

**DRAFT: TOWNS OF SOUTHERN SHORES, KITTY HAWK, &  
KILL DEVIL HILLS, NORTH CAROLINA**

**2023 SHORELINE & VOLUME CHANGE  
MONITORING REPORT**



**SUBMITTED TO:**

**TOWN OF SOUTHERN SHORES,  
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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**DATE**

**December 2023**

## EXECUTIVE SUMMARY

The Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills have implemented long-term beach management programs to sustain the beaches that support a significant portion of their local economy and maintain the tax base of the Towns. Between July and October 2017, the Towns of Kitty Hawk and Kill Devil Hills, in cooperation with Dare County, Duck, and Southern Shores, completed their initial beach nourishment projects, which placed approximately 2.66 million cubic yards of beach fill along 6.7 miles of shoreline. 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 to address the severe erosion.

In 2022, the Towns of Kitty Hawk and Kill Devil Hills completed their first renourishment along the same area nourished in 2017, placing approximately 565,600 cubic yards and 871,400 cubic yards of fill, respectively, between the Kitty Hawk pier (Sta. 0+00) and the Prospect Avenue Public Beach Access (Sta. 325+66). Additionally, the Town Southern Shores completed their first townwide beach nourishment project in 2022/2023, which placed approximately 1,048,400 cubic yards of beach fill along the Town's 3.8 miles of oceanfront shoreline.

This monitoring report evaluated shoreline and volumetric changes along the portions of beaches nourished in 2022/2023 within the Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills, as well as portions of the adjacent shoreline south of the Kill Devil Hills project. The results of the shoreline and volume change analysis are the first glimpse into the performance of the 2022/2023 beach nourishment projects. The shoreline and volume changes measured over the Year-1 monitoring cycle, were also compared to shoreline and volume changes measured between the 2017 and 2022/2023 beach nourishment projects. This comparison provides further insight into project performance.

The volumetric change analysis indicated net volume gains in each of the three (3) towns since the 2022/2023 Project Post-construction surveys were conducted. Table ES-1 summarizes the volumetric changes measured between the 2022 Post-construction and June 2023 surveys as well as volumetric changes measured between December 2017 and the 2022 Pre-construction surveys. While the shoreline change analysis results indicated negative shoreline change along each of the three (3) Towns between the Post-construction surveys and the June 2023 survey, this is likely driven by the equilibration of the beach fill following construction.

Project specific summaries are provided below for each of the three (3) Towns:

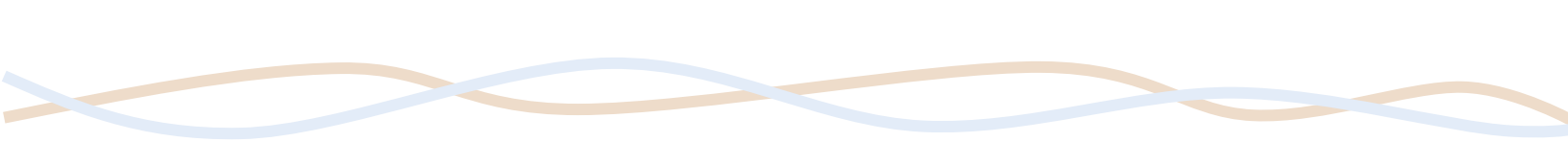
**Southern Shores:** The volumetric change analysis conducted along the Town of Southern Shores following the construction of the 2022/2023 project, indicated a net gain of sand along the Project Area between the November 2022 Post-construction survey and the June 2023 monitoring survey. Between November 2022 and June 2023, a volume change of approximately +399,900 cy of material was measured along the Southern Shores Project Area, which equates to an average density change of 20.9 cy/ft. With regards to the Northern, Central, and Southern Sections of the Southern Shores Project Area, this equates to a positive volume change of 161,400 cy, 140,600 cy,

and 97,900 cy, respectively (See Table ES-1). In terms of density change, those volumes would equate to positive changes of 35.5 cy/ft., 12.8 cy/ft., and 17.6 cy/ft. along the Northern, Central, and Southern Sections, respectively. As previously noted, the Northern Section volume and density changes between November 2022 and June 2023 were influenced in part by the additional placement of approximately 58,100 cy in early May 2023.

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

PROJECT AREA	Beach Profile-Based Volume Change Dec. 2017 to 2022 Pre-con (CY)	Beach Profile-Based Volume Change Post-Con to June 2023 (CY)	Hybrid Based Volume Change Post-Con to Year-1 (June 2023) (CY)		
			Landward Portion (Profiles)	Seaward Portion (Bathymetric Surface)	Total
<b>SOUTHERN SHORES (-197+12 TO 0+00)</b>	<b>131,000</b>	<b>399,900</b>	--	--	--
SOUTHERN SHORES Northern Section (-197+12 TO -153+00)	109,900	161,400	--	--	--
SOUTHERN SHORES Central Section (-153+00 TO -50+00)	17,200	140,600	--	--	--
SOUTHERN SHORES Southern Section (-50+00 TO 0+00)	4,000	97,900	172,000	-114,100	57,900
<b>KITTY HAWK (0+00 TO 189+87)</b>	<b>-650,000</b>	<b>191,200</b>	<b>723,100</b>	<b>-330,900</b>	<b>392,200</b>
KITTY HAWK Northern Section (0+00 TO 60+50)	-53,800	163,300	327,100	-164,300	162,800
KITTY HAWK Central Section (60+50 TO 119+99)	-248,900	34,400	237,000	-152,500	84,500
KITTY HAWK Southern Section (119+99 TO 189+87)	-347,300	-6,500	159,000	-14,200	144,900
<b>KILL DEVIL HILLS (189+87 TO 325+66)</b>	<b>-458,900</b>	<b>32,200</b>	<b>512,700</b>	<b>-389,200</b>	<b>123,400</b>
KILL DEVIL HILLS Northern Section (189+87 TO 229+83)	-215,100	-33,000	111,000	-107,000	4,000
KILL DEVIL HILLS Central Section (229+83 TO 289+99)	19,600	154,800	414,600	-205,900	208,800
KILL DEVIL HILLS Southern Section (289+99 TO 325+66)	-263,400	-89,500	-13,000	-76,400	-89,400
<b>KDH SOUTH MONITORING AREA (325+66 TO 369+89)</b>	<b>-900</b>	<b>90,200</b>	<b>--</b>	<b>--</b>	<b>--</b>

Historic volumetric trends measured along Southern Shores, prior to the construction of the beach nourishment project in 2022/2023, have been positive. Between October 2006 and April 2021, the Central Section experienced an average density change rate of +2.6 cy/ft./yr., while the Southern Section experienced an average density change rate of +1.4 cy/ft./yr. Between December



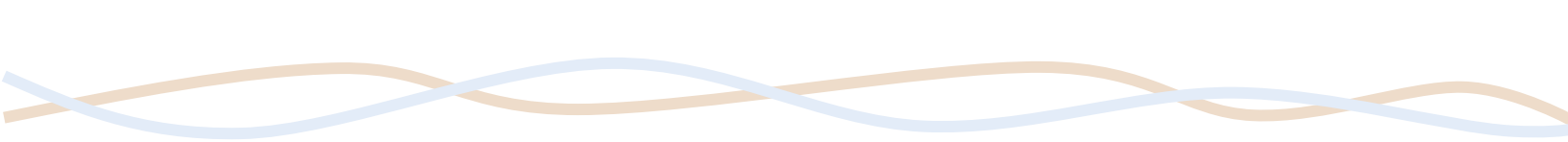
2017 and August 2022, the average density change rate along the entire Town was +1.8 cy/ft./yr. However, in the Central and Southern Sections, the density change rates were +0.4 and +0.1 cy/ft./yr., respectively, whereas in the Northern Section, the average density change rate was +5.3 cy/ft./yr. While the volumetric changes measured since the completion of the 2022/2023 project were positive, the positive volumetric trend is consistent with trends observed prior to the construction of the project.

As previously stated, the 2022/2023 beach nourishment project added approximately 1,048,400 cy of sand to Southern Shores beach. Of this total volume approximately 124,000 cy were placed in the Northern Section, 580,800 cy were placed in the Central Section, and 343,700 cy were placed in the Southern Section. The beach fill design was different north and south of 4th Avenue within Southern Shores. North of 4th Avenue, the goal of the project was to maintain a sufficient useable beach. South of 4th Avenue, the project was designed to provide a specific level of storm damage reduction.

In the Northern Section, the goal of the project was to maintain a healthy beach that provides sufficient useable beach. The term sufficient useable beach was defined as an average width of 84 feet as measured between the +12 ft. and +4 ft. NAVD88 contours along each beach profile. At the time of the Post-construction survey conducted in November 2022, the average useable beach width along the Northern Section was approximately 84 feet. As of June 2023, the average useable beach width along the Northern Section was approximately 82 feet.

South of 4th Avenue, along the Central and Southern Sections of the Southern Shores Project, the 2022/2023 beach nourishment project was designed to include approximately 286,200 cy of advanced fill based on a 5-year maintenance interval. Advanced fill is the additional fill required to protect the design section from anticipated sediment losses that may occur over the maintenance interval. Between November 2022 and June 2023, a volume change of approximately +238,200 cy of material was measured along the Southern Shores Project Area. Given the project south of 4th Avenue was designed with the expectation that approximately 286,200 cy of material could be lost before the beach fill design was compromised, and that the project has experienced a net gain of 238,200 cy since the Post-construction survey in November 2022, this section of the Southern Shores project is performing well.

**Kitty Hawk:** Volumetric changes along the Kitty Hawk Project Area used both the profile-based and the hybrid volumetric change methods. Results of both methods are provided in Table ES-1. Given the irregular offshore bathymetry off portions of the Kitty Hawk Project, the hybrid volumetric change method was instituted in 2019 as it is believed to better resolve volumetric changes along the Project Area as compared to the beach profile-based method. Both methods indicated a net gain of sand along the Kitty Hawk Project Area between the October/November 2022 Post-construction and June 2023 surveys. The hybrid method indicated that the net volume gain between the October/November 2022 and June 2023 surveys was +392,200 cy, which equates to an average density change of 20.7 cy/ft. With regards to the Northern, Central, and Southern Sections, this equates to volumetric gains of 162,800 cy, 84,500 cy, and 144,900 cy, respectively. In terms of density change, those volumes equate to +26.9 cy/ft., +14.2 cy/ft., and +20.7 cy/ft. along the Northern, Central, and Southern Sections, respectively.

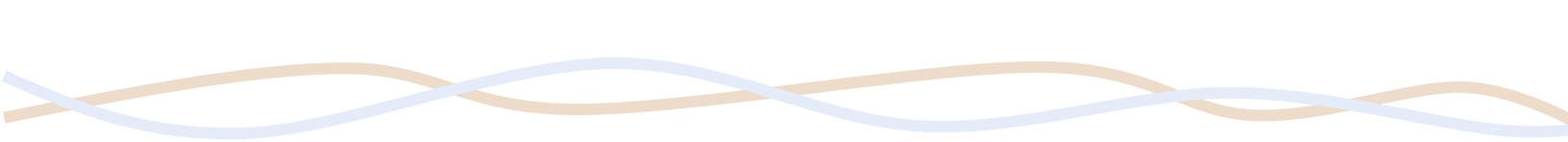


Volumetric trends measured along Kitty Hawk between the 2017 beach nourishment project and the 2022 project were negative. Between the December 2017 and 2022 Pre-construction surveys for the Town of Kitty Hawk, the measured volumetric change was approximately -650,000 cy, which equates to an average density change rate of -8.4 cy/ft./yr. Because the hybrid method was not fully implemented until 2019, the volumetric change and density change rate stated here, were computed using the beach profile-based method. In the Northern Section, the average density change rate between December 2017 and August 2022 was -1.8 cy/ft./yr. In the Central and Southern Sections, the density change rates were -8.6 cy/ft./yr. and -13.1 cy/ft./yr., respectively.

As previously stated, the 2022 beach nourishment project added approximately 871,400 cy of sand to the Kitty Hawk beach. Of this total volume approximately 272,500 cy were placed in the Northern Section, 182,600 cy were placed in the Central Section, and 416,300 cy were placed in the Southern Section. The Kitty Hawk beach nourishment project was designed to reduce flooding caused by ocean overwash and to mitigate long-term erosion that can reduce the flood protection provided by the beach fill. The Kitty Hawk project was designed to include approximately 750,000 cy of advanced fill based on a 5-year maintenance interval. Advanced fill is the additional fill required to protect the design section from anticipated sediment losses over the designed maintenance interval. The estimate of advanced fill used in the 2022 design was based on an anticipated rate of loss of -7.9 cy/ft./yr. over the 5-yr maintenance period. Between the October/November 2022 and June 2023 surveys, a volume change of +392,200 cy of material was measured along the Kitty Hawk Project Area. Given the project was designed with the expectation that approximately 750,000 cy of material could be lost before the beach fill design was compromised, and that the project has experienced a net gain of 392,200 cy since the Post-construction surveys in October/November 2022, the Kitty Hawk Project is performing well.

**Kill Devil Hills:** Volumetric changes along the Kill Devil Hills Project Area used both the profile-based and the hybrid volumetric change methods. Results of both methods are provided in Table ES-1. Given the irregular offshore bathymetry offshore of most of the Kill Devil Hills Project, the hybrid volumetric change method was instituted in 2019 as it is believed to better resolve volumetric changes along the Project Area as compared to the beach profile-based method. Both methods indicated a net gain of sand along the Kill Devil Hills Project Area between the July 2022 Post-construction and June 2023 surveys. The hybrid method indicated that the net volume gain between the July 2022 and June 2023 surveys was approximately 123,400 cy, which equates to an average density change of 9.1 cy/ft. With regards to the Northern and Central Sections, this equates to volumetric changes of approximately +4,000 cy and +208,800 cy, respectively. In terms of density change, those volumes equate to +1.0 cy/ft. and +34.7 cy/ft., respectively. In the Southern Section, the volumetric change measured using the hybrid method was negative, showing a loss of approximately 89,400 cy. In terms of density change, this volume equates to -25.4 cy/ft.

Volumetric trends measured along Kill Devil Hills between the 2017 beach nourishment project and the 2022 project were negative. Between the December 2017 and 2022 Pre-construction surveys for the Town of Kill Devil Hills, the measured volumetric change was approximately -458,900 cy, which equates to an average density change rate of -9.8 cy/ft./yr. Because the hybrid method was not fully implemented until 2019, the volumetric change and density change rate stated here, were computed using the beach profile-based method. In the Northern Section, the



average density change rate over this same period was -15.6 cy/ft./yr. In the Central and Southern Sections, the density change rates were -0.5 cy/ft./yr. and -18.4 cy/ft./yr., respectively.

As previously stated, the 2022 beach nourishment project added approximately 565,600 cy of sand to the Kill Devil Hills Project Area. Of this total volume approximately 183,200 cy were placed in the Northern Section, 240,800 cy were placed in the Central Section, and 142,600 cy were placed in the Southern Section. The Kill Devil Hills beach nourishment project was designed to provide a specific level of storm damage reduction and to mitigate long-term erosion that can reduce the protection provided by the beach fill. The Kill Devil Hills project was designed to include approximately 250,000 cy of advanced fill based on a 5-year maintenance interval. Advanced fill is the additional fill required to protect the design section from anticipated sediment losses over the designed maintenance interval. The estimate of advanced fill used in the 2022 design was based on an anticipated rate of loss of -4.0 cy/ft./yr. over the 5-yr maintenance period, which was based on the observed average rate between December 2017 and April 2021. The beach fill project also included the additional placement of approximately 75,000 cy in the Central Section, specifically between Sta. 220+00 (Near E Hayman Blvd) and Sta. 260+17 (Near Drifting Sands Motel) to mitigate potential hot spot erosion. Between the July 2022 (Post-construction) and June 2023 surveys, a volume change of approximately +123,400 cy of material was measured along the Kill Devil Hills Project Area. Given the project was designed with the expectation that approximately 250,000 cy of material could be lost before the beach fill design was compromised, the additional 75,000 cy of material that were placed in the Central Section to mitigate potential hot spot erosion, and that the project has experienced a net gain of approximately 123,400 cy since the Post-construction surveys in July 2022, the Kill Devil Hills Project is performing well.

**Recommendations:** 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. Future monitoring will be instrumental for the Towns to evaluate areas of concern and to develop successful shoreline management strategies to deal with issues as they arise. 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. For future monitoring events, CPE continues to recommend that the hybrid method be used to evaluate volume changes in Kitty Hawk and Kill Devil Hills. Moving forward, CPE no longer recommends the continued use of the hybrid method along the southern 5,000 feet of the Town of Southern Shores. The standard beach profile-based method should be sufficient for tracking volumetric changes along the entirety of Southern Shores.

**TOWNS OF SOUTHERN SHORES, KITTY HAWK,  
& KILL DEVIL HILLS**

**2023 SHORELINE & VOLUME CHANGE  
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**TOWNS OF SOUTHERN SHORES, KITTY HAWK, & KILL DEVIL HILLS  
2023 SHORELINE & VOLUME CHANGE  
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**I. INTRODUCTION**

The Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills have implemented long-term beach management programs to sustain the beaches that support a significant portion of their local economy, maintain the tax base of the Towns, retain existing recreational resources, and protect existing natural resources. In order to accomplish these stated goals, the Towns have taken steps to maintain and monitor their oceanfront beaches and dunes to a configuration that meets the unique goals set by each Town for the management of their beaches.

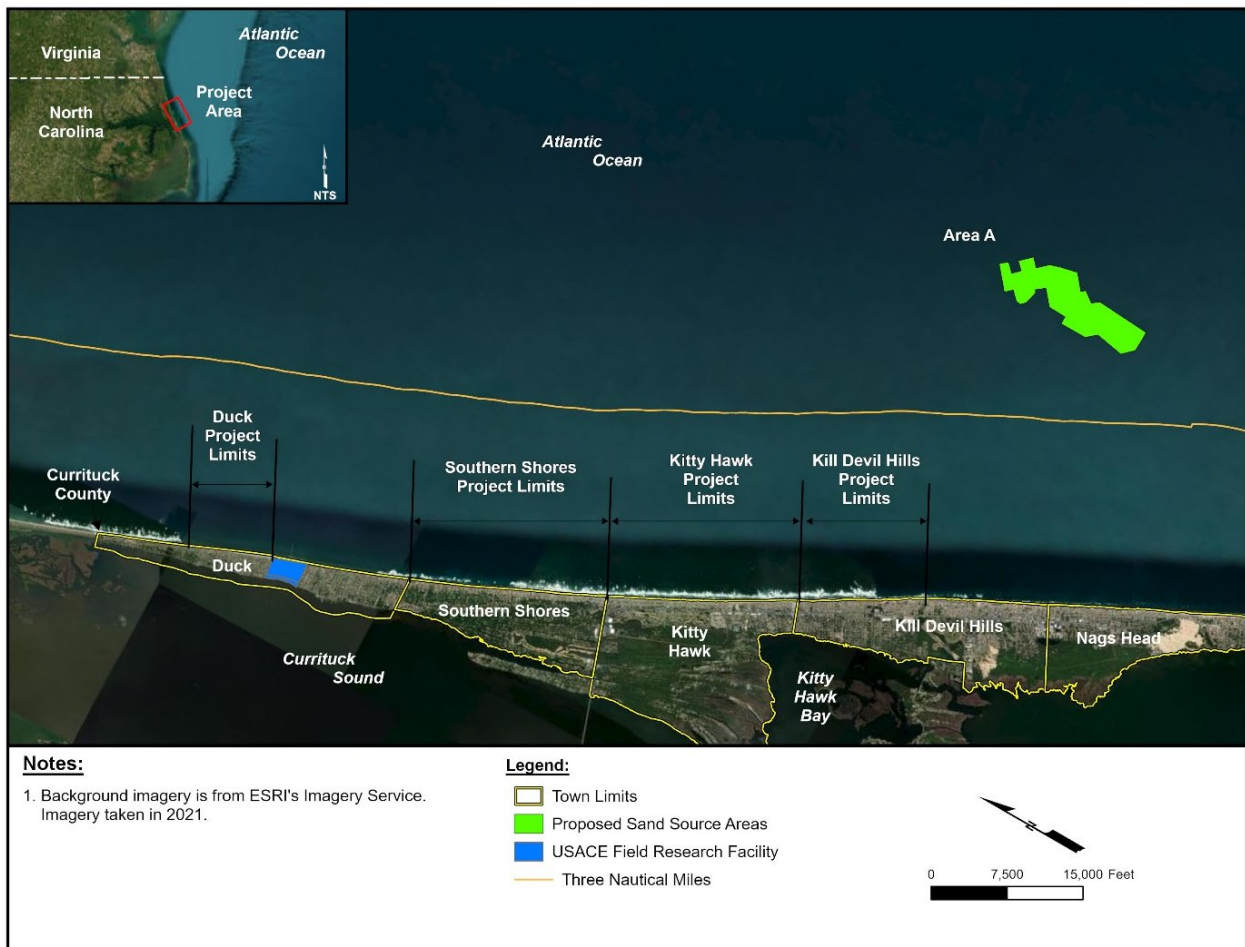
As part of their long-term shoreline management programs, the Towns of Kitty Hawk and Kill Devil Hills, in cooperation with Dare County, initially constructed beach nourishment projects in 2017 that placed approximately 2.66 million cy of sand along the entire Kitty Hawk shoreline, the northern 2.6 miles of the Kill Devil Hills shoreline, and the southern 1,500 feet of shoreline in Southern Shores, for a total length of approximately 8.3 miles.

In 2022/2023, the Towns of Kitty Hawk and Kill Devil Hills completed the first renourishment along the same area nourished in 2017 and the Town of Southern Shores completed the initial townwide beach nourishment project. In total, the three (3) projects placed approximately 2,485,400 cubic yards of sand along approximately 9.9 miles of shoreline within the Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills. All three projects were constructed in cooperation with Dare County and the neighboring Town of Duck. Construction of the Kill Devil Hills project was accomplished between June 13 and July 19, 2022, while construction of the Kitty Hawk project occurred between August 25 and October 16, 2022. The construction of the Southern Shores project occurred between October 7, 2022 and May 11, 2023; however, this period included a pause in construction between November 23, 2022 and May 8, 2023.

Each of the three Towns have implemented a beach monitoring programs to track the performance of the beach nourishment projects. This monitoring report describes shoreline changes and volume changes measured along each Town's oceanfront shoreline, focusing on assessing the performance of the beach nourishment projects constructed in 2022/2023 and providing guidance on planning for future maintenance events.

## II. PROJECT LOCATION

The Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills are located on the Outer Banks of North Carolina roughly 29, 37, and 40 miles south-southeast of the North Carolina and Virginia border, respectively. The Town of Southern Shores extends approximately 3.7 miles along Dare County’s oceanfront beach, while Kitty Hawk, located immediately south of Southern Shores, includes approximately 3.6 miles of oceanfront beach. Kill Devil Hills, located immediately south of Kitty Hawk, includes approximately 4.7 miles of oceanfront beach. Collectively, the three Towns are bordered to the north by the Town of Duck and to the south by the Town of Nags Head. A regional location map is provided in Figure 1. This location map highlights the nourishment projects along each Town’s oceanfront beach and the Outer Continental Shelf (OCS) borrow area used to construct the beach nourishment projects in 2022/2023. All sand placed along Southern Shores, Kitty Hawk, and Kill Devil Hills was dredged from Borrow Area A.



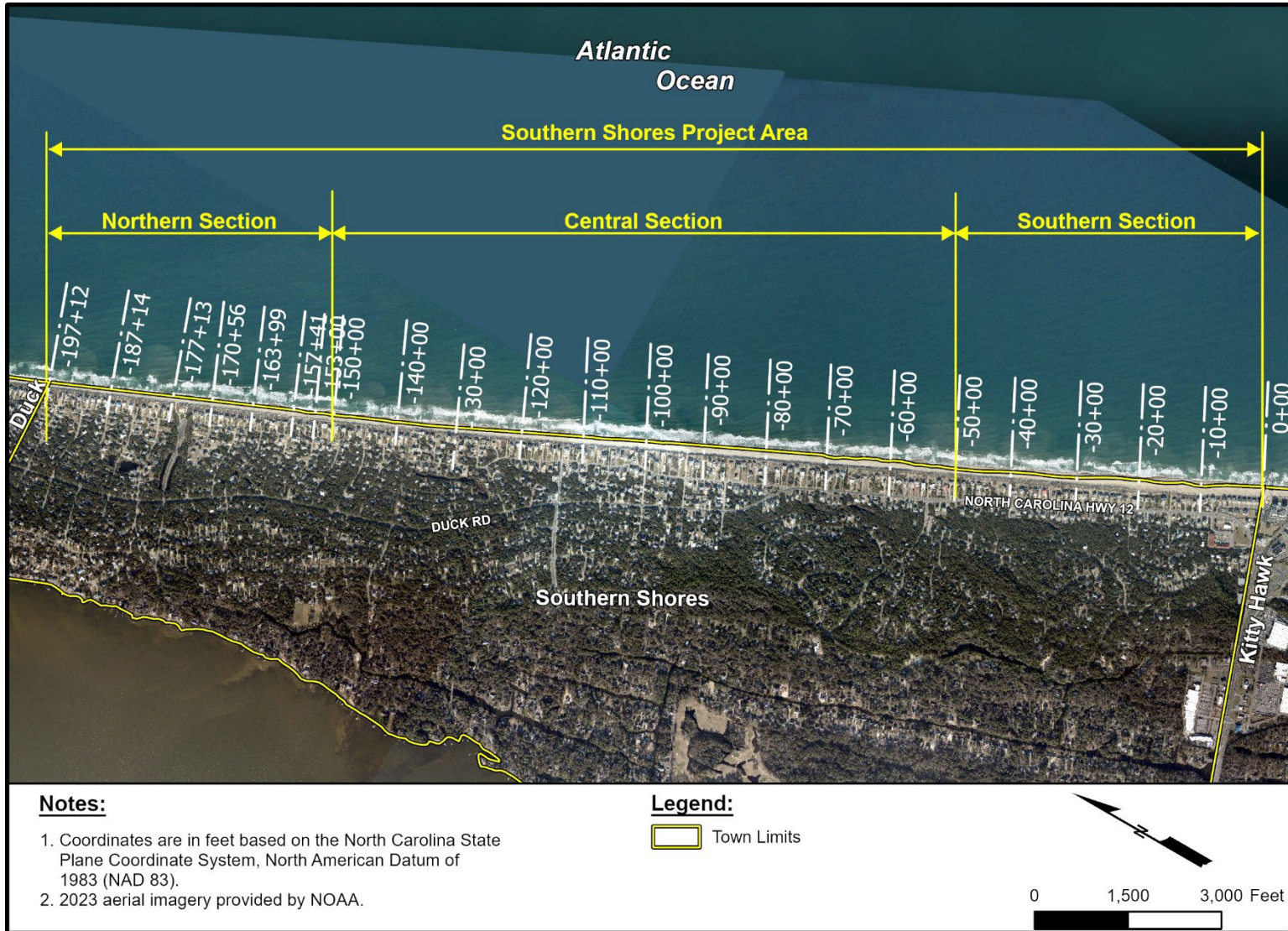
**Figure 1. Project Location Map**

For the purpose of monitoring, the oceanfront beaches of Southern Shores, Kitty Hawk, and Kill Devil Hills were separated into the “Southern Shores Project Area”, the “Kitty Hawk Project Area”, the “Kill Devil Hills Project Area” and the “Kill Devil Hills South Monitoring Area”. The Southern Shores Project Area includes the beach between the northern boundary of the Town of Duck (Sta. 197+12) to the southern boundary of Southern Shores (Sta. 0+00). The Kitty Hawk Project Area includes the beach between the southern boundary of the Town of Southern Shores (Sta. 0+00) to the northern boundary of the Town of Kill Devil Hills (Sta. 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 at the Prospect Ave beach access (Sta. 325+66). The “Kill Devil Hills South Monitoring Area” area includes an additional 4,472 ft. of beachfront (from Sta. 325+66 to 369+89) located within Kill Devil Hills, but south of the Kill Devil Hills Project Area.

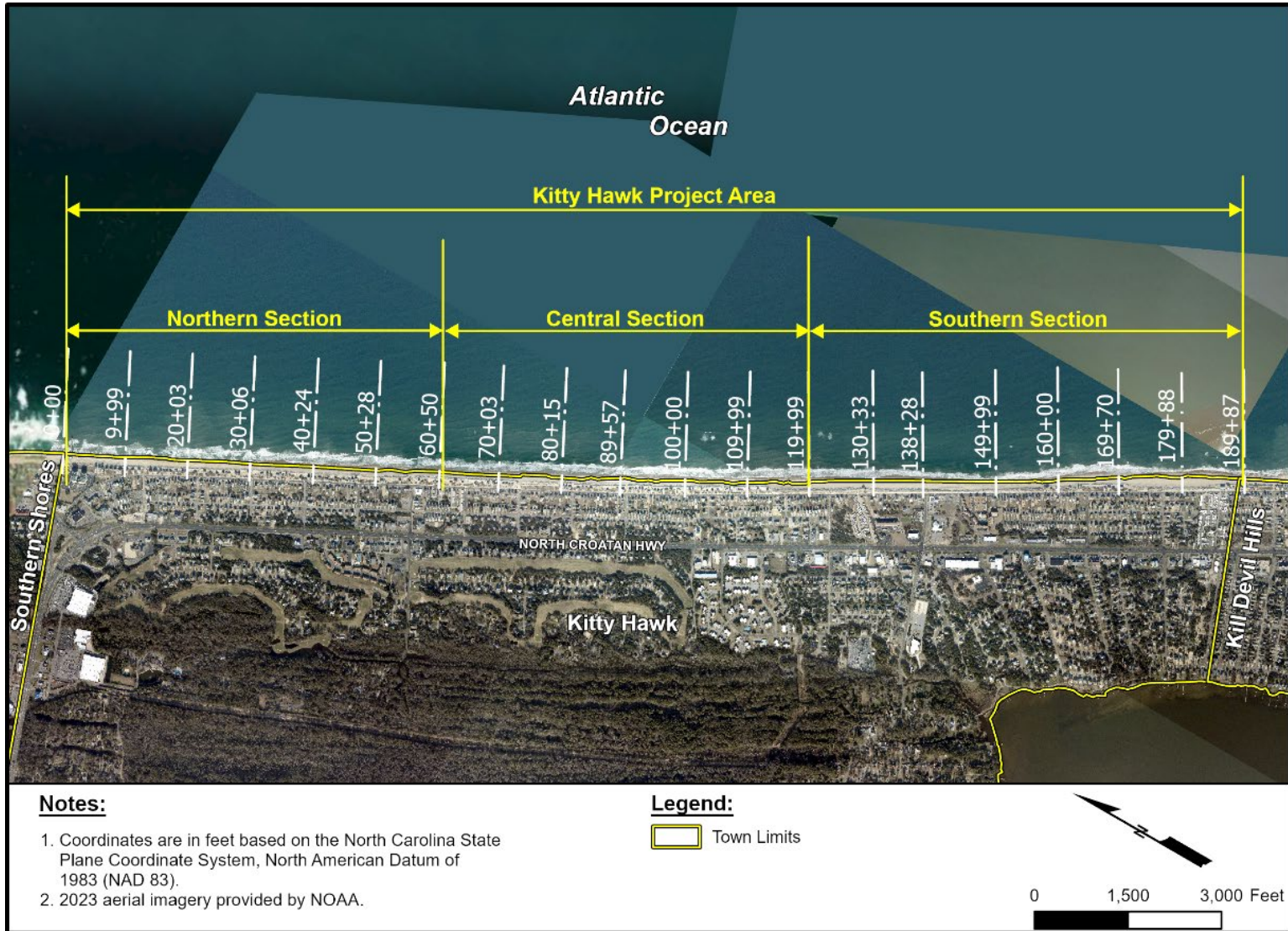
For analysis purposes, each Town’s Project Area was further divided into three sections: namely, the Northern, Central, and Southern Sections as provided in Table 1. Figure 2, Figure 3, and Figure 4 show the monitoring sections for each of the Towns and depicts the monitoring stations where the beach profile surveys were conducted.

**Table 1. Monitoring Sections Summary Table**

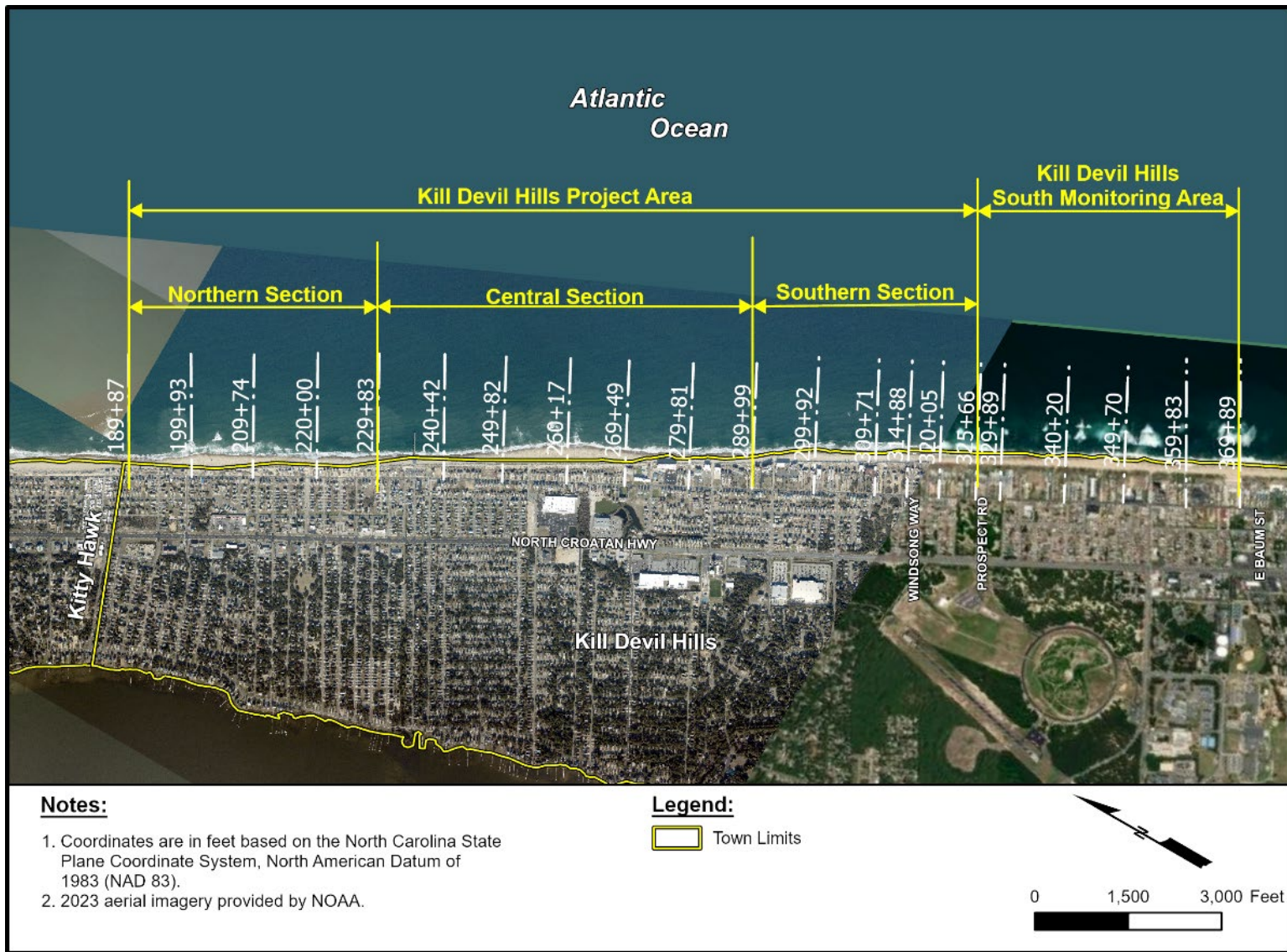
Project Area Section	Description	Monitoring Stations
SS Northern Section	Northern SS Town Boundary to 4 <sup>th</sup> Ave	-197+12 to -153+00
SS Central Section	4 <sup>th</sup> Ave to approximately 450 feet south of Chicahauk Trail	-153+00 to -50+00
SS Southern Section	Approximately 450 feet south of Chicahauk Trail to the Southern SS Town Boundary	-50+00 to 0+00
KH Northern Section	Northern KH Town Boundary to approximately 400 feet south of Eckner St.	0+00 to 60+50
KH Central Section	Approximately 400 feet south of Eckner St. to 300 feet north of Lindbergh Ave	60+50 to 119+99
KH Southern Section	300 feet north of Lindbergh Ave to the Southern KH Town Boundary	119+99 to 189+87
KDH Northern Section	Northern KDH Town Boundary to approximately Random St.	189+87 to 229+83
KDH Central Section	Approximately Random St. to approximately 300 feet north of 1 <sup>st</sup> St.	229+83 to 289+99
KDH Southern Section	Approximately 300 feet north of 1 <sup>st</sup> St. to just north of Prospect Ave	289+99 to 325+66
KDH South Monitoring Area	Just north of Prospect Ave to near E. Baum St.	325+66 to 369+89



**Figure 2. Map showing the Southern Shores Monitoring Sections and the location of the Monitoring Stations**



**Figure 3. Map showing the Kitty Hawk Monitoring Sections and the location of the Monitoring Stations**



**Figure 4. Map showing the Kill Devil Hills Monitoring Sections and the location of the Monitoring Stations**

### III. SURVEY DATA COLLECTION

Data used in this study included fourteen (14) different data sets including the most recent beach profile data acquired by CPE in June 2023. See Table 2 below for dates and description of the datasets that were used. The combined monitoring areas include 62 monitoring profiles from the northernmost limit of Southern Shores (Sta -197+12) to approximately 4,500 ft. south of the Kill Devil Hills project limits (Sta. 369+89) as shown in Figure 2, Figure 3, and Figure 4.

**Table 2. Dataset Description**

Agency/Firm	Survey Type	Date	Stations
TI Coastal	Profile Survey	June 2017	0+00 to 325+66
CPE (APTIM)	Profile Survey	December 2017	-197+12 to 369+89
CPE (APTIM)	Profile Survey	June 2018	-50+00 to 369+89
CPE (APTIM)	Profile Survey/Offshore Bathymetry	May 2019	-50+00 to 369+89
CPE (APTIM)	Profile Survey/Offshore Bathymetry	February 2020	-30+00 to 329+89
CPE	Profile Survey/Offshore Bathymetry	June 2020	-50+00 to 369+89
CPE	Profile Survey/Offshore Bathymetry	April 2021	-197+12 to 369+89
TI Coastal	Profile Survey	April 2022 ( <i>KDH Pre-con</i> )	189+87 to 325+66
TI Coastal	Profile Survey	June 2022 ( <i>KH Pre-con</i> )	0+00 to 189+87
TI Coastal	Profile Survey/Offshore Bathymetry	July 2022 ( <i>KDH Post-con</i> )	189+87 to 369+89
TI Coastal	Profile Survey	August 2022 ( <i>SS Pre-con</i> )	-197+12 to 0+00
TI Coastal	Profile Survey/Offshore Bathymetry	Oct. 2022 ( <i>KH Post-con</i> )	0+00 to 189+87
TI Coastal	Profile Survey/Offshore Bathymetry	Nov. 2022 ( <i>SS Post-con</i> )	-197+12 to 0+00
CPE	Profile Survey/Offshore Bathymetry	June 2023	-197+12 to 369+89

Beach profile surveys 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 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 survey extended into wading depths sufficiently to allow the offshore portion to overlap the upland portion by a minimum of 50 feet.

Beach profile data were collected along monitoring stations listed in Table 3. Coordinates shown in Table 3 are referenced to the North Carolina State Plane coordinate system in feet NAD83 and the profile azimuth refers to degrees referenced to true north. Detailed information on the survey conducted in June 2023 including detailed survey methodology, monument information, cross-section plots of the beach profiles, ground digital photography, and field book notes are provided in Appendix A – 2023 Dare County Beach Monitoring Data Acquisition Survey Report.

**Table 3. Monitoring Station Baseline and Azimuth**

Town	Station	Easting	Northing	Azimuth	Town	Station	Easting	Northing	Azimuth
Southern Shores	-197+12	2962839.6	889616.1	70.0	Kill Devil Hills	189+87	2980448.6	855301.2	59.6
	-187+14	2963230.4	888697.7	70.0		199+93	2980957.8	854433.7	59.6
	-177+13	2963619.0	887775.8	70.0		209+74	2981440.4	853579.1	60.5
	-170+56	2963880.5	887172.9	66.6		220+00	2981944.6	852686.2	60.5
	-163+99	2964142.0	886569.9	66.6		229+83	2982428.6	851830.2	60.5
	-157+41	2964403.5	885966.9	66.6		240+42	2982949.5	850908.8	60.5
	-153+00	2964579.0	885562.3	66.0		249+82	2983384.8	850076.1	61.9
	-150+00	2964665.0	885364.0	65.3		260+17	2983879.6	849166.0	61.9
	-140+00	2965116.0	884444.0	65.3		269+49	2984314.0	848341.7	62.2
	-130+00	2965239.0	883452.0	65.3		279+81	2984795.0	847429.1	62.2
	-120+00	2965920.0	882604.0	65.3		289+99	2985305.3	846547.0	62.2
	-110+00	2966366.0	881697.0	62.6		299+92	2985733.2	845649.7	62.2
	-100+00	2966790.0	880778.0	62.6		309+71	2986193.1	844785.8	62.0
	-90+00	2967110.0	879895.0	62.6		314+88	2986436.0	844329.4	62.0
	-80+00	2967533.0	878988.0	62.6		320+05	2986679.0	843873.0	62.0
	-70+00	2967951.0	878106.0	62.6		325+66	2986919.6	843418.4	62.0
	-60+00	2968381.0	877175.0	62.6		329+89	2987139.0	843003.8	62.1
	-50+00	2968838.0	876228.0	62.6		340+20	2987621.2	842092.3	62.1
	-40+00	2969249.0	875440.0	62.6		349+70	2988097.3	841269.6	62.1
	-30+00	2969731.6	874496.1	62.6		359+83	2988539.2	840357.5	62.1
-20+00	2970189.7	873607.2	62.6	369+89	2989042.0	839485.5	62.1		
-10+00	2970653.0	872721.0	62.6	189+87	2980448.6	855301.2	59.6		
0+00	2971224.2	871890.8	62.6	199+93	2980957.8	854433.7	59.6		
9+99	2971685.8	871003.3	62.6	209+74	2981440.4	853579.1	60.5		
20+03	2972153.2	870116.7	62.2	220+00	2981944.6	852686.2	60.5		
30+06	2972621.7	869230.0	62.2	229+83	2982428.6	851830.2	60.5		
40+24	2973097.5	868329.7	62.2	240+42	2982949.5	850908.8	60.5		
50+28	2973566.7	867441.7	62.2	249+82	2983384.8	850076.1	61.9		
60+50	2974044.0	866538.4	62.2	260+17	2983879.6	849166.0	61.9		
70+03	2974489.1	865695.8	62.2	269+49	2984314.0	848341.7	62.2		
80+15	2974962.0	864800.8	62.2	279+81	2984795.0	847429.1	62.2		
89+57	2975401.9	863968.2	62.2	289+99	2985305.3	846547.0	62.2		
100+00	2975900.2	863052.2	61.5	299+92	2985733.2	845649.7	62.2		
109+99	2976406.1	862189.9	59.6	309+71	2986193.1	844785.8	62.0		
119+99	2976911.9	861327.7	59.6	314+88	2986436.0	844329.4	62.0		
130+33	2977435.1	860436.0	59.6	320+05	2986679.0	843873.0	62.0		
138+28	2977811.3	859735.5	59.6	325+66	2986919.6	843418.4	62.0		
149+99	2978430.3	858740.1	59.6	329+89	2987139.0	843003.8	62.1		
160+00	2978966.6	857895.3	59.6	340+20	2987621.2	842092.3	62.1		
169+70	2979427.7	857040.4	59.6	349+70	2988097.3	841269.6	62.1		
179+88	2979942.7	856163.1	59.6	359+83	2988539.2	840357.5	62.1		
189+87	2980448.6	855301.2	59.6	369+89	2989042.0	839485.5	62.1		

As discussed in previous monitoring reports for Kill Devil Hills and Kitty Hawk (CPE, 2020b), the ocean floor offshore of the Kitty Hawk and Kill Devil Hills project areas is characterized by nearshore depressions or troughs. Given the potential influence of the troughs on the volume change results computed using beach profile surveys only, the Town of Kitty Hawk and Kill Devil Hills incorporated a supplemental bathymetric survey into their monitoring protocol. This survey is conducted annually with the beach profile surveys. The supplemental bathymetric survey includes a series of shore parallel survey lines spaced approximately 200 feet apart. The survey area generally covers the offshore bottom from about the -10-foot NAVD88 contour seaward for a distance of about 3,000 feet. Based on numerous verifications of comparing 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).

In June 2018, CPE surveyed an additional profile at station 314+88 and in April 2021, Sta. 325+66 was added to the annual monitoring program to include the profile where the southern taper ended in the 2017 beach nourishment project. These stations have been surveyed during each subsequent monitoring event. The monitoring stations are spaced approximately 1,000 feet apart along the Town's oceanfront beach. CPE also conducted an additional survey in February 2020 following Hurricane Dorian that included only the profiles within the Kitty Hawk and Kill Devil Hills monitoring areas (Sta. -30+00 to 329+89). This survey data was not used in the analysis but is included in the cumulative volume change plots.

#### IV. SHORELINE CHANGE RESULTS

A shoreline change analysis was completed to assess shoreline advance and recession along each Town's project. The shoreline is typically defined as a specified elevation contour. For this study, the shoreline was defined as the +6.0 ft. NAVD88 contour, which represents the beach nourishment project design berm elevation (CPE, 2021a and CPE, 2021b, CPE, 2022). Shoreline change is calculated by comparing shoreline position along shore perpendicular stations or profiles. Averages for the monitoring areas were determined by computing a weighted average based on distance between the monitoring stations relative to the overall distance of the area. Annualized rates computed for the monitoring were calculated using a linear regression method. The rate is calculated by determining the slope of the linear trendline for a certain shoreline position (+6 ft. NAVD88) for all available survey events. Shoreline changes and shoreline change rates are described in terms of positive ("+" or advance (shoreline moving seaward) and negative ("-") or recession (shoreline moving landward).

The Post-construction monitoring surveys have been adopted to represent the baseline conditions within the Southern Shores, Kitty Hawk, and Kill Devil Hills Project Areas. Future annual monitoring reports will reference shoreline changes in the Project Areas relative to the Post-construction condition to track the performance of the 2022 projects. Equilibration of the constructed beach fill typically occurs within 6 to 12 months following construction along the Outer Banks. This report also evaluated shoreline changes that occurred along each of the three (3) Towns between the 2022 Post-construction surveys and the June 2023 beach profiles surveys. The analysis discussed in this report also includes a shoreline comparison of the changes between 2017 and 2022 as a representation of changes that occurred between the 2017 and 2022 beach nourishment projects. The dates of these various surveys are provided in Table 2.

**Southern Shores.** Between December 2017 and August 2022 (Pre-construction), an average shoreline change of -14.1 ft. (landward movement) was measured along the Southern Shores Project Area. This equates to an average shoreline change rate of approximately -3.4 ft./yr. The individual measurements from profile to profile vary considerably as shown in Table 4. The shoreline change measured at Sta. -157+41 shows a seaward advancement (+18.9 ft.); whereas shoreline changes of -42.5 ft. and -40.0 ft., were measured at Sta. -70+00 and -10+00 respectively,

indicating landward movement over the 4.7-year period between December 2017 and August 2022.

Table 4 provides the measured shoreline changes between various surveys for each station where data exists and provides averages for the various areas monitored. The changes in the position of the +6.0 ft. NAVD88 contour measured between December 2017 and August 2022 (Pre-construction) represent the changes that occurred within the Project Area within the nourishment interval between the 2017 initial construction and the 2022 projects. Short-term measured changes of the +6.0 ft. NAVD88 contour that occurred between November 2022 (Post-construction) and June 2023 are also provided in Table 4. Table 5 shows rates of change for the +6.0 ft. NAVD88 contour determined using a linear regression method that considers each of the data sets available for the long-term period between December 2017 and August 2022 (Pre-construction).

**Table 4. Southern Shores Recent and Long-Term Shoreline Changes (ft.) (+6 ft. NAVD88)**

<b>MONITORING STATION</b>	<b>Dec. 2017 (2017 Post-con) to August 2022 (Pre-con)</b>	<b>Nov. 2022 (Post-Con) to June 2023 (Year-1 Monitoring)</b>
-197+12	-11.2	3.3
-187+14	-6.8	0.3
-177+13	-1.2	42.8
-170+56	9.0	-2.4
-163+99	-6.4	20.8
-157+41	18.9	2.0
-153+00	---	---
-150+00	-7.1	9.4
-140+00	-4.0	49.8
-130+00	-8.5	-70.3
-120+00	-13.0	-96.1
-110+00	-20.3	-102.1
-100+00	-6.2	-35.9
-90+00	-20.5	-16.5
-80+00	-36.0	-45.2
-70+00	-42.5	-41.0
-60+00	-12.6	-111.3
-50+00	-11.6	-4.6
-40+00	-2.6	2.7
-30+00	-22.5	1.1
-20+00	-15.8	-9.4
-10+00	-40.0	-37.8
0+00	-30.9	-2.4
<b>NORTHERN SECTION (-197+12 TO -153+00)</b>	-0.2	11.8
<b>CENTRAL SECTION (-153+00 TO -50+00)</b>	-16.9	-45.5
<b>SOUTHERN SECTION (-50+00 TO 0+00)</b>	-20.6	-9.4
<b>TOTAL SOUTHERN SHORES (-197+12 TO 0+00)</b>	-14.1	-23.8

**Table 5. Southern Shores Long-Term Shoreline Change Rates (ft./yr.) (+6 ft. NAVD88)**

<b>MONITORING STATION</b>	<b>Dec. 2017 (2017 Post-con) to August 2022 (Pre-con)</b>
-197+12	-2.7
-187+14	-0.4
-177+13	0.4
-170+56	2.7
-163+99	-0.7
-157+41	5.4
-153+00	---
-150+00	-0.8
-140+00	-1.7
-130+00	-2.7
-120+00	-2.4
-110+00	-3.2
-100+00	-2.1
-90+00	-5.9
-80+00	-9.9
-70+00	-7.9
-60+00	-1.9
-50+00	-5.8
-40+00	-4.8
-30+00	-4.8
-20+00	-5.1
-10+00	-7.8
0+00	-7.2
<b>NORTHERN SECTION (-197+12 TO -153+00)</b>	0.8
<b>CENTRAL SECTION (-153+00 TO -50+00)</b>	-4.0
<b>SOUTHERN SECTION (-50+00 TO 0+00)</b>	-5.8
<b>TOTAL SOUTHERN SHORES (-197+12 TO 0+00)</b>	-3.4

While the average shoreline change measured along the Southern Shores Project Area between December 2017 and August 2022 showed recession (landward movement of the shoreline), varying trends in the shoreline change and rates were observed throughout the project area. On average, shoreline change trends in the Northern Section tended to be lower than those in the Central and Southern Sections. As shown in Table 5, the average shoreline change rate in the Northern Section (Sta. -197+12 to -153+00) was 0.8 ft./yr. between December 2017 and August 2022. The average shoreline change rate measured between December 2017 and August 2022 in the Central Section of the project was -4.0 ft./yr. The highest shoreline changes were measured along the Southern Section of the project. The average shoreline change rate measured along this stretch over the 4.7-year monitoring period was -5.8 ft./yr.

In Southern Shores, the 2022/2023 project resulted in an average added beach width for the entire project of 101.2 feet at the design berm contour (+6 ft. NAVD88) based on comparisons of the Before Dredge (BD) and After Dredge (AD) surveys. This number reflects the As-Built change in the position of the +6 ft. NAVD88 contour based on the placement of unequilibrated fill within the construction beach fill template. As previously discussed, the Town of Southern Shores project had two separate design templates, one north of 4th Avenue and one south of 4th Avenue. The average added beach width north of 4th Avenue was 21.0 feet and the average added beach width south of 4th Avenue was 124.0 feet. The As-Built shoreline change is representative of changes measured between the 2022 BD and 2023 AD surveys from Sta. -197+12 to Sta. -170+56 and changes measured between the 2022 BD and 2022 AD surveys from Sta. -163+99 to 0+00.

Between November 2022 (Post-Construction) and June 2023, an average shoreline change of -23.8 ft. (landward movement) was measured along the Southern Shores Project Area. The individual measurements from profile to profile vary considerably as shown in Table 4. The shoreline change measured at Sta. -140+00 (approximately 200 ft south of 1<sup>st</sup> Ave) shows a large seaward advance (+49.8 ft.); whereas shoreline change of -111.3 ft., was measured at Sta. -60+00 (North of Chicahawk Trail). An average shoreline change of 11.8 ft. was measured along the Northern Section of the project (north of Sta. -153+00 located near 4<sup>th</sup> Ave.). It should be noted that shoreline changes and shoreline change rates measured along the Northern Section since November 2022 are likely influenced by the addition of 58,100 cy of fill that was placed between Sta. -169+00 and -199+00 between May 9<sup>th</sup> and May 11<sup>th</sup>, 2023.

An average shoreline change of 33.7 ft. (landward movement) was measured along the portion of the project south of 4<sup>th</sup> Ave (Sta. -153+00 to 0+00). The average shoreline changes measured over the 7-month period along the Central and Southern Sections were -45.5 ft. and -9.4 ft. (landward movement), respectively. The greatest negative shoreline changes in the Project Area were observed in the Central Section between Sta. -130+00 (Sandpiper Lane) and Sta. -60+00 (approximately 600 feet north of Chicahawk Trail).

**Kitty Hawk.** Beach profile data indicated that between December 2017 and June 2022 (Pre-construction), the average shoreline change of the +6 ft. NAVD88 contour within the Kitty Hawk Project Area was -70.5 ft. (landward movement). This is equivalent to a rate of change of -12.7 ft./yr. Table 6 provides the measured shoreline changes for each profile along the Kitty Hawk project area between December 2017 and June 2022 (Pre-construction) and between October 2022 (Post-construction) and June 2023 for each station where data exists. All values in Table 6 represent actual changes and not rates. Table 7 shows rates of change for the +6.0 ft. NAVD88 contour determined using a linear regression method that considers each of the data sets available for the periods between December 2017 and June 2022 and October 2022 and June 2023. Table 6 and Table 7 also provide averages for the entire Kitty Hawk Project Area as well as the Northern, Southern, and Central Sections of the Kitty Hawk Project Area.

**Table 6. Kitty Hawk Recent and Long-Term Shoreline Changes (ft.) (+6 ft. NAVD88)**

<b>MONITORING STATION</b>	<b>Dec. 2017 (2017 Post-con) to June 2022 (Pre-con)</b>	<b>Oct. 2022 (Post-Con) to June 2023 (Year-1 Monitoring)</b>
0+00	-11.6	-107.4
9+99	-50.2	-92.2
20+03	-27.6	-30.2
30+06	-35.8	-70.1
40+24	17.4	-17.9
50+28	-3.9	-74.3
60+50	-13.6	-18.8
70+03	-49.7	-15.0
80+15	-84.3	3.2
89+57	-104.0	31.2
100+00	-108.3	8.9
109+99	-86.1	12.8
119+99	-142.7	19.5
130+33	-144.6	63.1
138+28	-113.0	47.0
149+99	-151.7	4.4
160+00	-100.1	-36.9
169+70	-67.8	27.1
179+88	-47.6	3.6
189+87	-42.6	34.8
<b>NORTHERN SECTION (0+00 to 60+50)</b>	-18.7	-58.0
<b>CENTRAL SECTION (60+50 to 119+99)</b>	-85.4	7.0
<b>SOUTHERN SECTION (119+99 to 189+87)</b>	-102.6	18.6
<b>TOTAL KITTY HAWK (0+00 TO 189+87)</b>	-70.5	-9.4

**Table 7. Kitty Hawk Long-Term Shoreline Change Rates (ft./yr.) (+6 ft. NAVD88)**

<b>MONITORING STATION</b>	<b>Dec. 2017 (2017 Post-con) to June 2022 (Pre-con)</b>
0+00	-4.4
9+99	-7.9
20+03	-3.0
30+06	-4.7
40+24	5.6
50+28	0.0
60+50	-0.9
70+03	-12.4
80+15	-20.0
89+57	-19.8
100+00	-19.0
109+99	-17.7
119+99	-23.3
130+33	-25.6
138+28	-19.5
149+99	-36.5
160+00	-18.3
169+70	-12.2
179+88	2.9
189+87	-11.2
<b>NORTHERN SECTION (0+00 to 60+50)</b>	-2.1
<b>CENTRAL SECTION (60+50 to 119+99)</b>	-16.9
<b>SOUTHERN SECTION (119+99 to 189+87)</b>	-18.2
<b>TOTAL KITTY HAWK (0+00 TO 189+87)</b>	-12.7

Although the average shoreline change measured along the Kitty Hawk Project Area between December 2017 and June 2022 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 6). Over the 4.5-year monitoring period, the shoreline changes measured along the Kitty Hawk Project Area ranged from an advance of +17.4 ft. at Sta. 40+24 (approximately 120 feet south of Bennett St.) to a recession of -151.7 ft. at Sta. 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 rate along the Northern Section (Sta. 0+00 to 60+50) was -2.1 ft./yr. between December 2017 and June 2022. The average shoreline change rate measured between December 2017 and June 2022 in the Central Section of the project (Sta. 60+50 to 119+99) was -16.9 ft./yr. The highest shoreline changes were measured along the Southern Section of the project (Sta. 119+99 to

189+87). The average shoreline change rate measured along the Southern Section was -18.2 ft./yr., over the 4.5-year monitoring period. The higher average in the Southern Section was primarily driven by shoreline changes measured along the section from Sta. 119+99 (located approximately 300 feet north of Lillian St.) and 149+99 (located approximately 150 feet south of the Sea Dunes townhomes).

The construction of the beach nourishment project in 2022 resulted in an average added beach width at the +6 ft. NAVD88 contour of 88.3 ft. based on comparisons of the Before Dredge (BD) and After Dredge (AD) surveys. Consideration should be given to the fact that these numbers reflect the change based on the placement of the unequilibrated beach fill construction template.

Between October 2022 (Post-Construction) and June 2023, an average shoreline change of -9.4 ft. (landward movement) was measured along the Kitty Hawk Project Area. The individual measurements from profile to profile vary considerably. The shoreline change measured at Sta. 130+33 (approximately 250 ft south of Kitty Hawk RV Park) shows a large seaward advance (+63.1 ft.); whereas shoreline change of -107.4 ft., was measured at Sta. 0+00 (Kitty Hawk Pier). An average shoreline change of -58 ft. was measured along the Northern Section of the Kitty Hawk project (Sta. 0+00 to Sta. 60+50). The Northern Section was the only Section in which a negative change was measured at every station during this period. In the Central Section of the project, between Sta. 60+50 and 119+99, the average shoreline change measured over the 8-month period was +7.0 ft. The average shoreline change along the Southern Section (Sta. 119+99 to Sta. 189+87) was +18.6 ft. An examination of Table 6 shows that from Hawk St. (Sta. 80+15) north, negative shoreline changes were measured along each profile while South of Sta. 80+15 positive shoreline changes were measured along every station except Sta. 160+00.

**Kill Devil Hills.** Between December 2017 and April 2022 (Pre-construction), the average shoreline change of the +6.0 ft. NAVD88 contour position along the Kill Devil Hills Project Area (Sta. 189+87 to 325+66) was -32.2 ft. This equates to a shoreline change rate of -5.0 ft./yr. Table 8 provides the measured shoreline changes for each profile along the Kill Devil Hills project area between December 2017 and April 2022 and between July 2022 (Post-construction) and June 2023 for each station where data exists. Table 9 shows rates of change for the +6.0 ft. NAVD88 contour determined using a linear regression method that considers each of the data sets available for the periods between December 2017 and April 2022. Table 8 and Table 9 also provide averages for the entire Kill Devil Hills Project Area as well as the Northern, Southern, and Central Sections of the Kill Devil Hills Project Area as well as the KDH South Monitoring Area.

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 2022, ranging from an advance of 25.5 ft. at Sta. 229+83 (approximately 600 feet north of the Avalon Pier) to a recession of -103.7 ft. at Sta. 199+93 (approximately 300 feet north of Lillian St.) (Table 8). The average rate of change in the +6.0 ft. NAVD88 contour position along the Northern Section of the project from Sta. 189+87 (northern Town boundary) to 229+83 (approximately 600 ft. north of the Avalon Pier) was -13.2 ft./yr. over the 4.3-year period. Along the Central Section that extends from Sta. 229+83 to 289+99, the average position of the +6.0 ft. NAVD88 contour moved landward at a rate of -1.5 ft./yr. over the 4.3-year period. The average shoreline change rate measured along the Southern

Section that extends from Sta. 289+99 (approximately 300 ft. north of East First St.) to north of Sta. 325+66 (located near the Prospect Ave. beach access) was -1.8 ft./yr., over the 4.3-year monitoring period.

**Table 8. Kill Devil Hills Recent and Long-term Shoreline Changes (ft.) (+6 ft. NAVD88)**

MONITORING STATION		Dec. 2017 (2017 Post-con) to April 2022 (Pre-con)	July 2022 (Post-Con) to June 2023 (Year-1 Monitoring)
Kill Devil Hills Project Area	189+87	-42.6	-130.0
	199+93	-103.7	-17.0
	209+74	-92.4	26.1
	220+00	-50.4	-51.8
	229+83	25.5	-81.8
	240+42	-62.8	-106.0
	249+82	27.9	-133.4
	260+17	-16.3	56.0
	269+49	-40.7	41.4
	279+81	-9.5	-117.7
	289+99	-13.9	-115.6
	299+92	-24.9	-82.6
	309+71	-43.2	-120.0
	314+88	---	-82.0
	320+05	14.0	-34.0
	325+66	---	8.8
KDH South Monitoring Area	329+89	-12.9	4.4
	340+20	-2.5	5.6
	349+70	38.3	-8.4
	359+83	-27.9	-5.1
	369+89	-4.9	-21.1
<b>NORTHERN SECTION</b> (189+87 to 229+83)		-63.5	-37.3
<b>CENTRAL SECTION</b> (229+83 to 289+99)		-15.8	-60.5
<b>SOUTHERN SECTION</b> (289+99 to 325+66)		-22.8	-81.7
<b>TOTAL KDH</b> (189+87 to 325+66)		-32.2	-59.1
<b>KDH SOUTH MONITORING AREA</b> (325+66 to 369+89)		-1.9	-2.6



**Table 9. Kill Devil Hills Long-term Shoreline Change Rates (ft./yr.) (+6 ft. NAVD88)**

<b>MONITORING STATION</b>		<b>Dec. 2017 (2017 Post-con) to April 2022 (Pre-con)</b>
Kill Devil Hills Project Area	189+87	-11.6
	199+93	-26.8
	209+74	-18.9
	220+00	-3.7
	229+83	4.2
	240+42	-17.5
	249+82	11.8
	260+17	1.3
	269+49	-5.7
	279+81	-1.3
	289+99	1.2
	299+92	-3.8
	309+71	-7.3
	314+88	1.2
	320+05	-1.3
325+66	9.6	
KDH South Monitoring Area	329+89	-8.7
	340+20	5.8
	349+70	5.8
	359+83	-11.8
	369+89	-0.8
<b>NORTHERN SECTION</b> (189+87 to 229+83)		-13.2
<b>CENTRAL SECTION</b> (229+83 to 289+99)		-1.5
<b>SOUTHERN SECTION</b> (289+99 to 325+66)		-1.8
<b>TOTAL KDH</b> (189+87 to 325+66)		-5.0
<b>KDH SOUTH MONITORING AREA</b> (325+66 to 369+89)		-1.0

With the construction of the 2022 beach nourishment project, the position of the +6.0 ft. NAVD88 contour in Kill Devil Hills was moved seaward by an average of distance 86.8 ft. based on surveys collected during the construction of the project (As-Built). Consideration should be given to the fact that these numbers reflect the change based on the placement of the unequilibrated beach fill construction template.

Between the July 2022 (Post-construction) and June 2023 surveys, the +6.0 ft. NAVD88 contour position along the Kill Devil Hills Project Area (Sta. 189+87 to 325+66) receded an average

distance of 59.1 ft. (Table 8). A profile-by-profile analysis of the Kill Devil Hills Project Area showed a wide range of shoreline changes measured between the July 2022 and June 2023 surveys, ranging from an advance of 56.0 ft. at Sta. 260+17 (350 feet north of 4<sup>th</sup> St.) to recession of -133.4 ft. at Sta. 249+82 (400 feet north of 5<sup>th</sup> St.). The average change in the position of the +6.0 ft. NAVD88 contour along the Northern Section of the project from Sta. 189+87 to 229+83 (Approximately Random St.) was -37.3 feet (landward) over the 11-month period. Within the Central Section (from Sta. 229+83 to 289+99), the +6 ft contour retreated -60.5 feet (landward). The largest retreat of the shoreline was observed along the Southern Section that extends from Sta. 289+99 to 325+66, where an average landward movement of -81.7 ft. was measured over the 11-month period.

**Kill Devil Hills South Monitoring Area.** Beach profile data indicated that between December 2017 and April 2022 (Pre-construction), the average shoreline change of the +6 ft. NAVD88 contour within the KDH South Monitoring Area was -1.9 ft., which is equivalent to a rate of change of -1.0 ft./yr., indicating the shoreline south of the Kill Devil Hills Project Area experienced relative stability between the 2017 and 2022 beach nourishment projects.

Between the July 2022 (Post-construction) and June 2023 surveys, the position of the +6.0 ft. NAVD88 contour along the Kill Devil Hills South Monitoring Area (Sta. 325+66 to 369+89) receded an average of 2.6 ft. A profile-by-profile analysis of the Kill Devil Hills South Monitoring Area showed shoreline changes ranging from an advance of 8.8 ft. at Sta. 325+66 to a recession of -21.1 ft. at Sta. 369+89 (Table 8).

## V. VOLUMETRIC CHANGE RESULTS

Beach profile-based volumetric changes were calculated for all three (3) of the Towns and are reported herein. Two (2) different methods were used to assess volumetric changes along the Kitty Hawk and Kill Devil Hills Project Areas. Comparison of beach profile data is a standard method for assessing volumetric changes for a beach. The beach profile-based method used beach profile survey data collected in December 2017, the Pre-construction surveys collected in 2022 for each Town, the Post-construction surveys collected in 2022 for each Town, and the survey conducted in June 2023. Beach profile data are analyzed to determine the average density change along the various profiles, which is measured in cubic yards per linear foot (cy/ft.). The average end area method is then used to compute volumetric changes in cubic yards (cy). Volumetric changes and rates computed between December 2017 and the 2022 Pre-construction surveys represent the changes that occurred between the 2017 and 2022 beach nourishment projects.

The profile-based method was also used to measure volumetric changes that occurred along each of the three (3) Towns between the 2022 Post-construction surveys and the June 2023 beach profiles survey. The dates of these various surveys are provided in Table 2. The Post-construction monitoring surveys have been adopted to represent the baseline conditions within the Southern Shores, Kitty Hawk, and Kill Devil Hills Project Areas. Future annual monitoring reports will reference volumetric changes in the Project Areas relative to the Post-construction condition to track the performance of the 2022 projects.

The second method used in this analysis to assess volume changes in the Kitty Hawk and Kill Devil Hills Project Areas, which is referred to as the hybrid method, involved the combination of beach profile data and more densely spaced offshore bathymetric survey data. This method, instituted by CPE in 2018, has been shown to help resolve morphological irregularities in the bathymetry that occur offshore of Kitty Hawk and Kill Devil Hills. More information can be found about the method in the *2019 Shoreline & Volume Change Monitoring Report* (APTIM, 2019). The hybrid method was used to determine volumetric changes between the 2022 Post-construction surveys and the June 2023 surveys. The Post-construction offshore bathymetric data were collected alongshore from Sta. -50+00 in Southern Shores to Sta. 329+89 in Kill Devil Hills. The June 2023 offshore bathymetric survey collected data from Sta. -50+00 to Sta. 369+89 in Kill Devil Hills.

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 -12 ft. NAVD88 contour out to a depth of at least -30 ft. NAVD88, along which bathymetric data were collected.

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 portions of both the Kitty Hawk and Kill Devil Hills Project Areas between Sta. 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 topography 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 2022/2023 beach fill volumes is also provided for context.

### **Initial Beach Fill Volumes (2017)**

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 Sta. -25+00 in Southern Shores and Sta. 325+66 in Kill Devil Hills.

### **2022/2023 Beach Fill Volumes**

Based on volume changes computed using the profile-based method and the As-Built surveys, approximately 990,400 cubic yards of beach fill material was placed along the entire Southern Shores Project Area as of November 2022. It should be noted that in May 2023 an additional 58,100 cy was placed between Sta. -169+00 to Sta. -199+00 for a total combined As-Built volume of approximately 1,048,400 cubic yards of beach fill (CPE, 2023a). The As-Built volumes for the Kitty Hawk and Kill Devil Hills Projects were approximately 871,400 cubic yards and 565,600 cubic yards, respectively (CPE, 2023a). In total, approximately 2,485,400 cubic yards of beach fill material was placed within the construction template footprint (not out to the -24 ft. NAVD88 closure depth) along the three Towns. This includes the tapers north of Southern Shores (Sta. -197+00 to -202+00) and south of Kill Devil Hills (Sta. 314+88 to 325+66). Table 10 provides a summary of the As-Built volumes placed within the construction template footprint for each Project Area during the 2022 projects as well as the respective Northern, Central, and Southern Sections.

**Table 10. Summary of the 2022/2023 Project As-Built Volumetric Changes**

<b>PROJECT AREA</b>	<b>As-Built Volume Change* (CY)</b>
<b>SOUTHERN SHORES (-197+12 TO 0+00)</b>	<b>1,048,400</b>
Northern Section (-197+12 to -153+00)	124,000
Central Section (-153+00 to -50+00)	580,800
Southern Section (-50+00 to 0+00)	343,700
<b>KITTY HAWK (0+00 TO 189+87)</b>	<b>871,400</b>
Northern Section (0+00 to 60+50)	272,500
Central Section (60+50 to 119+99)	182,600
Southern Section (119+99 to 189+87)	416,300
<b>KILL DEVIL HILLS (189+87 TO 325+66)</b>	<b>565,600</b>
Northern Section (189+87 to 229+83)	182,300
Central Section (229+83 to 289+99)	240,800
Southern Section (289+99 to 325+66)	142,600

\*Volume change computed along the portion of the profile where BD and AD surveys overlap.

**Beach Profile Based Volume Changes**

As-Built surveys conducted throughout the course of the 2022/2023 beach nourishment project, show that approximately 2,485,400 cy of fill were placed along the three projects. The total volumetric change computed along the three (3) Town Project Areas (Sta. -197+12 to Sta. 325+66) between the Post-construction surveys and June 2023 was +680,400 cy. This volume change was computed using the beach profile-based method and includes total volumetric changes to the beach above the -24 ft. NAVD88 contour.

**Southern Shores:** The December 2017 survey covered the entire oceanfront beach along the Town of Southern Shores. While beach profile data from 2004 to 2006 were available along the Central and Southern Sections of Southern Shores (Sta. -153+00 to 0+00), the December 2017 survey is believed to be the first beach profiles survey conducted along the entire Town. The purpose of this survey was to serve as a baseline to evaluate volumetric change trends and storm vulnerability along the Town of Southern Shores. Between December 2017 and August 2022 (Pre-construction), a volume change of approximately 131,100 cubic yards was measured along the entire Town. This equates to a positive density change of 8.6 cy/ft. and a volume change rate of +1.8 cy/ft./yr., over the 4.7-year period. On average, the positive volume change trend in the Northern Section was significantly higher than in the Central and Southern Sections. The volume gain in the Northern Section (the northern 4,400 ft. of the Town) accounted for approximately 84% of the total volume gain measured along the Town between December 2017 and August 2022.

The analysis of the beach profile data collected in November 2022 (Post-construction) and June 2023 indicate that following the placement of beach fill in Southern Shores that took place in 2022, the Project Area experienced a net gain of approximately 399,900 cubic yards, which equates to a density change of approximately 20.9 cy/ft. This quantity is representative of volume change measured above the -24 ft. NAVD88 contour. Table 11 provides the volume changes measured between adjacent monitoring profiles based on comparisons of the November 2022 and June 2023 surveys.

In order to assess and compare the recent volume changes with previous monitoring results, the volume changes along the length of the Southern Shores Project were also analyzed in terms of Northern, Central, and Southern Sections. As previously stated, design goals of the 2022/2023 Southern Shores Project were different north and south of 4<sup>th</sup> Ave (Sta. -153+00). The Northern Section refers to the portion of the project between Sta. -197+12 (northern Town boundary) and Sta. -153+00 (located approximately 100 feet south of 4<sup>th</sup> Ave.), which is also the same spatial extent as the Northern Project Area. The combined 2022/2023 As-Built surveys indicated approximately 124,000 cy of material were placed within the construction template footprint along the Northern Section (Table 10). Values reported in Table 11 show a volumetric gain of approximately 161,400 cy between the November 2022 and the June 2023 surveys. It should be considered that between the time that the November 2022 and June 2023 surveys were conducted, an additional 58,100 cy of fill was placed within the Northern Project Area. Figure 5 shows the cumulative change in volume along the Southern Shores Project Area since December 2017 as well as the Northern, Central, and Southern Sections.

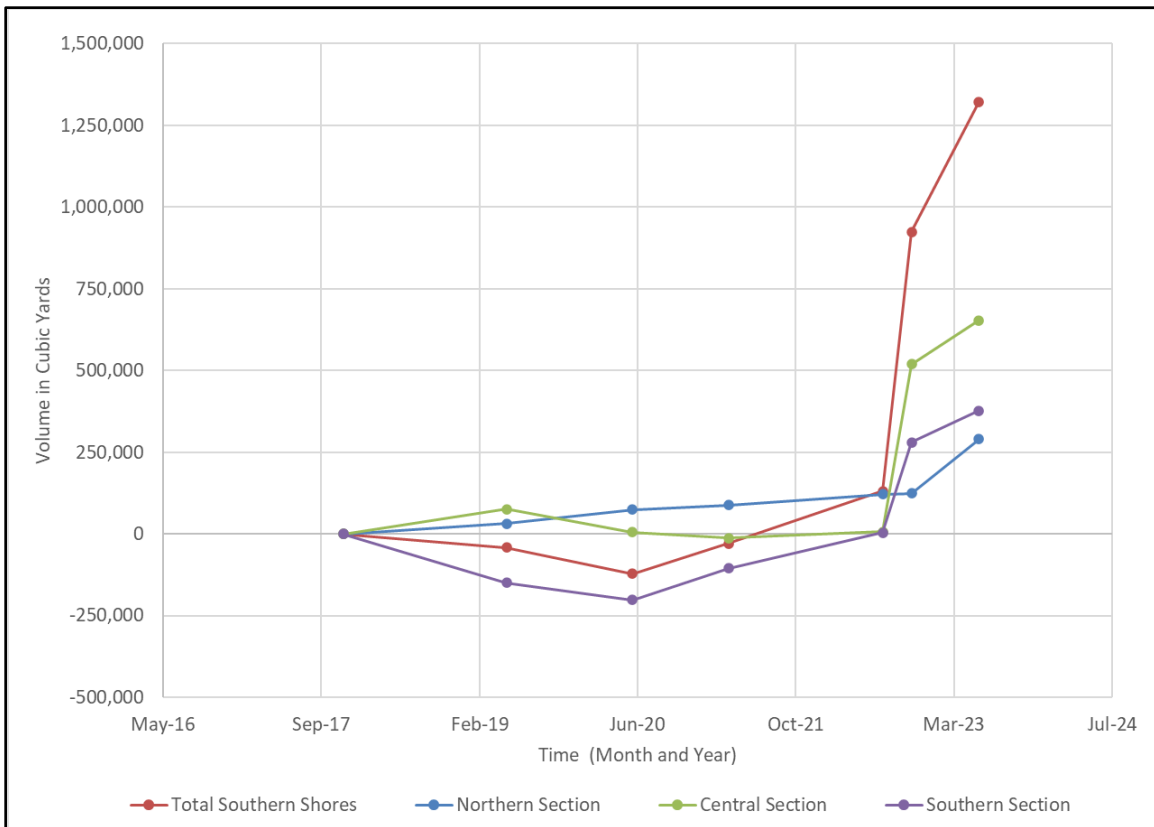
Along the Central Section of the Southern Shores Project Area (Sta. -153+00 to Sta. -50+00) As-Built surveys indicated approximately 580,800 cy of material were placed within the construction template footprint as shown in Table 10. A net gain of approximately 140,600 cy was measured between the November 2022 and June 2023 surveys along the Central Section.

Along the Southern Section of the Project Area between Sta. -50+00 and Sta 0+00, As-Built surveys indicate approximately 343,700 cy of material were placed within the construction template footprint (Table 10) as a result of the beach nourishment project. A net gain of approximately 97,900 cy was measured between the November 2022 and June 2023 surveys along the Southern Section.

**Table 11. Profile-Based Volumetric Changes along Southern Shores, above -24 ft. NAVD88**

<b>MONITORING STATION</b>			<b>Dec. 2017 (2017 Post-con) to August 2022 (Pre-con) (CY)</b>	<b>Nov. 2022 (Post-Con) to June 2023 (Year-1 Monitoring) (CY)</b>
-197+12	To	-187+14	2,000	32,100
-187+14	To	-177+13	16,600	52,300
-177+13	To	-170+56	16,500	26,100
-170+56	To	-163+99	23,000	17,800
-163+99	To	-157+41	31,200	22,500
-157+41	To	-153+00	20,700*	10,600*
-153+00	To	-150+00	10,400*	5,300*
-150+00	To	-140+00	39,800	22,000
-140+00	To	-130+00	25,700	21,400
-130+00	To	-120+00	-9,600	16,400
-120+00	To	-110+00	-30,700	22,300
-110+00	To	-100+00	-100	8,700
-100+00	To	-90+00	2,300	13,600
-90+00	To	-80+00	-13,200	25,900
-80+00	To	-70+00	-17,900	12,500
-70+00	To	-60+00	2,700	-1,300
-60+00	To	-50+00	7,700	-6,400
-50+00	To	-40+00	-14,400	19,100
-40+00	To	-30+00	-8,200	43,500
-30+00	To	-20+00	1,800	26,800
-20+00	To	-10+00	9,000	4,000
-10+00	To	0+00	15,800	4,400
<b>NORTHERN SECTION (-197+12 to -153+00)</b>			109,900	161,400
<b>CENTRAL SECTION (-153+00 to -50+00)</b>			17,200	140,600
<b>SOUTHERN SECTION (-50+00 to 0+00)</b>			4,000	97,900
<b>TOTAL SOUTHERN SHORES (-197+12 to 0+00)</b>			131,000	399,900

\*Sta. -153+00 was not surveyed during the Dec. 2017, 2022 Pre-construction, and 2022 Post-construction surveys. The volumes calculated between Sta. -150+00 and Sta. -157+41 were interpolated according to the distance between those stations and Sta. -153+00.



**Figure 5. Graph showing Cumulative Volume Changes along Southern Shores since December 2017 as Calculated using Profile-Based Volume Changes**

**Kitty Hawk:** Volume change was computed between the December 2017 and June 2022 (Pre-construction) surveys to assess the overall performance of the 2017 beach nourishment project. Over the approximate 4.5 years between December 2017 and June 2022 a volumetric change rate of -8.4 cy/ft./yr. was measured along the Kitty Hawk Project Area. This rate is considered the most representative rate of volumetric change observed within the Kitty Hawk Project Area between the 2017 initial construction and the 2022 renourishment project. However, Figure 6, which shows the cumulative volume change along the Kitty Hawk Project Area since June 2017, illustrates that the volumetric changes between December 2017 and June 2022 varied considerably. As shown in Table 12, the total volumetric change measured between December 2017 and June 2022 was equivalent approximately -650,000 cubic yards. Table 12 also provides the volume change measured between each adjacent monitoring profile between December 2017 and June 2022. Based on the measured effective volumetric gain along the Kitty Hawk Project Area as a result of the 2017 project (2,119,700 cubic yards), approximately 69.3% of the initial volume placed along the Town of Kitty Hawk in 2017 remained in the Project Area above the -24-foot NAVD88 contour as of June 2022.

Beach profile surveys indicate that the Kitty Hawk beach renourishment project gained approximately 191,200 cubic yards between the October 2022 (Post-construction) and June 2023 surveys above the -24 ft. NAVD88 contour. The average density change measured along the project area was 10.4 cy/ft.; however, the measured volume change of beach fill was not uniform



along the length of the Kitty Hawk project. Table 12 shows the volume change measured between each adjacent monitoring profile as well as the total volume change measured between the October 2022 and June 2023 surveys.

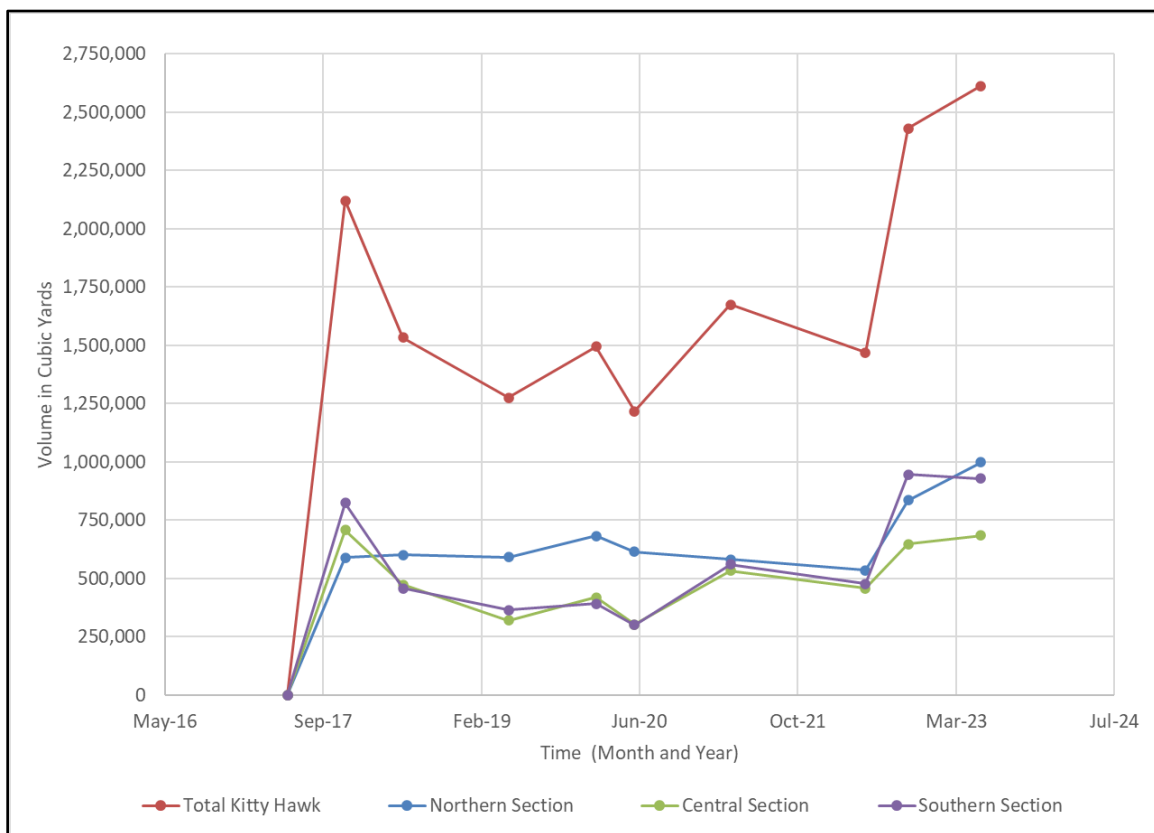
In order to assess and compare the recent volume changes with previous monitoring results, the volume changes along the length of the Kitty Hawk Project were also analyzed in terms of Northern, Central, and Southern Sections. Table 10 shows the 2022 As-Built surveys indicated approximately 272,500 cy of material were placed along the Northern Section of the 2022 project within the construction template footprint. Values reported in Table 12 show a volumetric gain of approximately 163,300 cy between the October 2022 (Post-construction) and June 2023 surveys in the Northern Section. The blue trend line in Figure 6 shows the cumulative volume trend measured between June 2017 and June 2023 along the Northern Section.

**Table 12. Profile-Based Volumetric Changes along Kitty Hawk, above -24 ft. NAVD88**

MONITORING STATION			Dec. 2017 (2017 Post-con) to June 2022 (Pre-con) (CY)	Oct. 2022 (Post-Con) to June 2023 (Year-1 Monitoring) (CY)
0+00	To	9+99	-35,500	-1,000
9+99	To	20+03	-36,600	23,300
20+03	To	30+06	-11,300	44,500
30+06	To	40+24	21,300	35,000
40+24	To	50+28	19,000	35,300
50+28	To	60+50	-10,700	26,300
60+50	To	70+03	-15,400	16,200
70+03	To	80+15	-37,500	18,900
80+15	To	89+57	-42,900	14,600
89+57	To	100+00	-60,400	-13,600
100+00	To	109+99	-52,300	-8,000
109+99	To	119+99	-40,400	6,100
119+99	To	130+33	-44,900	16,000
130+33	To	138+28	-6,100	26,400
138+28	To	149+99	-64,200	5,200
149+99	To	160+00	-123,300	-16,200
160+00	To	169+70	-74,300	1,200
169+70	To	179+88	27,000	-19,200
179+88	To	189+87	-61,600	-19,900
<b>NORTHERN SECTION</b> (0+00 to 60+50)			-53,800	163,300
<b>CENTRAL SECTION</b> (60+50 to 119+99)			-248,900	34,400
<b>SOUTHERN SECTION</b> (119+99 to 189+87)			-347,300	-6,500
<b>TOTAL KITTY HAWK</b> (0+00 to 189+87)			-650,000	191,200

The Central Section refers to the portion of the project between Sta. 60+50 and Sta. 119+99 (located approximately 300 feet north of Lillian St.). The As-Built surveys indicated approximately 182,600 cy of beach fill were placed along the Central Section of the project within the construction template footprint as shown in Table 10. Values reported in Table 12 show a volumetric gain of approximately 34,400 cy between October 2022 and June 2023. The green trend line in Figure 6 shows the cumulative volume trend measured between the October 2022 and June 2023 surveys along the Central Section.

The Southern Section refers to the portion of the project between Sta. 119+99 and Sta 189+87 (southern Town boundary). The As-Built survey indicated approximately 416,300 cy of beach fill were placed along this portion of the project within the construction template footprint (Table 10) as a result of the beach nourishment project. As shown in Table 12, a volumetric loss of approximately 6,500 cy was measured along the Southern Section between October 2022 (Post-construction) and June 2023. This is the only one of the three Sections along Kitty Hawk where a net negative volume change was observed over this time period. The purple trend line in Figure 6 shows the cumulative volume trend measured between October 2022 and June 2023 along the Southern Section.



**Figure 6. Graph showing Cumulative Volume Changes along Kitty Hawk as Calculated using Profile-Based Volume Changes**

**Kill Devil Hills:** Volume change was computed between the December 2017 and April 2022 (Pre-construction) surveys to assess the overall performance of the 2017 beach nourishment project. Over the approximate 4.3 years between December 2017 and April 2022 a volumetric change rate of -9.8 cy/ft./yr. was measured along the Kill Devil Hills Project Area. However, Figure 7, which shows the cumulative volume change along the Kill Devil Hills Project Area since June 2017, illustrates that the volumetric changes between December 2017 and April 2022 varied considerably. As shown in Table 13, the total volumetric change measured between December 2017 and April 2022 was a loss of approximately 458,900 cubic yards. Table 13 also provides the volume change measured between each adjacent monitoring profile between December 2017 and April 2022. Based on the measured effective volumetric gain along the Kill Devil Hills Project Areas as a result of the 2017 project (843,600 cubic yards), approximately 45.6% of the initial volume placed along the Town of Kill Devil Hills in 2017 remained in the Project Area above the -24-foot NAVD88 contour.

Results from the profile-based method of computing volumetric change along the Kill Devil Hills Project Area show a net positive volumetric change of 32,200 cubic yards, above the -24 ft. NAVD88 contour between July 2022 (Post-construction) and June 2023 surveys. This equates to an average density change of +2.7 cy/ft. Table 13 shows the volume change measured between adjacent monitoring profiles as well as the total volume change measured between the July 2022 and June 2023 surveys.

The measured volume changes were not uniform along the length of the Kill Devil Hills Project and as such this report discusses changes in terms of the Northern, Central, and Southern Sections of the Kill Devil Hills project. The As-Built surveys indicate approximately 182,300 cy of fill was placed along the Northern Section of the 2022 project within the construction template footprint as shown in Table 10. Values reported in Table 13 show a volumetric change of approximately -33,000 cy along the Northern Section between July 2022 and June 2023. The blue trend line in Figure 7 shows the cumulative volume trend measured between June 2017 and June 2023.

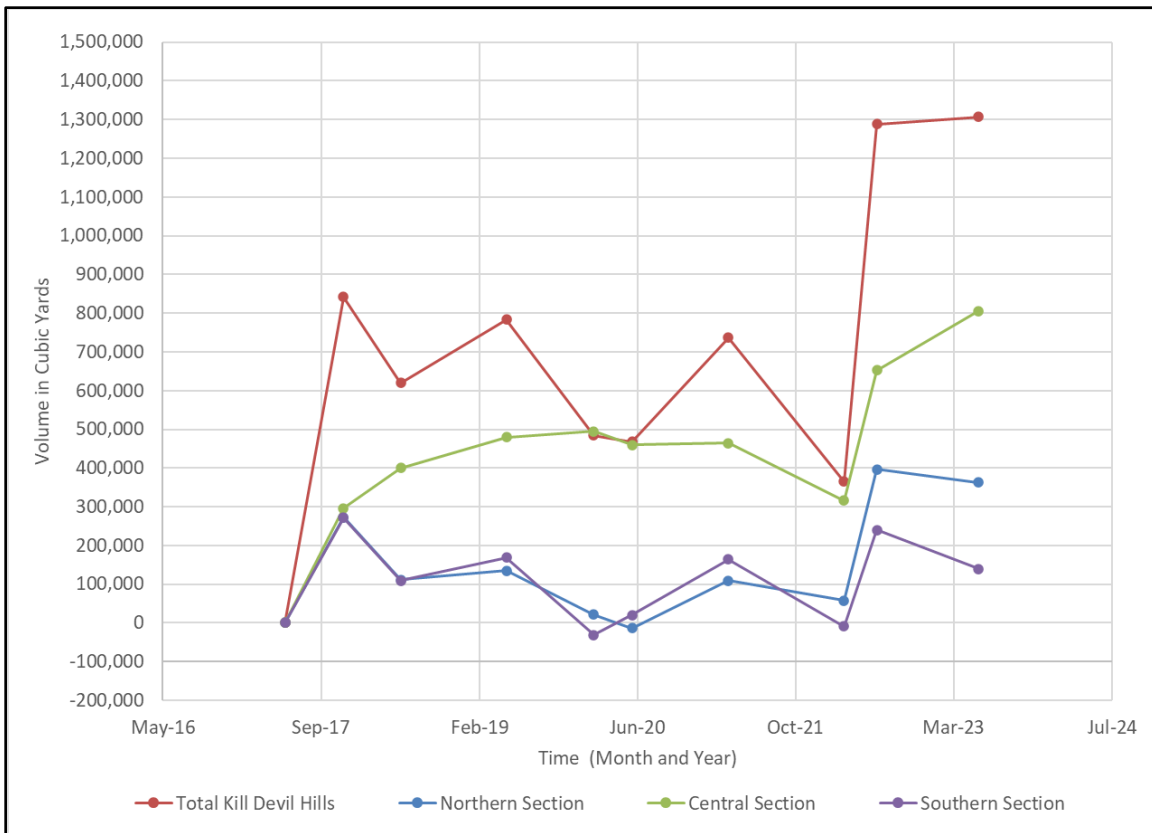
The As-Built surveys indicated that approximately 240,800 cy of fill was placed along the Central Section within the construction template footprint (Table 10) as a result of the beach nourishment project. Values reported in Table 13 show a volumetric change of approximately 154,800 cy along the Central Section between July 2022 and June 2023. The green trend line in Figure 7 shows the cumulative volume trend measured between June 2017 and June 2023 in the Central Section.

The As-Built surveys indicated that approximately 142,600 cy of fill was placed along the Southern Section of the 2022 project within the construction template footprint (Table 10). Values reported in Table 13 show a volumetric change of approximately -89,500 cy along the Southern Section between July 2022 and June 2023. The purple trend line in Figure 7 shows the cumulative volume trend measured between June 2017 and June 2023 in the Southern Section.

**Table 13. Profile-Based Volumetric Changes along Kill Devil Hills and KDH South Monitoring Area, above -24 ft. NAVD88**

MONITORING STATION				Dec. 2017 (2017 Post-con) to April 2022 (Pre-con) (CY)	July 2022 (Post-Con) to June 2023 (Year-1 Monitoring) (CY)
Kill Devil Hills Project Area	189+87	To	199+93	-163,900	-69,900
	199+93	To	209+74	-83,900	-30,200
	209+74	To	220+00	6,600	50,200
	220+00	To	229+83	26,200	17,000
	229+83	To	240+42	-89,200	27,400
	240+42	To	249+82	-38,500	-35,600
	249+82	To	260+17	89,100	2,600
	260+17	To	269+49	64,300	87,100
	269+49	To	279+81	16,900	52,600
	279+81	To	289+99	-23,000	20,800
	289+99	To	299+92	-33,100	-39,800
	299+92	To	309+71	-47,100	-42,200
	309+71	To	314+88	-65,300*	-3,600
314+88	To	320+05	-65,100*	-9,000	
320+05	To	325+66	-52,700*	5,100	
KDH South Monitoring Area	325+66	To	329+89	-48,100*	9,600
	329+89	To	340+20	-28,400	-800
	340+20	To	349+70	26,500	3,200
	349+70	To	359+83	47,700	30,200
	359+83	To	369+89	1,400	47,900
<b>NORTHERN SECTION</b> (189+87 to 229+83)				-215,100	-33,000
<b>CENTRAL SECTION</b> (229+83 to 289+99)				19,600	154,800
<b>SOUTHERN SECTION</b> (289+99 to 325+66)				-263,400	-89,500
<b>TOTAL KILL DEVIL HILLS</b> (189+87 to 325+66)				-458,900	32,200
<b>KDH SOUTH MONITORING AREA</b> (325+66 to 369+89)				-900	90,200

\*Sta. 314+88 and 325+66 were not surveyed during the Dec. 2017 survey. The volumes calculated between Sta. 309+71, 320+05, and 329+89 were interpolated according to the distance between those stations.



**Figure 7. Graph showing Cumulative Volume Changes along Kill Devil Hills as Calculated using Profile-Based Volume Changes**

**Kill Devil Hills South Monitoring Area:** Profile-based volumetric changes measured between December 2017 and April 2022 (Pre-construction), were calculated along the approximately 4,500 feet south of the project (between Sta. 325+66 and 369+89). A negative volumetric change of approximately 900 cy was measured between December 2017 and April 2022. Beach profile-based volumetric changes measured between the July 2022 (Post-construction) and June 2023 surveys indicated this section experienced a positive volume change of approximately 90,200 cy during this period as shown in Table 13.

### **Hybrid Volume Changes**

As stated previously, a second calculation method was used 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 the offshore portions of the beach profiles surveys, to create a “hybrid” bathymetric surface of the seafloor between Sta. -50+00 in Southern Shores and Sta. 369+89 in Kill Devil Hills. Figure 8, Figure 9, and Figure 10 are maps showing the shore-parallel nearshore single beam bathymetric data collected by CPE in June 2023. Figure 11, Figure 12, and Figure 13 are maps showing the changes in the measured depth between the Post-construction bathymetric surveys (collected by the dredge contractor’s surveyor, TI Coastal Services, Inc.) and the June 2023 bathymetric survey.

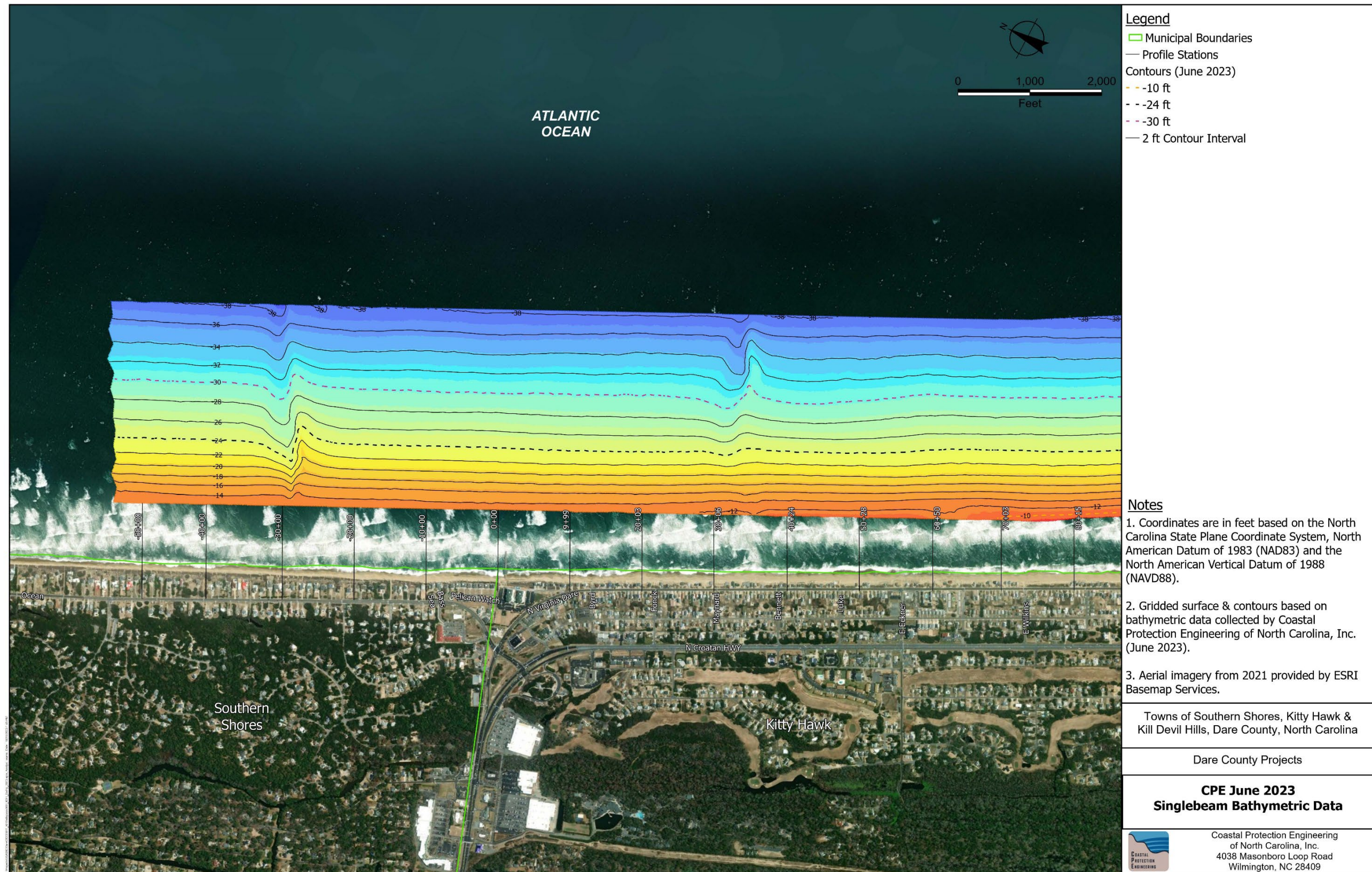


Figure 8. Map Illustrating the Shore-Parallel Nearshore Single Beam Bathymetric Data Collected by CPE in June 2023 between Baseline Stations -50+00 and 80+15

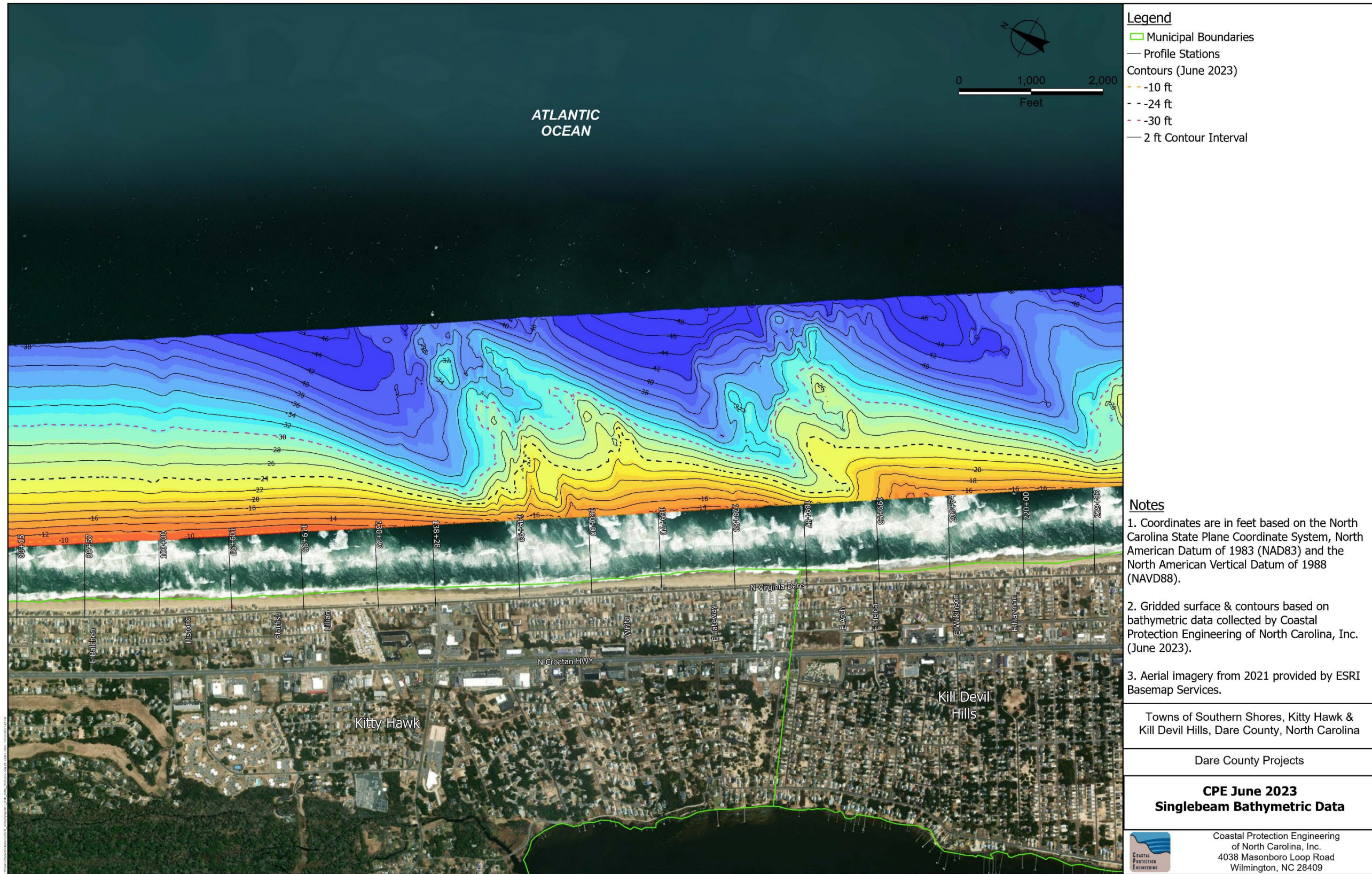


Figure 9. Map Illustrating the Shore-Parallel Nearshore Single Beam Bathymetric Data Collected by CPE in June 2023 between Baseline Stations 80+15 and 229+83

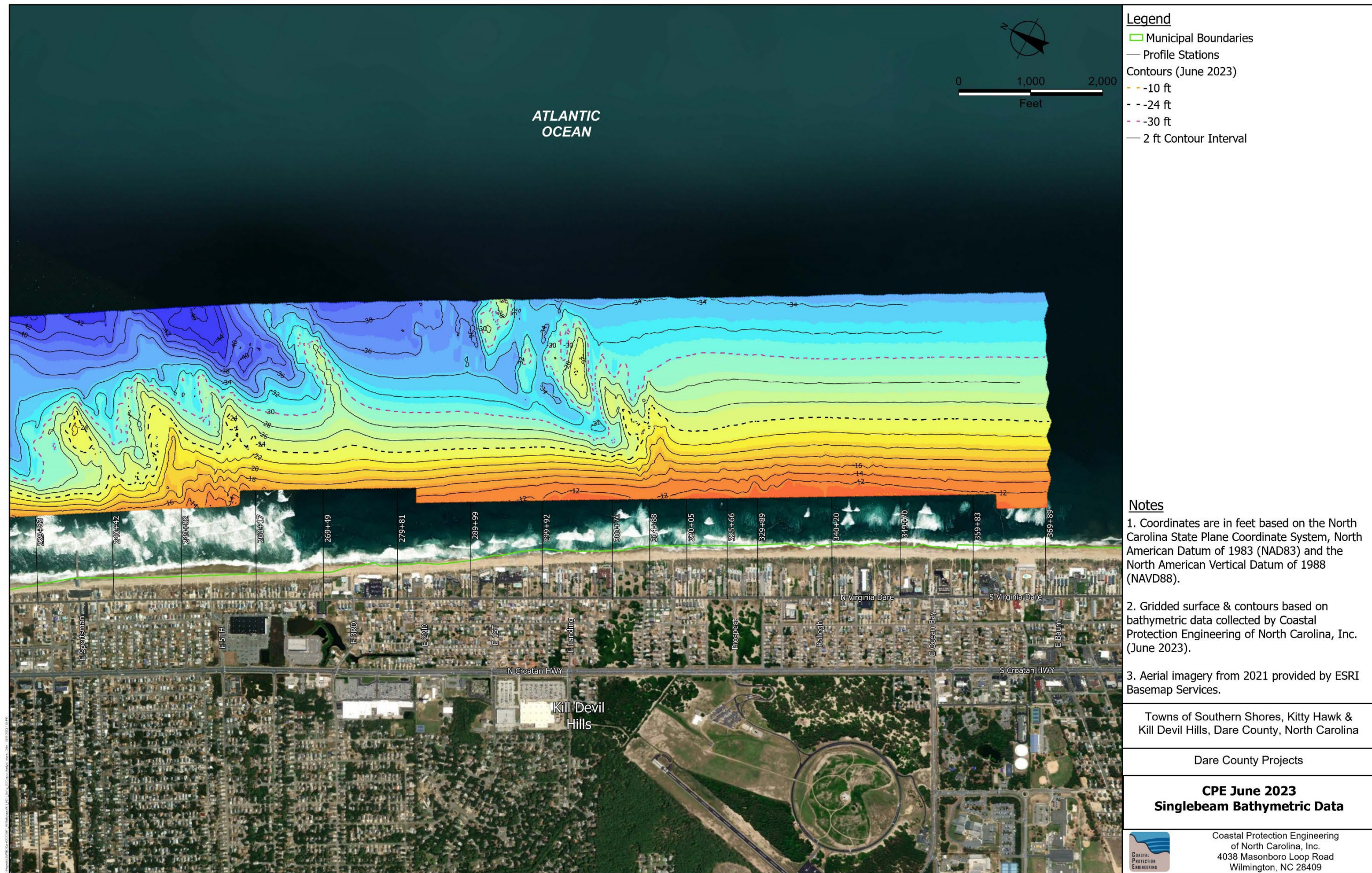


Figure 10. Map Illustrating the Shore-Parallel Nearshore Single Beam Bathymetric Data Collected by CPE in June 2023 between Baseline Stations 229+83 and 369+89



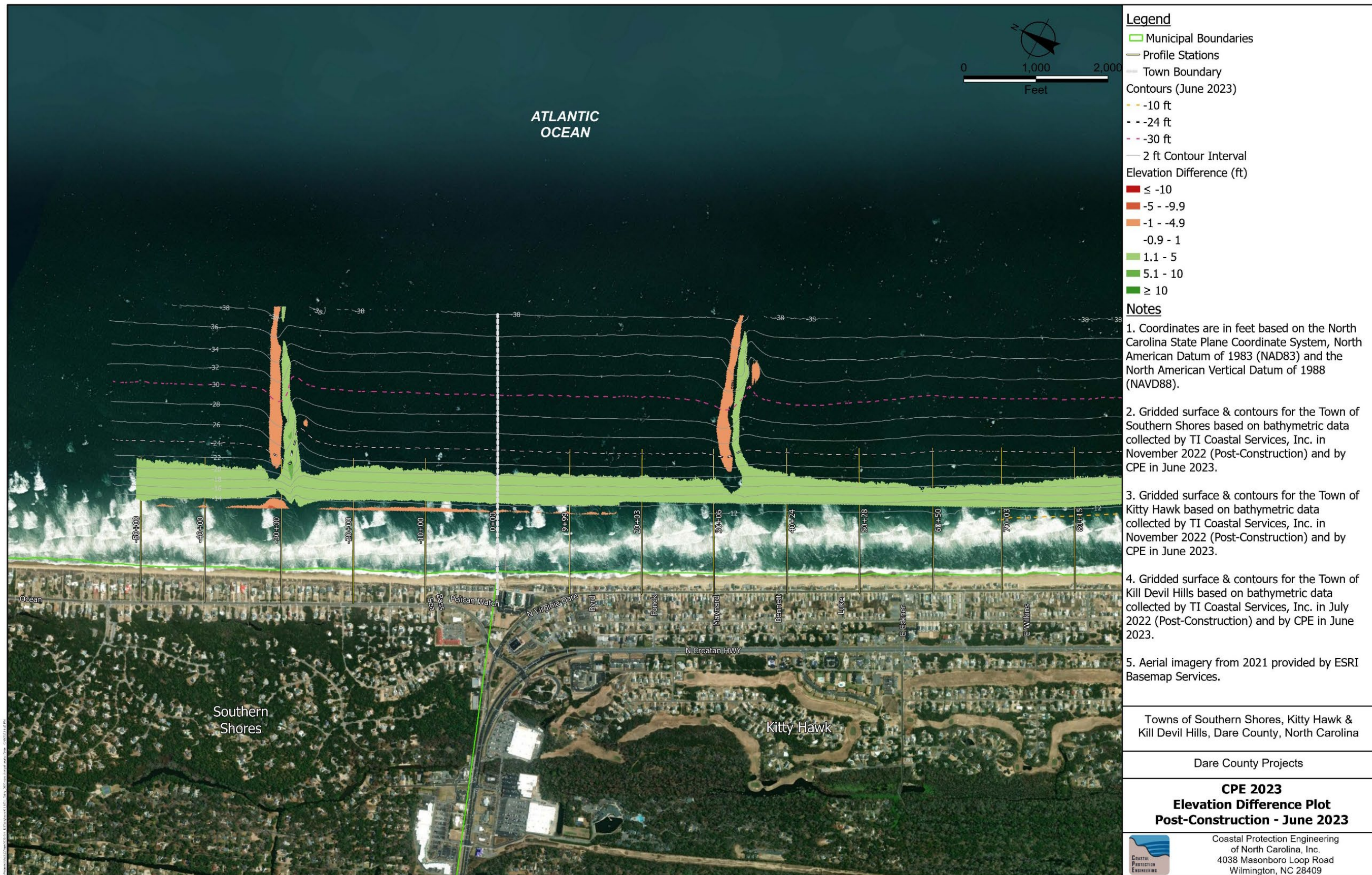


Figure 11. Map Illustrating the Changes in the Measured Depth between the Post-Con Collected by TI Coastal and June 2023 Bathymetric Surveys Conducted by CPE between Baseline Stations -50+00 and 80+15

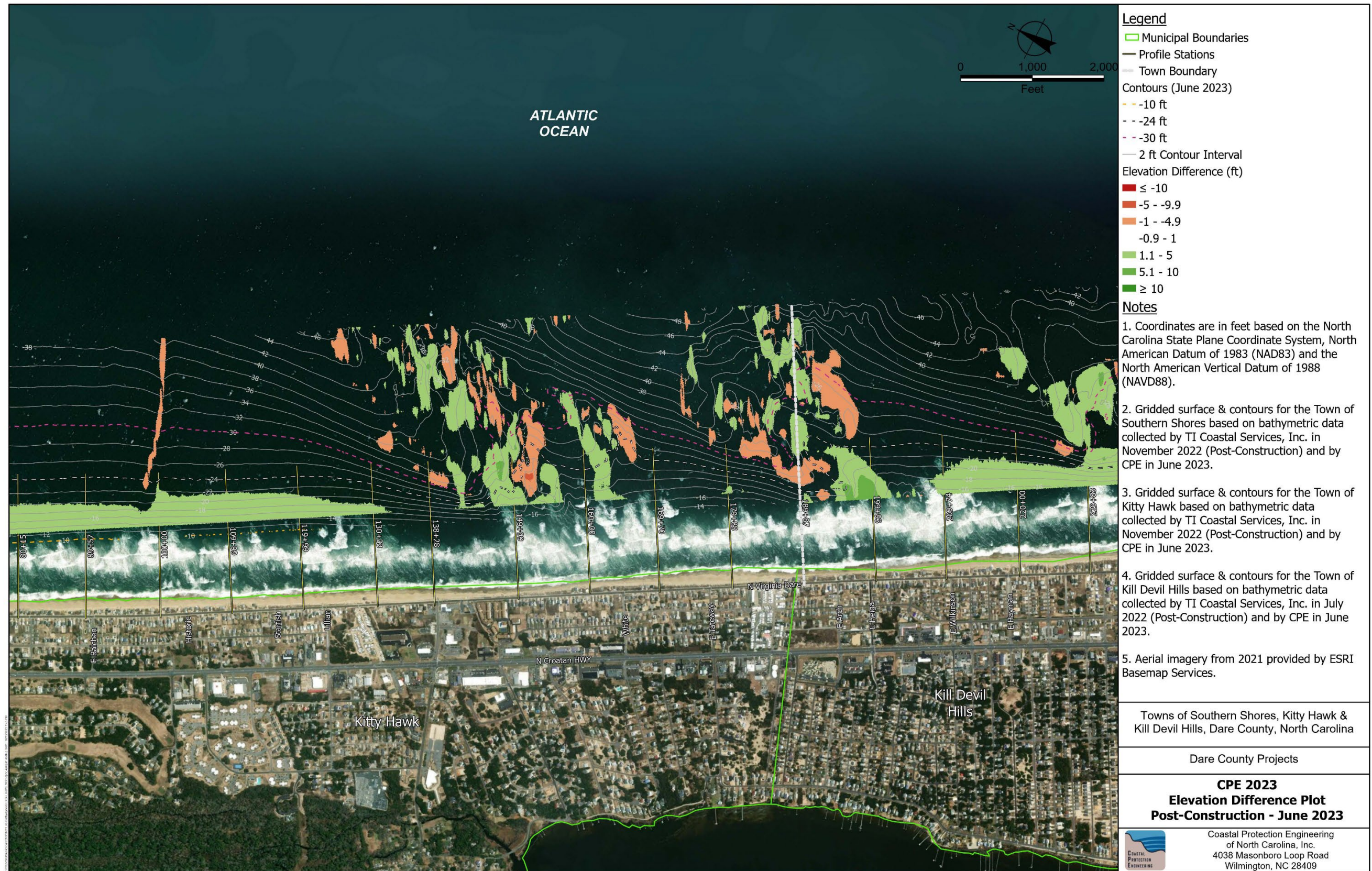


Figure 12. Map Illustrating the Changes in the Measured Depth between the Post-Con Collected by TI Coastal and June 2023 Bathymetric Surveys Conducted by CPE between Baseline Stations 80+15 and 229+83

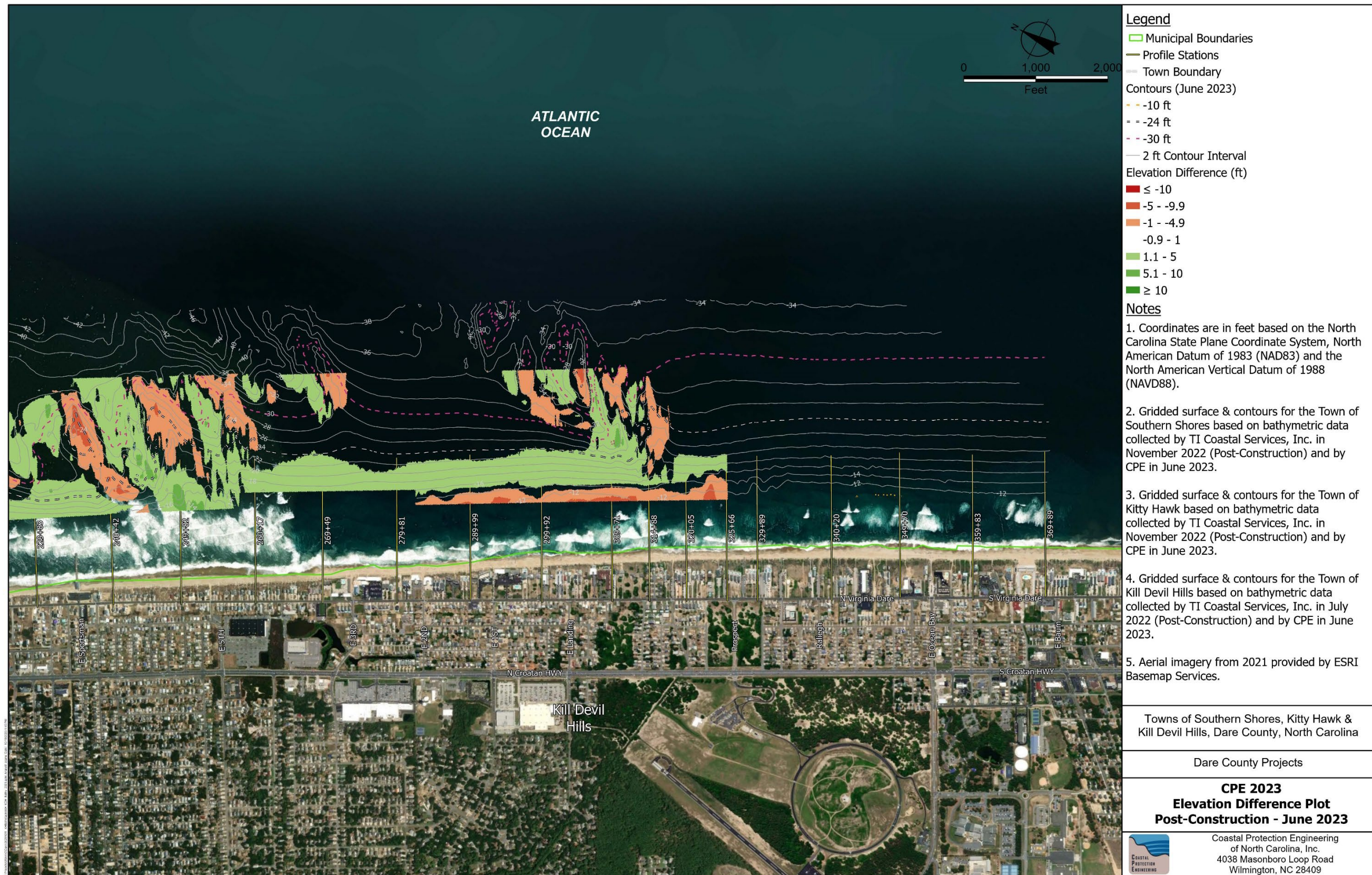


Figure 13. Map Illustrating the Changes in the Measured Depth between the Post-Con Collected by TI Coastal and June 2023 Bathymetric Surveys Conducted by CPE between Baseline Stations 229+83 and 369+89

An examination of the data collected during the June 2023 nearshore data acquisition, indicated nearshore depressions or troughs and associated shore oblique shoals between the -12 ft. and -30 ft. NAVD88 contours in the following portions of the Southern Shores, Kitty Hawk, and Kill Devil Hills Project Areas:

- Near Sta. -30+00 located near 50 Ocean Blvd in Southern Shores
- Between Sta. 30+06 and 40+24 (Maynard St. to Bennett St.) in Kitty Hawk
- Near Sta. 100+00 located approximately 300 ft. north of Historic St. in Kitty Hawk
- Between Sta. 130+33 and 320+05 (200 ft. south of Kitty Hawk RV Park to 200 ft. south of Asheville Dr. in Kill Devil Hills)

The shore-perpendicular bathymetric irregularities identified at Sta. -30+00, between Sta. 30+06 and 40+24, and at Sta. 100+00 are attributed to areas where the sublimes were located during the construction phase of the projects and left temporary depressions on the seafloor that were captured during the Post-construction and June 2023 surveys. These areas are also visible on the maps showing the changes in measured depth when comparing the Post-construction and June 2023 bathymetric surfaces. However, these areas are expected to fill in over time. The larger nearshore depressions or troughs and associated shore-oblique shoals located between Sta. 130+33 and 320+05 are the types of persistent bathymetric features for which the hybrid method was originally designed.

Table 14 provides a summary of the volumetric changes calculated using the hybrid method compared to the beach profile-based method discussed in the previous section. It is important to note that the Post-construction shore parallel surveys were conducted within two weeks after the associated beach profile surveys in Kill Devil Hills; however, in the southern part of Southern Shores and in Kitty Hawk the beach profile surveys were conducted in mid Oct. 2022 and the shore parallel survey was conducted in mid Nov. 2022.

**Table 14. Comparison of Profile-Based and Hybrid Profile/Offshore Shore-Parallel Bathymetric Volume Changes**

PROJECT AREA	Hybrid Based Volume Change 2022 Post-Construction to June 2023 (CY)			Beach Profile-Based Volume Change Post-Con to June 2023 (CY)
	Landward Portion (Beach Profiles)	Seaward Portion (Bathy Surface)	Total	
<b>SS - Southern Section (-50+00 to 0+00)</b>	172,000	-114,100	57,900	97,900
<b>KITTY HAWK (0+00 to 189+87)</b>	<b>723,100</b>	<b>-330,900</b>	<b>392,200</b>	<b>191,200</b>
Northern Section (0+00 to 60+50)	327,100	-164,300	162,800	163,300
Central Section (60+50 to 119+99)	237,000	-152,500	84,500	34,400
Southern Section (119+99 to 189+87)	159,000	-14,200	144,900	-6,500
<b>KILL DEVIL HILLS (189+87 TO 325+66)</b>	<b>512,700</b>	<b>-389,200</b>	<b>123,400</b>	<b>32,200</b>
Northern Section (189+87 to 229+83)	111,000	-107,000	4,000	-33,000
Central Section (229+83 to 289+99)	414,600	-205,900	208,800	154,800
Southern Section (289+99 to 325+66)	-13,000	-76,400	-89,400	-89,500

The hybrid method was used to compute volumetric change for the Kitty Hawk, and Kill Devil Hills projects, as well as the Southern Section (Sta. -50+00 to 0+00) of the Southern Shores project (Table 14). Since implementing the hybrid method in 2018, differences between the beach profile-based method and hybrid method have ranged from the hybrid method 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 2022 Post-construction survey data versus the June 2023 data for the Southern Section of the Southern Shores project, showed an approximate 41% decrease in the calculated volume change when comparing the hybrid method vs. the beach profile-based method. In contrast, the analysis of the Kitty Hawk and Kill Devil Hills projects indicated that the volume changes calculated using the hybrid method were 105% and 283% greater, respectively, than the volume changes calculated using the beach profile-based method. 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.

**Kitty Hawk:** Like the beach profile-based volume change analysis, the hybrid volume change method indicated a positive volume change along the Kitty Hawk Project between October/November 2022 (Post-Construction) and June 2023. As shown in Table 14, the hybrid method indicated that the Kitty Hawk beach renourishment project gained approximately 392,200 cubic yards between the October/November 2022 and June 2023 surveys, which is approximately 201,000 cubic yards more than the beach profile-based method indicated. The average density change measured along the Project Area was 20.7 cy/ft. Table 15 provides a comparison of the density changes computed by the two volumetric analysis methods for the Kitty Hawk Project Area and the associated Northern, Central, and Southern Sections.

**Table 15. Comparison of Kitty Hawk Project Profile-Based and Hybrid Method Density Changes**

PROJECT AREA	Beach Profile-Based Density Change 2022 Post-con to June 2023 (CY/FT)	Hybrid-Based Density Change 2022 Post-con to June 2023 (CY/FT)
<b>KITTY HAWK (0+00 to 189+87)</b>	<b>10.4</b>	<b>20.7</b>
Northern Section (0+00 to 60+50)	25.1	26.9
Central Section (60+50 to 119+99)	6.0	14.2
Southern Section (119+99 to 189+87)	0.3	20.7

Similar to the beach profile-based method, the volume changes are discussed in terms of the Northern, Central, and Southern Sections of the Kitty Hawk Project. Between Oct. 2022 (Post-construction) and June 2023 the hybrid method volumetric change indicated the Northern Section gained approximately 162,800 cy. This volume change is roughly equivalent to the volume change determined by the beach profile-based method (163,300 cy). The comparable volume change between the two methods is likely due to the absence of the irregular offshore bathymetric features in this section, as seen in Figure 8.

The volumetric change calculated by hybrid method in the Central Section showed a gain of approximately 84,500 cy, compared to the 34,400 cy of material calculated using the beach profile-based method between Oct. 2022 (Post-construction) and June 2023. While the Central Section of Kitty Hawk does not appear to be influenced heavily by the irregular offshore bathymetric features present south of Sta. 130+33, the divergence of these two volumes may be attributed to the offshore feature at Sta. 100+00, previously mentioned as being the result of the placement of a subline during the project. If as shown in Figure 12, changes were concentrated at Sta. 100+00, the profile-based approach may have over emphasized those changes.

The difference in the volume change results between the two methods were the highest along the Southern Section of the Kitty Hawk Project Area located roughly between Lindbergh Ave and the Town’s southern boundary (Sta. 119+99 and Sta 189+87). The bathymetric irregularities are the dominant features offshore in this section, as shown in Figure 9. Between Oct. 2022 (Post-construction) and June 2023, the hybrid method measured a volumetric gain of approximately 144,900 cy, whereas the beach profile-based method computed a loss of approximately 6,500 cy, a difference of approximately 151,400 cy.

**Kill Devil Hills:** The hybrid method indicated that the Kill Devil Hills beach renourishment project gained approximately 123,400 cubic yards between the July 2022 (Post-construction) and June 2023 surveys. This is approximately 91,200 cubic yards more than the beach profile-based method. The average density change measured along the Project Area was 9.1 cy/ft. Table 16 provides a comparison of the density changes computed by the two volumetric analysis methods for the Kill Devil Hills Project Area and the associated Northern, Central, and Southern Sections.

**Table 16. Comparison of Kill Devil Hills Project Profile-Based and Hybrid Method Density Changes**

PROJECT AREA	Beach Profile-Based Density Change 2022 Post-con to June 2023 (CY/FT)	Hybrid-Based Density Change 2022 Post-con to June 2023 (CY/FT)
<b>KILL DEVIL HILLS (189+87 to 325+66)</b>	<b>2.7</b>	<b>9.1</b>
Northern Section (189+87 to 229+83)	-5.7	1.0
Central Section (229+83 to 289+99)	23.5	34.7
Southern Section (289+99 to 325+66)	-12.3	-25.4

Similar to the beach profile-based method, the volume changes are discussed in terms of the Northern, Central, and Southern Sections of the Kill Devil Hills Project. Between July 2022 (Post-construction) and June 2023 the hybrid method volumetric change indicated the Northern Section gained approximately 4,000 cy. In contrast, the volume change determined by the beach profile-based method was a loss of approximately 33,000 cy. The variability is attributed to the irregular offshore bathymetric features in this section, as seen in Figure 9 and Figure 12.

Along Kill Devil Hills, the difference in the volume change results between the two methods were the highest along the Central Section of the Kill Devil Hills Project Area located roughly between Palmetto St. and E. 1st St. (Sta. 229+83 and Sta 289+99). The bathymetric irregularities are the dominant features offshore in this section, as shown in Figure 10. Between July 2022 (Post-

construction) and June 2023, the hybrid method measured a volumetric gain of approximately 208,800 cy, whereas the beach profile-based method computed a gain of approximately 154,800 cy, a difference of approximately 54,000 cy.

The volumetric change calculated by hybrid method in the Southern Section showed a loss of approximately 89,400 cy, which is roughly equivalent to the volume change determined by the beach profile-based method (-89,500 cy). Figure 10 shows the irregular offshore bathymetric features in this section in June 2023.

## VI. DISCUSSION

This monitoring report evaluated shoreline and volumetric changes along the portions of beaches nourished in 2022/2023 within the Towns of Southern Shores, Kitty Hawk, and Kill Devil Hills, as well as portions of the adjacent shoreline south of the Kill Devil Hills project. The monitoring area extends south from the northern boundary of the Town of Southern Shores (Sta. -197+12) to Sta. 369+89 located near E. Baum St. in Kill Devil Hills. The results of the shoreline and volume change analysis are the first glimpse into the performance of the 2022/2023 beach nourishment projects. The shoreline and volume changes measured over the Year-1 monitoring cycle, were also compared to shoreline and volume changes measured between the 2017 and 2022/2023 beach nourishment projects. This comparison provides further insight into project performance.

As previously stated in *Section V. Volumetric Change Results*, the volumetric change analysis indicated net volume gains in each of the three (3) towns since the Post-construction surveys were conducted. While the shoreline change analysis results indicated negative shoreline change along each of the three (3) Towns between the Post-construction surveys and the June 2023 survey, this is likely driven by the equilibration of the beach fill over time. Typically, a beach nourishment project experiences equilibration or the decrease in width in the months following construction as the profile equilibrates (Willson et al., 2017). This equilibration process often results in a relatively higher level of negative shoreline change.

**Southern Shores:** As previously stated, volumetric changes along the Southern Shores Project Area only used the profile-based volumetric change method given the relatively uniform shore parallel offshore contours along the Southern Shores Project Area. The volumetric change analysis indicated a net gain of sand along the Southern Shores Project Area between the November 2022 Post-construction survey and the June 2023 survey. Between November 2022 and June 2023, a volume change of approximately +399,900 cy of material was measured along the Southern Shores Project Area, which equates to an average density change of 20.9 cy/ft. With regards to the Northern, Central, and Southern Sections, this equates to volumes of 161,400 cy, 140,600 cy, and 97,900 cy, respectively. In terms of density change, those volumes would equate to positive changes of 35.5 cy/ft., 12.8 cy/ft., and 17.6 cy/ft. along the Northern, Central, and Southern Sections, respectively. As previously noted, the Northern Section volume and density changes between November 2022 and June 2023 were influenced in part by the additional placement of approximately 58,100 cy in early May 2023.

Historic volumetric trends measured along Southern Shores, prior to the construction of the beach nourishment project in 2022/2023, have been positive. Between October 2006 and April 2021,

the Central Section experienced an average density change rate of +2.6 cy/ft./yr., while the Southern Section experienced an average density change rate of +1.4 cy/ft./yr. (CPE, 2021b). Between the December 2017 and August 2022 Pre-construction surveys for the Town of Southern Shores, the average density change rate along the entire Town was +1.8 cy/ft./yr. However, in the Central and Southern Sections, the density change rates were +0.4 and +0.1 cy/ft./yr., respectively, whereas in the Northern Section, the average density change rate was +5.3 cy/ft./yr. While the volumetric changes measured since the completion of the 2022/2023 project were positive, this trend is consistent with trends observed prior to the construction of the project.

With regards to the relatively minimal volumetric change experienced between December 2017 and August 2022 along the Central and Southern Sections, an examination of Figure 5 shows that the volumetric trend over this period of time was not consistent or continuous. In the Central Section, a positive volume change was observed between December 2017 and May 2019, followed by a negative volumetric trend between May 2019 and June 2020, followed by relatively no volume change between June 2020 and August 2022 (green trend line in Figure 5). In contrast, the Southern Section experienced a steady negative volumetric change between December 2017 and June 2020, followed by a steady positive volumetric change between June 2020 and August 2022 (purple trend line in Figure 5). In the Northern Section, Figure 5 shows that a steady positive volumetric change was observed between December 2017 and August 2022 (blue trend line).

The 2022/2023 beach nourishment project added approximately 1,048,400 cy of sand to Southern Shores Beach (CPE, 2023a). Of this total volume approximately 124,000 cy were placed in the Northern Section, 580,800 cy were placed in the Central Section, and 343,700 cy were placed in the Southern Section. As previously stated, the beach fill design along Southern Shores was different north and south of 4<sup>th</sup> Avenue. North of 4<sup>th</sup> Avenue, the goal of the project was to maintain a sufficient useable beach. South of 4<sup>th</sup> Avenue, the project was designed to provide a specific level of storm damage reduction.

In the Northern Section, the goal of the project was to maintain a healthy beach that provides sufficient useable beach, which was defined as an average width of 84 feet (CPE, 2021b). This distance was measured between the +12 ft. and +4 ft. NAVD88 contours along each beach profile. At the time of the Post-construction survey, conducted in November 2022, the average useable beach width along the Northern Section was approximately 84 feet. As of June 2023, the average useable beach width along the Northern Section was approximately 82 feet.

South of 4<sup>th</sup> Avenue along the Central and Southern Sections of the Southern Shores Project, the 2022/2023 beach nourishment project was designed to include approximately 286,200 cy of advanced fill based on a 5-year maintenance interval (CPE, 2021b). Advanced fill is the additional fill required to protect the design section from anticipated sediment losses over the maintenance interval. Between November 2022 and June 2023, a volume change of approximately +238,200 cy of material was measured along the Southern Shores Project Area. Given the project south of 4<sup>th</sup> Avenue was designed with the expectation that approximately 286,200 cy of material could be lost before the beach fill design was compromised, and that the project has experienced a net gain of 238,200 cy since the Post-construction survey in November 2022, this section of the project is performing well.



**Kitty Hawk:** As previously stated, volumetric changes along the Kitty Hawk Project Area used both the beach profile-based and the hybrid volumetric change methods. Given the irregular offshore bathymetry off portions of the Kitty Hawk Project, the hybrid volumetric change method was instituted in 2019 as it is believed to better resolve volumetric changes along the Project Area as compared to the beach profile-based method. Both methods indicated a net gain of sand along the Kitty Hawk Project Area between the October/November 2022 Post-construction and June 2023 surveys. The hybrid method indicated that the net volume gain between the October/November 2022 and June 2023 surveys was +392,200 cy, which equates to an average density change of 20.7 cy/ft. With regards to the Northern, Central, and Southern Sections, this equates to volumetric changes of +162,800 cy, +84,500 cy, and +144,900 cy, respectively. In terms of density change, those volumes equate to +26.9 cy/ft., +14.2 cy/ft., and +20.7 cy/ft. along the Northern, Central, and Southern Sections, respectively.

Volumetric trends measured along Kitty Hawk between the 2017 beach nourishment project and the 2022 project were negative. Between the December 2017 and June 2022 Pre-construction survey for the Town of Kitty Hawk, the measured volumetric change was approximately -650,000 cy, which equates to an average density change rate of -8.4 cy/ft./yr. It should be noted that because the hybrid method was not fully implemented until 2019, the volumetric change and density change rate stated here, was computed using the beach profile-based method. In the Northern Section, the average density change rate over this same period was -1.8 cy/ft./yr. In the Central and Southern Sections, the density change rates were -8.6 cy/ft./yr. and -13.1 cy/ft./yr., respectively.

With regards to the volume change measured between December 2017 and June 2022 along the Central and Southern Sections, an examination of Figure 6 shows that the volumetric trend over this period of time was not consistent or continuous. In the Northern Section, where the volume change was smallest, a slight volumetric gain was measured between December 2017 and February 2020, followed by a slight volumetric loss between February 2020 and June 2022 (blue trend line in Figure 6). In contrast, the Central and Southern Sections experienced a more significant volumetric loss between December 2017 and June 2020, followed by a recovery between June 2020 and June 2022 of approximately 38% and 34% of the volumetric loss measured between December 2017 and June 2020, respectively. These changes are seen in the green and purple trend lines in Figure 6.

The 2022 beach nourishment project added approximately 871,400 cy of sand to the Kitty Hawk beach (CPE, 2023a). Of this total volume approximately 272,500 cy were placed in the Northern Section, 182,600 cy were placed in the Central Section, and 416,300 cy were placed in the Southern Section. The Kitty Hawk beach nourishment project was designed to reduce flooding caused by ocean overwash and to mitigate long-term erosion that can reduce the flood protection provided by the beach fill. The Kitty Hawk project was designed to include approximately 750,000 cy of advanced fill based on a 5-year maintenance interval (CPE, 2021a). Advanced fill is the additional fill required to protect the design section from anticipated sediment losses over the designed maintenance interval. The estimate of advanced fill used in the 2022 design was based on an anticipated rate of loss of -7.9 cy/ft./yr. over the 5-yr maintenance period. Between the October/November 2022 (Post-construction) and June 2023 surveys, a volume change of +392,200 cy of material was measured along the Kitty Hawk Project Area. Given the project was designed

with the expectation that approximately 750,000 cy of material could be lost before the beach fill design was compromised, and that the project has experienced a net gain of 392,200 cy since the Post-construction survey in October/November 2022, the Kitty Hawk Project is performing well.

**Kill Devil Hills:** As previously stated, volumetric changes along the Kill Devil Hills Project Area used both the profile-based and the hybrid volumetric change methods. Given the irregular offshore bathymetry off most of the Kill Devil Hills Project, the hybrid volumetric change method was instituted in 2019 as it is believed to better resolve volumetric changes along the project area as compared to the beach profile-based method. Both methods indicated a net gain of sand along the Kill Devil Hills Project Area between the July 2022 Post-construction and June 2023 surveys. The hybrid method indicated that the net volume gain between the July 2022 and June 2023 surveys was 123,400 cy, which equates to an average density change of 9.1 cy/ft. (Table 16). With regards to the Northern and Central Sections, this equates to volumetric changes of approximately +4,000 cy and +208,800 cy, respectively. In terms of density change, those volumes equate to +1.0 cy/ft. and 34.7 cy/ft., respectively as shown in Table 16. In the Southern Section, the volumetric change measured using the hybrid method was negative, showing a loss of approximately 89,400 cy. In terms of density change, this volume equates to -25.4 cy/ft.

Volumetric trends measured along Kill Devil Hills between the 2017 beach nourishment project and the 2022 project were negative. Between the December 2017 and April 2022 Pre-construction surveys for the Town of Kill Devil Hills, the measured volumetric change was approximately -458,900 cy, which equates to an average density change rate of -9.8 cy/ft./yr. It should be noted that because the hybrid method was not fully implemented until 2019, the volumetric change and density change rate stated here, was computed using the beach profile-based method. In the Northern Section, the average density change rate over this same period was -15.6 cy/ft./yr. In the Central and Southern Sections, the density change rates were -0.5 cy/ft./yr. and -18.4 cy/ft./yr., respectively.

With regards to the volume change measured between December 2017 and July 2022 (Post-construction) along the Central and Southern Sections, an examination of Figure 7 shows that the volumetric trend over this period of time was not consistent or continuous. In the Northern and Southern Sections, where the negative average volumetric changes were relatively large, a general trend of volumetric loss was observed between December 2017 and June 2020. Some recovery of that volume was measured between Juene 2020 and April 2021, followed by volumetric loss between April 2021 and July 2022. These changes are seen in the blue and purple trend lines in Figure 8. In contrast, the Central Section experienced a volumetric gain between December 2017 and February 2020, followed by a volumetric loss from February 2020 to July 2022 (green trend line in Figure 7). The net volumetric gains that occurred between December 2017 and February 2020 were essentially offset by the volumetric losses that occurred between February 2020 and July 2022, which resulted in a cumulative volumetric change of approximately +19,600 cy.

The 2022 beach nourishment project added approximately 565,600 cy of sand to the Kill Devil Hills Project Area (CPE, 2023a). Of this total volume approximately 183,200 cy were placed in the Northern Section, 240,800 cy were placed in the Central Section, and 142,600 cy were placed in the Southern Section. The Kill Devil Hills beach nourishment project was designed to provide a specific level of storm damage reduction and to mitigate long-term erosion that can reduce the

protection provided by the beach fill. The Kill Devil Hills project was designed to include approximately 250,000 cy of advanced fill based on a 5-year maintenance interval (CPE, 2022). Advanced fill is the additional fill required to protect the design section from anticipated sediment losses over the designed maintenance interval. The estimate of advanced fill used in the 2022 design was based on an anticipated rate of loss of -4.0 cy/ft./yr. over the 5-yr maintenance period, which was based on the observed average rate between December 2017 and April 2021 (CPE, 2022). The beach fill project also included the additional placement of approximately 75,000 cy in the Central Section, specifically between Sta. 220+00 (Near E Hayman Blvd) and Sta. 260+17 (Near Drifting Sands Motel) to mitigate potential hot spot erosion (CPE, 2022). Between the July 2022 (Post-construction) and June 2023 surveys, a volume change of approximately +123,400 cy of material was measured along the Kill Devil Hills Project Area. Given the project was designed with the expectation that approximately 250,000 cy of material could be lost before the beach fill design was compromised, an additional 75,000 cy of material were placed in the Central Section to mitigate potential hot spot erosion, and that the project has experienced a net gain of 123,400 cy since the Post-construction surveys in July 2022, the Kill Devil Hills Project is performing well.

**Positive Volumetric Trend Along Three (3) Towns:** Based on the overall negative volumetric trend observed between the 2017 and 2022 beach nourishment projects in Kitty Hawk and Kill Devil Hills, the volumetric gains measured between the Post-construction surveys and the June 2023 monitoring surveys were somewhat unexpected. However, as described in the preceding sections, and illustrated in Figure 6 and Figure 7, net volumetric gains have been measured along portions of the Kitty Hawk and Kill Devil Hills Project Areas between June 2020 and June 2022. Similar trends have recently been observed by CPE through the monitoring of the beaches along Currituck County, north of Duck. That analysis included the specific calculation of volumetric change relative to various depth contours to better understand where along the profiles the majority of volumetric changes were occurring. CPE concluded that a significant portion of the net positive volumetric change along the Assessment Area was occurring between the -6.0 ft. NAVD88 contour seaward to the -19.0 ft. NAVD88 contour, which was established as the depth of closure used in the Currituck County study (CPE, 2023b). The concept of depth of closure is used in coastal engineering applications to define a theoretical depth along a beach profile where sediment transport is very small or non-existent, dependent on wave characteristics and sediment grain size. The significant volumetric change measured between May 2020 and June 2023 along the Currituck assessment area between the -6 ft. NAVD88 and -19 ft. NAVD88 contour led CPE to theorize that the positive volumetric changes may be due to sand migrating inshore from deeper water, seaward of the depth of closure.

As stated above, the depth of closure typically refers to a theoretical depth along a beach profile where sediment transport is very small or non-existent. Kraus (1998) states that the “depth of closure for a given or characteristic time interval is the most landward depth seaward of which there is no significant change in bottom elevation and no significant net sediment transport between the nearshore and the offshore.” Given this definition, one would not expect to find considerable volumetric changes occurring seaward of an established depth of closure. However, in the 2023 Currituck County study, volumetric change was also assessed seaward of the established depth of closure. That assessment also found a net volumetric gain.

Numerous monitoring programs throughout the east coast and gulf coast of the US have documented a phenomenon in which a large storm or a period of time with multiple large storms, resulted in the movement of sediment from the active beach seaward of the typical depth of closure. Furthermore, these studies have also demonstrated that a multi-year recovery period may follow these storm events, during which sand that had previously migrated into deeper water, migrates landward into the active beach profile. This principle was documented in a white paper published by Keehn and Pierro (2003) which demonstrated similar storm response and multi-year recovery that occurred along beach nourishment projects in Fire Island, New York, and Panama City Beach, Florida in the 1990's and early 2000's. As described in the white paper, one contributing factor that both locations had in common was the presence of large sand bar systems. More recently, this phenomenon was described with regards to two beach nourishment projects constructed in the Town of Southampton, New York following the impacts of Super Storm Sandy (Kaczkowski, 2020). In this case, the post-construction monitoring of the beach nourishment projects indicated that the project maintained over 100% of the volume placed 6 years into the beach nourishment project. The author concluded that the additional sand gained in the Assessment Area migrated landward from deposits of sand that were moved into relatively deep water during Super Storm Sandy.

A general review of wave data reflective of conditions offshore Dare County was conducted to evaluate whether patterns in the offshore wave climate might support this concept. Figure 14 shows the measured significant wave heights from a waverider buoy located in approximately 26 m of water offshore of the Duck Field Research Facility pier. An examination of the wave data shown in the lower panel of Figure 14, indicates that generally, the period from May 2020 to June 2023 included no wave events in which significant waves heights exceeded 20 ft., less wave events in which significant wave heights exceeded 15 ft., and generally experienced an overall wave climate that was calmer than the preceding three years shown in the upper panel from January 2017 to January 2020.

The observation of these wave data, coupled with the observations along beaches in Duck and Southern Shores, which also experienced positive volumetric changes during similar period, along with observations of positive volumetric changes along the Currituck County Beaches, suggests that the positive volumetric changes experienced between June 2020 and June 2023, may be explained as a recovery following storm induced migration of sand into deeper depths offshore of the Project Areas. Furthermore, if this explanation holds true, then negative volume change trends may follow this temporary period of recovery.

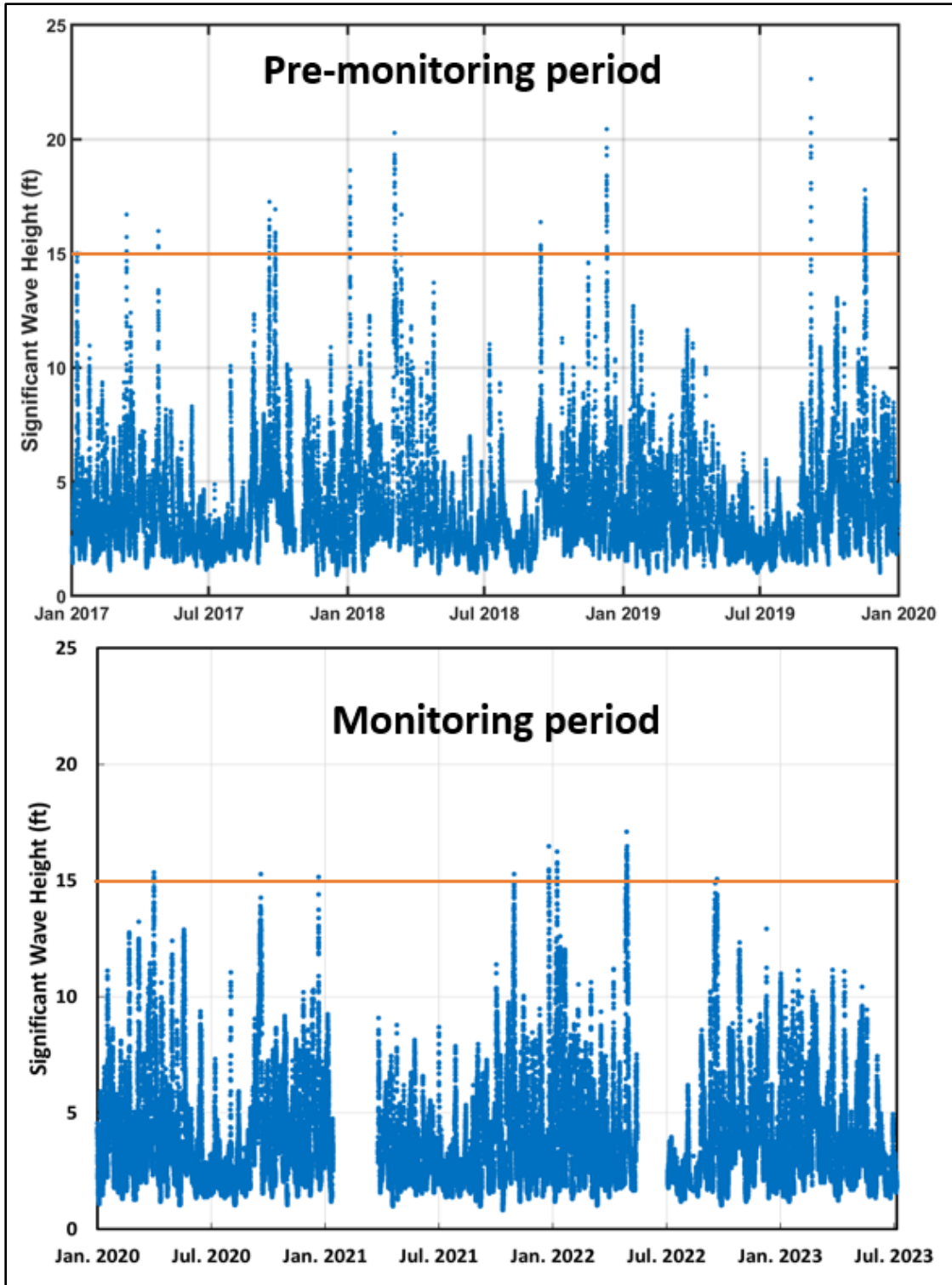


Figure 14. Significant Wave Height data for waverider buoy located in 26 m of water offshore Duck, NC (Station 44100) prior to and during the monitoring period.

## 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. Future monitoring will be instrumental for the Towns to evaluate future areas of concern and to develop successful shoreline management strategies to deal with issues as they arise. The monitoring program will continue to provide valuable information on the performance of the 2022/2023 beach nourishment projects and aid in the determination as to when additional nourishment is needed in the Project Areas. Pre-construction beach profile data collected in Kitty Hawk and Kill Devil Hills indicates that the 2017 project eroded at rates of -8.4 cy/ft./yr. and -9.8 cy/ft./yr., respectively, when compared to the Dec. 2017 Post-construction survey. The Town of Southern Shores did not construct a town-wide project in 2017; however, the entire Town was surveyed in December 2017 and a positive rate of 1.8 cy/ft./yr. was measured, when compared to the August 2022 Pre-construction survey. The erosion rates and rates computed through the continued monitoring of the 2022/2023 projects will be used to design the next renourishment event for each Town. The Post-construction surveys in this report will serve as the baseline for this cycle and the June 2023 survey serves as the Year-1 monitoring survey.

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 the hybrid method be used to evaluate volume change in Kitty Hawk and Kill Devil Hills. The parallel lines should cover the offshore area from near the -12 ft. NAVD88 contour to at least 3,000 feet offshore. All future monitoring surveys should be conducted in the same timeframes from year to year to mitigate the influence of seasonal discrepancies. Moving forward, CPE no longer recommends the continued use of the hybrid method along the southern 5,000 feet of the Town of Southern Shores. The standard beach profile-based method should be sufficient for tracking volumetric changes along the entirety of Southern Shores. It may benefit future modeling efforts to collect several additional shore parallel lines along Kitty Hawk and Kill Devil Hills at a 1,000-foot spacing, potentially extending coverage to approximately 5,000 feet offshore.

The greater density of bathymetric data obtained through the hybrid method has aided in the design of the 2022 beach renourishment projects, specifically regarding the numerical modeling that was conducted. The modeling was specifically used to better evaluate how the nearshore depressions impacted the performance of the initial project and to design alternatives that may provide improvements in future project performance. The numerical model developed for the design of the 2022 project should be given due consideration as the Towns consider project optimization for future projects.

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