NUMERICAL MODELING OF SHINNECOCK INLET, NEW YORK, FOR COASTAL EROSION CONTROL SUPPORT AND INLET SEDIMENT MANAGEMENT

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The Shinnecock Inlet on the south shore of Long Island, New York, has experienced chronical erosion at the down-drift beaches which require periodic nourishment to stabilize the local shoreline. The potential sand borrow site is selected outside the inlet with minimum impact to the natural bypass process at the inlet. Supported by the US Army Corps of Engineers (USACE) District, New York, a numerical sediment transport modeling study is presently conducted to explore engineering solutions for the sand borrow area and structural alternatives to reduce the down-drift beach erosion. New field surveys have indicated a drastic decrease of sand outside inlet and along the adjacent coast. The modeling result shows a partial ebb shoal borrow area design without structural alternatives performs better together with the down-drift beach nourishment applications.

Keywords: Shinnecock Inlet; Sediment transport, structural alternative, Coastal Modeling System

INTRODUCTION

Shinnecock Inlet, the easternmost of 6 major inlets on south shore of Long Island, New York, is the primary outlet connecting Shinnecock Bay to the Atlantic Ocean (Figure 1). The inlet, opened in 1938 during a major hurricane, was stabilized by a pair of stone jetties constructed in 1953. The entrance channel is approximately 1.1-km (0.7-mile) long, 61-m (200-ft) wide, and 3-m (10-ft) deep, referenced to the mean low water datum. Because of the large bay of approximate 9,000-acre surface area, strong tidal currents appear through the inlet, with the maximum over 3 knots, tend to scour the channel and skew the sand-bypassing ebb shoal to the west. The net longshore transport, around 120k cubic-yard/year, is directed westward at the inlet. The beach to the west of Shinnecock Inlet (WOSI) and further down-drift Tiana Beach have experienced persistent erosion and required periodic nourishment projects. The USACE is presently conducted a numerical modeling study for the Shinnecock Inlet to evaluate structural and non-structural alternatives to reduce dredging cycle and optimize sand borrow site at the inlet in support of storm damage risk management projects on the south shore of Long Island from Fire Island Inlet to Montauk Point at the east end of Long Island (USACE, 2020).

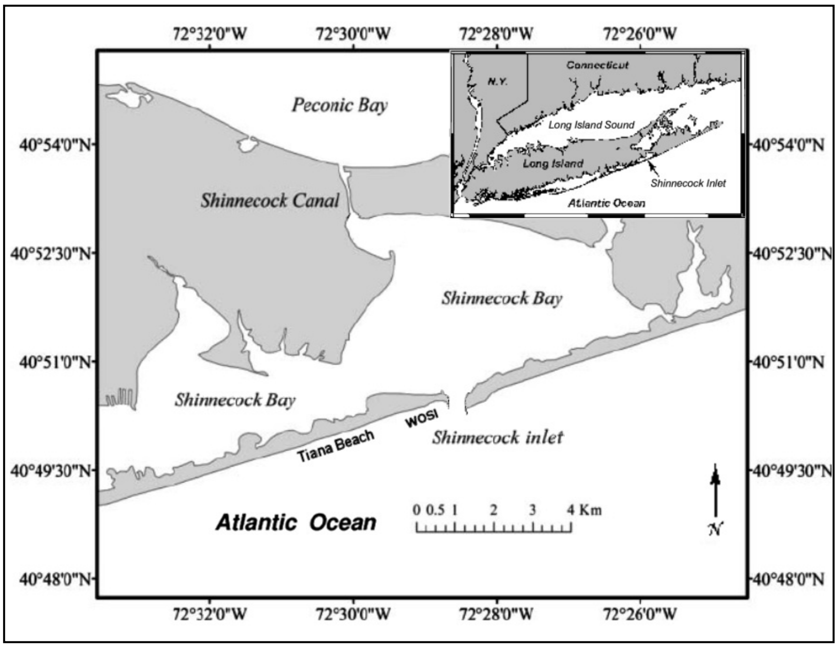

Figure 1. Location map of Shinnecock Inlet and Shinnecock Bay.

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DATA USED IN THE STUDY

Digital shoreline data used in this study were extracted from the National Geophysical Data Center (NGDC, https:// www.ngdc.noaa.gov/mgg/shorelines/), and a georeferenced image downloaded from Google Earth Pro 7.3 (https://www.google.com/earth/). The bathymetry and topography data were obtained from previous studies (USACE, 2007, 2020) covering the land, bays, rivers, waterways, nearshore, and offshore area. For inlets and their surrounding areas, and along bayside of FIMP, the update of bathymetry data is mainly based on NOAA 2020 Lidar (https://www.coast.noaa.gov/dataviewer/#/lidar), and USACE channel surveys (http://navigation.usace.army.mil/Survey/Hydro) completed in 2020 and 2021.

Figure 2. Location of NOAA, USGS, and NDBC Stations.

The long-term water level data are available from two NOAA coastal stations (https://tidesandcurrents.noaa.gov/), Sta 8531680 (SDHN4) at Sandy Hook, NJ (40° 28' 1” N, 74° 0' 34”W) and Sta 8510560 (MTKN6) at Montauk, NY (41° 2' 53” N, 71° 57' 34” W), and a USGS station (https://waterdata.usgs.gov/nwis/rt) Sta 01304746 in Shinnecock Bay at Ponquegue, NY (40° 51' 2” N, 72° 30' 11.8” W). The long-term wind and wave data are available from a National Data Buoy Center (NDBC) Buoy 44017 offshore Shinnecock Inlet and Montauk Point, NY (40° 41' 34” N, 72° 2' 56” W). Figure 2 shows the location of NOAA Sta 8510560, USGS Sta 01304746, and NDBC Buoy 44017.

NUMERICAL MODELING

A Coastal Modeling System (CMS) developed at ERDC was applied in the present study to calculate wave fields, water level change, circulation, sediment transport, and corresponding morphology change. The CMS is an integrated modeling system that consists of a steady-state, two-dimensional spectral wave model (CMS-Wave), and a time-dependent circulation model (CMS-Flow) which also computes sediment transport and morphology change (Demirbilek and Rosati, 2011). CMS-Wave was driven by winds and incident wave conditions (Lin et al. 2008, 2011). CMS-Flow was driven by winds, atmospheric pressures, river inflow, and tides (Sanchez et al. 2014). CMS-Wave and CMS-Flow can run in a coupling mode to calculate wave, current, and water level interactions. The coupling is operated through the Surface-water Modeling System (Zundel, 2006).

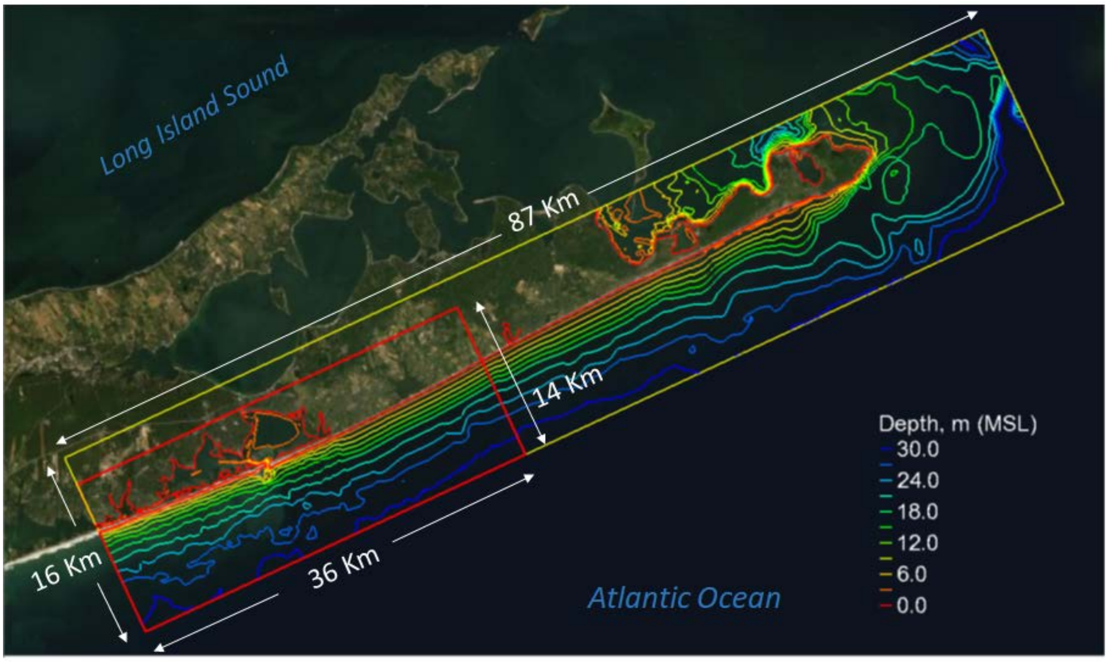

Figure 3. CMS model parent grid domain (yellow box) and child grid domain (red box).

Coupling CMS-Wave and CMS-Flow can simulate many important coastal processes like wave-current interaction, longshore current, channel infilling, beach erosion, coastal inundation, storm surge, and storm damage to nearshore structures. For Shinnecock Inlet modeling, a nested grid system consisting of two grids was used in the CMS simulations: (1) a parent grid with coarser resolution covering the southeast coast of Long Island, and (2) a child grid with finer resolution covering the Shinnecock Bay, Inlet, and adjacent shorelines (Figure 3). The parent grid domain covers a rectangular area of 16 km x 87 km (10 mile x 55 mile). The child grid domain is approximately 14 km x 36 km (9 mile x 23 mile). Both parent and child grid domains extend southward to around a 30-m (100-ft) depth contour in the Atlantic Ocean. The CMS model cell resolution varies from 15 m (50 ft) around the inlet to 180 m (590 ft) in the offshore area.

The parent grid simulation was driven by directional spectra, based on wave data from NDBC Buoy 44017, and water level data, based on data from NOAA Sta 8531680 (SDHN4), specified along open water boundaries with surface wind forcing, based on Buoy 44017 data, over the model domain. The parent grid model results, including water levels, currents and wave spectra, were used as input forcing to the child grid. Model calibration and verification were conducted and compared with water level data available at NOAA Sta 8510560 (MTKN6) and USGS Sta 01304746 for October 2018 and April 2019, respectively. Figure 4, for example, shows hourly water level data, referenced to the mean sea level (MSL) at NOAA Sta 8531680 (SDHN4) in October 2018.

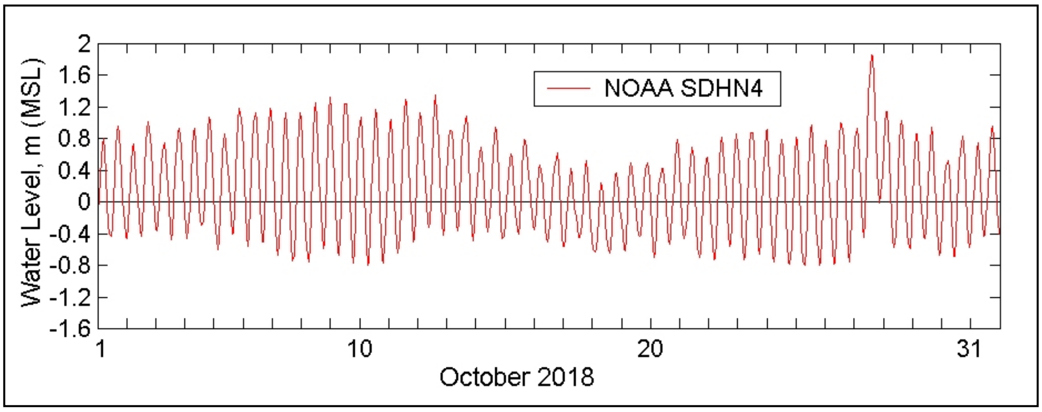

Figure 4. Hourly water level data collected at NOAA Sta SDHN4 for October 2018.

Figures 5 and 6 show hourly wind and wave data, respectively, collected at NDBC Buoy 44017 in October 2018 as input forcing to the CMS models. In general, the wind magnitude and wave height data are correlated well at Buoy 44017. Wave directions are normally consistent with wind directions based on data collected at this buoy location. On average, wave periods ranging from 4 to 16 seconds are typically observed along the south shore of Long Island.

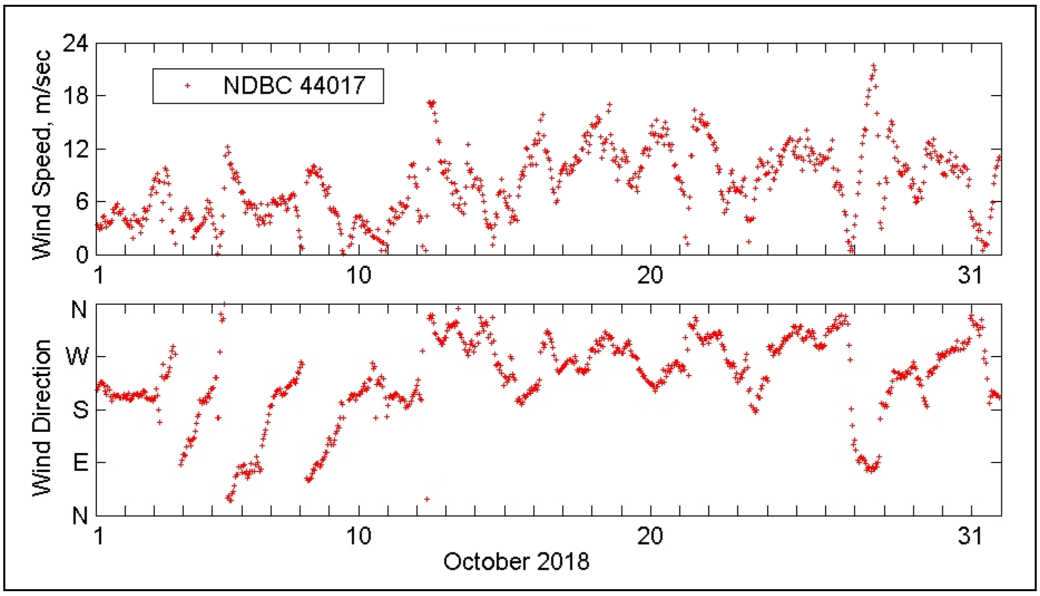

Figure 5. Hourly wind data collected at NDBC Buoy 44017 in October 2018.

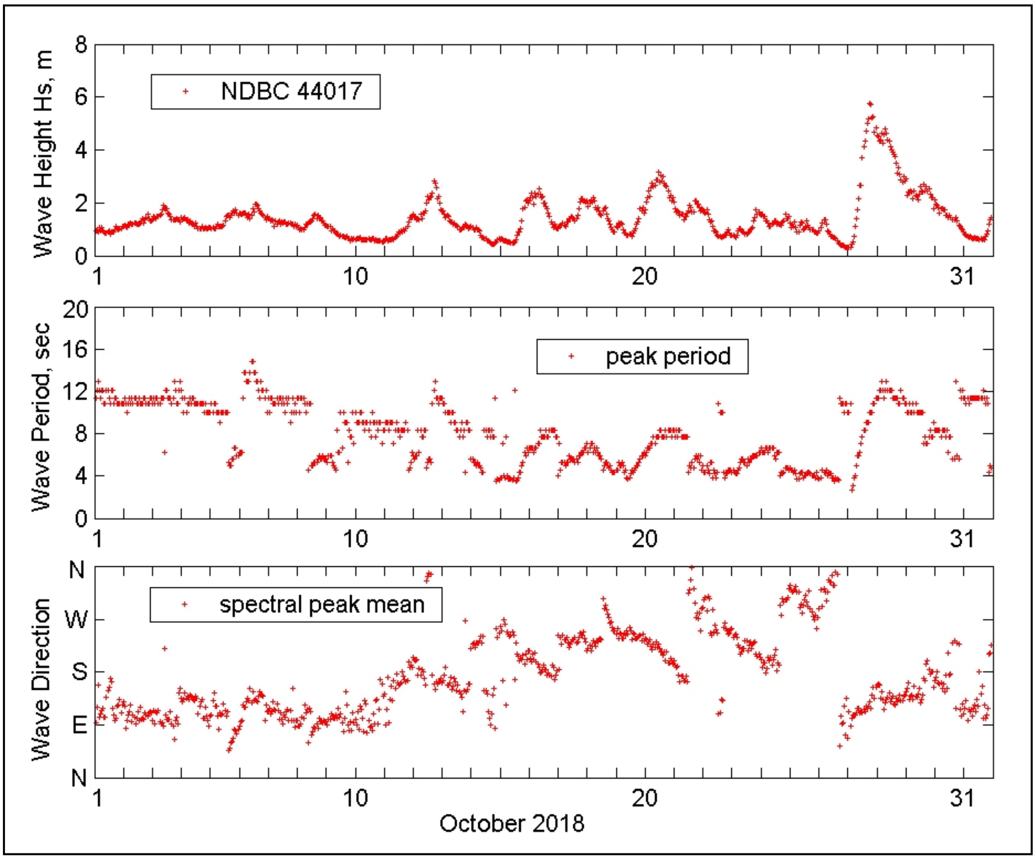

Figure 6. Hourly wave data collected at NDBC Buoy 44017 in October 2018.

Figures 7 and 8 compare model water levels and data at NOAA Sta 8510560 (MTKN6) and USGS Sta 01304746 for October 2018 and April 2019, respectively. The maximum of bias and root-mean-square error for the model water levels are smaller than 0.04 m and 0.16 m, respectively. The correlation (coefficient) between model water levels and data are all greater than 0.9. Model validation for waves and currents is coming soon as a field data collection with several Acoustic Doppler Current Profilers (ADCP) installed bayside and outside of the inlet is presently underway.

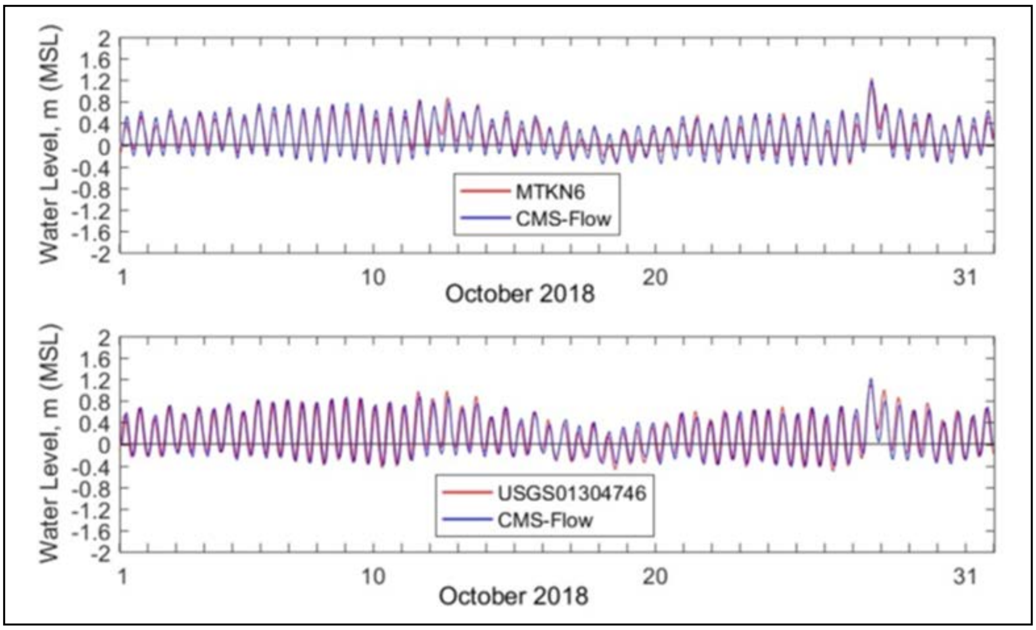

Figure 7. Model water levels versus data at NOAA MTKN6 and USGS 01304746 for October 2018.

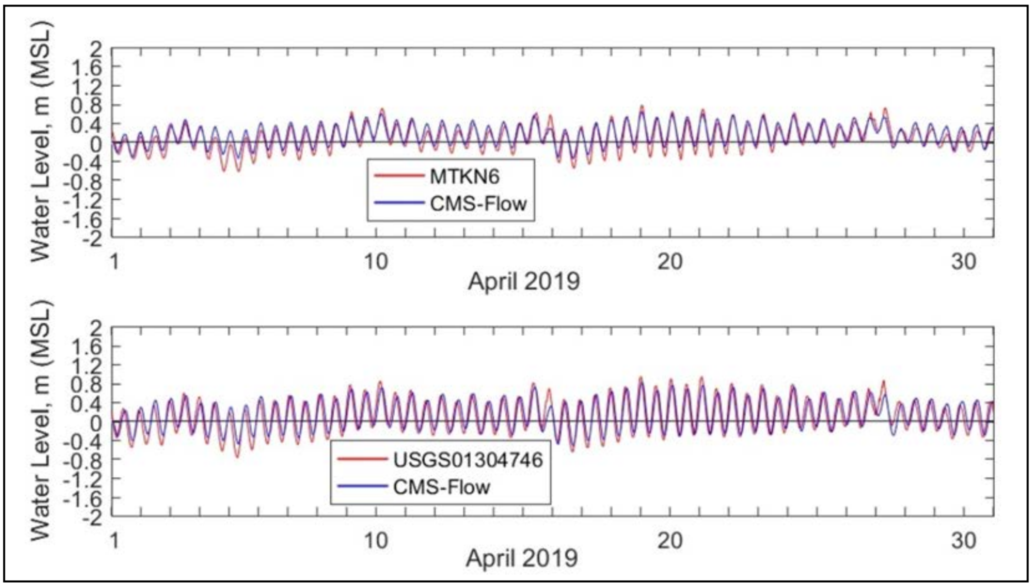

Figure 8. Model water levels versus data at NOAA MTKN6 and USGS 01304746 for April 2019.

The model sediment transport was calibrated with two channel surveys of the inlet channel conducted by the USACE in May 2019 and April 2020. A constant median grain size (D50) of 0.35 mm, based on sand samples taken around the inlet, was specified in the model. The Manning's coefficient for the model bottom friction is set to 0.014 bayside and 0.025 outside of the inlet. The model calibration indicates the littoral process at the inlet is dominated by the bedload transport under strong tidal current presence and wider wave breaking environment outside inlet along shoreline and over the ebb shoal area.

Figure 9 shows the difference of inlet surveys in navigation channel and deposition basin (red polygon area) between 30 May 2019 and 28 April 2020. Figure 10 shows the model 11-month morphology change from 1 June 2019 to 30 April 2020. Table 1 presents model sediment accretion volumes versus data from the 11-month simulation. The model sediment accretion volume matches well the field survey data in the inlet channel and deposition basin. Comparing with the field sediment accretion and erosion pattern, model results shows more scour at the inlet throat, a wider deposition south of the west breakwater, and increased accretion bayside of the inlet. Model morphology results at the inlet could be improved with wider surveys covering the ebb shoal and adjacent beach shore area, and by using more representative and mixed sediment size in the future study.

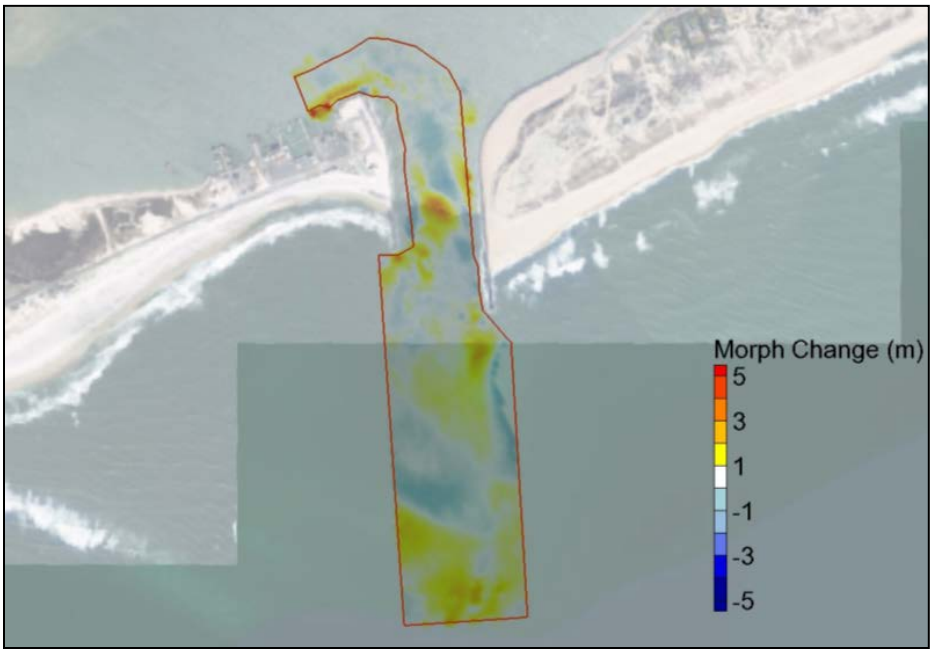

Figure 9. Morphology change at Shinnecock Inlet between May 2019 and April 2020 surveys.

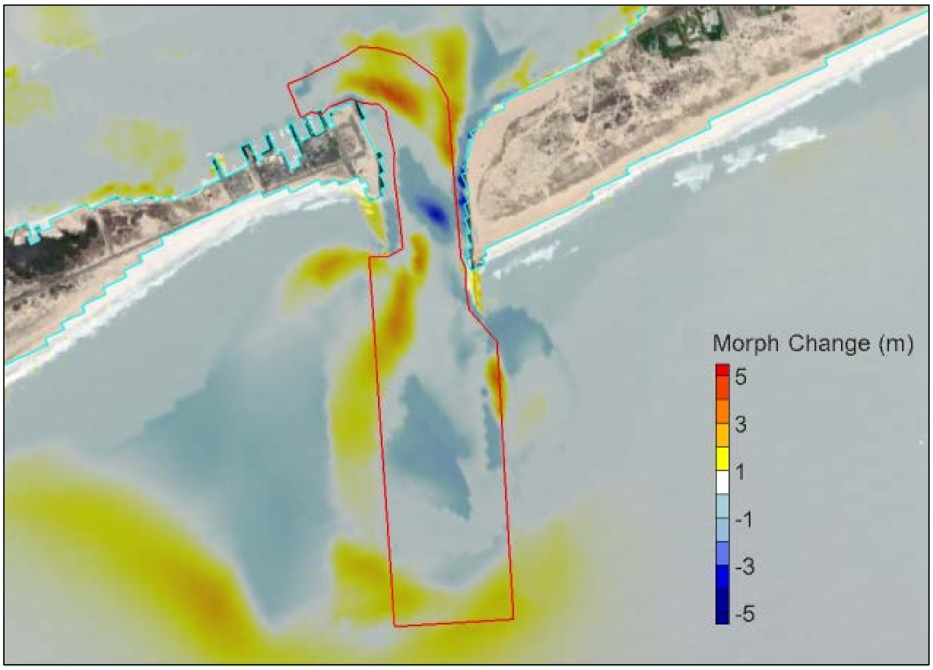

Figure 10. Model 11-month morphology change from June 2019 to April 2020.

Table 1. Model sediment accretion (m³) versus data at Shinnecock Inlet.		
Case	**Time Period**	**Sand Accretion Volume****
Field Surveys*	5/30/2019 – 4/28/2020	153,500
Model Simulation	6/1/2019 – 4/30/2020	157,800
* Two condition surveys of inlet channel at 30 May 2019 and 28 April 2020 ** Sediment accretion volume in the navigation channel and deposition basin		

MODELING SCENARIOS AND RESULTS

A total of eight alternatives including four structural alternatives at WOSI and four non-structural alternatives with different borrow areas outside inlet, were modeled for the Shinnecock Inlet. Four non-structural alternatives, denoted as Alts 1 to 4, are (1) Alt 1 – with the potential borrow site "6B", a square area of 305 m x 305 m, located east of inlet outer channel and south of the east jetty, (2) Alt 2 – with the potential borrow site "6A", a rectangular area of 400 m x 800 m, located west of the inlet and south of the west jetty, (3) Alt 3 – with the borrow area "6D", a rectangular area of 350 m x 800 m, which extends sideway and seaward over the entrance channel outside the inlet, and (4) Alt 4 – with the borrow area "6E", a 1.7-km long polygon area which includes the large outer portion of the ebb shoal.

Four structural alternatives at WOSI, denoted as Alts 5 to 8, are (5) Alt 5 – same as Alt 1 but with the extension of west jetty seaward by 120 m, (6) Alt 6 – same as Alt 5 but with addition of three low-crest groins to reduce the shoreline erosion west of Shinnecock Inlet, (7) Alt 7 – same as Alt 2 but with the extension of west jetty seaward by 120 m, and (8) Alt 8 – same as Alt 7 but with addition of three low-crest groins at WOSI. In all alternatives except Alt 3, roughly 220,000 to 250,000 cubic m of sand were removed for a 2-year dredge cycle from the borrow area and narrow deposition basins, located on both sides of the entrance channel outside inlet. In Alt 3, approximately 360,000 cubic m of sand were removed for a 4-year dredge cycle from the borrow area "6D" and deposition basin. All of these alternatives include the down-drift beach nourishment, placing 210,000 cubic m of sand evenly in the 1-km long shoreline at WOSI and further west along the 1-km long shoreline at Tiana Beach. Figures 11 and 12 show initial model configurations and bathymetry, referenced to MSL, of Alts 1-4 and 5-8, respectively.

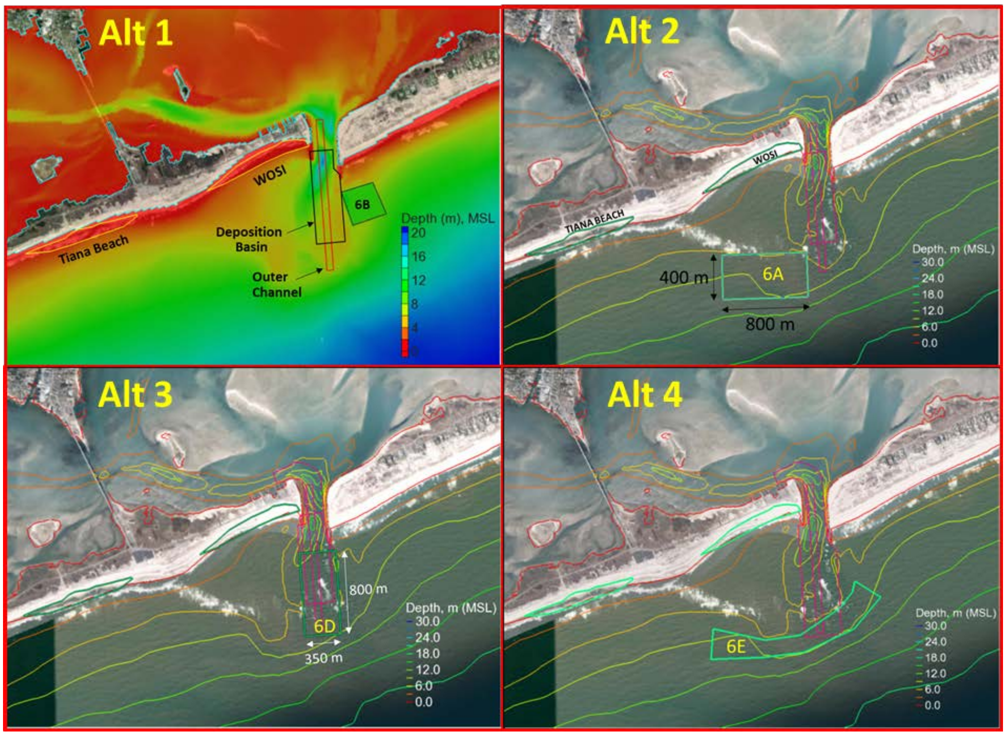

Figure 11. Model initial bathymetry for non-structural Alts 1 – 4.

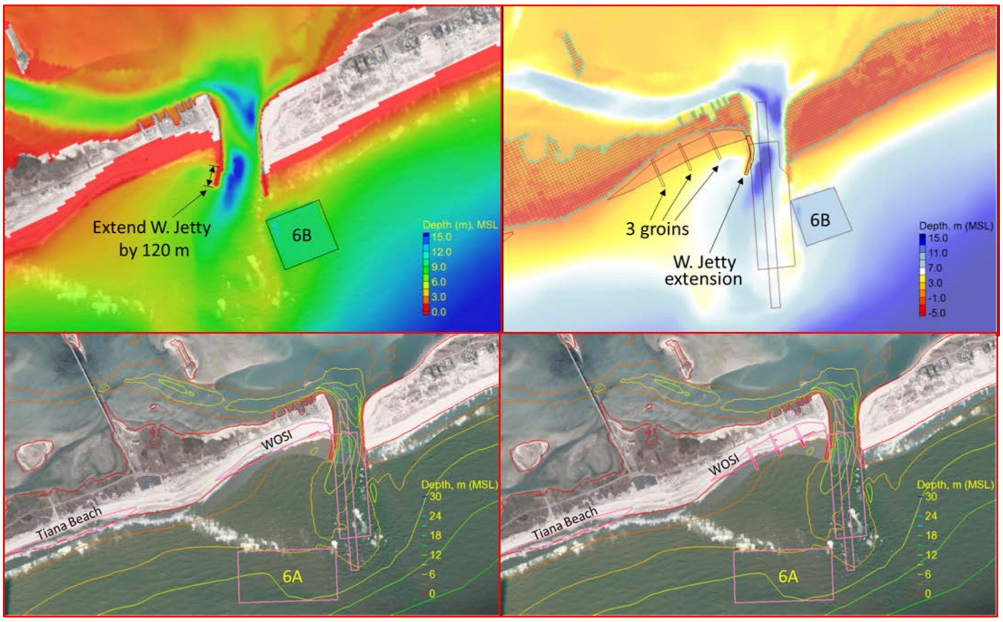

Figure 12. Model initial bathymetry for structural Alts 5 – 8.

The extension of west jetty by 120 m in Alts 5-8 will match the seaward length of west jetty with the east jetty. The purpose of this west jetty extension is to guide the tidal flow more symmetrical at the jetty entrance with more uniform current though the inlet. Alts 6 and 8 also include a group of three low-crest groins, each groin is 180-m long and 200-m apart, intend to reduce shoreline erosion at the WOSI. The crest elevation of groin is approximately 0.5 m above the MSL, which is slightly higher than the mean higher high tide line. Table 2 summarizes the configuration of all eight alternatives modeled for the Shinnecock Inlet.

Table 2. A list of model alternatives.

Alternatives	Borrow Area ID	West Jetty Extension*	Low-Crest Groins at WOSI**	Design Dredge Cycle (year)
Alt 1	6B (east bar)			2
Alt 2	6A (ebb shoal)			2
Alt 3	6D (deposition basin extension)			4
Alt 4	6E (ebb shoal)			2
Alt 5	6B	X		2
Alt 6	6B	X	X	2
Alt 7	6A	X		2
Alt 8	6A	X	X	2

* Extended the west jetty seaward by 120 m
** Consisted of 3 groins, each is 180-m long, 200-m apart, with 0.5-m height above the MSL

Figures 13 and 14 show model 11-month morphology change (red color for the area with accretion and blue color for erosion) for Alts 1-4 and 5-8, respectively, with model sediment volume changes (positive sign for accretion and negative sign for erosion) in the general inlet survey area (including the inlet channel and deposition basin), sediment borrow site (i.e., “6A”, “6B”, “6D”, or “6E”), and down-drift beach placement area, including WOSI and Tiana Beach.

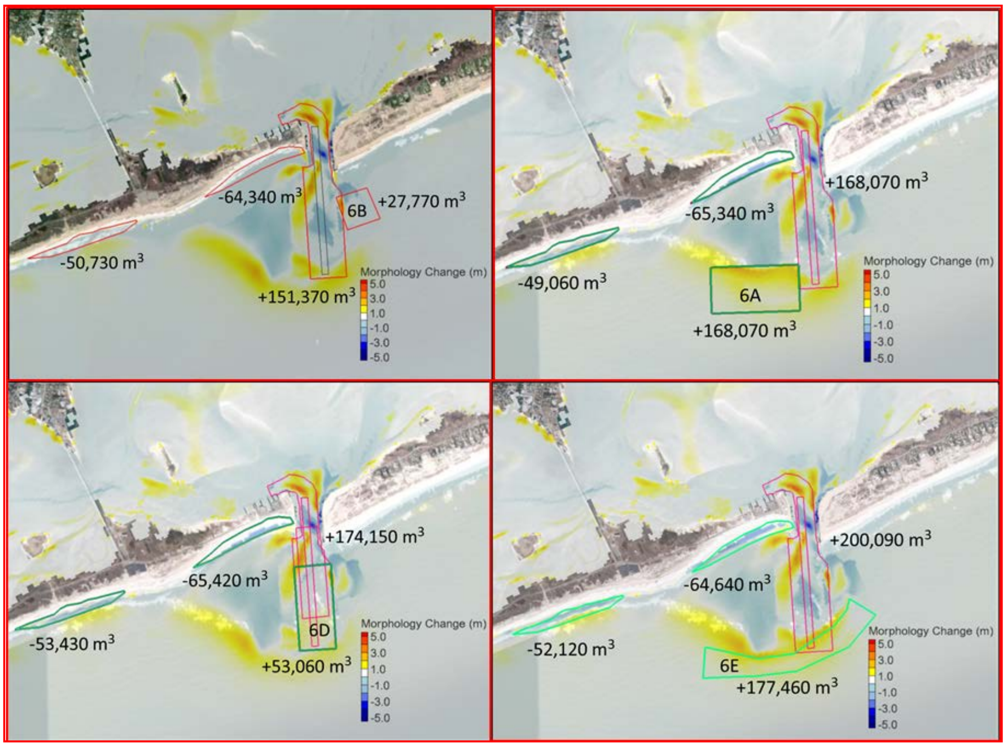

Figure 13. Model 11-month morphology change for Alts 1 – 4.

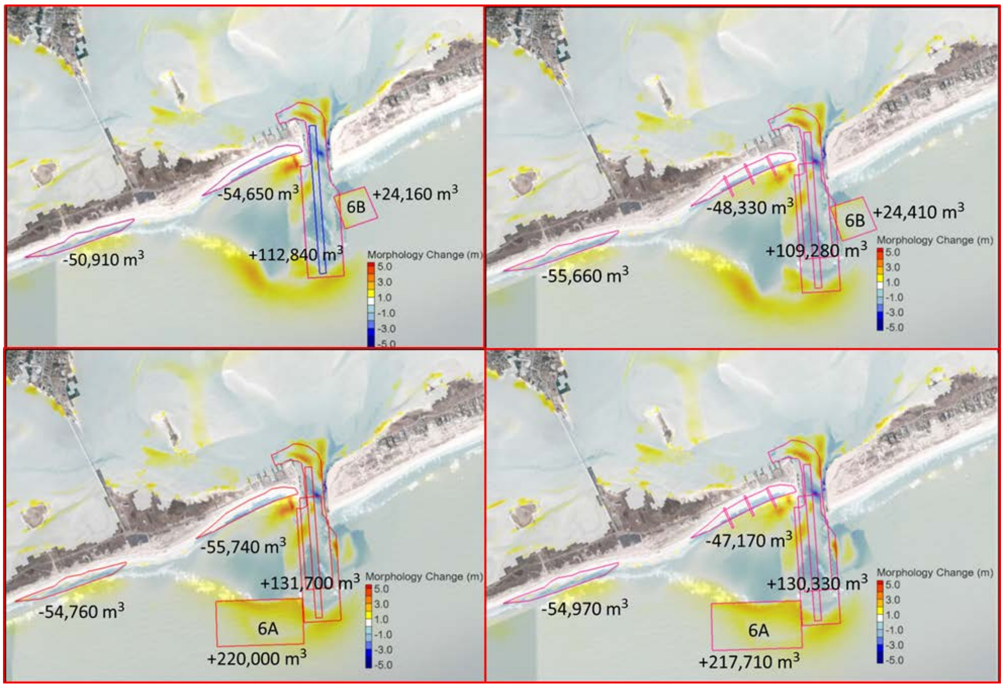

Figure 14. Model 11-month morphology change for Alts 5 – 8.

It should be noted that the rate of sediment accretion in the entrance channel, deposition basin, and borrow areas, as well as erosion in the down-drift placement areas, is much higher in the beginning of the simulation and reduced gradually in the model as the shoreline and ebb shoal become more stabilized towards their natural forms. Figures 15 and 16 show the example of model monthly accumulated sand volume accretion and erosion in different areas of interest for Alts 1 and 3, respectively.

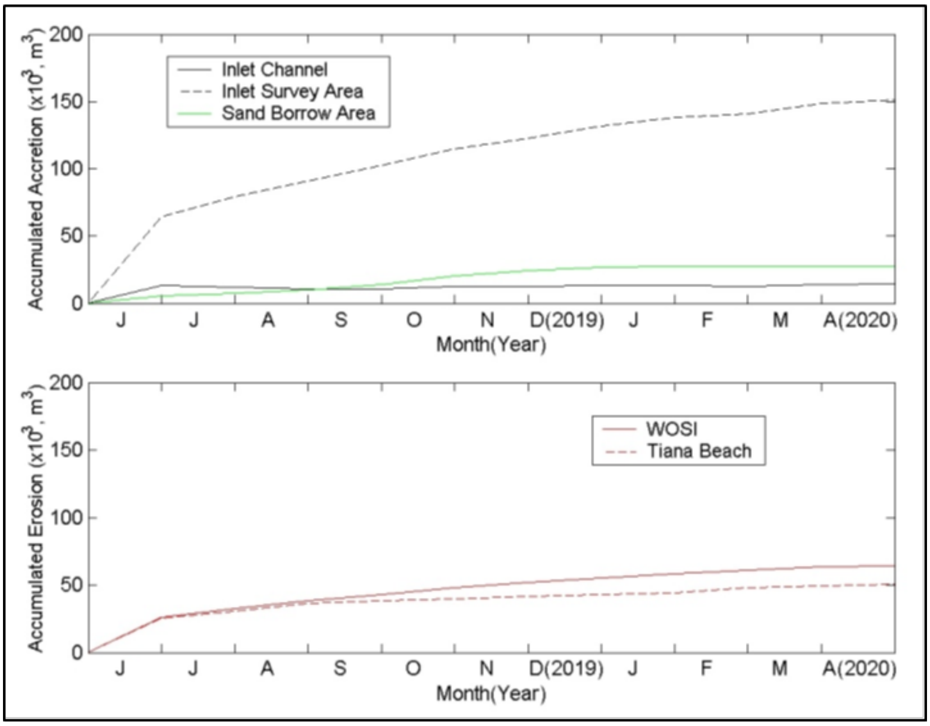

Figure 15. Model accumulated sand volume changes in Alt 1.

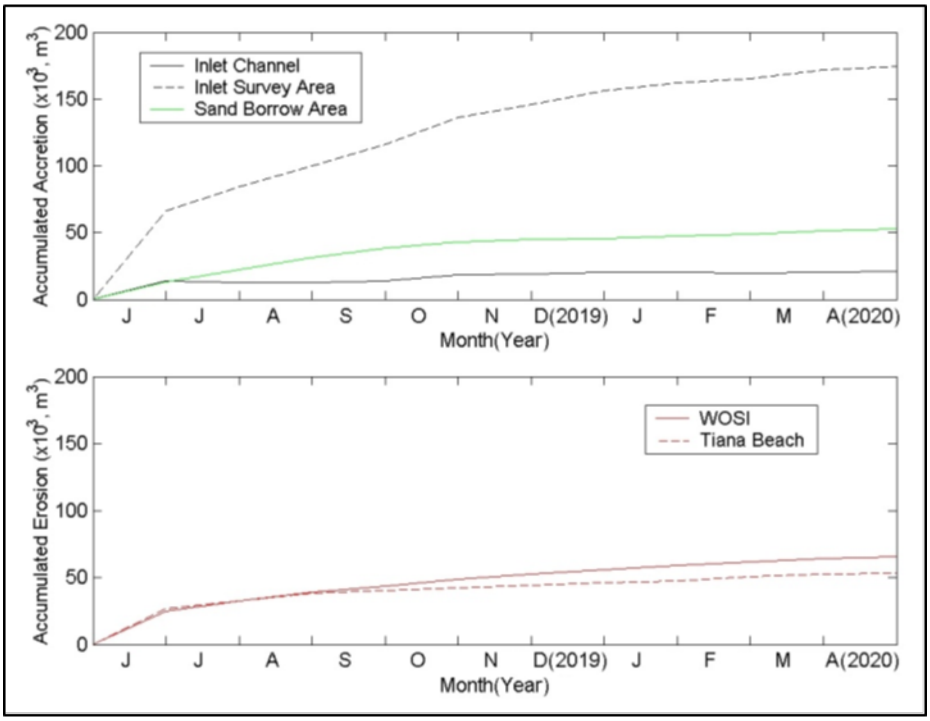

Figure 16. Model accumulated sand volume changes in Alt 3.

Model results of the morphology change in different areas could be extrapolated to a longer period for the comparison of performance of alternatives. Such an extrapolation should be kept within two or three times of the simulation period according to the common extrapolation method. In the present study, the 11-month model result of accumulated sand volume accretion or erosion was extrapolated to the more general 2-year dredging cycle period by using the curve fitting method.

Tables 3 and 4 present the total accumulated sand volume change in different areas of interest for 11-month model simulation and 2-year projection (based on the extrapolation of the 11-month model result), respectively. The sand accretion in the borrow areas is much greater in Alts 2, 4, 7, and 8, with borrow areas covering a large portion of the ebb shoal, than the accretion in Alts 1, 3, 5, and 6, with borrow areas adjacent or expanded from the existing deposition basin. In the general survey area (include inlet channel and existing deposition basin), the sand accretion in the 2-year projection for non-structural alternatives (Alts 1 to 4) is twice much as the accretion for structural alternatives (Alts 5 to 8). With the west jetty extension in structural alternatives (Alts 5 to 8), more symmetric and streamlined currents through the inlet and around the entrance channel may have reduced the excessive sediment accretion in the general survey area.

Table 3. Model 11-month sand accretion/erosion volumes (m^3) for Shinnecock Inlet alternatives.

Alternatives	Borrow Area	Survey Area*	WOSI**	Tiana Beach**
Alt 1	27,770	151,370	-64,340	-50,730
Alt 2	207,070	168,070	-65,340	-49,060
Alt 3*	53,060	174,150	-65,420	-53,430
Alt 4	177,460	200,090	-64,640	-52,120
Alt 5	24,160	112,840	-54,650	-50,910
Alt 6	24,410	109,280	-48,330	-55,660
Alt 7	220,000	131,700	-55,740	-54,760
Alt 8	217,710	130,330	-47,170	-54,970

* General survey area included inlet channel and authorized deposition basin.
** Each of WOSI and Tiana Beach placement areas covers approximately 1-km long shoreline.
*** Alt 3 has a 4-year design dredging cycle while all other Alts have a 2-year design dredging cycle.

Table 4. Projected 2-year sand accretion/erosion volumes (m^3) for Shinnecock Inlet alternatives.

Alternatives	Borrow Area	Survey Area*	WOSI**	Tiana Beach**
Alt 1	27,770	199,190	-77,640	-67,480
Alt 2	228,540	222,580	-86,300	-60,480
Alt 3*	74,660	228,590	-81,180	-65,100
Alt 4	213,730	225,050	-79,110	-70,180
Alt 5	24,160	112,840	-82,000	-68,550
Alt 6	24,410	109,280	-64,900	-70,800
Alt 7	235,000	131,700	-83,250	-74,260
Alt 8	233,860	130,330	-67,160	-70,950

* General survey area included inlet channel and authorized deposition basin.
** Each of WOSI and Tiana Beach placement areas covers approximately 1-km long shoreline.
*** Alt 3 has a 4-year design dredging cycle while all other Alts have a 2-year design dredging cycle.

In the WOSI, the 2-year projection of sand erosion volume is around 80,000 cubic m from nonstructural alternatives (Alts 1 to 4). The extension of west jetty alone in Alts 5 and 7 does not change much the sand erosion condition in WOSI. The addition of a group of three low-crest groins in the WOSI, as modeled in Alts 6 and 8, can reduce the local sand volume erosion (the 2-year projection) by about 20% as comparing to nonstructural alternatives. In the further down-drift Tiana Beach, the projected 2-year erosion volume is around 60,000 to 75,000 cubic m for all alternatives. At the Tiana Beach placement area, structural alternatives may have slightly higher erosion rate than non-structural alternatives.

SUMMARY AND CONCLUSIONS

This paper describes the numerical modeling of structural and non-structural alternatives for optimizing ebb shoal borrow site configuration, entrance channel dredging, and down-drift beach nourishment at Shinnecock Inlet as part of the FIMP reformation study (USACE, 2020). The USACE Coastal Modeling System (CMS) numerical models were applied to simulate water levels, currents, waves, and morphology change at the inlet. Forcing functions include time-varying water surface elevation, wind input, incident waves in the Atlantic coast, and wave radiation stress. A grid-nesting system consisting of a Shinnecock Inlet to Montauk Point grid and a Shinnecock Inlet sub-grid was used in the modeling study. Model bathymetry and topography are mainly based on NOAA Lidar dataset in 2020 and USACE channel surveys conducted in 2019 and 2020.

A total of four structural and four non-structural alternatives were modeled (Table 2). The non-structural alternatives (Alts 1 to 4) involve different borrow areas outside the inlet. Alt 1 has the borrow site located east of inlet entrance channel and south of the east jetty. Alt 2 has the borrow site located west of the entrance channel around the south end portion of the ebb shoal. Alt 3 widens the existing deposition basin on both sides of entrance channel and also extends seaward for the borrow area. Alt 4 uses the outer bar and outer portion of ebb shoal following the sediment bypass path for the borrow area. The structural alternatives (Alts 5-8) involve the combination of three low-crest groins in WOSI and west jetty extension together with Alt 1 or 2. Alt 5 is the same as Alt 1 but with the extension of west jetty by 120 m. Alt 6 is the same as Alt 5 but with three low-crest groins in WOSI. Alt 7 is the same as Alt 2 but with the west jetty extension. Alt 8 is the same as Alt 7 but with three low-crest groins in WOSI. All of these alternatives include the down-drift beach nourishment, placing 210,000 cubic m of sand evenly in the 1-km long shoreline at WOSI and further west along the 1-km long shoreline at Tiana Beach. Except Alt 3 which is designed for a 4-year dredging cycle with 360,000 cubic m of sand removed from the borrow site, all others alternatives are designed for a 2-year dredging cycle with roughly 220,000 to 250,000 cubic m of sand removed from borrow areas.

The modeling of Shinnecock Inlet alternatives was conducted for an 11-month simulation of June 2019 to April 2020. The rate of sediment accretion in the entrance channel, deposition basin, and borrow areas, as well as erosion in the down-drift placement areas, is much higher in the beginning of the simulation and reduced gradually as the shoreline and ebb shoal become more stabilized towards their natural forms. Model sand volume accretion and erosion in different areas from the 11-month simulation were extrapolated by curve fitting to the more general 2-year dredging cycle period.

Based on the 2-year projection volume change, model alternatives with the borrow area covering a large portion of the ebb shoal (Alts 2, 4, 7, and 8) will have much greater sand accretion in the borrow area than those alternatives with borrow areas adjacent or expanded from the existing deposition basin (Alts 1, 3, 5, and 6). The corresponding sand accretion in the borrow area is around 225,000 cubic m in Alts 2, 4, 7, and 8, and 24,000 to 75,000 cubic m in Alts 1, 3, 5, and 6. In the general survey area, which included inlet channel and existing deposition basin, the sand accretion from nonstructural alternatives (Alts 1 to 4) is approximately twice much as the accretion from structural alternatives (Alts 5 to 8). The corresponding sand accretion in the general survey area is around 220,000 cubic m for nonstructural alternatives and 120,000 cubic m for structural alternatives. With the model west jetty extension in structural alternatives (Alts 5 to 8), more symmetric and streamlined currents in the entrance channel have prevented excessive sediment accretion in the general survey area.

Based on the 2-year projection volume change, the sand erosion volume in the WOSI is around 80,000 cubic m for nonstructural alternatives (Alts 1 to 4). Structural alternatives with the west jetty extension alone (Alts 5 and 7) do not change much the sand erosion condition in the WOSI. On the other hand, structural alternatives with three low-crest groins in WOSI (Alts 6 and 8) can reduce the local sand volume erosion by about 20% as comparing to nonstructural alternatives. In the further down-drift Tiana Beach, the sand erosion condition along the placement area is similar in all alternatives, with projected 2-year erosion volume around 60,000 to 75,000 cubic m. At the Tiana Beach placement area, structural alternatives may have slightly higher erosion condition than non-structural alternatives. Overall, the effect of west jetty extension and low-crest groin addition in WOSI to reduce the down-drift erosion is considerably small.

The present study performed the numerical modeling of potential alternatives investigating borrow site selection, inlet entrance channel dredge cycle, and adjacent beach placement area for Shinnecock Inlet. The modeling result will depend crucially on the environmental forcing (e.g., tides, winds, waves, and storms) and accurate bathymetry applied in the study. For better representation of model forcing and bathymetry in the study area, a new field data collection including water level, current and wave measurements at and near inlets has been launched in early 2022 and new field surveys for larger coverage area of inlet channel, ebb shoal, and adjacent beaches have been completed in 2021 and 2022. The CMS models will be recalibrated and revalidated with new channel surveys and field measurements. Based on new surveys of ebb shoal and nearshore area outside and inside the inlet, the USACE will revise the alternatives and update model results for optimization of ebb shoal borrow site selection, entrance channel dredge cycle, and adjacent beach placement to assist the coastal erosion control and regional sediment management at Shinnecock Inlet.

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