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Coastal and Hydraulics Laboratory

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Regional Sediment Management (RSM) Program

Addressing Nearshore Placement near Lake Worth Inlet, Florida

Andrew Condon, Kelly Legault, and Brian McFall

January 2019

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Addressing Nearshore Placement near Lake Worth Inlet, Florida

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Final report

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Abstract

The purpose of this study was to investigate the nearshore hydrodynamics around Lake Worth Inlet, Florida, by utilizing the U.S. Army Research and Development Center Coastal Modeling System to address the feasibility of nearshore placement of dredged materials south of the inlet. The study area includes Palm Beach Harbor, Lake Worth Inlet, and the adjacent shorelines north and south of the inlet.

The effectiveness of the nearshore placement in mitigating beach impacts was examined in terms of wave energy reaching a point landward of the placement area. Different alternatives were examined. The closer to shore the material is placed (which leads to shallower depths), the greater the wave energy reduction. Thin placement in deeper water along the nearshore placement area resulted in little change in wave energy reaching the shore. Material should be placed as close to shore as practicable to result in less wave energy reaching the beach.

The Sediment Mobility Tool indicates the material will migrate onshore and remain within the nearshore system even when transported down-drift to the south. Nearshore placement of dredged material south of Florida Department of Environmental Protection Range Monument R-77 offers tangible benefits to the shoreline in the lee of the placement.

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Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE), National Regional Sediment Management (RSM) Program, Work Unit 33143, “Lake Worth Inlet, Florida, Study.” The National RSM Program Manager was Ms. Linda S. Lillycrop, U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Navigation Division (HN), Coastal Engineering Branch (HN-C). Mr. Jeffrey A. McKee was the Headquarters, USACE Navigation Business Line Manager overseeing the RSM Program.

The work was performed by the U.S. Army Engineer District, Jacksonville, and by the ERDC CHL HN-C. At the time of publication of this technical report, Ms. Mary A. Bryant was Acting Chief, HN-C; Dr. Jacqueline S. Pettway was Chief, HN; and Mr. W. Jeff Lillycrop (CHL) was the ERDC Technical Director for Civil Works and Navigation Research, Development, and Technology Transfer (RD&T) portfolio. The Deputy Director of CHL was Mr. Jeffrey R. Eckstein, and the Director was Dr. Ty V. Wamsley.

The commander of ERDC was COL Ivan P. Beckman, and the Director was Dr. David W. Pittman.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.76455	cubic meters
cubic yards per year	0.76455	cubic meters per year
feet	0.3048	meters
inch	25.4	millimeters
miles	1.609	kilometers

1 Introduction

Regional Sediment Management (RSM)

RSM is a system-based approach to manage sediments and is implemented collaboratively with other federal, state, and local agencies. The objective of the U.S. Army Corps of Engineers (USACE) National RSM Program is to improve the management of sediments across multiple projects, manage sediments as a regional-scale resource, and implement adaptive management strategies that support sustainable navigation and dredging, flood and storm damage reduction, and environmental practices that increase operational efficiencies, the value of sediments, and social and environmental/ecosystem benefits while reducing lifecycle costs. RSM is also a means of involving stakeholders to leverage resources, share technology and data, identify needs and opportunities, and develop and implement solutions to improve the utilization and management of sediments.

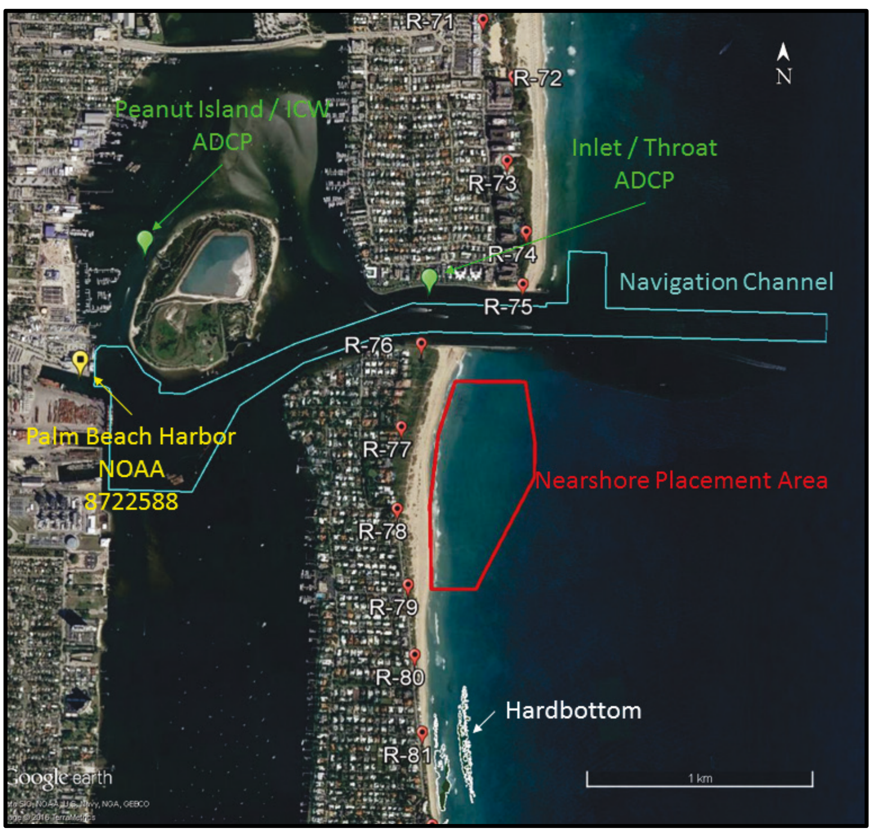
Implementation of RSM provides a better understanding of the regional sediment transport processes through integration of regional data and application of tools that improve knowledge of the regional processes, provides a means to understand and share demands for sediment, and results in identifying and implementing adaptive management strategies to optimize use of sediments and streamline projects. The adaptive management strategies are developed and implemented through application of the best available science and engineering practices and use of policies and authorities that facilitate regional approaches. Benefits of this approach are improved partnerships with stakeholders, improved sediment utilization and project management on a regional scale, improved environmental stewardship, and reduced overall lifecycle costs (Lillycrop et al. 2011).

Background

Lake Worth Inlet (Figure 1), also known as Palm Beach Inlet, is a federally maintained inlet, which serves as the entrance to the deep-draft Port of Palm Beach along the Atlantic coast of south Florida. The USACE has maintained the Palm Beach Harbor Navigation Project since 1934. This project includes the jetty structures north and south of the inlet, the navigation channel, a turning basin, inlet revetments, and a settling basin located north of the entrance channel. The navigation channel is 400 feet (ft) wide at the bottom with side slopes of 1V:3H. It has a required depth of 37 ft with 2 ft of allowable overdepth. The turning basin is 39 ft deep with a 1,200 ft diameter and a 150 ft extension beyond that diameter to the south.

Due to rapid infilling, maintenance dredging of the inlet occurs on an annual to biennial frequency. The Florida Department of Environmental Protection (FDEP) Lake Worth Inlet Management Study Implementation Plan was approved for adoption in 1996. The FDEP plan was based on the Lake Worth Inlet Management Plan (Applied Technology and Management, Inc. 1995). This plan recommends bypassing of all beach-compatible material dredged during channel maintenance activities to downdrift beaches, either on the beach or in the nearshore (Figure 1). The sediment budget developed as part of the study estimated the need to bypass 171,300 cubic yards (cy) annually to offset the impacts of the inlet.

Figure 1. Lake Worth Inlet project area. Image shows the nearshore placement area in red, navigation channel in cyan, nearshore hard bottom in white, and acoustic Doppler current profiler (ADCP) and water level recording stations.



As part of navigation channel deepening studies, a Final Integrated Feasibility Report and Environmental Impact Statement was released in January 2014 (USACE SAJ 2014). The report notes that shoaling rates in the inner and entrance channel, turning basin, settling basin, and advance maintenance areas average approximately 117,500 cy per year in total and that operation and maintenance (O&M) dredging of the shoaled material occurs once per year. Additionally, the sand transfer plant, located on the north jetty, currently pumps 160,000 cy per year from north of the inlet to south of the inlet. As part of the channel deepening studies, a new advance maintenance plan was established that changed the frequency and volume of O&M dredging events to 240,000 cy of sand every 2 years (2,500 cy per year increase annually).

Traditionally, the beach quality material has been placed either on the beach (between mean high water [MHW] line up to vegetation) between FDEP Range Monuments (R-Monument) R-76 to R-79 or in the nearshore below MHW to the -17 ft mean low water contour between 500 ft south of R-76 to R-79 (area outlined in red in Figure 1). Concerns have been raised on the efficacy of nearshore placement. With placement in the nearshore, the visible extent of the beach is not enhanced, which causes many to question whether the nearshore placement generates any benefits to coastal infrastructure. Additional concerns have been raised that, due to the close proximity to the inlet, much of the placed material simply returns into the inlet necessitating more frequent or larger-scale maintenance dredging events.

Objective

The objective of this USACE RSM study was to investigate the nearshore wave and hydrodynamic conditions around Lake Worth Inlet, Florida, to address the feasibility and efficacy of nearshore placement of dredged material south of the inlet. The U.S. Army Engineer Research and Development Center (ERDC) Coastal Modeling System (CMS) was employed for this study. The study area includes Palm Beach Harbor, Lake Worth Inlet, and the adjacent shorelines north and south of the inlet. The study region is entirely within the U.S. Army Engineer District, Jacksonville, area of responsibility.

This technical report documents nearshore hydrodynamic studies to examine nearshore currents in the vicinity of the inlet and wave energy at the beach to determine to what extent the nearshore placement acts to mitigate impacts to the dry beach. Finally, a brief evaluation was performed regarding what portion of the nearshore placed sediment is likely to be mobilized.

Approach

The study approach was to first perform a review of an average year-long wave climate that forms the basis of the numerical model input to predict nearshore hydrodynamics. Different randomizations of the climate were then developed. The model was then applied for a year-long simulation to predict nearshore currents and to evaluate wave energy in the nearshore. This technical report discusses the components of this study and the results, as well as the efficacy of nearshore placement south of Lake Worth Inlet.

2 Wave Climatology

The study area is urbanized and has been heavily studied over the years. As such, the wave climate was previously analyzed and most recently documented in the Southern Palm Beach Island Comprehensive Shoreline Stabilization Project Final Environmental Impact Statement (EIS) (USACE SAJ 2016). The EIS focused on a segment of shoreline approximately 12 miles south of Lake Worth Inlet. The wave data in the study were obtained from Wave Information Study (WIS) (Hubertz 1992) hindcast data at Station 63461 over the time period between 1980 and 2012. The WIS station is located approximately 12 miles offshore in approximately 1,070 ft water depth. Given the proximity of Station 63461 to Lake Worth Inlet, and the considerable analysis of the wave climate previously completed, the same wave characteristics developed in the EIS were used in this study.

In light of the long time period of the wave data and computational limitations, a representative year of wave data was developed. The data were derived using the Hypercube technique developed by the Environmental Hydraulic Institute of the University of Cantabria, Spain (Bonanata et al. 2010). The Hypercube method involves simulating a large number of deep-water cases in a numerical wave model that covers all combinations of wave height, period, and direction. The nearshore wave field is then constructed using three-dimensional (3D) linear interpolation based on the deep-water wave modeling output at a nearshore location. This is a similar method to the lookup method used to couple GENESIS (GENEralized model for SImulating Shoreline change) (Hanson and Kraus 1989) to an external wave transformation model. In the EIS 1,111 deep-water wave cases were modeled using wave heights from 1.6 to 34.4 ft at 1.6 ft intervals, wave periods from 2 to 20 seconds (sec) at 1 sec interval, and wave directions from 0 to 360 degrees (deg) at 22.5 deg intervals. The simulated wave heights, periods, and directions were recorded for each wave case at a nearshore output location. The multi-year WIS wave record and the 1,111 wave cases were fed into a 3D linear interpolation algorithm to estimate the nearshore wave characteristics for all wave combinations in the WIS record.

The selection of nearshore wave cases were obtained based on the wave energy flux. The offshore direction bands generating 95 percent (%) of the nearshore energy were identified (5 deg to 155 deg azimuth), and within those bands, six directional bins were established representing a nearly equal amount of wave energy. Each of the six bins were further divided into three height classes, with each height class representing nearly equal amounts of wave energy in shallow water and resulting in 18 wave cases as presented in Table 1. An additional case was developed representing calm conditions, or when wave direction was offshore. Based on the analysis of the WIS data, the annual percent occurrence of each wave case was obtained to determine the number of days per year each wave case typically occurs.

Table 1. Wave cases for the Hypercube method.

Wave Case	Significant Wave Height, Hs (ft)	Peak Wave Period, Tp (sec)	Mean Wave Approach Direction (deg)	Percent Wave Occurrence in 1 Year	Days Modeled in 1 Year
1	2.9	9.35	37.93	5.52	20.15
2	3.7	5.64	119.07	4.11	15.00
3	9.8	10.09	18.06	0.93	3.39
4	6.0	10.10	29.55	1.53	5.58
5	6.8	6.98	74.42	1.11	4.05
6	5.2	7.80	51.83	1.84	6.72
7	3.4	7.60	16.90	8.26	30.15
8	8.3	9.87	37.90	0.67	2.45
9	2.2	5.30	119.89	11.75	42.89
10	6.1	8.72	17.13	2.44	8.91
11	6.3	6.51	121.16	1.17	4.27
12	2.7	7.01	77.08	7.45	27.19
13	8.8	10.84	29.20	0.7	2.56
14	5.5	9.58	38.03	1.57	5.73
15	3.3	8.78	26.61	5.31	19.38
16	7.8	8.56	51.10	0.75	2.74
17	4.5	6.51	76.13	2.91	10.62
18	2.9	8.36	52.20	5.43	19.82
Calm	1.0	6.00	20.00	36.55	133.41

3 Coastal Modeling System (CMS)

Model setup

The ERDC CMS was applied to evaluate the nearshore hydrodynamics and wave characteristics. The CMS is an integrated suite of numerical models for waves, flows, and sediment transport, which is widely used to examine nearshore hydrodynamics and waves. The CMS is composed of a hydrodynamic and sediment transport model CMS-Flow (Buttolph et al. 2006; Wu et al. 2011; Sanchez et al. 2011a; Sanchez et al. 2011b) and a spectral wave transformation model CMS-Wave (Lin et al. 2008; Lin et al. 2011). CMS-Flow is a finite-volume, depth-averaged model that calculates water surface elevation, current, sediment transport, and morphology change. CMS-Wave calculates spectral wave propagation with wave refraction, reflection, shoaling, and breaking. For this application CMS-Flow was forced along the northern, eastern, and southern boundaries with tidal constituents obtained from the National Oceanic and Atmospheric Administration (NOAA) Lake Worth Pier tide gage located close to the southern boundary.

A CMS-Flow model grid was developed encompassing the Lake Worth Inlet, adjacent shorelines, Port of Palm Beach, and the Intracoastal Waterway (ICW) (Figure 2). Black lines in Figure 2 and subsequent figures are bathymetry contours in meters, mean sea level (MSL). The cross-shore distance of the CMS-Flow grid is approximately 16.4 miles, and the alongshore distance is approximately 15.9 miles. CMS-Flow utilized a telescoping grid with a grid cell resolution between 41 ft in the inlet throat and 2,625 ft along the offshore boundary and has a total of 167,232 grid cells. A CMS-Wave model grid was also established (Figure 3), which has a variable grid cell resolution between approximately 30 ft and 65 ft. The CMS-Wave grid has a total of 32,538 grid cells and covers approximately 14.4 miles in the cross-shore direction and 16.2 miles in the alongshore direction. While Figures 2 and 3 appear similar, the telescoping grid used in the CMS-Flow model allows for greater resolution in the nearshore areas, as seen upon close comparison of the figures. The bathymetry of both grids was developed from a variety of elevation datasets, including USACE Palm Beach Harbor surveys, beach profile surveys, ICW surveys, lidar surveys, and the NOAA Palm Beach, Florida, Digital Elevation Model (Friday et al. 2010).

Figure 2. CMS-Flow model bathymetry (a) for the entire domain and (b) close-up view of Lake Worth Inlet area.

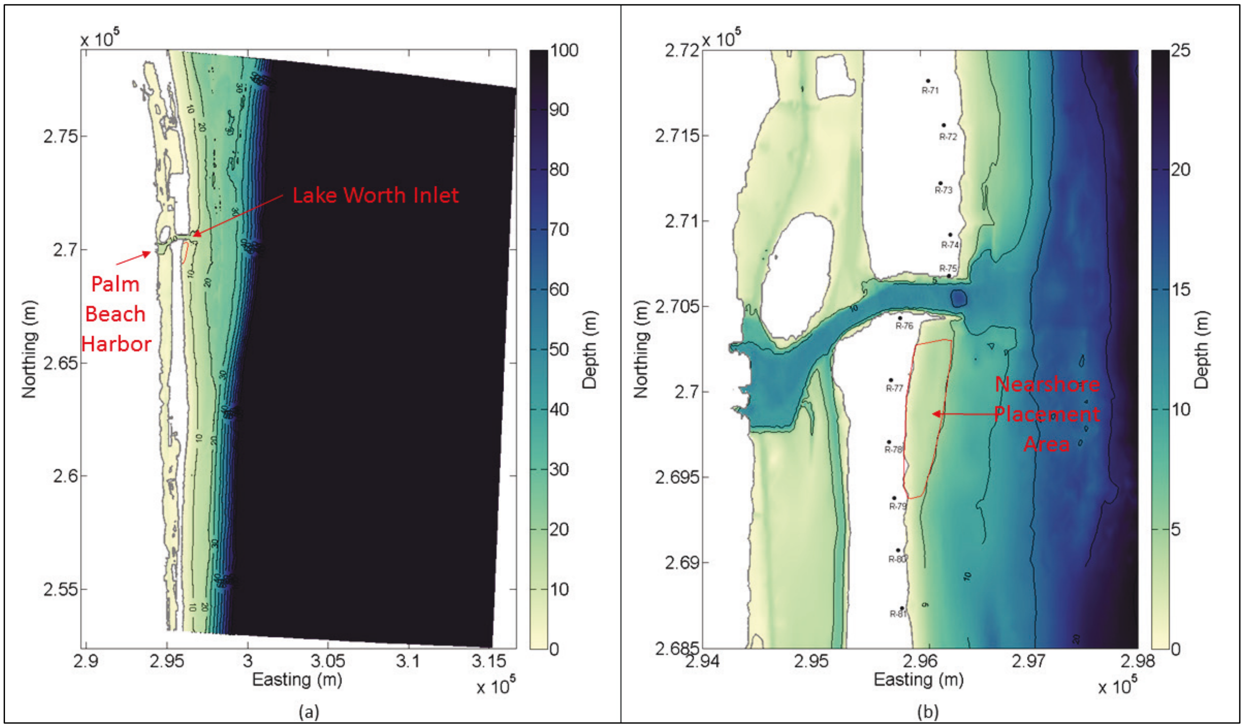
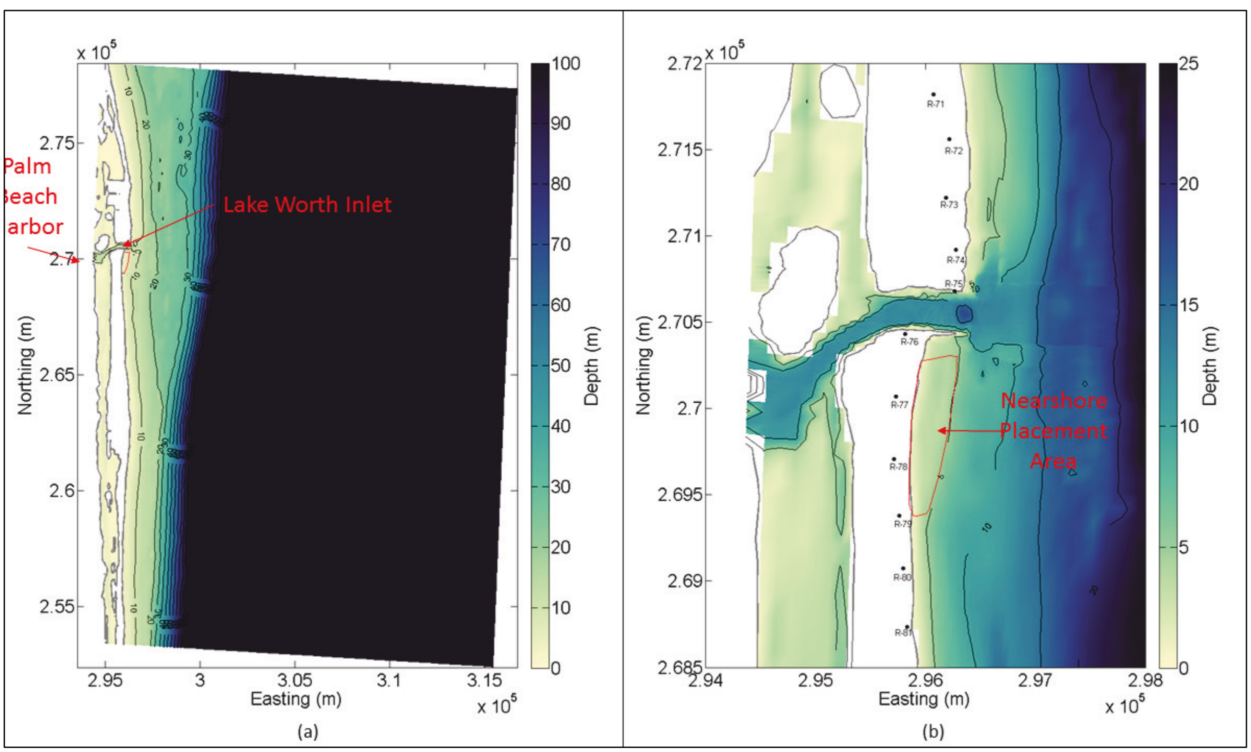


Figure 3. CMS-Wave model bathymetry (a) for the entire domain and (b) close-up view of Lake Worth Inlet area.



Model calibration and validation

The CMS-Flow model was calibrated to predicted tides at the NOAA Port of Palm Beach Station 8722588 (Figure 1). The calculated water levels with different tidal constituent forcing and the observed water levels were evaluated before deciding on the NOAA constituents for the Lake Worth Pier (NOAA Station 8722670). These constituents produced the best comparison to predicted water levels at the Port of Palm Beach, based on standard skill metrics for a week-long, tides-only, simulation (mean absolute error, root mean squared error, mean absolute relative error, and mean absolute percentage error).

The calibrated setup was then validated against two ADCP datasets that were collected over both a spring tide and neap tide period in 2008. One ADCP was located in the ICW channel just west of Peanut Island, and the other was located in the Lake Worth Inlet throat (Figure 1). Model-computed tidal velocity amplitude and phase were compared with the ADCP observations for both the spring tide (Figure 4) and neap tide (Figure 5) periods. Comparisons show a consistent phase difference across both spring and neap tide time periods. Since the phase difference is consistent throughout the time periods, it is not a concern over the year-long simulation. However, the current magnitude did present a concern as it was underestimated by the model, particularly in the inlet throat. To ensure a range of expected conditions are encountered, a second set of tidal forcing with a doubled constituent amplitude was developed. The results of the velocity comparison for this forcing is presented in Figures 6 and 7. Between the two sets of tidal forcing, the model-predicted current magnitude tends to bracket the range in the ADCP data. Both tidal forcing scenarios were then used to drive the model for analysis of the velocity nodal point.

Figure 4. CMS-Flow model-computed current magnitude and current direction comparison to ADCP data (a) within the Lake Worth Inlet throat and (b) just west of Peanut Island in the ICW. Also provided is (c) NOAA-predicted, NOAA-observed, and CMS-predicted water levels at Palm Beach Harbor during spring tide conditions.

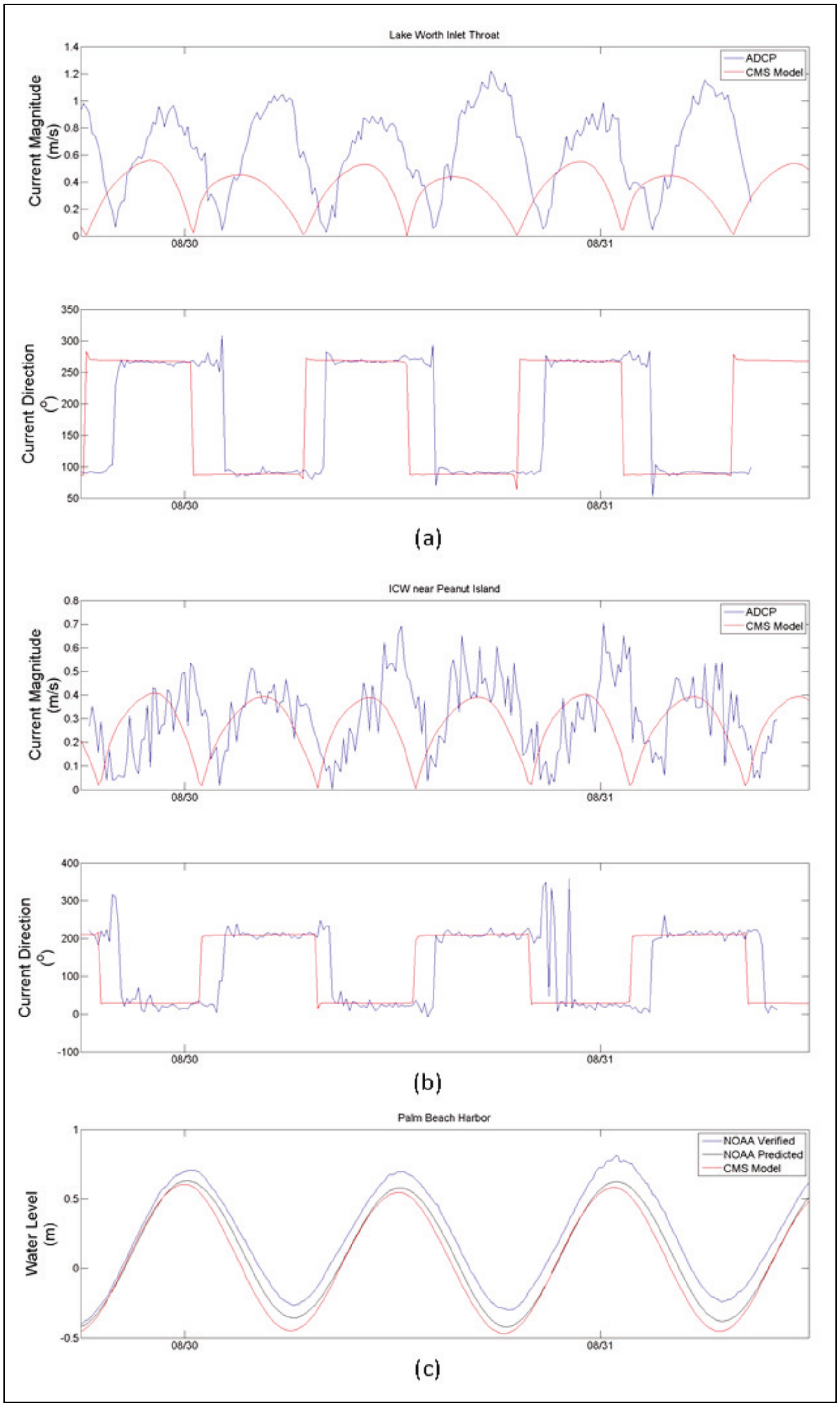


Figure 5. CMS-Flow model-computed current magnitude and current direction comparison to ADCP data (a) within the Lake Worth Inlet throat and (b) just west of Peanut Island in the ICW. Also provided is (c) NOAA-predicted, NOAA-observed, and CMS-predicted water levels at Palm Beach Harbor during neap tide conditions.

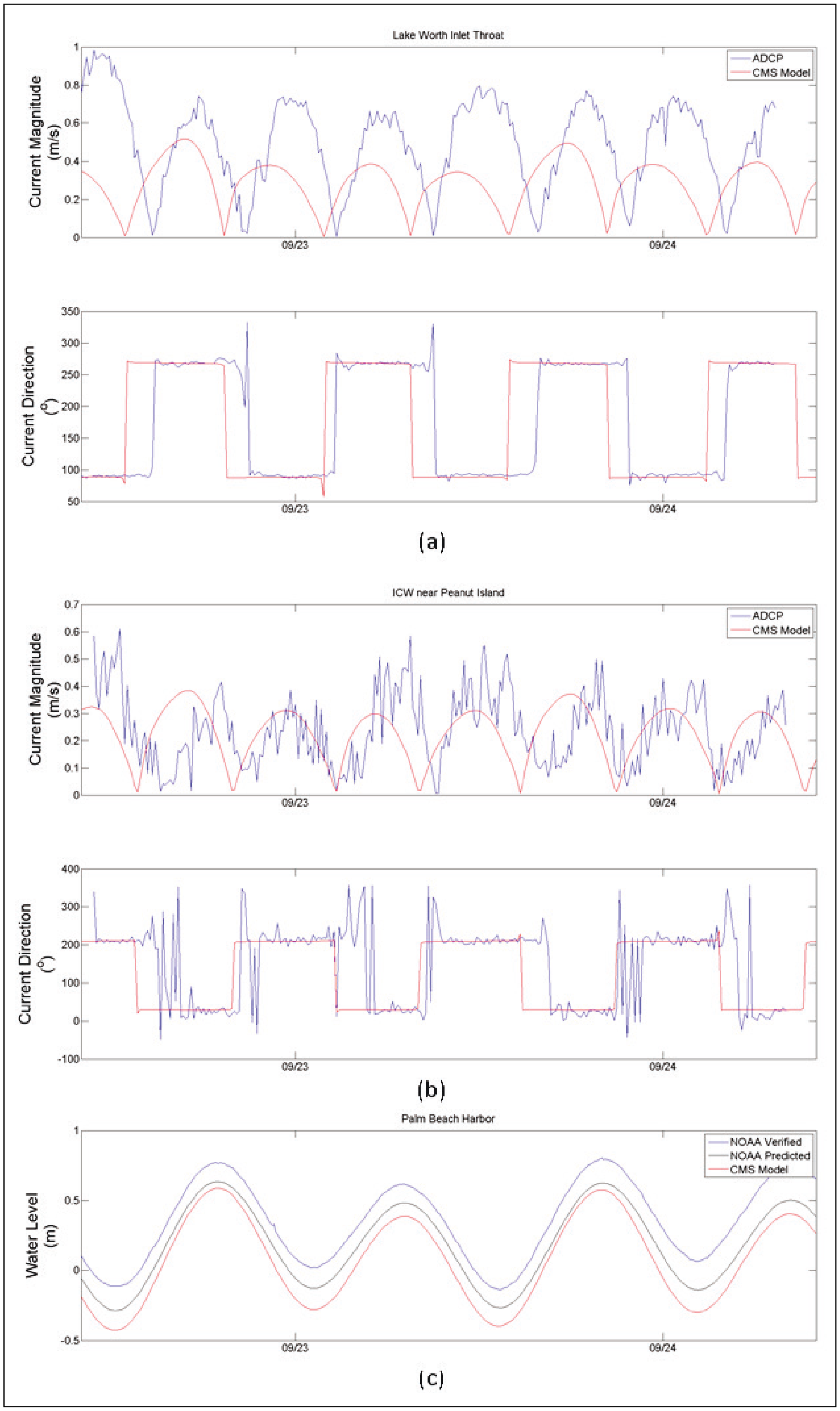


Figure 6. CMS-Flow model-computed current magnitude and current direction (with doubled amplitude tidal constituents) comparison to ADCP data (a) within the Lake Worth Inlet throat and (b) just west of Peanut Island in the ICW. Also provided is (c) NOAA-predicted, NOAA-observed, and CMS-predicted water levels at Palm Beach Harbor during spring tide conditions.

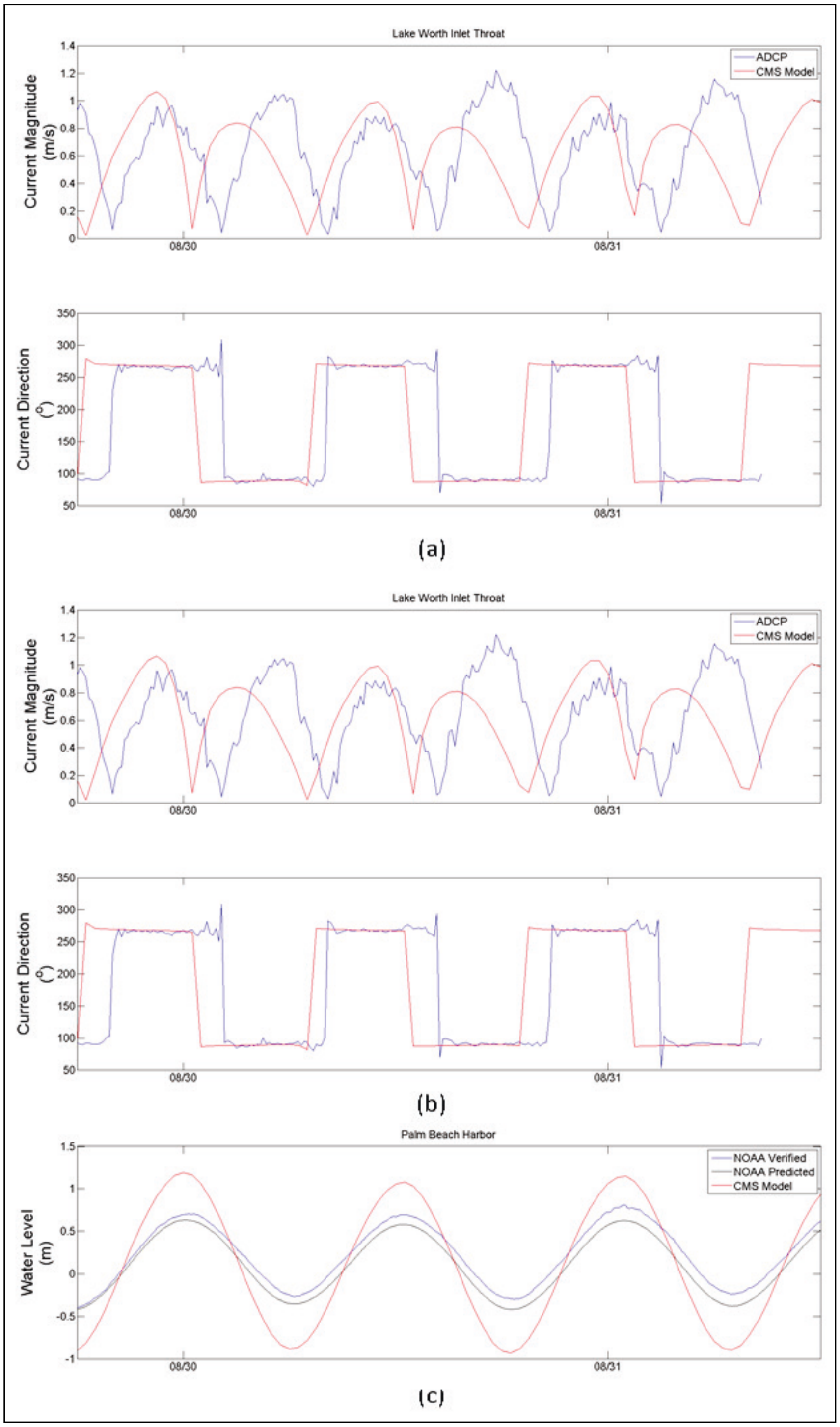
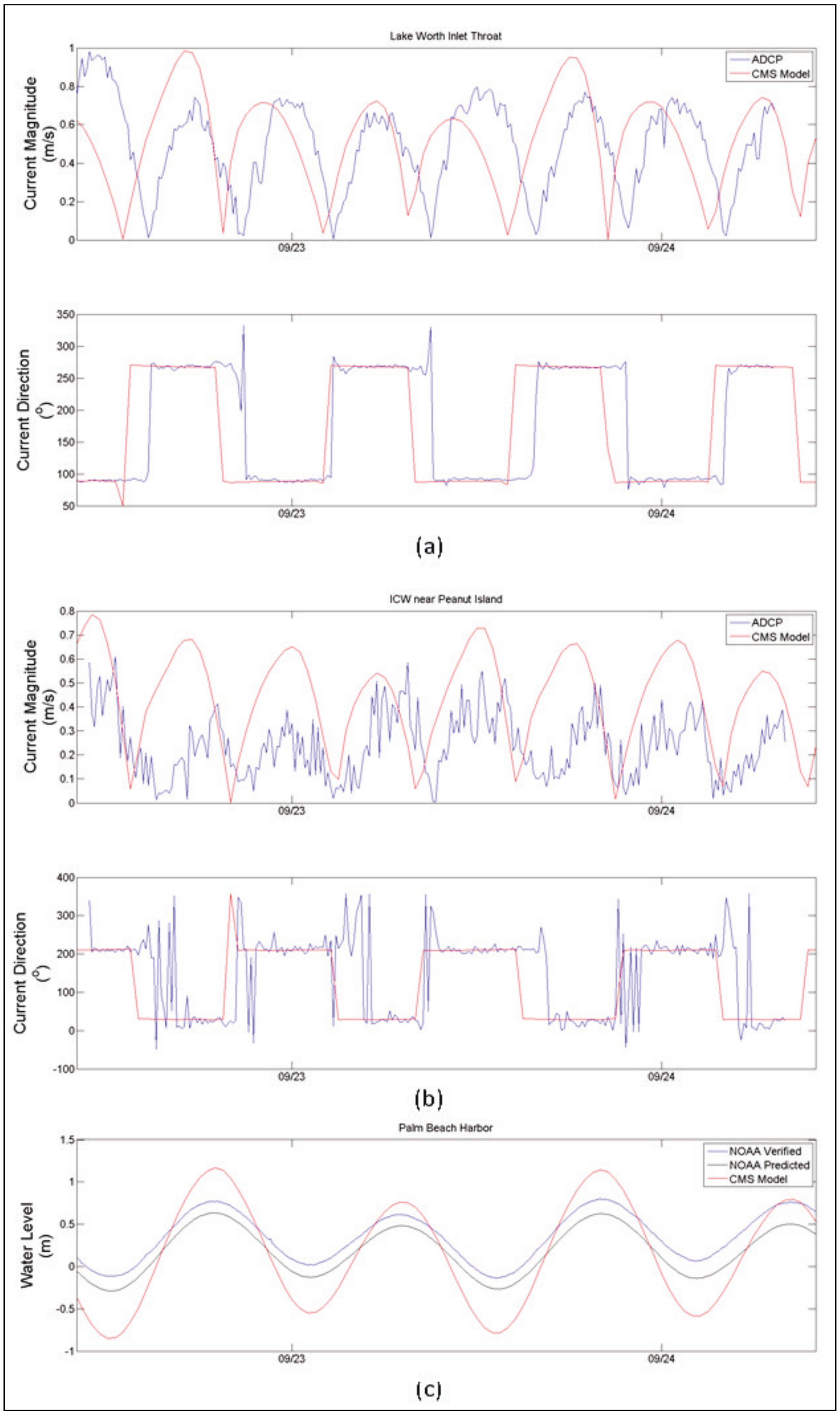


Figure 7. CMS-Flow model-computed current magnitude and current direction (with doubled amplitude tidal constituents) comparison to ADCP data (a) within the Lake Worth Inlet throat and (b) just west of Peanut Island in the ICW. Also provided is (c) NOAA-predicted, NOAA-observed, and CMS-predicted water levels at Palm Beach Harbor during neap tide conditions.



4 North-South Velocity Nodal Point

The coupled CMS model was run for year-long simulations using both the regular Lake Worth Pier tidal constituents and the double amplitude constituents with wave coupling occurring every 3 hours. Three different randomizations of the wave climate were established. In each randomization, as presented in Table 1, the yearly percent occurrence for each wave case was met. This resulted in a total of six, year-long simulations. Between each wave case in a simulation, a calm wave period was run. Current and water level data were output hourly from each simulation.

The cumulative velocity for the east-west (U) and north-south (V) components, along with the average cumulative velocity, was analyzed for each model run. In general, the randomization of the wave climate did not have a large influence on the model results. Although different wave events occurred at different times in each randomization, the same wave climate is represented, and differences in the cumulative hydrodynamics are small. As such, the cumulative velocity for the three wave randomizations of the regular tidal constituents were averaged together. The same was done for the three randomizations of the double amplitude tidal constituent runs.

Results are provided in Figures 8–11 for the cumulative U and V components (Figures 8 and 10, regular and doubled amplitude, respectively) and cumulative velocity (Figures 9 and 11, regular and doubled amplitude, respectively). As illustrated in Figure 8a, the cumulative velocity in the east-west direction is directed offshore in the nearshore placement area. More pertinent to the placement of material in the nearshore (due to its proximity to the inlet) is the cumulative north-south velocity component (Figure 8b) over the year-long simulation. Figure 8b shows a cumulative northerly directed current across the northern portion of the nearshore placement area. This feature extends south just past R-77 and implies that nearshore placement of material north of R-77 is subject to a net current towards the inlet.

Figure 9 presents the cumulative velocity in the area of interest. Like the velocity components presented in Figure 8, the nodal point offshore of R-77 is visible. In general, the velocity magnitude directed towards the inlet increases from R-77 to the north. Similarly, the southerly directed velocity increases from approximately R-77 moving south to R-79.

To bracket the range of expected hydrodynamics, the same three wave cases were simulated using the doubled amplitude tidal constituents. Similarly, the averaged cumulative U and V velocity components are provided in Figures 10 and 11. The overall differences are small, indicating that the hydrodynamics are wave and not tidally dominated. The location of the nodal point offshore of R-77 is shifted slightly to the south but in the same general location. Given nearshore complex interactions, R-77 appears to be a good landmark for identifying the nodal point location.

Figure 8. Velocity (a) cumulative U (east-west) component and (b) cumulative V (north-south) component, for year-long coupled CMS model run with regular tidal constituent amplitude forcing.

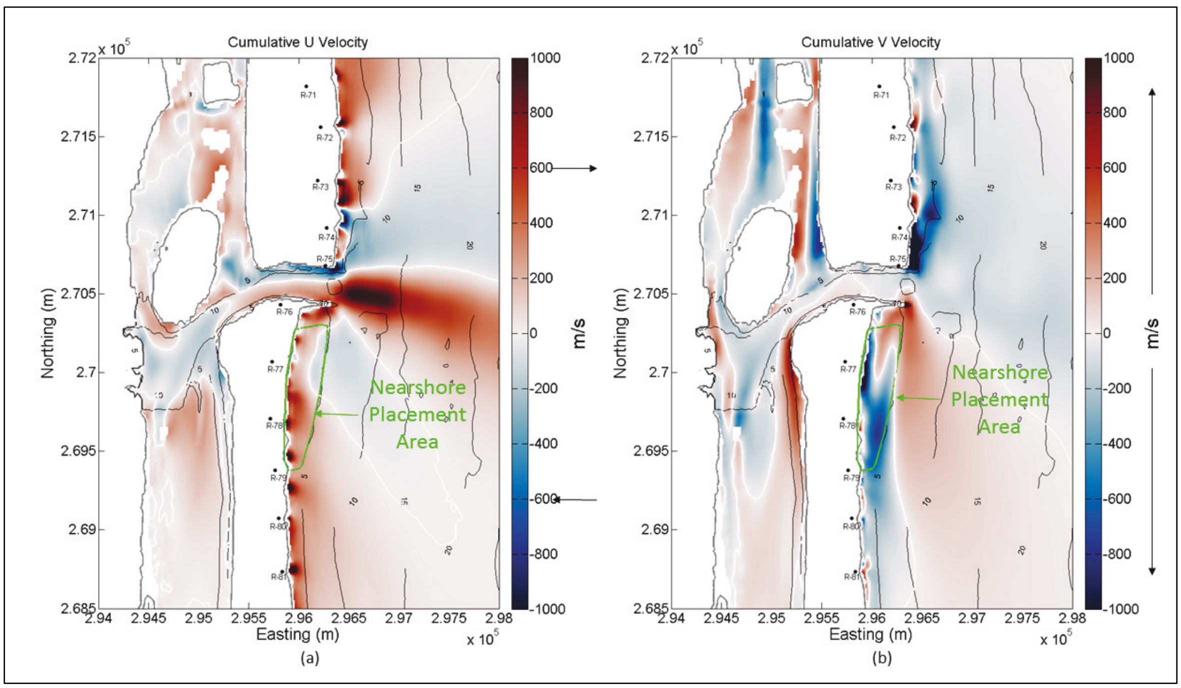


Figure 9. Cumulative velocity for year-long coupled CMS model run with regular tidal constituent amplitude forcing.

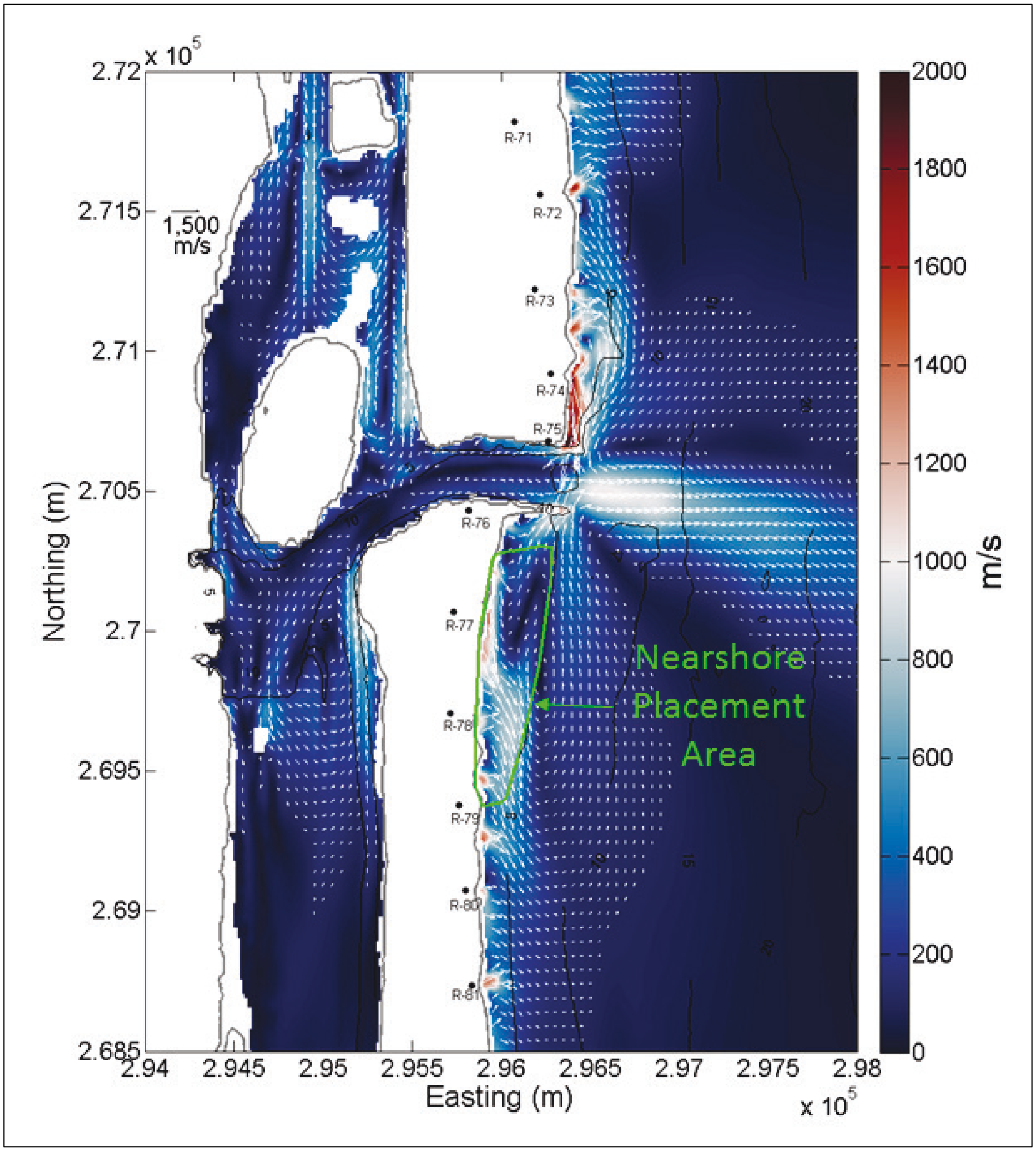


Figure 10. Velocity (a) cumulative U (east-west) component and (b) cumulative V (north-south) component, for year-long coupled CMS model run with double tidal constituent amplitude forcing.

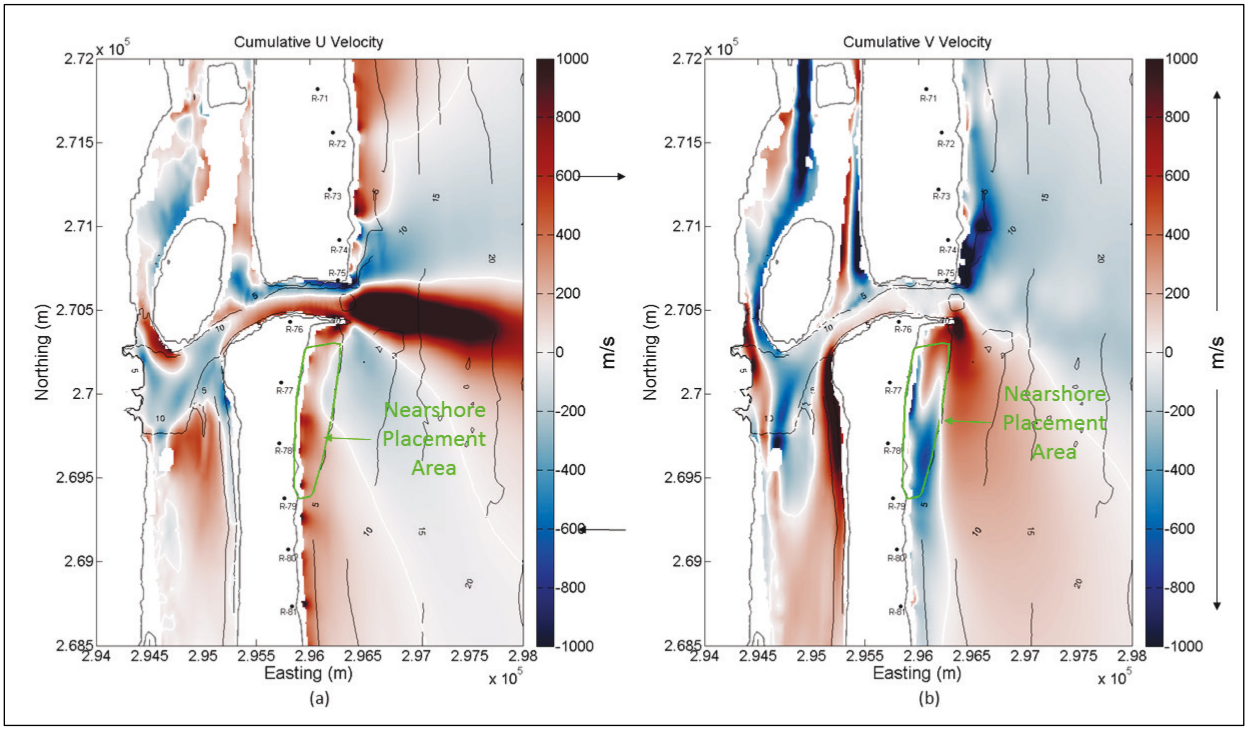
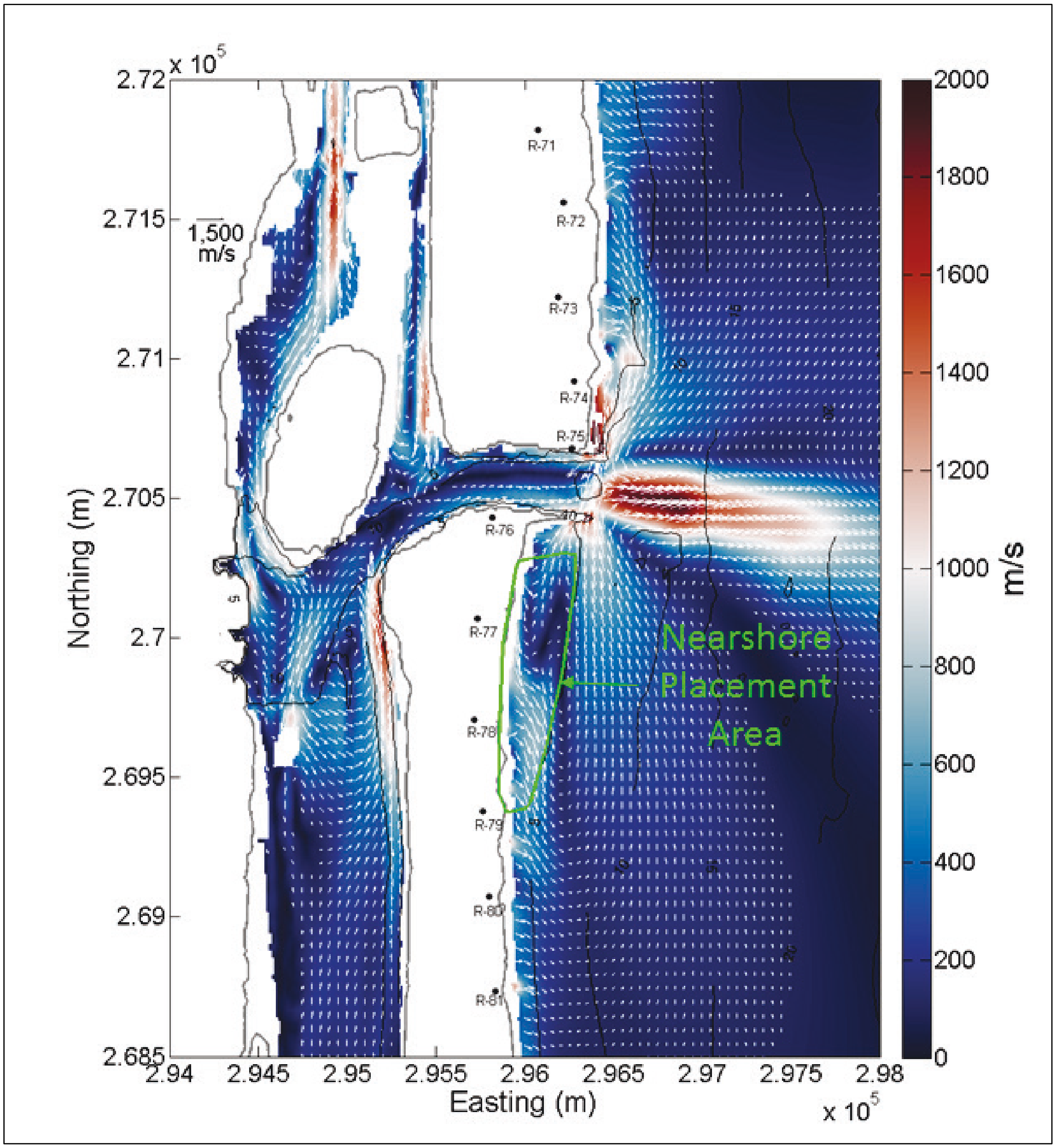


Figure 11. Cumulative velocity for year-long coupled CMS model run with double tidal constituent amplitude forcing.

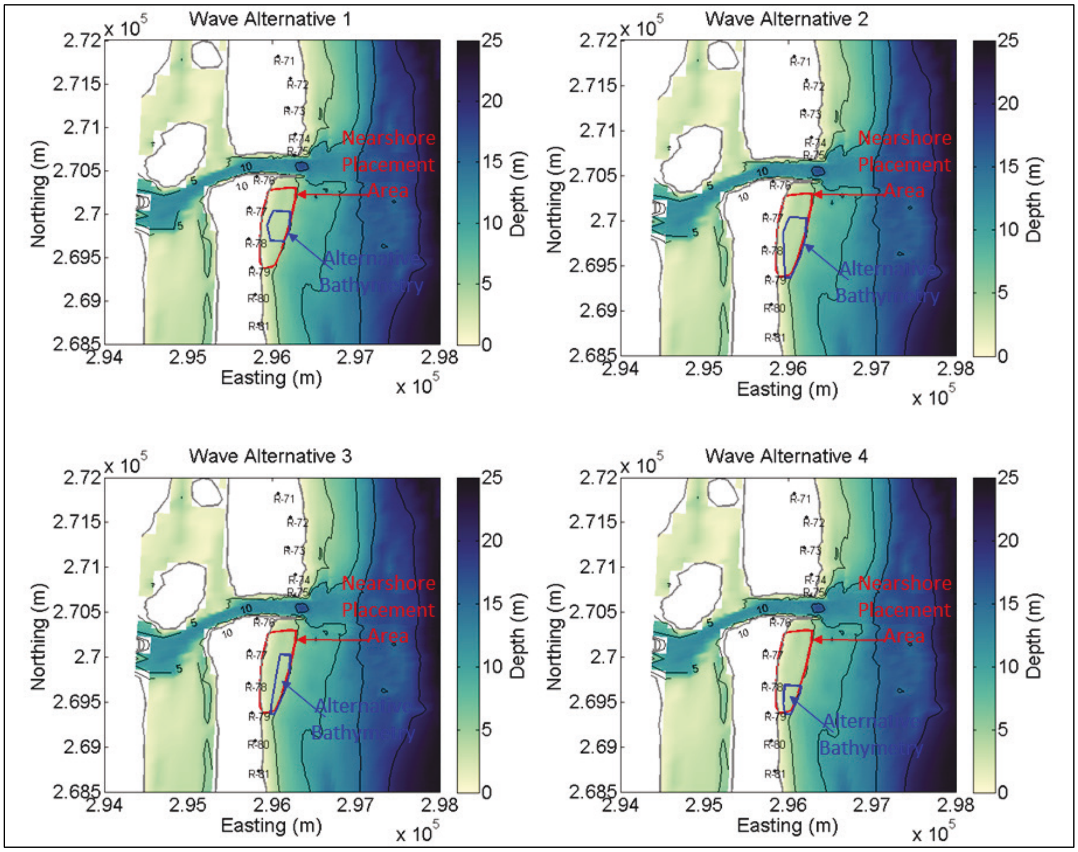


5 Wave Energy

Based on the Final Integrated Feasibility Report and Environmental Impact Statement for the channel deepening, approximately 120,000 cy per year should be dredged from the channel and placed in the nearshore (USACE SAJ 2014). To examine the extent of protection from wave energy that the nearshore placement provides, four nearshore placement scenarios were compared to current conditions. CMS-Wave was run using one of the three wave case randomizations presented earlier, where all wave cases and calm periods represent the climatology. The model bathymetry was altered within the nearshore placement area and south of the approximate nodal point at R-77 to replicate an approximately 120,000 cy placement. The area of altered elevation is illustrated in Figure 12. The alternatives are the following:

- Alternative 1: Between R-77 and R-78, added 4.0 ft between the -10 and -17 ft MSL contour
- Alternative 2: Between R-77 and R-79, added 2.5 ft between the -10 and -17 ft MSL contour
- Alternative 3: Between R-77 and R-79, added 4.0 ft between the -12 and -17 ft MSLcontour
- Alternative 4: Between R-78 and R-79, added 6.0 ft between the -8 and -17 ft MSL contour.

Figure 12. Areas of altered bathymetry (blue line) for wave energy analysis within the nearshore placement area (red line) for each of the four alternatives.



The total cumulative wave energy was estimated as the sum of the squares of the wave height and approximated along a north-south running profile at the -5 ft MSL water depth. Figure 13 presents the comparison between the computed wave energy for each of the alternatives compared with the baseline (unaltered) bathymetry, along with the percent reduction in wave energy (the secondary axis). The plot shows that the magnitude of the energy reduction varies up to approximately 50% for the alternatives considered. Alternative 4 provides the largest reduction in wave energy. This alternative consisted of placing all 120,000 cy of material between R-78 and R-79. Due to the rapidly increasing depth with distance offshore and the approximately 1,000 ft alongshore distance, the room within the nearshore placement area where sediment could be placed was small. This required a large input (6 ft relief) of sediment from the -8 to -17 ft contour to meet the annual placement load. The resulting shallow depths in the altered placement area showed a large reduction in wave energy reaching the -5 ft contour. This also led to a seaward migration of the -5 ft contour, as shown by the green line in Figure 14. Figure 14 shows the overall percent change in wave energy from the baseline in plan view for the nearshore placement area. Changes under 0.5% were not plotted. This figure, along with the transects in Figure 13, demonstrate that the majority of the change in wave energy as a result of the nearshore placement is directly in the lee of the placement, with minor alongshore spreading.

Figure 13. Wave energy (square meters) at the -5 ft contour for each of the four alternatives. Black line displays unaltered bathymetry; blue line displays energy for the altered bathymetry; red line shows the percent reduction.

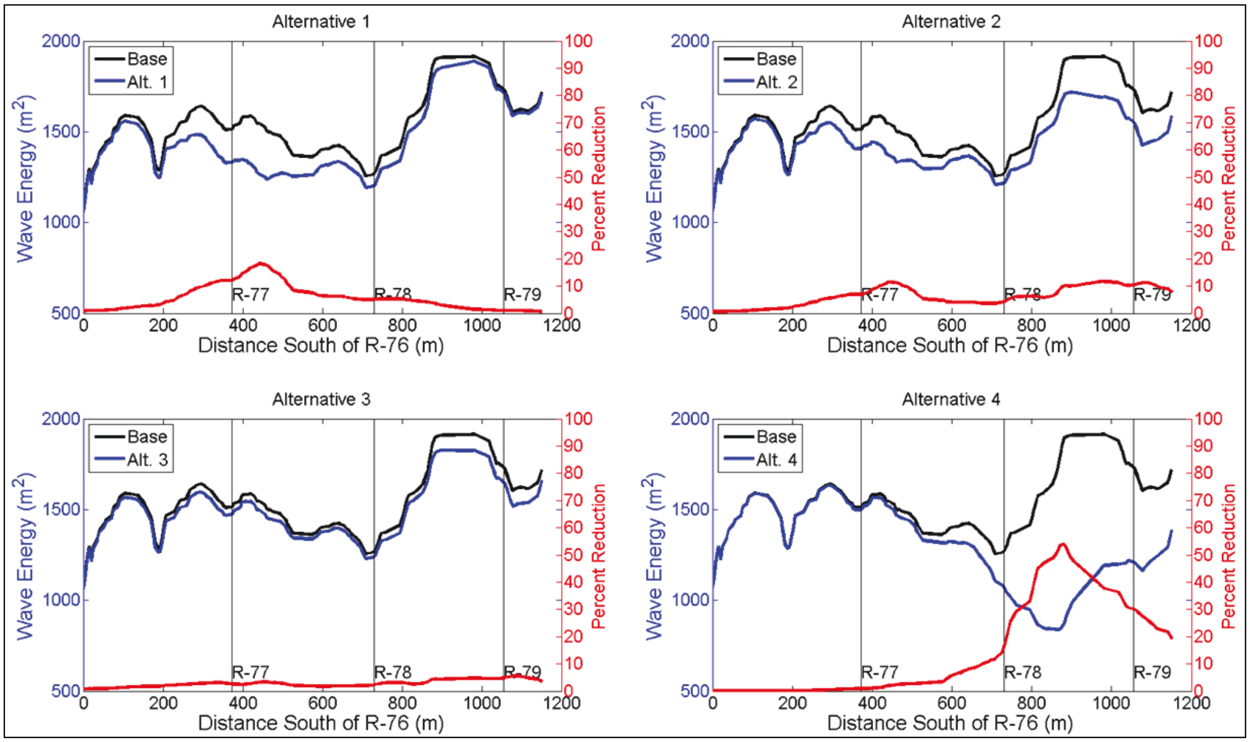
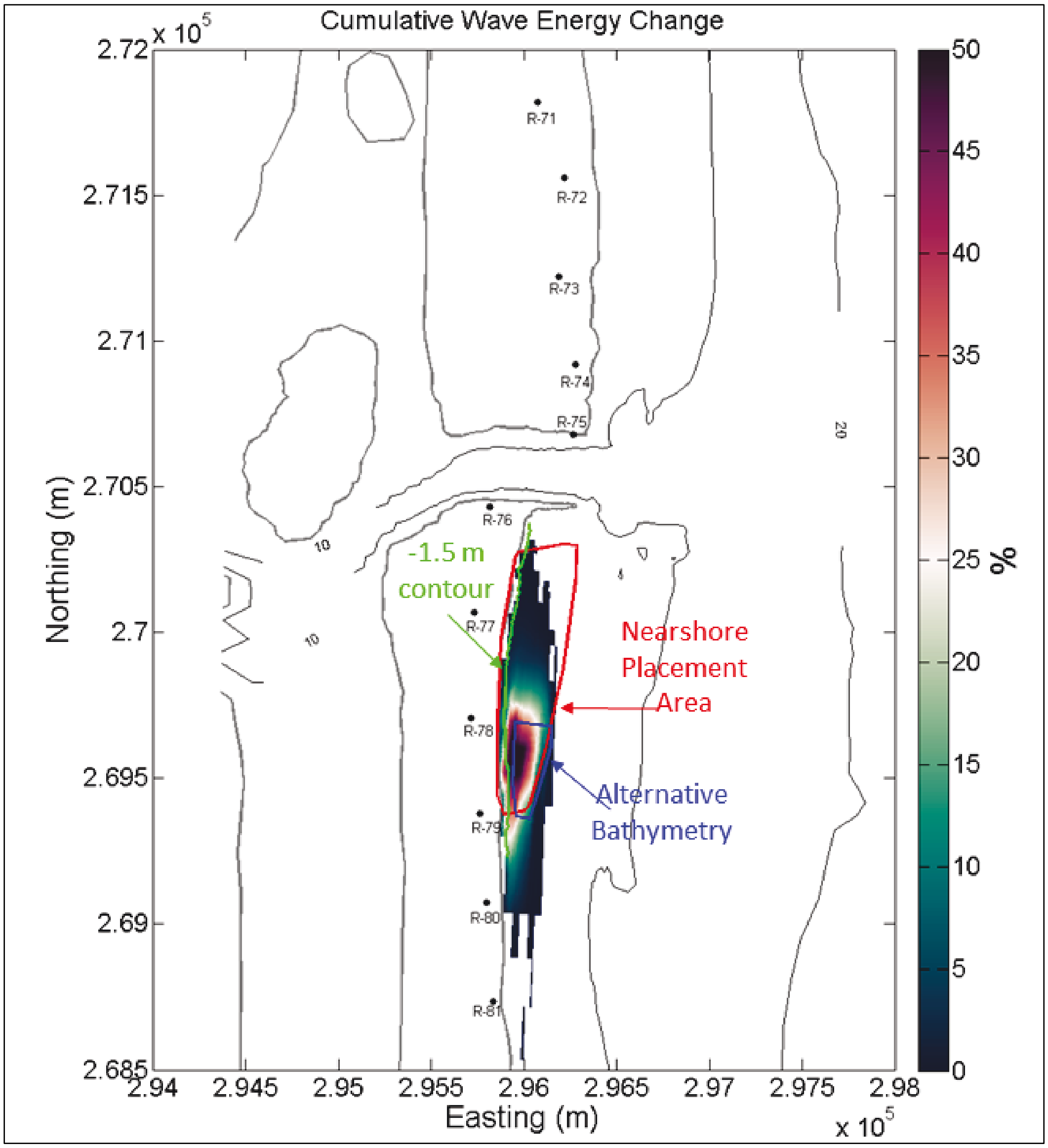


Figure 14. Wave energy percent change for Alternative 4, showing large decrease in energy in the lee of the nearshore placement area.



The total cumulative wave energy is reduced the least in Alternative 3. In Alternative 3, the placement area stretches from R-77 to R-79 between the -12 and -17 ft contour. Adding 4.0 ft of sand to this area does not have much effect on the wave energy. Both Alternative 1 and Alternative 2 show larger reductions in the wave energy than Alternative 3. The commonality between these two alternatives is that the bathymetry change occurs between the -10 and -17 ft contour. This confirms that the closer to shore the material is placed (shallower depth), the greater the wave energy reduction. However, in practice, the placement location will be limited by the equipment performing the placement.

6 Mobilization of Nearshore Sediment

Sediment Mobility Tool

Based on the CMS model results and the draft limitations of commercial dredging equipment, a preliminary assessment of the sediment mobility at prospective sites was performed utilizing the web-based Sediment Mobility Tool (SMT) (McFall et al. 2016). The SMT calculates the frequency of sediment mobility using both linear and nonlinear stream function wave theories with procedures described in McFall et al. (2016). The cross-shore sediment migration is calculated using an empirical relationship described by Larson and Kraus (1992). The tool applied the CMS model wave conditions at seven different cross-shore depths. The dredged sediment median grain size, d_{50}, is 0.14 millimeters (mm) (0.0055 inches [in.]) (USACE SAJ 2012).

The first method used to estimate the sediment mobility analyzes the bed shear stress using linear wave theory, and the second method analyzes the near-bottom velocity using nonlinear stream function wave theory. Stream function wave theory generally produces larger velocities than linear wave theory, resulting in an increased frequency of sediment mobility. Additional details about these two methods are described by McFall et al. (2016).

The frequency of mobility and mean mobility score were applied to the specified median grain size diameter of 0.14 mm. Sediments with smaller grain size diameter will be mobilized more frequently than those with larger diameters. The mean mobility score is evaluated to analyze the predictive sediment mobility by assessing how much the maximum bottom stress or velocity exceeds the critical threshold on average. The mobility score can be particularly useful when comparing sites with similar frequencies of mobility, and mobility score values can be negative in sites where the average maximum bottom stress is less than the critical bottom stress.

The frequency of sediment mobility and mean mobility score for the median grain size of 0.14 mm is shown in Table 2 using linear and stream function wave theories. The results show that within the nearshore placement zone (17 ft), the sediment is extremely likely to mobilize based on both wave theories.

Table 2. SMT frequency of sediment mobility and mean mobility scores for the median grain size, d_{50}, of 0.14 mm (0.0055 in.) at several cross-shore depths.

Depth (ft)	Linear Wave Theory		Stream Function Wave Theory	
	Frequency of Sediment Mobility	Mean Mobility Score <M>	Frequency of Sediment Mobility	Mean Mobility Score <M_u>
10.0	99.9%	3.61	100%	4.69
15.0	99.9%	2.15	99.9%	3.53
20.0	93.6%	1.45	99.9%	2.84
25.0	93.6%	1.01	99.9%	2.29
30.0	93.5%	0.67	93.6%	1.87
35.0	82.0%	0.43	93.6%	1.53
40.0	41.3%	0.25	93.6%	1.26

Dean Number

To predict the cross-shore sediment migration of nearshore berms constructed of dredged sediment, Larson and Kraus (1992) hypothesized that nearshore berm behavior should be similar to natural sand bars and studied the onshore and offshore migration of the offshore bar in Duck, NC, from 1981 to 1989. The dimensionless Dean Number is generally used to determine bar migration and is given as follows:

$$\boldsymbol{D} = \frac{\boldsymbol{H}_0}{\boldsymbol{\omega T}} \tag{1}$$

where H_0 is the offshore wave height, ω is the sediment fall speed, and T is the wave period. Dean Number, D, values greater than 7.2 were found to induce erosive offshore bar migration, and values less than 7.2 resulted in accretionary onshore bar migration. The sediment fall speed is dependent on the grain size diameter and was calculated with the equations derived by Hallermeier (1981). The Dean Number is calculated for each wave record, and the predicted sediment migration results for several grain sizes are shown in Table 3. The results show that for the median grain size and larger sediment, onshore migration is predicted.

Table 3. Predicted sediment migration for various sediment sizes using the Dean Number.

d_{50} (mm)	Predicted Sediment Migration
0.1	72% erosive, offshore migration
0.14	84% accretion, onshore migration
0.2	97% accretion, onshore migration
0.3	100% accretion, onshore migration
0.4	100% accretion, onshore migration
0.5	100% accretion, onshore migration

7 Conclusions

Using the CMS, the wave and hydrodynamic conditions around Lake Worth Inlet, Florida, were investigated to aid in identifying areas for nearshore placement of dredged material from the inlet. The tidal amplitudes and current magnitudes were bracketed with expected conditions, and three randomizations of the wave climatology were simulated for each of the tidal conditions. The randomizations of the wave climate produced similar average and cumulative current results. The results of these simulations point to a north-south velocity nodal point located offshore of FDEP Range Monument R-77. Material placed in the nearshore north of R-77 is likely to be transported back towards or into the inlet. Placement south of R-77 is subject to a southerly current on average and will likely aid in the replenishment of downdrift beaches. To satisfy placement needs and minimize maintenance dredging, nearshore placements should be confined between R-77 and R-79. The double amplitude tide simulations showed approximately the same current velocity nodal point, indicating that the tidal influence is minimal and the nearshore hydrodynamics are dominated by wave energy around the placement area.

The effectiveness of the nearshore placement in mitigating beach impacts was examined in terms of wave energy reaching a point landward of the placement area. Different alternatives were examined, and as expected, the closer to shore the material is placed (which leads to shallower depths and increased wave dissipation), the greater the wave energy reduction. Thin placement in deeper water along the length of the nearshore placement area resulted in little change in the wave energy reaching the shore. The amount of wave energy dissipation was proportional to the negative freeboard that results from the volume of sand placed and to the height of the nearshore placement above the seabed. As the negative freeboard gets closer to zero (i.e., the difference between the still water level and the seabed with material placed on it gets smaller), wave breaking is induced, and less energy transverses the placement area and reaches the beach. To maximize wave energy dissipation, the material should be placed as close to shore as practicable to result in smaller negative freeboards and less wave energy reaching the beach.

An assessment of the frequency of mobility was examined using the SMT and the Dean Number. Based on both the SMT and the Dean Number, sediment within the nearshore placement area is very likely to mobilize, and the mobilization is likely to result in a net onshore migration. The CMS modeling indicates an approximately 10% reduction in wave energy reaching the shore in its lee due to the nearshore placement. The SMT shows that, in general, the material migrating onshore remains within the nearshore system even when transported down-drift to the south. The results of this study indicate that nearshore placement south of R-77 does indeed offer tangible benefits to the shoreline in the lee of the placement.

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14. ABSTRACT
The purpose of this study was to investigate the nearshore hydrodynamics around Lake Worth Inlet, Florida, by utilizing the U.S. Army Research and Development Center Coastal Modeling System to address the feasibility of nearshore placement of dredged materials south of the inlet. The study area includes Palm Beach Harbor, Lake Worth Inlet, and the adjacent shorelines north and south of the inlet.
The effectiveness of the nearshore placement in mitigating beach impacts was examined in terms of wave energy reaching a point landward of the placement area. Different alternatives were examined. The closer to shore the material is placed (which leads to shallower depths), the greater the wave energy reduction. Thin placement in deeper water along the nearshore placement area resulted in little change in wave energy reaching the shore. Material should be placed as close to shore as practicable to result in less wave energy reaching the beach.Sediment Mobility Tool modeling indicates the material will migrate onshore and remain within the nearshore system even when transported down-drift to the south. Nearshore placement of dredged material south of Florida Department of Environmental Protection Range Monument R-77 offers tangible benefits to the shoreline in the lee of the placement.

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