVD88).

Results of both the profile-based volumetric analysis and the hybrid method are provided in the following sections. Furthermore, a recount of initial beach fill volumes is also provided for context.

### **Initial Beach Fill Volumes**

Based on volume changes computed using the profile-based method, between the June 2017 Pre-construction survey and the December 2017 Post-construction survey, approximately 211,700 cubic yards of beach fill material resided along the southern 2,500 feet of the Southern Shores Project Area with approximately 2,119,700 cubic yards retained along the 18,987 feet of the Kitty Hawk Project Area. The Kill Devil Hills project contained approximately 843,600 cubic yards of fill along the 13,579 feet of its Project Area. In all, between June and December 2017, an increase of approximately 3,174,900 cubic yards of beach fill material were measured on the active profile (above the -24-foot NAVD88 contour) between station -25+00 in Southern Shores and station 325+66 in Kill Devil Hills.

## **Beach Profile Based Volume Changes**

**Southern Shores.** For the 2,500-foot project along the southern end of the Town of Southern Shores (which includes the 1,000-foot taper), beach profile surveys indicate a volumetric change of approximately -69,400 cubic yards between December 2017 and April 2021, or approximately -29.4 cy/ft. This volume is significantly less than the volumetric loss reported in the 2020 monitoring report (CPE, 2020b), due to the gain of approximately 40,400 cubic yards of material between June 2020 and April 2021. As of April 2021, the profile-based analysis suggests that approximately 67.2% of the volume measured along the Southern Shores portion of the beach fill project in December 2017 above the -24-foot NAVD88 contour, was still present.

Table 4 includes both profile by profile and average profile-based volumetric changes measured between June 2017 (Pre-construction) and December 2017 (Post-construction), between December 2017 and April 2021, and between June 2020 and April 2021 for the Southern Shores and Kitty Hawk portions of the project.

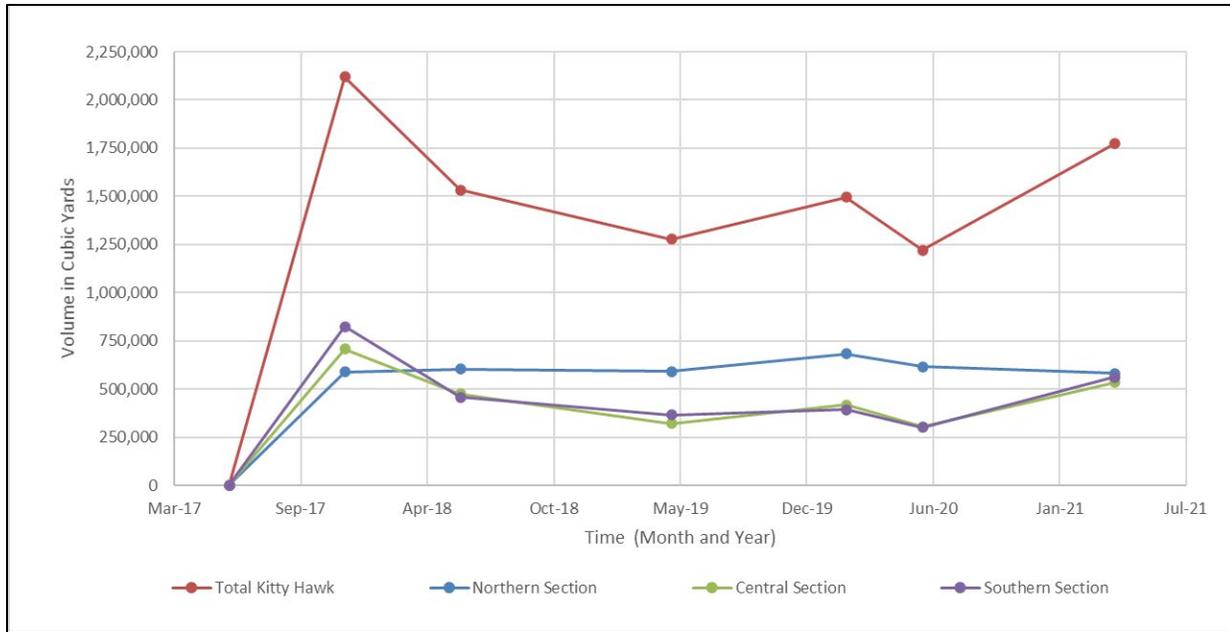
**Kitty Hawk.** Beach profile surveys indicate that the Kitty Hawk beach fill project lost approximately 444,400 cubic yards between December 2017 and April 2021. This equates to net negative change of approximately -26.3 cy/ft. As of April 2021, the profile-based analysis suggests that approximately 79% of the volume measured along the Kitty Hawk portion of the beach fill project in December 2017, above the -24 ft. NAVD88 contour, was still present.

Similar to Southern Shores, the profile-based analysis indicated a net gain of material between June 2020 and April 2021. During the 10-month period a net gain of approximately 456,900 cy was measured. Figure 7 shows the cumulative profile-based volumetric changes for the Town of Kitty Hawk Project measured since the June 2017 pre-construction survey. The positive volumetric change measured over the recent 10-month period represents a recovery of approximately half of the negative volumetric change measured between December 2017 and June 2020.

The measured volumetric change was not uniform along the length of the Kitty Hawk Project. This report discusses changes in terms of the Northern, Central, and Southern Sections of Kitty Hawk. The Northern Section refers to the portion of the project between stations 0+00 (northern Town boundary) to 60+50 (located approximately 400 feet south of Eckner St.). Analysis of beach profile data indicate that between June 2017 and December 2017, a positive volume change of approximately 588,600 cy occurred along this portion of the project as a result of construction of the beach fill project. As shown in Figure 7, between December 2017 and April 2021, the volume measured along this section of beach has remained relatively steady. In fact, the average volumetric density change rate along this portion of the project between December 2017 and April 2021 was less than -1 cy/ft./yr.

**Table 4. Profile-Based Volumetric Changes (cy) North of Project Area and along Southern Shores and Kitty Hawk, above -24 ft. NAVD88**

STATION		Pre-Con (June 2017) to Post-Con (December 2017)	Post-Con (December 2017) to Year-4 Monitoring (April 2021)	Year-3 Monitoring (June 2020) to Year-4 Monitoring (April 2021)
North of Project	-50+00 To -40+00	---	-19,800	7,500
	-40+00 To -30+00	---	-9,500	30,400
	-30+00 To -25+00	---	-6,100	18,700
So. Shores	-25+00 To -20+00	32,000	-6,100	18,700
	-20+00 To -10+00	76,900	-36,700	13,700
	-10+00 To 0+00	102,800	-26,600	8,000
Kitty Hawk Project Area	0+00 To 9+99	84,500	-22,900	38,000
	9+99 To 20+03	74,300	-19,400	25,200
	20+03 To 30+06	107,100	-5,500	-59,700
	30+06 To 40+24	119,500	16,000	-28,100
	40+24 To 50+28	108,500	17,500	18,100
	50+28 To 60+50	94,700	6,700	-27,100
	60+50 To 70+03	99,200	3,700	-13,100
	70+03 To 80+15	113,700	-21,400	13,900
	80+15 To 89+57	105,100	-36,700	34,400
	89+57 To 100+00	150,100	-46,000	69,900
	100+00 To 109+99	135,500	-38,000	67,400
	109+99 To 119+99	103,600	-34,900	57,900
	119+99 To 130+33	127,800	-34,300	72,300
	130+33 To 138+28	119,300	-12,600	32,300
	138+28 To 149+99	143,500	-74,400	13,000
	149+99 To 160+00	80,900	-85,300	-17,900
160+00 To 169+70	84,000	-32,100	-7,300	
169+70 To 179+88	107,100	23,900	84,000	
179+88 To 189+87	161,300	-48,900	83,700	
<b>NORTH OF PROJECT</b> (-50+00 To -25+00)		---	-35,400	56,600
<b>SOUTHERN SHORES</b> (-25+00 To -0+00)		211,700	-69,400	40,400
<b>KITTY HAWK</b> (0+00 To 189+87)		2,119,700	-444,400	456,900



**Figure 7. Graph showing Cumulative Volume Changes along Kitty Hawk as Calculated using Profile-Based Volume Changes**

The Central Section refers to the portion of the project between station 60+50 (located approximately 400 feet south of Eckner St.) and station 119+99 (located approximately 300 feet north of Lillian St.). Beach profile surveys indicate that between June 2017 and December 2017, a positive volume change of approximately 707,200 cy occurred along this portion of the project as a result of construction of the beach fill project. As shown by the green trend line in Figure 7, a net negative volume change was measured between December 2017 and April 2021 along the Central Section. Values reported in Table 4 show the volumetric change amounts to approximately -173,300 cy. This net loss equates to approximately 24.5% of the volume increase measured between June and December 2017, which is attributed to the construction of the project. Figure 7 also indicates an increase in the cumulative volume between June 2020 to April 2021. The values reported in Table 4 show this net positive volumetric change to be approximately 230,400 cy.

The Southern Section refers to the portion of the project between station 119+99 (located approximately 300 feet north of Lillian St.) and station 189+87 (southern Town boundary). Beach profile surveys indicate that between June 2017 and December 2017, a positive volume change of approximately 823,900 cy occurred along this portion of the project as a result of construction of the beach fill project. As shown by the purple trend line in Figure 7, a net negative volume change was measured between December 2017 and April 2021. Values reported in Table 4 show the volumetric change amounts to approximately -263,700 cy. This loss equates to approximately 32% of the volume increase measured between June and December 2017, which is attributed to the construction of the project. Figure 7 also indicates an increase in the cumulative volume between June 2020 to April 2021. The values reported in Table 4 show this net positive volumetric change to be approximately 260,100 cy.

**Kill Devil Hills.** Results from the profile-based method of computing volumetric change for the Kill Devil Hills beach fill project shows a negative volumetric change of -105,800 cubic yards between December 2017 and April 2021. This equates to approximately -12.9 cy/ft. As of April 2021, the profile-based analysis suggests that approximately 87.5% of the volume measured along the Kill Devil Hills portion of the beach fill project in December 2017, above the -24-foot NAVD88 contour, was still present.

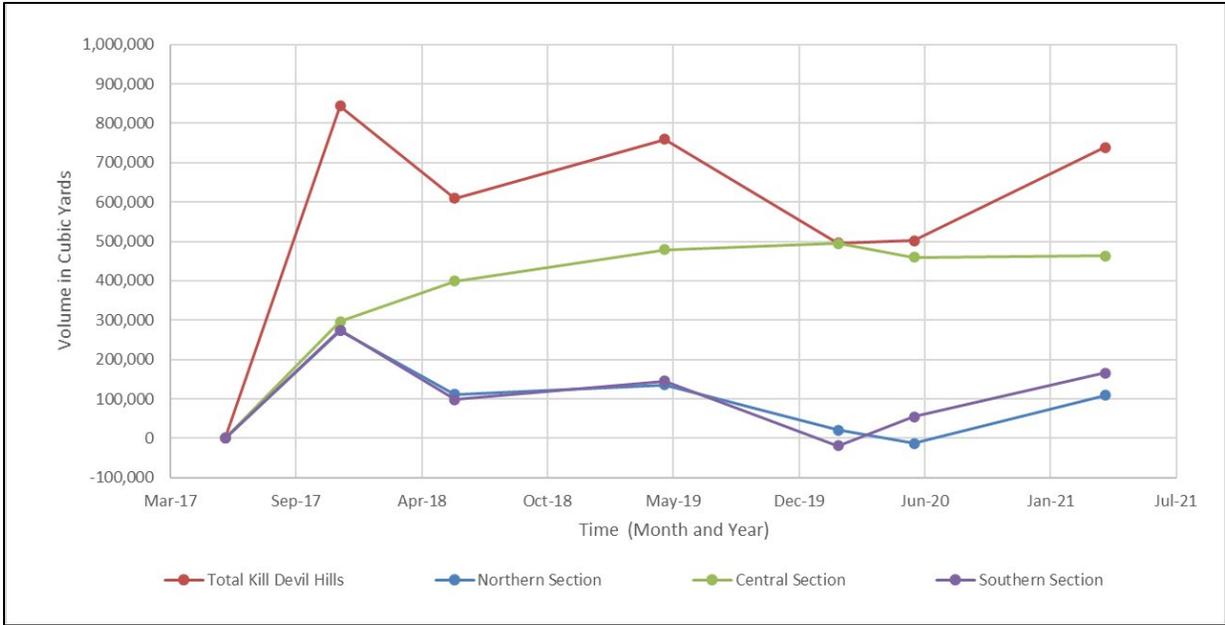
Similar to Southern Shores and Kitty Hawk, the profile-based analysis indicated a net gain of material between June 2020 and April 2021. During the 10-month period a net gain of approximately 250,800 cubic yards was measured. Figure 8 shows the cumulative profile-based volumetric changes for the Town of Kill Devil Hills Project since the June 2017 Pre-construction survey. The positive volumetric change measured over the recent 10-month period represents a recovery of approximately 72% of the negative volumetric change measured between December 2017 and June 2020.

The measured volume changes were not uniform along the length of the Kill Devil Hills Project. This report discusses changes in terms of the Northern, Central, and Southern Sections of the Kill Devil Hills Project. The Northern Section refers to the portion of the project between stations 189+87 (northern Town boundary) to 229+83 (located approximately 600 feet north of the Avalon Pier, near Random St.). Beach profile surveys indicate that between June 2017 and December 2017, a positive volume change of approximately 273,200 cy occurred along this section of the project as a result of construction of the beach fill project. Between December 2017 and April 2021, a negative volume change of approximately -164,400 cy was measured along this section of the Project. This net loss represents approximately 60% of the volume increase measured between June and December 2017, which is attributed to the construction of the project. Figure 8 illustrates that a general trend of losses along the Northern Section occurred between December 2017 and June 2020, followed by a net increase of approximately 122,000 cy between June 2020 and April 2021.

The Central Section refers to the portion of the project between station 229+83 (located approximately 600 feet north of the Avalon Pier, near Random St.) and station 289+99 (located approximately 320 feet north of East 1<sup>st</sup> St.). Beach profile surveys indicate that between June 2017 and December 2017, a positive volumetric change of approximately 296,100 cy occurred along this portion of the project as a result of construction of the beach fill project. As shown by the green trend line in Figure 8, a net positive volumetric change was measured between December 2017 and April 2021 along the Central Section. Values reported in Table 5 show the volumetric change amounts to approximately 167,800 cy. This net gain equates to an approximate 57.0% increase in the volume measured between June and December 2017 (project construction). Figure 8 also illustrates that a positive volume change trend was measured between each survey in the Central Section between December 2017 and February 2020; however, following the February 2020 (post-Dorian) survey, a modest decrease in the cumulative volume was measured between February and June 2020. Between June 2020 and April 2021, the cumulative volume remained relatively unchanged.

**Table 5. Profile-Based Volumetric Changes (cy) along Kill Devil Hills and South of Project Area, above -24 ft. NAVD88**

STATION				Pre-Con (June 2017) to Post-Con (December 2017)	Post-Con (December 2017) to Year-4 Monitoring (April 2021)	Year-3 Monitoring (June 2020) to Year-4 Monitoring (April 2021)
Kill Devil Hills Project Area	189+87	To	199+93	149,200	-111,900	41,500
	199+93	To	209+74	92,600	-53,900	23,400
	209+74	To	220+00	60,300	6,000	34,600
	220+00	To	229+83	-28,900	-4,600	22,500
	229+83	To	240+42	-10,300	-87,000	-95,000
	240+42	To	249+82	39,400	33,700	-40,900
	249+82	To	260+17	41,100	137,000	82,000
	260+17	To	269+49	53,600	53,900	43,900
	269+49	To	279+81	76,500	17,300	8,800
	279+81	To	289+99	95,800	12,900	5,100
	289+99	To	299+92	95,600	9,800	46,900
	299+92	To	309+71	71,000	6,900	62,600
	309+71	To	314+88	40,400	-31,900	18,900
314+88	To	320+05	40,400	-31,900	11,600	
320+05	To	325+66	26,900	-62,100	-15,100	
South of Project	325+66	To	329+89	-	-46,800	-11,400
	329+89	To	340+20	-	-75,900	-46,900
	340+20	To	349+70	-	-800	40,000
	349+70	To	359+83	-	-5,000	10,700
	359+83	To	369+89	-	-27,500	-12,700
<b>KILL DEVIL HILLS (189+87 To 325+66)</b>				843,600	-105,800	250,800
<b>SOUTH OF PROJECT (325+66 To 369+89)</b>				---	-156,000	-20,300



**Figure 8. Graph showing Cumulative Volume Changes along Kill Devil Hills as Calculated using Profile-Based Volume Changes**

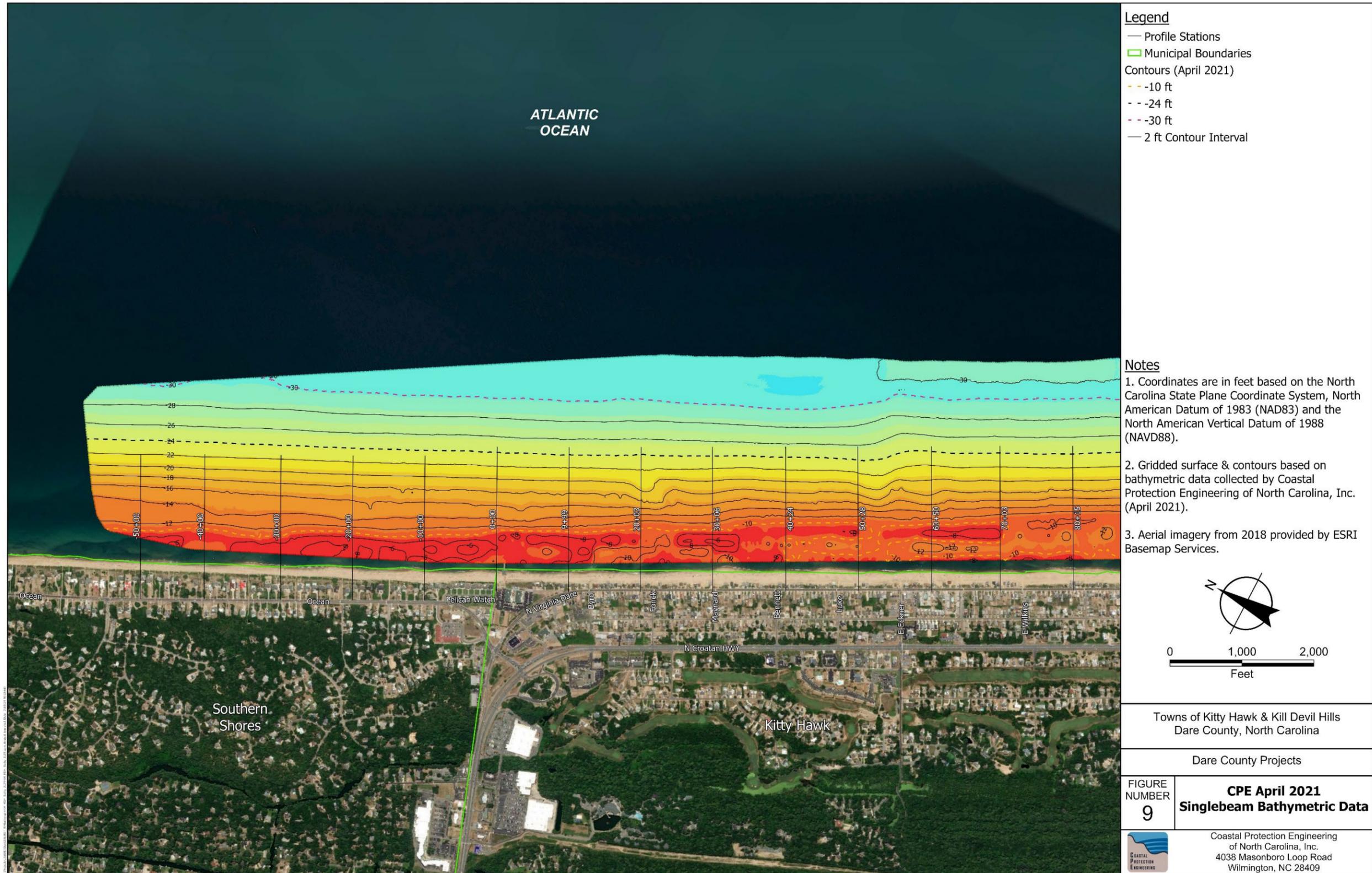
The Southern Section refers to the portion of the project between station 289+99 (located approximately 320 feet north of East 1<sup>st</sup> St.) and station 325+66 (located near the Prospect Ave. beach access). Beach profile surveys indicate that between June 2017 and December 2017, a positive volume change of approximately 274,300 cy occurred along this portion of the project as a result of construction of the beach fill project. Similar to the trend measured in the Northern Section of the project, Figure 8 shows an overall negative volume change between December 2017 and April 2021. Between December 2017 and June 2018, the Southern Section experienced negative volumetric changes equivalent to approximately 64% of the positive volumetric changes that occurred due to construction of the project. Between June 2018 and May 2019 this section experienced modest positive volumetric changes. Post-storm surveys (February 2020) indicated significant losses between May 2019 and February 2020. As of February 2020, more than 100% of the volumetric changes attributed to the construction of the project in the Southern Section, had been lost. Since February 2020, a positive volumetric change has been measured along the Southern Section of the project. While the net volumetric change measured between December 2017 and April 2021 was approximately -109,200 cy, which equates to approximately 39.8% of the volume measured between June and December 2017 (project construction), the net volumetric change measured since June 2020 is +124,900 cy.

**North of Project.** Profile-based volumetric changes measured between December 2017 and April 2021 were also calculated along the 2,500 feet of shoreline north of the Project Area (stations -50+00 to -25+00). The measured volumetric change along the 2,500 feet section north of the project between December 2017 and April 2021 was approximately -35,400 cubic yards. Between June 2020 and April 2021 profile-based volume change analysis indicated a positive volume change of approximately 56,600 cy (Table 4).

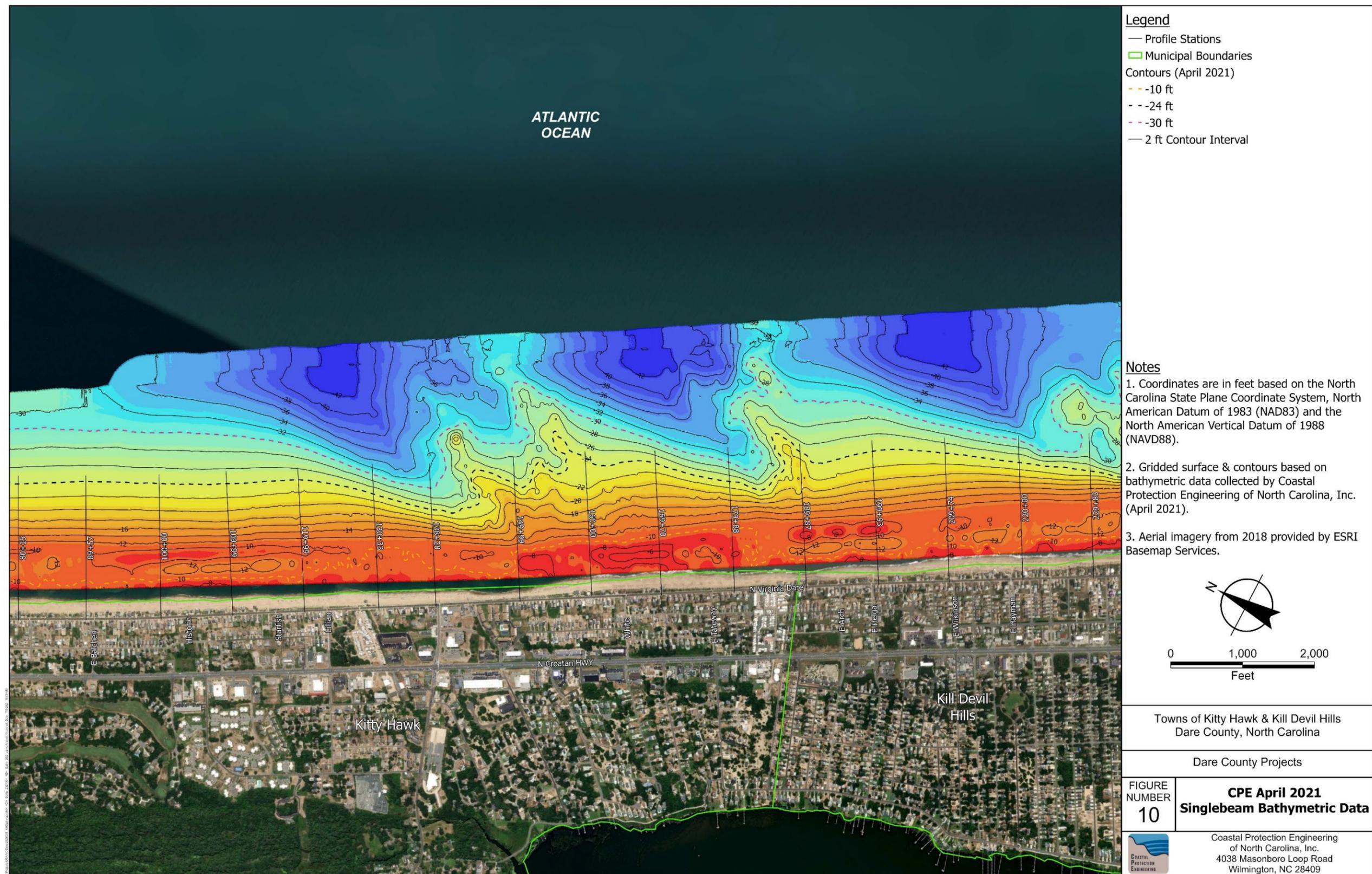
**South of Project.** Profile-based volumetric changes measured between December 2017 and April 2021, were calculated along the approximately 4,400 feet south of the project (between stations 325+66 and 369+89). A negative volumetric change of -156,000 cy was measured between December 2017 and April 2021 (Table 5). During the period between June 2020 and April 2021, this section experienced a negative volume change of approximately -20,300 cy.

### **Hybrid Volume Changes**

As stated previously, a second method was used in this study to assess volumetric changes, which involved the use of more densely spaced offshore bathymetric data to help resolve irregularities that occur offshore of Kitty Hawk and Kill Devil Hills. Data collected along approximately 200-foot spaced, shore-parallel track lines were merged with offshore data, collected as part of beach profile surveys, to create a bathymetric surface of the seafloor between station -50+00 in Southern Shores and station 329+89 in Kill Devil Hills. Figure 9, Figure 10 and Figure 11 are maps showing the shore-parallel nearshore single beam bathymetric data collected by CPE in April 2021. Figure 12, Figure 13 and Figure 14 are maps showing the changes in the measured depth between the June 2020 and April 2021 bathymetric surveys conducted by CPE.



**Figure 9. Map Illustrating the Shore-Parallel Nearshore Single Beam Bathymetric Data Collected by CPE in April 2021 between Baseline Stations -50+00 and 80+15**



**Figure 10. Map Illustrating the Shore-Parallel Nearshore Single Beam Bathymetric Data Collected by CPE in April 2021 between Baseline Stations 80+15 and 229+83**

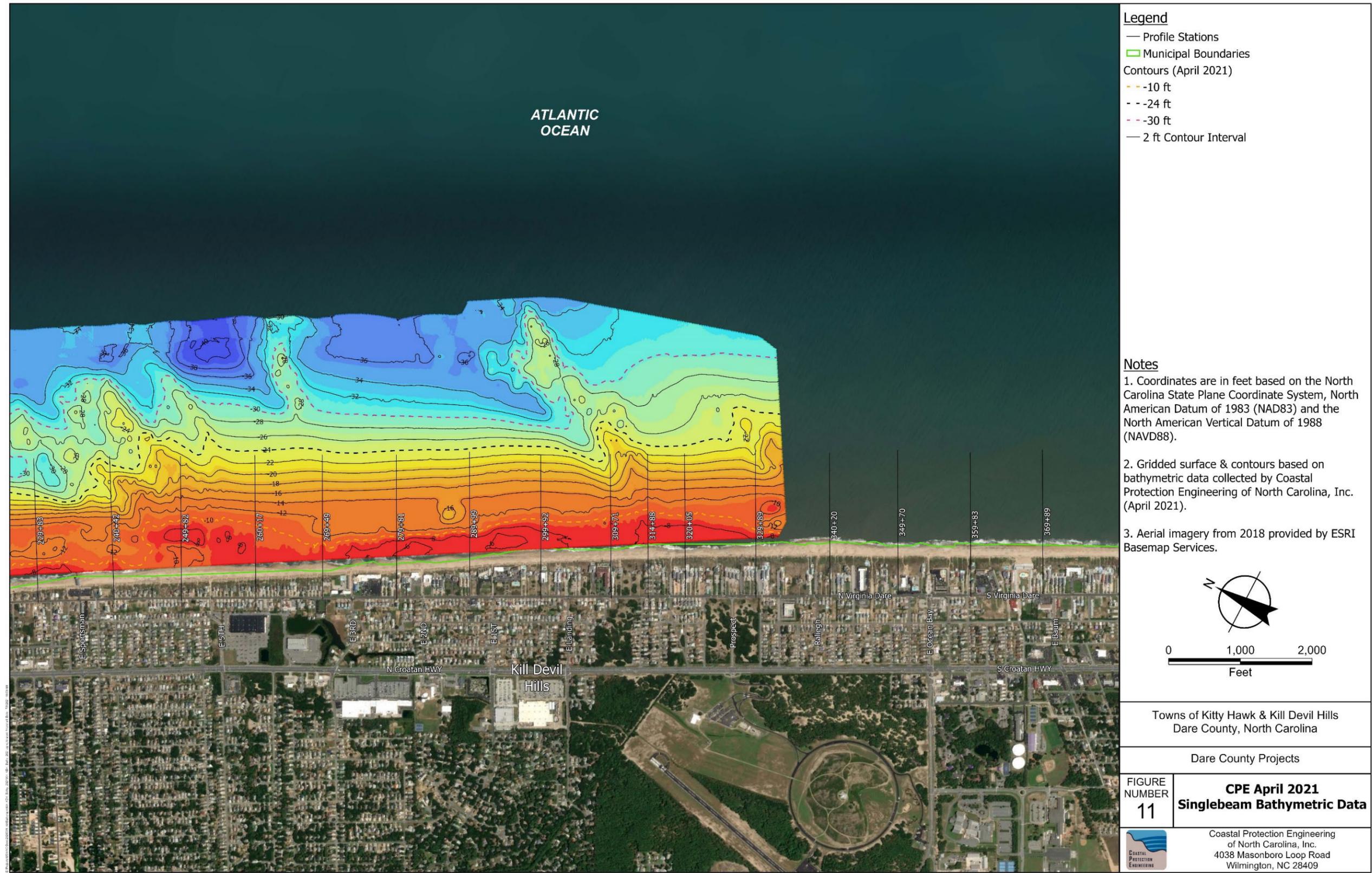


Figure 11. Map Illustrating the Shore-Parallel Nearshore Single Beam Bathymetric Data Collected by CPE in April 2021 between Baseline Stations 229+83 and 329+89

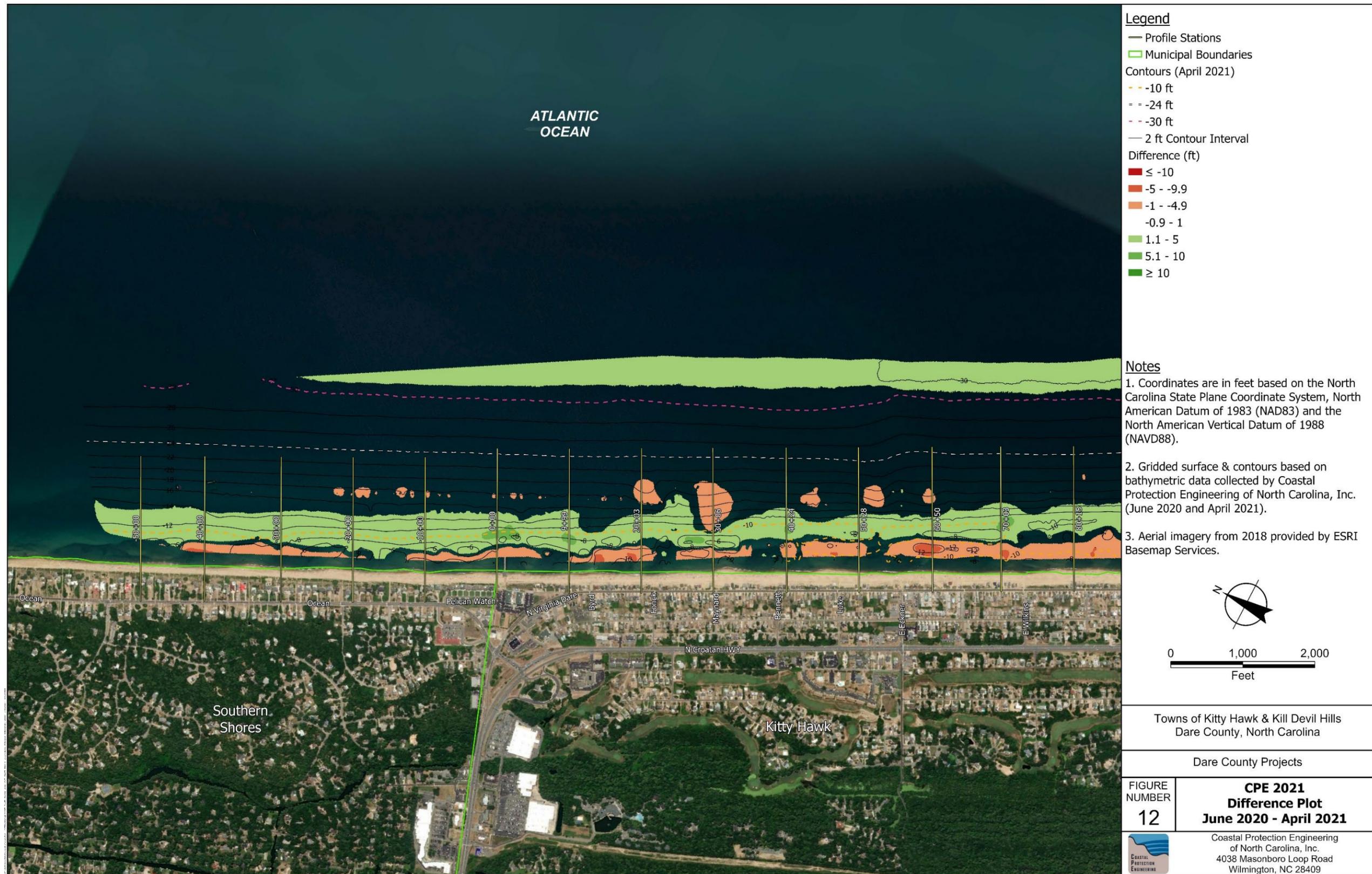


Figure 12. Map Illustrating the Changes in the Measured Depth between the June 2020 CPE and April 2021 Bathymetric Surveys Conducted by CPE between Baseline Stations -50+00 and 80+15



Figure 13. Map Illustrating the Changes in the Measured Depth between the June 2020 CPE and April 2021 Bathymetric Surveys Conducted by CPE between Baseline Stations 80+15 and 229+83



Figure 14. Map Illustrating the Changes in the Measured Depth between the June 2020 CPE and April 2021 Bathymetric Surveys Conducted by CPE between Baseline Stations 229+83 and 329+89

An examination of the data collected during the April 2021 nearshore data acquisition, indicated nearshore depressions or troughs and associated bar systems between the -10-foot and -30-foot NAVD88 contours in the following portions of the Kitty Hawk and Kill Devil Hills Project Areas:

- Between stations 119+99 and 269+49 (approximately 300 feet north of Lillian St. in Kitty Hawk to 400 feet north of 3<sup>rd</sup> St. in Kill Devil Hills); and
- Between stations 289+99 and 329+89 (approximately 320 ft. north of E 1<sup>st</sup> St. to Woodmere Ave. public access).

Table 6 shows a comparison between the volumetric changes calculated using beach profile-based method and the hybrid method. It is important to note that the volumes shown in the “Landward Portion” column were calculated using the same June 2020 and April 2021 beach profile data as is used to compute the volumes shown in the “Beach Profile-Based Volumetric Change Year 3 to Year 4” column. However, the volumes computed in the “Seaward Portion” column used the offshore shore-parallel bathymetric data collected in June 2020 and April 2021.

**Table 6. Comparison of Profile-Based Volumetric Changes and Hybrid Profile/Offshore Shore-Parallel Bathymetric Volume Changes along the Project Area Between June 2020 and April 2021**

Project Area	Volume Change Year-3 (June 2020) to Year-4 (April 2021) (Cubic Yards)			Beach Profile-Based Volume Change Year-3 to Year-4 (Cubic Yards)
	Landward Portion (Profiles)	Seaward Portion (Bathymetric Surface)	Total	
<b>NORTH OF PROJECT</b> (-50+00 To -25+00)	63,700	-2,000	61,700	56,600
<b>SOUTHERN SHORES</b> (-25+00 To -0+00)	64,300	-14,700	49,600	40,400
<b>KITTY HAWK</b> (0+00 To 189+87)	463,300	-48,700	414,600	456,900
<b>KILL DEVIL HILLS</b> (189+87 To 325+66)	171,200	67,300	238,500	250,800

The hybrid method was used to compute volumetric change along the Southern Shores, Kitty Hawk, and Kill Devil Hills portions of the project, as well as the North of Project area (Table 6). Since implementing the hybrid method in 2018, differences between the profile-based method and hybrid method have ranged from the hybrid showing greater volumetric changes, less volumetric changes, and even different trends for Kitty Hawk than Kill Devil Hills in the same year. The updated analysis of 2020 vs. 2021 data, provided in Table 6, showed approximately 23% more volumetric gains when using the hybrid method vs. the profile-based method for the Southern Shores portion of the project and 9% and 5% less volumetric gains when using the hybrid method vs. the profile method for Kitty Hawk and Kill Devil Hills portions of the project, respectively. The discrepancies between the two methods are interpreted as being due to the fact that changes that occur on a particular profile are more heavily weighted over the distance between beach profiles (approximately 1,000 feet), as opposed to the way the offshore volumes are computed using the hybrid method, which has greater resolution between individual profiles.

As previously stated, 2018 was the first-time that data was collected along the entire Project Area, which allowed for the use of the hybrid method. However, in 2018, the beach profile data were collected in June whereas the offshore data were not collected until October. The May 2019 data was the first set of profile and offshore shore-parallel data to be collected simultaneously. Data from May 2019 and April 2021 were used to evaluate volumetric changes using the hybrid method over a longer period of time. The computed volumetric changes are provided in Table 7. From May 2019 to April 2021 (1.9 years) the hybrid method showed essentially no volumetric change along the Southern Shores portion of the project compared to an approximate gain of 19,100 cy measured using the profile-based method. Along the Kitty Hawk portion of the project, where the profile-based method indicated a gain of approximately 399,300 cy between May 2019 and April 2021, the hybrid method showed a gain approximately 40% less than the profile-based method. Along the Kill Devil Hills portion of the project, where the profile-based method indicates essentially no volumetric change, the hybrid method shows a net loss of approximately -45,300 cy over the 1.9-year period.

**Table 7. Comparison of Profile-Based Volumetric Changes and Hybrid Profile/Offshore Shore-Parallel Bathymetric Volume Changes along the Project Area From May 2019 to April 2021**

Project Area	Volume Change Year-2 (May 2019) to Year-4 (April 2021) (Cubic Yards)			Beach Profile-Based Volume Change Year-2 to Year-4 (Cubic Yards)
	Landward Portion (Profiles)	Seaward Portion (Bathymetric Surface)	Total	
<b>NORTH OF PROJECT</b> (-50+00 To -25+00)	63,900	-52,400	11,500	24,900
<b>SOUTHERN SHORES</b> (-25+00 To -0+00)	62,400	-60,900	1,500	19,100
<b>KITTY HAWK</b> (0+00 To 189+87)	537,300	-298,900	238,400	399,300
<b>KILL DEVIL HILLS</b> (189+87 To 325+66)	82,700	-128,000	-45,300	-16,700

When considering how the nearshore depressions migrate slowly to the south, it stands to reason that depending on where the profiles are located in relation to these features, the profile-based method may over or under-estimate volumetric changes. Therefore, CPE continues to assert that the volumetric changes computed using the hybrid method more accurately represent changes along the beach fill project.

## VI. DISCUSSIONS

This monitoring report evaluated shoreline and volumetric changes along the portions of beaches nourished in 2017 within the Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills, as well as portions of the adjacent shorelines to the north and south. The monitoring area extends south from station -50+00, which is located approximately 500 feet south of Chicahawk Trail within the Town of Southern Shores, to station 369+89 located near E. Baum St. in Kill Devil Hills. Data collected in April 2021 was used to evaluate shoreline and volumetric changes that have occurred

since the 2017 beach nourishment project and between the most recent two monitoring events (June 2020 to April 2021).

With the construction of the beach nourishment project in 2017, the monitoring area was divided into five sections; the Southern Shores Project Area (stations -25+00 to 0+00), the Kitty Hawk Project Area (stations 0+00 to 189+87), the Kill Devil Hills Project Area (stations 189+87 to 325+66), the North of Project area (stations -50+00 to -25+00), and the South of Project area (stations 325+66 to 369+89).

### **Shoreline Change Results**

The shoreline change monitoring tracks the location of the +6.0 ft. NAVD88 contour, which was the design berm elevation used for the 2017 beach fill projects. In general, average shoreline changes measured over the life of the projects from December 2017 to April 2021 show retreat of the +6.0 ft. NAVD88 contour for the portions of the project within each of the three (3) Towns. The average shoreline retreat measured for the portions of the project within Southern Shores, Kitty Hawk, and Kill Devil Hills was -36.4 ft., -42.7 ft., and -5.8 ft., respectively. The short-term shoreline change trend between June 2020 and April 2021 was negative for Southern Shores and Kitty Hawk (-10.9 ft. and -2.8 ft., respectively) and positive for Kill Devil Hills (+0.7 ft.).

For the North of Project area, the average shoreline change relative to the +6.0 ft. NAVD88 contour has been relatively stable, having experienced a net movement of only +1.6 feet between December 2017 and April 2021. A shoreline change of +4.9 ft. was measured along the same stretch between the most recent two monitoring events (June 2020 and April 2021). For the South of Project area, an average net shoreline change of -14.0 ft. was measured over the 3.3-year period between December 2017 and April 2021, the average shoreline change over the most recent 10-month period was -14.5 feet. Numerical modeling conducted for the design of the proposed 2022 project suggested that offshore features at the south end of the project were impacting volumetric changes in this area. The Recommendations Section of this report suggests extending the shore parallel lines further south to better resolve the offshore features immediately south of the project.

### **Volumetric Change Results**

As previously discussed, two (2) different methods were used to assess volumetric changes throughout the Project Area, namely the profile-based method and the hybrid method.

**Southern Shores.** Volumetric changes computed using the profile-based method, indicate that approximately 67.2% of the volume increase measured between June and December 2017 remains within the project area. The 2020 monitoring report stated that as of June 2020 approximately 47.5% of the volume increase measured between June and December 2017 remained within the project; however, the net gain of approximately 40,400 cy over the 10-month period between June 2020 and April 2021, resulted in the higher percent retention. Given the Southern Shores section was only placed to mitigate erosion over the 5-year renourishment period, this project section is performing well as more than half of the fill placed remains 3.3 years following the post-construction baseline survey and with approximately 1-year left before re-nourishment. Furthermore, the profile-based analysis using data collected by CPE in June 2020, indicated a loss

of approximately -13,900 cy between May 2019 and June 2020. The June 2020 to April 2021 profile-based analysis indicates that gains occurred on the dry beach, swash zone, and along the offshore portion of the profiles station -20+00 and -10+00, whereas most of the gains observed at station 0+00 occurred seaward of the -12.0 ft. NAVD88 contour. The cross sections comparing the June 2020 survey to the April 2021 survey can be found in Appendix A.

Volumetric changes computed using the hybrid method also suggested positive volumetric changes have occurred along the 2,500 feet of Southern Shores. As shown in Table 6 the hybrid method showed a volumetric change of 49,600 cy. The comparison of the landward and seaward portion of the hybrid volume change, indicates a positive increase of approximately 64,300 cy in the nearshore area and a negative change of -14,700 cy in the offshore portion, resulting in the net gain of 49,600 cy. Based on numerous verifications of both the hybrid and profile based volumetric change methods and an evaluation of the difference plot shown in Figure 12, the hybrid method is believed to better represent volumetric changes occurring along this section of the project area.

**Kitty Hawk.** As previously stated, the profile-based volumetric change analysis indicated approximately 79% of the beach fill measured in December 2017 remained in place in April 2021. As is typically the case for beach nourishment projects, the rate in which volumetric changes have occurred has not been linear. As shown in Figure 7, the greatest volumetric losses occurred between December 2017 and June 2018. The rate of negative volumetric change tapered off between June 2018 and May 2019. Analysis of the post-Hurricane Dorian data collected in February 2020 indicated volumetric gains occurred along the Kitty Hawk Project Area between May 2019 and February 2020 and losses between February 2020 and June 2020. The most recent data indicated a gain from June 2020 to April 2021 (Figure 7). The net gain of 456,900 cy measured along the Kitty Hawk portion of the project between June 2020 and April 2021 represents more than a 50% recovery of the net losses measured over the rest of the post-construction monitoring period from December 2017 to June 2020.

The overall performance of the project based on the profile-based volumetric analysis varies throughout the length of the Kitty Hawk Project as shown in Figure 7. The Northern Section of the project, between the station 0+00 (northern Town boundary) and station 60+50, which is located approximately 400 feet south of Eckner St., has performed very well, having been relatively stable along this section since December 2017. The Central Section of the project area, defined as the area between station 60+50 and station 119+99 (located approximately 300 feet north of Lillian St.), and the Southern Section, which runs from station 119+00 to the southern boundary of the Town, have experienced net losses since December 2017; however, gains measured between June 2020 and April 2021 have reduced the net losses measured since December 2017. Figure 7 illustrates the trend of higher rates of loss occurring between December 2017 and June 2018, followed by a tapering off of volumetric losses between June 2018 and June 2020, followed by net gains over the 10 months between June 2020 and April 2021.

Volumetric changes computed using the hybrid method also showed positive volumetric changes occurring along the Kitty Hawk portion of the project area between June 2020 and April 2021. However, the volume change measured using the hybrid method (414,600 cy) was slightly less than what was measured using the profile method (456,900 cy) (Table 6). With the presence of

extensive nearshore depressions and troughs offshore of Kitty Hawk, CPE maintains that the hybrid method provides a more accurate representation of volumetric changes occurring along the beach project. The May 2019 survey was the first time both the shore perpendicular beach profile surveys and the nearshore shore-parallel surveys were conducted at the same time. Since that time, each monitoring survey included both beach profile and shore-parallel data acquisition conducted at the same time.

In preparation for the proposed 2022 re-nourishment project at Kitty Hawk, the data collected since December 2017 have been used to evaluate volume change rates to determine how much erosion to account for over the 5-year nourishment interval. The long-term rate measured between December 2017 and April 2021 indicates an average density change rate of -7.9 cy/ft./yr. Analysis of the data also considered that higher rates of loss were observed in the 6-months following the initial December 2017 post-construction baseline survey. To that end, a density rate was calculated based on the volumetric changes measured between June 2018 and April 2021. The average density change rate over this period was +3.0 cy/ft./yr. Furthermore, given the assertion that the hybrid method may provide a better representation of volumetric changes along the project area, rates based on this method were also evaluated. As previously stated, the beach profile and shore parallel data have only been collected simultaneously starting in May 2019, therefore the analysis of volumetric changes using the hybrid method was limited to the period between May 2019 and April 2021. The average density change rate using the hybrid method over this period was +6.5 cy/ft./yr. Table 8 provides a summary of these various rates.

**Table 8. Comparison of Average Density Change Rates Along the Kitty Hawk Project Area Based on Various Time Periods and Methods**

Period of Time	Method	Average Density Change Rate (cy/ft./yr.)
December 2017 to April 2021	Profile-Based Method	-7.9
June 2018 to April 2021	Profile-Based Method	+3.0
May 2019 to April 2021	Hybrid Method	+6.5

**Kill Devil Hills.** As previously stated, the profile-based volumetric change analysis indicated approximately 87.5% of the beach fill measured in December 2017 remained in place as of April 2021. As shown in Figure 8, following initial negative volumetric losses between December 2017 and June 2018, the Kill Devil Hills project experienced a net positive volumetric change between June 2018 and May 2019. Between May 2019 and February 2020, post-Hurricane Dorian data indicated significant negative volumetric changes that were attributed to the impact of Hurricane Dorian in September 2019 (CPE, 2020a). Analysis of June 2020 data indicated a slight recovery of material between February 2020 and June 2020. The most recent data indicated a gain from June 2020 to April 2021 (Figure 8). The net gain of 250,800 cy measured along the Kill Devil Hills portion of the project between June 2020 and April 2021 represents more than a 72% recovery

of the net losses measured over the rest of the post-construction monitoring period from December 2017 to June 2020.

As with the Kitty Hawk Project Area, the overall performance of the project based on the profile-based volumetric analysis varies throughout the length of the Kill Devil Hills Project as shown in Figure 8. The Northern Section of the Project Area, defined as the area between the Town boundary and station 229+83, located approximately 600 feet north of the Avalon Pier, near Random St., and the Southern Section, which runs from station 289+99, located approximately 320 feet north of East 1<sup>st</sup> St., to station 325+66, located near the Prospect Ave. beach access, have performed similarly since December 2017. A trend of higher rates of loss occurring between December 2017 and June 2018 were followed by a modest positive volumetric change between June 2018 and May 2019. Both sections experienced significant negative volumetric changes between May 2019 and February 2020 attributed to Hurricane Dorian. The only difference in the profile-based volumetric changes measured along the Northern and Southern Sections of the Kill Devil Hills Project occurred between February 2020 and June 2020, during which time the Northern Section experienced a modest negative volumetric change, whereas the Southern Section showed some recovery of volume. Between June 2020 and April 2021, both the Northern and Southern Sections experienced considerable gains. As seen in Figure 8, the gains that occurred in the Northern and Southern Section's make up almost all of the measured gains that occurred along the Kill Devil Hills portion of the project over this 10-month period. The Central Section of the project, between station 229+83, located approximately 600 feet north of the Avalon Pier, near Random St., and station 289+99, located approximately 320 feet north of East 1<sup>st</sup> St., has performed very well, having initially gained volume between December 2017 and May 2019, and remaining relatively consistent between May 2019 and April 2021 (Figure 8).

Volumetric changes computed using the hybrid method showed positive volumetric changes occurring along the Kill Devil Hills portion of the project area between June 2020 and April 2021. Although the profile-based method also indicated positive volumetric change during the same period, the hybrid method indicated approximately 5% less positive volumetric change. As previously stated, with the presence of extensive nearshore depressions and troughs offshore the project area, CPE maintains that the hybrid method provides a better representation of volumetric changes occurring along the beach project.

As is the case for Kitty Hawk, in preparation for the proposed 2022 re-nourishment project at Kill Devil Hills, the data collected since December 2017 have been used to evaluate volume change rates to determine how much erosion to account for over the 5-year nourishment interval. The long-term rate measured between December 2017 and April 2021 indicates an average density change rate of -3.9 cy/ft./yr. Analysis of the data also considered that higher rates of loss were observed in the 6-months following the initial December 2017 post-construction baseline survey. To that end, a density rate was calculated based on the volumetric changes measured between June 2018 and April 2021. The average density change rate over this period was +6.2 cy/ft./yr. Furthermore, given the assertion that the hybrid method may provide a better representation of volumetric changes along the project area, rates based on this method were also evaluated. As previously stated, the beach profile and shore parallel data have only been collected simultaneously starting in May 2019, therefore the analysis of volumetric changes using the hybrid method was limited to the period between May 2019 and April 2021. The average density change rate using

the hybrid method over this period was -1.7 cy/ft./yr. Table 9 provides a summary of these various rates.

**Table 9. Comparison of Average Density Change Rates Along the Kill Devil Hills Project Area Based on Various Time Periods and Methods**

Period of Time	Method	Average Density Change Rate (cy/ft./yr.)
December 2017 to April 2021	Profile-Based Method	-3.9
June 2018 to April 2021	Profile-Based Method	+6.2
May 2019 to April 2021	Hybrid Method	-1.7

Comparison of the bathymetric charts developed for the 2019 and 2020 monitoring, and those included in this report (Figures 9 through 11) illustrate the migratory nature of the nearshore depressions and troughs along both the Kitty Hawk and Kill Devil Hills projects. The migratory nature of the features is even more clearly illustrated in Figures 12 through 14, which show difference plots indicating a general southerly migration of the features between June 2020 to April 2021. Based on comparison of CPE data collected in 2017, 2018, 2019, 2020, and 2021, as well as a multibeam survey data set conducted by the USACE FRF in 2009, the features appear to have been migrating south since at least as far back as 2009.

**North of Project and South of Project.** Volumetric changes measured between December 2017 and April 2021 along the 2,500 feet of shoreline north of the project area (stations -50+00 to -25+00) indicates a loss of approximately -35,400 cubic yards. Over the 10-month period between June 2020 and April 2021, a volumetric gain of approximately 56,600 cy was measured using the profile-based method.

South of the project (between stations 325+66 and 369+89), the total profile-based volume change measured was a loss of approximately -156,000 cubic yards between December 2017 and April 2021. This includes a negative volume change of approximately -20,300 cy during the 10-month period between June 2020 and April 2021.

## VII. RECOMMENDATIONS

Regular monitoring of the projects has been instrumental for the Towns to evaluate project performance and anticipate future project needs. This is pivotal in the adaptive management strategy that must be part of the successful long-term maintenance of a shore protection program. CPE recommends that the entire Project Area within the Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills continue to be monitored on an annual basis. As part of the beach renourishment project proposed for 2022, the dredge contractor will conduct pre-construction surveys within 60 days of commencement of dredging operations. This survey should serve as the

year-5 monitoring survey. CPE recommends that as the Towns transition into the next phase of their long-term shore protection programs, with the construction of the proposed 2022 project, both beach profile surveys and shore-parallel surveys should be conducted at the immediate conclusion of each project (Town of Kitty Hawk and Town of Kill Devil Hills). These surveys will establish the immediate post-project baseline condition and can be used to track performance of the project over the course of the subsequent nourishment interval. CPE included this task into the bidding documents for the upcoming 2022 beach nourishment project, and it is currently included in the contract between Dare County and Weeks Marine.

Continued annual monitoring not only allows for the continued assessment of volume trends, which are used to optimize future renourishment projects, but they also serve to provide a pre-storm condition survey that can be used to estimate storm damages. This was the case following the impact of Hurricane Dorian in 2019. For future monitoring events, CPE continues to recommend that both 1,000-foot beach profile surveys and supplemental single beam survey data be collected along lines running parallel to the shoreline similar to the procedures used since October 2018. Given the presence of offshore troughs and depressions at the south end of the Kill Devil Hills project area, CPE recommends extending the shore parallel lines south so that they include the entire beach from station -50+00 to 369+89. The parallel lines should cover the offshore area from near the -12 ft. NAVD88 contour to at least 3,000 feet offshore. Furthermore, it may benefit future modeling efforts to collect several shore parallel lines at a 1,000-foot spacings, for a distance of 5,000 feet. The monitoring surveys should be conducted in the same timeframes from year to year to mitigate the influence of seasonal discrepancies.

The greater density of bathymetric data obtained through the combination of beach profile surveys and the more closely spaced shore-parallel bathymetric surveys, has aided in the design of the proposed re-nourishment project, specifically regarding the numerical modeling that was conducted. The modeling was specifically used to better evaluate how the nearshore depressions impact the performance of the initial project and to design alternatives that may provide improvements in future project performance.

## VII. REFERENCES

APTIM, 2019. APTIM Coastal Planning & Engineering of North Carolina, Inc. *Town of Kitty Hawk and Kill Devil Hills 2018 Shoreline & Volume Change Monitoring Report*. Prepared for the Towns of Kitty Hawk and Kill Devil Hills, North Carolina by Aptim Coastal Planning & Engineering of North Carolina, Inc. Wilmington, NC.

Bernstein, D.J.; Freeman, C.; Forte, M.F.; Park, J.; Gayes, P.T.; Mitsova, H.; 2003. *Survey Design Analysis for Three-Dimensional Mapping of Beach and Nearshore Morphology*. CiteSeer – College of Information Sciences and Technology, Pennsylvania State University.

CPE, 2020a. Coastal Protection Engineering of North Carolina, Inc. *Post-Storm Design Report: Hurricane Dorian Town of Kitty Hawk and Town of Kill Devil Hills Shore Protection Project Repair Dare County, NC*. Prepared for Towns of Kitty Hawk and Kill Devil Hills. Wilmington, NC.

CPE, 2020b. Coastal Protection Engineering of North Carolina, Inc., *Town of Kitty Hawk & Town of Kill Devil Hills, North Carolina 2020 Shoreline & Volumetric Change Monitoring Report*. Prepared for Towns of Kitty Hawk and Kill Devil Hills. Wilmington, NC.

CPE, 2022. Coastal Protection Engineering of North Carolina, Inc., *Town of Kill Devil Hills, North Carolina Erosion and Shoreline Management Design Report*. Prepared for the Town of Kill Devil Hills. Wilmington, NC.

CPE-NC, 2015a. Coastal Planning & Engineering of North Carolina, Inc. *Town of Kitty Hawk North Carolina Erosion & Shoreline Management Design Report*. Prepared for the Town of Kitty Hawk, North Carolina by Coastal Planning & Engineering of North Carolina, Inc. August 2015. Wilmington, NC.

CPE-NC, 2015b. Coastal Planning & Engineering of North Carolina, Inc. *Town of Kill Devil Hills North Carolina Erosion & Shoreline Management Design Report*. Prepared for the Town of Kill Devil Hills, North Carolina by Coastal Planning & Engineering of North Carolina, Inc. July 2015. Wilmington, NC.