APPENDIX G

ENGINEERING ANALYSIS AND NUMERICAL MODELING STUDY

EXECUTIVE SUMMARY

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SOUTHERN PALM BEACH ISLAND COMPREHENSIVE SHORELINE STABILIZATION PROJECT ENGINEERING ANALYSIS AND NUMERICAL MODELING STUDY EXECUTIVE SUMMARY

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1.0 INTRODUCTION

The Town of Palm Beach and Palm Beach County (County) have each proposed shoreline stabilization projects that are adjacent to one another. These projects will require Department of the Army (DA) permits authorizing the discharge of dredge or fill material into waters of the United States (US), under Section 404 of the Clean Water Act (CWA). Accordingly, the United States Army Corps of Engineers (USACE) is evaluating the anticipated combined direct and indirect effects of both projects together through the preparation of an Environmental Impact Statement (EIS). After review of the data and previous work, the USACE has determined that numerical modeling and engineering analysis is required to obtain necessary data that is not currently available.

The Project Area for the Southern Palm Beach Island Comprehensive Shoreline Stabilization Project (the Project) comprises approximately 2.07 miles of shoreline and nearshore environment. The northern and southern limits are defined by Florida Department of Environmental Protection (FDEP) range monuments (R-monuments) R-129-210 (south end of Lake Worth Municipal Beach) and R-138+551 (south of the Eau Palm Beach Resort and Spa in Manalapan), respectively (Figure 1-1). For the purposes of the report, the Town of Palm Beach portion of the Project Area extends from R-129-210 to R-134+135 and is referenced to as the “Town.” The Palm Beach County portion extends from R-134+135 to R-138+551 and is referenced to as the “County.”

The Project Area’s beaches provide storm protection to residential and public infrastructure, and serve as nesting areas for marine turtles. The area is characterized by a narrow beach with seawalls and dunes along its landward boundary and by ephemeral hardbottom formations in the nearshore. The active hurricane and tropical storm activity that occurred between 2004 and 2008 has resulted in a narrow, low profile beach along the majority of Project Area’s shoreline. Over the past 8 years, the annual shoreline change has averaged a loss of 2.25 feet per year (CPE, 2013). Previous attempts to rebuild dunes in the Project Area have not resulted in a stable beach and dune system. The coastline within the Project Area and to the south has been designated by FDEP as “critically eroded” (FDEP, 2015). The alternatives evaluated in the EIS intend to stabilize and widen the beach through combinations of periodic sand nourishments and installation of groins.

The following was assessed to obtain the necessary data for the EIS.

- Storm Protection: The SBEACH model was utilized to analyze the level of storm protection. The IH2VOF model was utilized to evaluate the amount of dune/seawall overtopping during storm events.

- Potential Hardbottom Impacts: The DELFT3D model was utilized to simulate the movement of sand within the littoral system in the vicinity of ephemeral hardbottom. The equilibrium toe of fill (ETOF) due to cross-shore spreading was evaluated based on analytic engineering analysis.

- Surfability: The BOUSS2D model was utilized to assess wave breaking and associated surfing conditions within and adjacent to the Project Area.

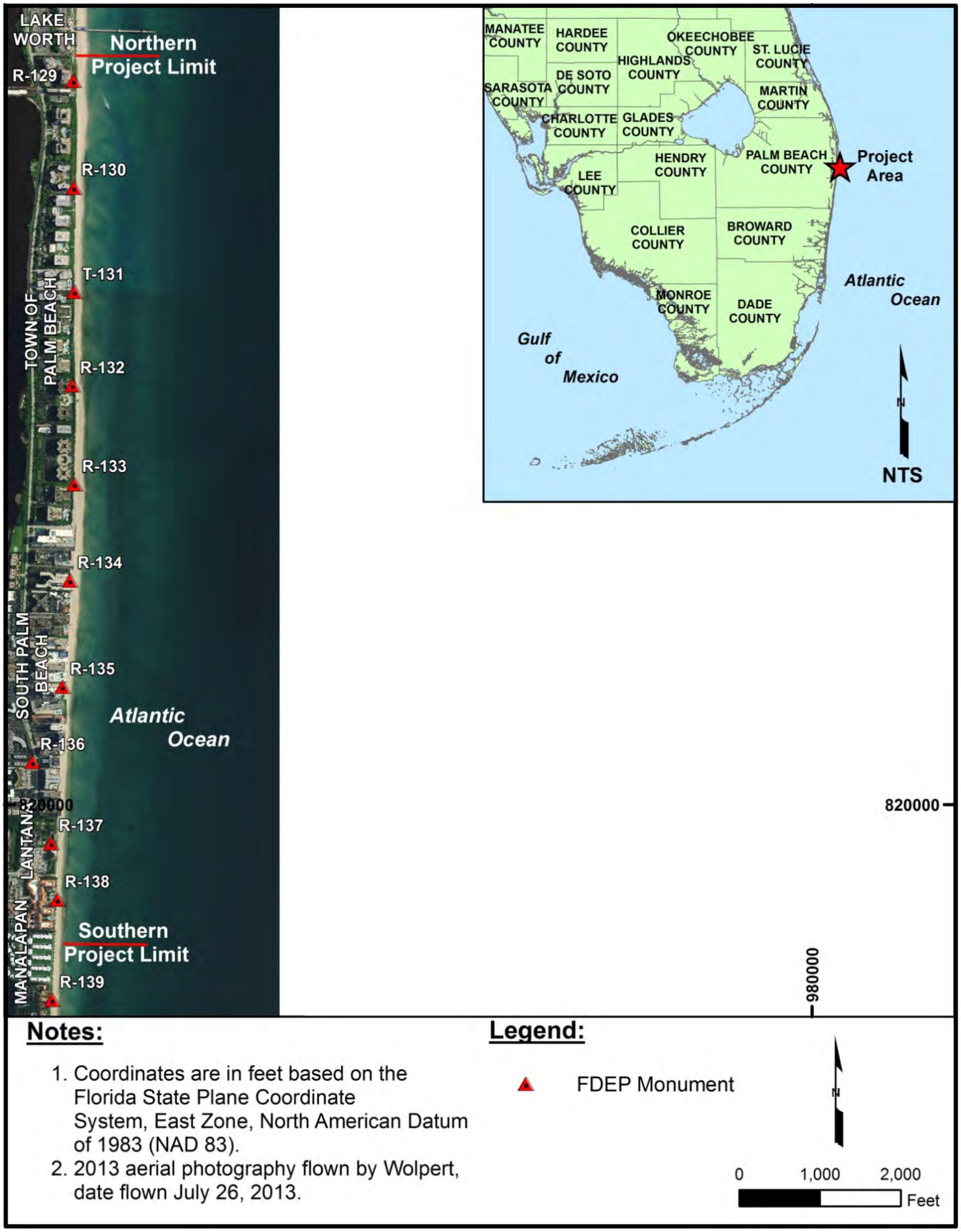

Figure 1-1. Southern Palm Beach Island Comprehensive Shoreline Stabilization Project Location.

2.0 DESCRIPTION OF ALTERNATIVES

Preliminary screening of alternatives was performed to identify a range of reasonable and practical alternatives to be considered for further evaluation. The screening process resulted in six alternatives to be considered. Two additional alternatives, based on options proposed by residents within the Town of Palm Beach, were also considered as the modeling effort evolved.

- <u>Alternative 1</u> is the No Action (Status Quo) alternative where the Applicants would continue the measures presently being implemented in the Project Area (R-129-210 to R-138+551) without any additional actions. No sand placement would occur below the mean high water (MHW) and seasonal high tide line, nor would groins be constructed. However, the dunes may continue to be enhanced periodically through placement of small volumes of sand in portions of the Project Area. For the analysis, Alternative 1 was assumed to be the existing conditions and served as the baseline for which all other alternatives were compared.

- <u>Alternative 2</u> is the Applicants' Preferred Alternative (Proposed Action): Beach and Dune Fill with Shoreline Protection Structures. From north to south, the project would include placing sand to enhance the dune from R-129-210 to R-129+150, dune and beach berm from R-129+150 to R-131, dune from R-131 to R-134+135 (Town of Palm Beach southern limit), and beach berm from R-134+135 to R-138+551 (Figure 2-1). South of the Town of Palm Beach within the County seven (7) low-profile groins were included from R-134+135 to R-138+551. The volume of fill required to fill the construction template within the Town of Palm Beach (R-129-210 to R-134+135) was estimated at 75,000 cy based on September 2009 beach profiles surveys (CSI, 2011). The fill volume required to fill the construction template within the County (R-134+135 to R-138+551) was estimated at 75,000 cy based on December 2008 beach profile surveys (CPE, 2011). This equated to a total fill volume of 150,000 cy.

While maintaining the seaward berm crest location of the fill template, the volume of sand required to fill the template based on the winter 2011/2012 conditions was estimated at 117,300 cy (Table 2-1) and 142,800 cy based on summer 2014 conditions (Table 2-2). The fill volume was further delineated above the high tide line (HTL = +2.6 feet, NAVD), between MHW (MHW = +0.4 feet, NAVD) and the HTL, and below MHW. A schematic of the delineations is shown in Figure 2-1.

The footprint of the construction template was estimated at 24.3 acres based on the winter 2011/2012 beach profiles surveys (Table 2-3). Similar to the volume estimates, the acreages were further delineated landward of HTL, MHW to HTL, and seaward of MHW.

Table 2-1. Construction template fill volumes based on 2011/2012 conditions for Alternative 2.

Alternative 2	Template Volume (CY)					
	Estimated based on Winter 2011/2012 Survey				Prior Estimate	
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total	Total	Survey Date
Town	34,500	9,300	10,000	53,800	75,000	Sept. 2009
County	33,200	10,800	19,500	63,500	75,000	Dec. 2008
Total	67,700	20,100	29,500	117,300	150,000	

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-2. Construction template fill volumes based on 2014 conditions for Alternative 2.

Alternative 2	Template Volume (CY)			
	Estimated based on 2014 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	59,700	2,100	3,400	65,200
County	37,400	13,600	26,600	77,600
Total	97,100	15,700	30,000	142,800

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

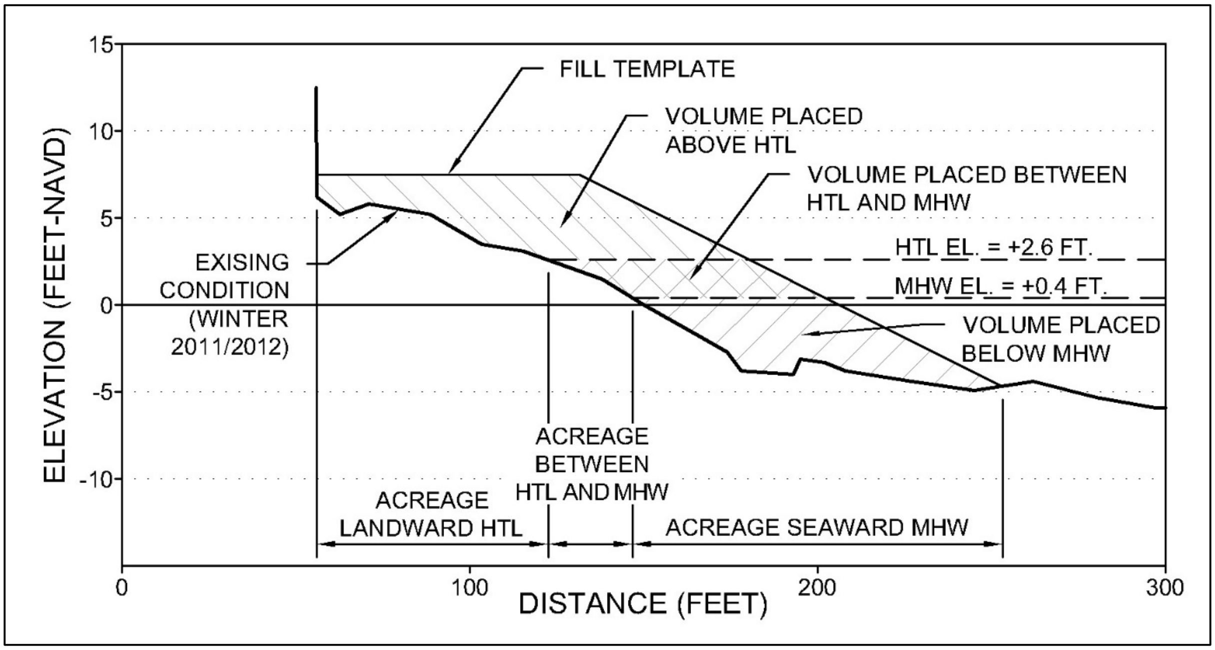

Figure 2-1. Schematic of construction volume and acreage estimates.

Table 2-3. Construction template acreages based on 2011/2012 conditions for Alternative 2.

Alternative 2	Template Acerage (acres) Landward HTL[1]	MHW[2] to HTL[1]	Seaward MHW[2]	Total
Town	7.2	1.7	3.1	12.0
County	3.9	2.4	6.0	12.3
Total	11.1	4.1	9.1	24.3

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

- Alternative 3 is the Applicants' Preferred Project (Proposed Action) without Shoreline Protection Structures. The template fill volumes and acreages are the same as those shown in Table 2-1, Table 2-2 and Table 2-3.

- Alternative 4 is the Town of Palm Beach Preferred Project and County Increased Sand Volume Project without Shoreline Protection Structures. The alongshore extents of the fill defined by Alternative 2 are maintained. The sand volume within the County (R-134+135 to R-138+551) was increased by advancing the beach berm on average 50 feet seaward as compared to Alternative 2. The shoreline protection structures (groins) from Alternative 2 are not included. A breakdown of the construction template fill volumes and acreages are shown in Table 2-4, Table 2-5, and Table 2-6.

Table 2-4. Construction template fill volumes based on 2011/2012 conditions for Alternative 4.

Alternative 4	Template Volume (CY) Estimated based on Winter 2011/2012 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	34,500	9,300	10,000	53,800
County	78,700	27,600	65,800	172,100
Total	113,200	36,900	75,800	225,900

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-5. Construction template fill volumes based on 2014 conditions for Alternative 4.

Alternative 4	Template Volume (CY) Estimated based on 2014 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	59,700	2,100	3,400	65,200
County	84,200	31,800	71,800	187,800
Total	143,900	33,900	75,200	253,000

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-6. Construction template acreages based on 2011/2012 conditions for Alternative 4.

Alternative 4	Template Acerage (acres)			
	Landward HTL[1]	MHW[2] to HTL[1]	Seaward MHW[2]	Total
Town	7.2	1.7	3.1	12.0
County	3.9	2.4	12.5	18.8
Total	11.1	4.1	15.6	30.8

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

- Alternative 5 is the Town of Palm Beach Increased Sand Volume and County Preferred Project. The alongshore extents of the fill defined by Alternative 2 are maintained. The sand volume within the Town of Palm Beach was increased by advancing the dune and beach berm on average 10 feet seaward from R-129-

210 to R-131 and the dune on average 50 feet seaward from R-131 to R-134+135 as compared to Alternative 2. The shoreline protection structures (groins) from Alternative 2 were included. A breakdown of the construction template fill volumes and acreages are shown in Table 2-7, Table 2-8, and Table 2-9.

Table 2-7. Construction template fill volumes based on 2011/2012 conditions for Alternative 5.

Alternative 5	Template Volume (CY) Estimated based on Winter 2011/2012 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	75,100	11,700	14,100	100,900
County	33,200	10,800	19,500	63,500
Total	108,300	22,500	33,600	164,400

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-8. Construction template fill volumes based on 2014 conditions for Alternative 5.

Alternative 5	Template Volume (CY) Estimated based on 2014 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	106,900	7,100	7,700	121,700
County	37,400	13,600	26,600	77,600
Total	144,300	20,700	34,300	199,300

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-9. Construction Template Acreages 2011/2012 – Alternative 5.

Alternative 5	Template Acerage (acres)			
	Landward HTL[1]	MHW[2] to HTL[1]	Seaward MHW[2]	Total
Town	9.5	3.1	3.4	16.0
County	3.9	2.4	6.0	12.3
Total	13.4	5.5	9.4	28.3

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

- Alternative 6 is the Town Increased Sand Volume and County Increased Sand Volume without Shoreline Protection Structures. The alongshore extents of the fill defined by Alternative 2 are maintained. The volume was increased by advancing the dune and beach berm on average 10 feet seaward from R-129-210 to R-131, the dune on average 50 feet seaward from R-131 to R-134+135, and the beach berm on average 50 feet seaward from R-134+135 to R-138+551 as compared to Alternative 2. The shoreline protection structures (groins) from Alternative 2 were not included. A breakdown of the construction template fill volumes and acreages are shown in Table 2-10, Table 2-12, and Table 2-12.

Table 2-10. Construction template fill volumes based on 2011/2012 conditions for Alternative 6.

Alternative 6	Template Volume (CY) Estimated based on Winter 2011/2012 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	75,100	11,700	14,100	100,900
County	78,700	27,600	65,800	172,100
Total	153,800	39,300	79,900	273,000

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-11. Construction template fill volumes based on 2014 conditions for Alternative 6.

Alternative 6	Template Volume (CY) Estimated based on 2014 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	106,900	7,100	7,700	121,700
County	84,200	31,800	71,800	187,800
Total	191,100	38,900	79,500	309,500

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-12. Construction Template Acreages 2011/2012 – Alternative 6.

Alternative 6	Template Acerage (acres)			
	Landward HTL[1]	MHW[2] to HTL[1]	Seaward MHW[2]	Total
Town	9.5	3.1	3.4	16.0
County	3.9	2.4	12.5	18.8
Total	13.4	5.5	15.9	34.8

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

- Alternative 7a was based on an option presented by The Coalition to Save Our Shoreline, Inc. (SOS). The fill template consists of beach fill and dune restoration between R-129+210 and R-134+135 with shoreline protection structures. The shore line protection structures included two (2) T-head groins positioned in the southern portion of the Town's project area between R-132+550 and R-132+270. The sand fill volumes required for the alternative are greater than the volumes for Alternative 6 over the same shoreline extents. The sand volume within the Town of Palm Beach was increased by advancing the dune on average 30 feet from R-129-210 to R-131, advancing the beach berm on average 70 feet seaward from R-129-210 to R-131, and including a beach berm with an average width of 135 feet from R-130 to R-134 as compared to Alternative 2. For the purpose of modeling, Alternative 7a was defined as the SOS option north of R-134+135 and Alternative 2 to the south. The shoreline protection structures (groins) from Alternative 2 were included. A breakdown of the construction template fill volumes and acreages are shown in Table 2-13, Table 2-14, and Table 2-15.

Table 2-13. Construction template fill volumes based on 2011/2012 conditions for Alternative 7a.

Alternative 7a	Template Volume (CY) Estimated based on Winter 2011/2012 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	153,900	49,500	134,700	338,100
County	33,200	10,800	19,500	63,500
Total	187,100	60,300	154,200	401,600

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-14. Construction template fill volumes based on 2014 conditions for Alternative 7a.

Alternative 7a	Template Volume (CY) Estimated based on 2014 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	182,200	41,900	101,400	325,500
County	37,500	13,600	26,500	77,600
Total	219,700	55,500	127,900	403,100

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-15. Construction template acreages based on 2011/2012 conditions for Alternative 7a.

Alternative 7a	Template Acerage (acres)			
	Landward HTL[1]	MHW[2] to HTL[1]	Seaward MHW[2]	Total
Town	9.5	3.1	22.5	35.1
County	3.9	2.4	6.0	12.3
Total	13.4	5.5	28.5	47.4

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

- Alternative 7b was based on the preferred option presented by The Coalition to Save Our Shoreline, Inc. (SOS). The fill template consisted of beach fill and dune restoration between R-129+210 and R-134+135 with shoreline protection structures. The shore line protection structures included two (2) T-head groins positioned in the southern portion of the Town's project area between R-132+550 and R-132+270. The sand fill volumes required for the SOS preferred option are smaller than the volumes for Alternative 7a over the same shoreline extents. For the purpose of modeling, Alternative 7b was defined as the SOS preferred option north of R-134+135 and Alternative 2 to the south. A breakdown of the construction template fill volumes and acreages are shown in Table 2-16, Table 2-17, and Table 2-18.

Table 2-16. Construction template fill volumes based on 2011/2012 conditions for Alternative 7b.

Alternative 7b	Template Volume (CY) Estimated based on Winter 2011/2012 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	69,600	29,100	67,800	166,500
County	33,200	10,800	19,500	63,500
Total	102,800	39,900	87,300	230,000

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-17. Construction template fill volumes based on 2014 conditions for Alternative 7b.

Alternative 7b	Template Volume (CY) Estimated based on 2014 Survey			
	Above HTL[1]	MHW[2] to HTL[1]	Below MHW[2]	Total
Town	97,700	19,100	58,700	175,500
County	37,400	13,600	26,600	77,600
Total	135,100	32,700	85,300	253,100

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

Table 2-188. Construction template acreages based on 2011/2012 conditions for Alternative 7b.

Alternative 7b	Template Acerage (acres)			
	Landward HTL[1]	MHW[2] to HTL[1]	Seaward MHW[2]	Total
Town	9.5	3.1	16.2	28.8
County	3.9	2.4	6.0	12.3
Total	13.4	5.5	22.2	41.1

[1]High tide line (HTL) defined at +2.6 feet, NAVD.

[2]Mean high water (MHW) defined at +0.4 feet, NAVD.

3.0 STORM PROTECTION

The coastline within the Project Area provides storm protection to upland property. The width and elevation of the beach and dune system and the presence of seawalls are factors that contribute to the storm protection afforded by the coastline.

3.1 SBEACH

The level of storm protection was analyzed using the Storm Induced Beach Change Model (SBEACH) (Larson and Kraus, 1989). The model results are detailed in Sub-Appendix G-1. The objectives of analysis were as follows:

- To verify the need for a project along all sections of the Project Area
- Determine the level of storm protection provided by the existing conditions
- Evaluate the range of storm protection associated with proposed fill alternatives

SBEACH simulates changes to beach (and dune) profile due to storm-driven erosion. Inputs to the model include the initial profile, the time histories of the waves and water levels during each storm, and a set of model calibration parameters. Changes to the beach and dune profiles were simulated for storms event with return periods of 5, 15, 25, 50, and 100 years. The level of storm protection afforded was defined by the storm return period that causes a 0.5 foot vertical loss at the landward limit of the beach. The impacts from the return period storm events were modeled for each of the following scenarios:

- Existing conditions (Alternative 1): The existing conditions were modeled to provide a baseline if no action was taken. The seawalls that existed at R-monuments were included in the model and assumed to not fail.

- Seawall failure: The existing conditions were modeled, but the existing seawalls were omitted to simulate the impacts associated with seawall failure during the storm events.

- Future scenarios without Project: The profiles from the existing conditions were translated landward based on background erosion rates to forecast future scenarios after 10 and 50 years. These scenarios assumed that no periodic sand placement would occur.

- Alternative 3 and Alternative 6: Alternatives 3 (Alternative 2 without shoreline protection structures) and 6 bracketed the level of protection that could be achieved as they included the smallest and greatest fill volumes, respectively.

Alternatives 2, 4, and 5 were not modeled as they were various combinations of fill volumes were bracketed by Alternatives 3 and 6. Alternatives 7a and 7b were not included as they were not being considered at the time the modeling was conducted. Groins were not included since SBEACH is a cross-shore model and shoreline protection structures (groins) oriented perpendicular to shore are not applicable.

The simulated conditions were identified to represent extreme storm events, but there is considerable variability among events that may be encountered. The following are the primary findings based on the results of the SBEACH modeling analysis:

- The critical return interval storm resulting in property damage under existing conditions is between a 15-year and 25-year storm. On average, 7.3 to 7.7 cubic yards per foot was simulated to erode from the beach above mean low water during a 15-year and 25-year storm, respectively. This volumetric loss coincides with a steepening of the dune face, shoreline retreat and lowering of the beach profile elevation. Based on 2011/2012 conditions, erosion and wave impacts were simulated to extend landward damaging infrastructure and maintained (landscaped) property areas at FDEP R-monuments R-130, R-133, R-135 and R-137. These locations lack seawalls or have seawalls located further landward on the property.
- Seawalls prevent erosion into the upland property until wall failure. Scouring at the toe of exposed seawalls increases their likelihood of failure. Based on the 2011/2012 conditions response to a storm event, the berm elevation adjacent to exposed seawalls will lower increasing the likelihood of seawall failure during storms. If seawall failure is assumed to occur along the Project Area, infrastructure would be impacted from R-130 through R-138. A detailed analysis of the structural stability of the individual seawalls along the Project Area would

be necessary to truly assess the vulnerability of this critical component of storm protection infrastructure.

- Alternative 1 was the No Action (Status Quo) alternative, in which fill placement would occur periodically to enhance the dunes. This alternative was assumed to be represented by the existing conditions (winter 2011/2012). Alternative 1 is unlikely to sustain the existing conditions based on erosion during the modeled storm events (above MLW), background erosion rates, and regulatory constraints limiting sand placement to the dry beach.
- Two future scenarios were simulated to represent the beach conditions after 10 and 50 years of erosion assuming that no periodic sand placement would occur. For both scenarios, all remaining storm protection provided by the dune between R-130 and R-134 would be lost after a single 15-year storm event. Seawalls that were buried within the dune would become exposed and subjected to wave action. The seawalls between R-136 and R-138 would possibly fail due to toe scour depending on the depth of the wall, allowing erosion of upland property and damage to infrastructure.

3.1.1 Additional SBEACH Modeling

Following completion of the initial SBEACH modeling study and receipt of public comments, it was determined that an additional modeling study within the Town's portion of the Project Area (R-129-210 to R-134+135) was needed. The additional study evaluated additional sediment grain sizes (0.25 mm and 0.60 mm) to maintain flexibility with respect to potential sand sources for the Town's portion of the Project and assess the level of storm protection afforded by the proposed alternatives for the range of gain sizes. Model setup and calibration described in Sub-Appendix G-1 was used for the additional modeling study, but the input pre-storm conditions were updated based on the 2014 beach profile surveys. Scenarios developed and alternatives considered for the previous study were evaluated, but Alternative 7a and 7b were included. The results are detailed in Sub-Appendix G-1, Attachment E and the primary findings are as follows:

- The 2014 survey were used as existing conditions for the additional modeling study, which represented a more eroded beach condition as compared to the

2011/2012 survey used in the previous modeling study. This eroded conditions provided less storm protection and damages to property landward of the Project Area were simulated at profiles R-131, R-133 and R-134 for storms with 15 return periods and greater.

- Model simulations with sediment grain size of 0.25 mm showed differences in erosion as compared to simulations with grain sizes of 0.36 mm and 0.60 mm. Beach profiles simulated with a finer fill sediment grain size of 0.25 mm experienced higher erosion above mean low water (-2.3 feet, NAVD) than the beach profiles simulate with a coarser grain size of 0.36 and 0.60 mm. Profiles with coarser grain size experienced less cross-shore redistribution of the sand during model simulations as compared to the profiles with finer grain sizes.
- Landward limit of erosion was positioned further seaward with increasing in sediment grain size for a given return period storm. For the alternatives and return period storms analyzed, the seaward shift did not have an effect on the impacts to upland property during the higher frequency storms (i.e. 15 and 25 year return period storms), but the seaward shift did have an effect on whether impacts to property were incurred for the lower frequency storms (i.e. 50 and 100 year return period storms).

3.2. IH2VOF

The SBEACH model was utilized to analyze the level of storm protection that the existing conditions and alternatives provide to upland property. While erosion of the beach profile during these return period storm events is anticipated, the elevated water levels and large waves can cause additional damage if the dune and seawalls are overtopped. Overtopping water can cause flooding, erosion on landward (back) slopes, and seawall failure. The IH2VOF model was used to evaluate the amount of overtopping during the 15, 25, and 50 year return period storm events. The model results are detailed in Sub-Appendix G-2.

The IH2VOF model uses the "volume of fluids" approach and was run at two beach profile locations. Based on the winter 2011/2012 beach conditions, one location was characterized with a dune and no seawall (R-131), and the other with a seawall that was partially buried by a dune (R-137). The profiles at each location used in the model were the storm profiles generated during the SBEACH analysis. The profiles after being exposed to wave action and elevated water levels at the peak of the storm events were exported from the SBEACH model and imported into the IH2VOF model to provide a better representation of the overtopping that could be anticipated. At each location, the following were simulated.

- Existing conditions (Alternative 1)
- Alternative 2 (or Alternative 3)
- Alternative 6

Similar to the SBEACH model, the IH2VOF model is a cross-shore model. The storm erosion profiles from SBEACH are used as the input profile for IH2VOF. The shoreline protection structures (groins) proposed in the various alternatives were oriented perpendicular to shore and are not applicable in the model. The fill templates for Alternative 3 and Alternative 2 were the same, but Alternative 2 included structures. Alternatives 2 and 3 would require the same model inputs yielding the same model output. Alternatives 4 and 5 were not modeled as they were various combinations of fill volumes bracketed by Alternatives 2 and 6. Alternatives 7a and 7b were not modeled as they was not being considered at the time of the SBEACH modeling.

The simulated conditions were identified to represent extreme storm events, but there is considerable variability among events that may be encountered. The following are the primary findings from the IH2VOF modeling analysis:

- The existing beach conditions are susceptible to wave overtopping during 15, 25 and 50 year return period storms. Overtopping increases as wave and water level conditions increase. This is attributed to the reduction in dry beach width and the dune crest (or seawall) height above the waves and water level.
- For the return period storms, the alternatives provide a reduction in overtopping and consequently an increase in storm protection as compared to the existing conditions.

- o At R-131, the overtopping during the 15 year storm was reduced up to 67% for the alternatives as compared to the existing conditions. Similarly, the overtopping during 25 and 50 year storms were reduced up to 75% and 58%, respectively.
- o At R-137, the larger fill volume associated with Alternative 6 provided greater storm protection by reducing overtopping as compared to Alternative 2. The incremental benefit of Alternative 6 was 50% less overtopping for the 15 year return period storm, 22% less for the 25 year storm, and 8% less for the 50 year storm as compared to the existing conditions. Similarly, Alternative 2 provided 25% less overtopping for the 15 year storm, 0% for the 25 year storm, and 8% for the 50 year storm.

- Given the existing conditions, seawalls are subject to wave attack during storm events. These wave forces to which the seawalls are exposed increase with the intensity of the storm events. The exposure of seawalls to waves can cause damage thereby reducing the designed level of protection and/or increasing the frequency and need for structural repairs in order to maintain their integrity. Sand fill placed in front of the seawalls may offer additional protection.
- According to the USACE safety criteria, the mean overtopping discharge during the storm events is expected to cause some level of damage to the dune (or seawall) and create unsafe, dangerous situations for vehicles and pedestrians at the point of overtopping. Overtopping was not eliminated by having the alternatives in place. However, the alternatives did reduce overtopping, which would in turn reduce damage and unsafe, dangerous situations during storm events.

4.0 POTENTIAL HARDBOTTOM IMPACTS

The SBEACH and IH2VOF modeling analyzed the level of protection and evaluated the overtopping during storm events in order to identify the anticipated benefits of the additional fill volumes associated with the alternatives. The additional fill introduced into the littoral system will be transported offshore and alongshore over time as the sand is reworked by wave action. While the additional sand will create a wider beach increasing storm protection and benefiting nesting marine sea turtles, the reworked sand may be deposited offshore causing adverse impacts to ephemeral, nearshore hardbottom.

The Project is proposed along a 2.07-mile segment of the Atlantic Ocean shoreline in the Towns of Palm Beach, South Palm Beach, Lantana, and Manalapan, in eastern Palm Beach County, Florida. The Project is located between FDEP R-monuments R-129-210 and R-138+551. The Study Area is located between R-127 and R-141+586 and is characterized as a dynamic coastal marine system with a supra-littoral dune, beach, and intertidal beach with discontinuous nearshore hardbottom resources. The hardbottom is subject to periodic burial and exposure. Based on the most recent aerial photographs from March 2013, hardbottom was detected up to 700 feet from the shoreline.

The area has been the subject of more than 10-years of hardbottom mapping and analysis. Over the years, the data has been compiled and analyzed to differentiate the areas of ephemeral and persistent hardbottom exposure. Described here are the Delft3D coastal process modeling and analytical assessments using equilibrium profile theory that have been performed to serve as the basis to assess potential impacts on hardbottom resources attributable to placement and equilibration of the fill for the project alternatives.

4.1. DELFT3D

4.1.1 Model Development

As part of a separate study conducted for the County, a Delft3D numerical model (CPE, 2013) was developed, calibrated and applied to evaluate Project alternatives along the shoreline of South Palm Beach, Lantana and Manalapan. The model application was originally focused on the County project area and was expanded in order to evaluate the combined project area, with the Town of Palm Beach. The existing model was updated and recalibrated for use in evaluating the proposed actions and alternatives in the EIS and quantifying the estimating potential hardbottom coverage. The model results are detailed in Sub-Appendix G-3. The Delft3D morphological model from separate studies of Southern Palm Beach Island (CB&I, 2013) was recalibrated (updated) based on more recent erosion patterns and available data.

4.1.2 Inclusion of Hardbottom in Delft3D

Hardbottom was incorporated into the Delft3D model by spatially varying the erodible sediment depth and sediment thickness based on physical measurements, survey data and aerial delineations. Erodible sediment depth is defined by an elevation fixed in time demarking the surface of the hardbottom such that erosion of sand cannot occur below this depth in the model.

4.1.3 Model Simulations

The Delft3D model was utilized to simulate the movement of sand within the littoral system and the results were used to quantify the potential impacts to the ephemeral hardbottom. Eight “combined” alternatives and seven “separated” alternatives were modeled for a total of 15 simulations. The “combined” alternatives are defined in Section 2.0 and included both the Town of Palm Beach and County. The “separated” alternatives (2T, 2C, 3C, 6T, 6C, 7aT, and 7bT) were modeled individually to evaluate the effects/impacts attributable to the individual projects within the Town of Palm Beach and County. In the following Alternatives "C" refers to the County-only project and "T" refers to the Town of Palm Beach-only project:

- Alternative 1

- Alternative 2
  - Alternative 2T (The portion of Alternative 2 within the Town)
  - Alternative 2C (The portion of Alternative 2 within the County)

- Alternative 3
  - Alternative 3C (The portion of Alternative 3 within the County)

- Alternative 4

- Alternative 5

- Alternative 6
  - Alternative 6T (The portion of Alternative 6 within the Town)
  - Alternative 6C (The portion of Alternative 6 within the County)

- Alternative 7a
  - Alternative 7aT (The portion of Alternative 7a within the Town of Palm Beach)

- Alternative 7b
  - Alternative 7bT (The portion of Alternative 7b within the Town of Palm Beach)

4.1.4 Model Simulation Results

The performance and impact of each alternative over a 3 year simulation period was assessed using the updated calibrated model on the model grid extended north into the Town. The performance and impacts were assessed in terms of volume changes and erosion/sedimentation patterns at 1 year increments during simulation period. The following are the primary findings based on the Delft3D model results.

- Greater fill volumes result in increased sedimentation areas and net hardbottom coverage as the fill is redistributed cross shore and transported alongshore.

- Alternative 2 resulted in the least area of sedimentation and net hardbottom coverage as compared to the other combined alternatives. Groins retain a portion of the sand that otherwise would be transported downdrift to adjacent beaches. The model indicated that with the same fill volumes the groins within the County for Alternative 2 (and Alternative 2C) resulted in greater sedimentation offshore of the groin field as compared to Alternative 3 (and Alternative 3C), but with less downdrift sedimentation. This is attributed to a greater volume of sand being retained within the groin field and being redistributed cross shore as opposed to alongshore in the absence of the groins. The net hardbottom coverage was less for Alternative 2 (and Alternative 2C) as compared to Alternative 3C.

- When comparing the “combined” and “separated” alternatives for Alternative 6, the fill placed south of R-134+135 within the County spreads north resulting in increased sedimentation within the Town of Palm Beach.
- When comparing the “combined” and “separated” alternatives for Alternative 7, the fill placed north of R-134+135 within the Town of Palm Beach is transported south resulting in increased sedimentation within the County.

4.1.5 Additional Delft3D Modeling

Following completion of the initial Delft3D modeling study and receipt of public comments, it was determined that an additional modeling study within the Town’s portion of the Project Area (R-129-210 to R-134+135) was needed. The additional study evaluated a range of sediment grain sizes (0.25 mm and 0.60 mm) to maintain flexibility with respect to potential sand sources for the Town’s portion of the Project and to quantify the potential hardbottom coverage by the proposed alternatives for the range of gain sizes. Model setup and calibration described in Sub-Appendix G-3 was used for the additional modeling study. Alternatives considered for the previous study were evaluated. The results are detailed in Sub-Appendix G-3, Attachment A. The following are the primary findings based on the results of the additional Delft3D modeling analysis:

- Sediment grain size has an influence on the cross-shore redistribution and the downdrift migration of the fill placed to construct the alternatives. The model results indicated that finer fill material (i.e. sediment grain size of 0.25 mm) was redistributed further offshore and downdrift during the 3 year simulation periods as compared to coarse fill material (i.e. sediment grain size of 0.60 mm).
- The influence of grain size on the movement of fill material becomes more apparent as the volume of fill increases and more sand is placed within the water. Alternatives 2 and 3 included the smallest fill volumes and the influence of

grain size was not as readily apparent. Alternative 7 contained the greatest fill volumes and the influence of grain size was most apparent.

- While finer fill material tends to be redistributed further offshore and downdrift, this may not result in a direct correlation to increased hardbottom impacts. Hardbottom within the project area are highly ephemeral and the impacts attributed to the project's fill material are highly dependent upon the spatial relationship between the areas of the sedimentation and exposed hardbottom.

- The downdrift impact analysis indicated that two factors increase the likelihood of erosion downdrift (south) of the project area for the alternatives considered. These factors include shoreline protection structures (i.e. groins) and coarser fill material (i.e. larger sediment grain sizes). The downdrift impact analysis indicated that larger fill volumes increased the likelihood of accretion downdrift of the project area, but greater hardbottom coverage.

4.2. ANALYTICAL EQUILIBRIUM TOE OF FILL

While the Delft3D model simulates the nearshore morphology evolution, the use of an analytical technique is useful for confirming the some of the modeling results. After fill placement, it is anticipated that the constructed profile would equilibrate due to natural coastal processes adjusting back to the shape of the pre-construction profile. However, the cross-shore extent of this equilibration process is limited by the low density fill placements and alongshore current that exists in the Project Area. The volumes of fill required to construct the eight alternatives were estimated based on the condition of the beach as surveyed in 2011/2012. The beach conditions were represented by profile surveys spaced approximately 1,000 feet alongshore at the FDEP R-Monuments within the Project Area (R-129 through R-138).

The equilibrium profiles were developed by translating the pre-construction profiles using the method described in the Coastal Engineering Manual, Part 5, Chapter 4. The profile translation theory conserves volume by redistributing the fill cross-shore to an estimated depth of closure (DOC). The DOC for the Project Area was defined to be -

19.9 feet, NGVD (-21.5 NAVD88), consistent with previous studies (FDEP, 2012). Application of this method results in the Equilibrium Toe of Fill (ETOF coinciding with the DOC in all locations. Consequently, the ETOF would encompass a vast majority of the ephemeral hardbottom without regard to the volume of fill placed at a given profile.

Considering the relatively low density of fill proposed, the ETOF analysis was further evaluated to account for the alongshore variability of the fill placement. The following procedures were followed:

- At each FDEP R-Monument, the equilibrium profile was compared to the pre-construction profile. To determine the cross-shore location beyond which the profile variability could be considered insignificant, the vertical change between existing and translated profiles was evaluated.

- Each profile was divided into 100-foot cross-shore increments to a point 2,300 feet seaward of the R-monument for vertical change assessment. The volumetric change within each increment was estimated and the average vertical difference between the profiles was determined. The equilibrium profile was determined to close with the preconstruction profile at the cross-shore location where the profiles varied by ≤0.25 feet. The tolerance of 0.25 feet was selected in the analysis as a fraction of typical survey error, which is on the order of +/-0.4 feet. The equilibrium profile landward of the point of close was then retained, while the profile seaward of this point was omitted.

- The remainder of each equilibrium profile was then adjusted to ensure that the fill volume was conserved resulting in the adjusted ETOF.

It is noted that cross-shore fill equilibration is not instantaneous as the theory suggests because sand migrates alongshore due to background erosion and littoral transport. Therefore, the reasonably anticipated extent of hardbottom impacts account for the analytical estimation of the ETOF and the Delft3D model results described above.

4.3. CALCULATION OF HARDBOTTOM COVERAGE

Hardbottom exposure along the Project Area and the adjacent beaches varies widely over time with hardbottom being covered and uncovered due to natural processes (CPE 2007a). Potential coverage of hardbottom attributable to the project alternatives was assessed based on the erosion and deposition patterns simulated by the Delft3D model and the analytical equilibrium toe of fill analysis. The Delft3D modeling was used to identify areas of sediment accumulation in excess of the baseline (No Action) condition and that occurred in thicknesses greater than 0.2 feet. The thickness threshold was selected based on reasonable model capabilities and account for potential survey error. The areas of sediment accumulation were extracted from the Delft3D model and the areas encompassed by the equilibrium toe of fills from the analytical analysis were overlain on historical aerial delineations of exposed hardbottom. These areas and aerial delineations were analyzed using a time-average approach to assess project-related impacts to hardbottom, which is described in Chapter 4, Section 4.4 of the main EIS document.

5.0 SURFABILITY

The potential impacts to surfing was expressed in the public scoping meeting for the proposed Project. In order to evaluate Project-related effects on surfing, the BOUSS-2D model was used in this study to simulate breaking waves within the Project Area. BOUSS-2D model was developed by the U.S. Army Corps of Engineers (Nwogu and Demirbilek, 2001) and utilized through the Surface Water Modeling System (SMS) interface (Aquaveo, 2008). The model results are detailed in Sub-Appendix G-4.

To assess the potential impacts on surfability within the Study Area (R-127 to R-141+586), resulting bathymetries from the 3 year simulation period with the Delft3D model were exported and imported into the BOUSS2D model. These bathymetries were the basis for evaluating the impacts to surfability within the Project Area and adjacent areas. The alternatives that were considered in the analysis included:

- Alternative 1

- Alternative 2
- Alternative 6
- Alternative 7a (referred to as Alternative 7 in Sub-Appendix G-4)

The remainder of the alternatives (Alternatives 3, 4, and 5) were not included in the analysis. They consisted of various combinations of the sand fill volumes and shoreline protection structures comprising Alternatives 2 and 6. Alternative 7b was not included as it was not being considered at the time the modeling was conducted.

In particular, the surfability was evaluated at two popular southern Palm Beach surf spots, Lantana Park and the Lake Worth Pier. Three wave conditions: (i) southeast, (ii) cold front and (iii) hurricane (pre-landfall), were used to replicate the range of surfing conditions experienced at the two locations. The significant wave height for existing conditions (Alternative 1) was analyzed as well as the relative differences (%) between existing conditions and the other alternatives. In addition, the main parameters to assess surfability (Iribarren number, peel angle, velocity of wave, peel rate and velocity of surfer) were compared to evaluate the quality of the waves for surfing. The following are the primary findings based on the model results:

- The minimum skill level required of surfers to surf at the two locations was rated at 5 (out of 10), representing an intermediate skill level.
- Differences of significant wave heights (Hs) between existing and alternatives scenarios were more noticeable for alternatives with higher amount of sediment placement.
- A decrease of wave height was observed near the beach for all alternatives. This decrease would not impact surfing directly since the location was landward of optimal surfing areas.
- The wave condition that showed more impact from the alternatives was the southeast waves (smaller waves with smaller periods as compared to the other

wave conditions). Under the southeast wave condition, the waves would break close to the beach where the differences in bathymetry (between alternatives and existing) are higher. For hurricane and cold front wave conditions (higher waves with higher periods) the waves would break offshore where the bathymetry presents little or no differences between existing and alternatives.

- An increase of wave height before wave breaking is observed for southeast waves conditions in Alternative 7a. This wave height increase is noticed due to the combination of the wave condition used in the model and the bathymetry of Alternative 7a. The southeast wave condition represents the smallest simulated wave height and period and Alternative 7a presents the highest amount of sediment placed.

- Although there were small variations in the Iribarren number, there were no changes in the breaker wave type for the alternatives.

- In general, a small variation in peel angle, peel rate and velocity of surfer was observed in the wave conditions for the different alternatives. The changes in the surfability at the two locations due to the alternatives were also small.

6.0 ALTERNATIVE 2: FILL VOLUMES, BACKGROUND EROSION RATES, AND APPLICANTS' NEEDS

The fill volumes to construct the fill template for Alternative 2 (the Applicants' Preferred Alternative) were compared to the background erosion rates and the USACE's understanding of the Applicants' purposes and needs for the project. Alternative 2 includes the placement of approximately 117,300 cubic yards of sand throughout the Project Area based on the 2011/2012 beach profiles. Of this volume, approximately 53,800 cubic yards would be placed within the Town and approximately 63,500 cubic yards within the County. Based on a background shoreline recession rate of 2.25 feet/year and an active profile height of approximately 29 feet (between the beach berm elevation and depth of closure), the background erosion was estimated at approximately

16,000 cubic yards per year within the Town and approximately 10,500 cubic yards per year within the County.

- The Town's purpose and need is to maintain 15 to 25 year return period storm protection to upland property through periodic sand placement at an approximate 4 year nourishment interval. The background erosion rate of 16,000 cubic yards per year and a fill volume for Alternative 2 of 53,800 based on the 2011/2012 conditions suggests an approximate project life of 3 to 4 years at which point there would likely be a net loss (erosion) of sand as compared to the 2011/2012 conditions. In order to evaluate this, a more eroded condition of the beach (represented by the 2014 beach profiles) was evaluated during the additional SBEACH modeling study, which suggested the reduced level of storm protection increased damages to upland property. Increased fill volumes within the Town's portion of the Project Area may be warranted to provide additional assurance that the Town's purpose and need is maintained throughout the nourishment interval and allow for fluctuation of the beach due to storms. Increased sand volumes were evaluated as Alternatives 5, 6, 7a, and 7b.

- The County's purpose and need for the project is to maintain a recreational beach through periodic sand placement at an approximate 3 year nourishment interval. The background erosion rate of 10,500 cubic yards per year and a fill volume of 63,500 based on the 2011/2012 conditions suggests that Alternative 2 is sufficient to achieve the County's purpose and need, while allowing for fluctuation of the beach due to storms.

7.0 LITERATURE CITED

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