MODELING OF MORPHOLOGIC CHANGES CAUSED BY INLET MANAGEMENT STRATEGIES AT BIG SARASOTA PASS, FLORIDA

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Abstract

Inlets are everchanging coastal features. Change in morphology at coastal inlets, which may include change due to natural processes or artificial change due to mining, modifies the incident waves, circulation, and sediment pathways. Advances in numerical modeling make predicting morphology change feasible despite the large number of interacting processes. Simulation of morphologic changes at inlets is essential for inlet management strategies such as borrow area design of ebb or flood shoals for beach nourishment and navigation channel design.

This Study focuses on simulating the effects of modifications to Big Sarasota Pass on the system's morphology. In order to predict these effects, a morphology change model, based on coupling CMS-M2D and WABED models, was developed within the Surface-Water Modeling System (SMS) to simulate existing conditions based on a bathymetric survey conducted in 2006 and two inlet management strategies, which included 1) relocation of Big Sarasota Pass's channel off Siesta Key and closing off the existing channel and 2) contour dredging of the ebb shoal.

1.0 Introduction

Big Sarasota Pass and New Pass are located on Florida's West Coast south of Tampa Bay (Figure 1). Along with adjacent interior and exterior shorelines of Longboat Key, Lido Key and Siesta Key, Big Pass and New Pass comprise a unique resource that affects a wide range of public interests including beach preservation and navigation. According to the Florida Department of Environmental Protection (2006), the entire 5.4-mile long shoreline segment from the northern Sarasota County border line to New Pass is a critically eroded area. This means that the recession of the beach or dune system threatens upland development, recreational interests, wildlife habitat, or important cultural resources throughout the area. The north end of Lido Key fronting on New Pass is a critically eroded inlet shoreline area for 0.3 miles and nearly all of Lido

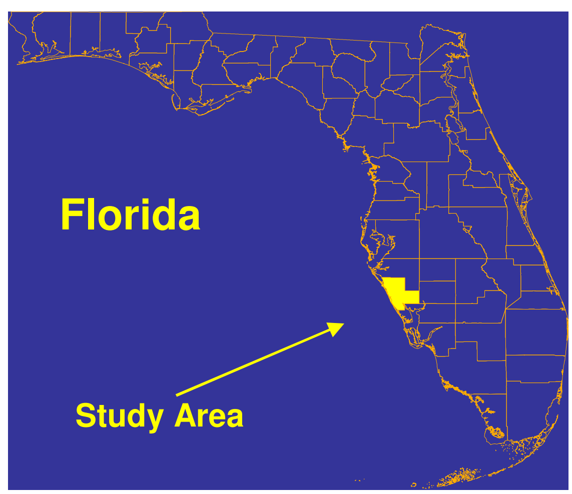

Figure 1. Study Area Location.

Key has critically eroded beach that has threatened private development and recreational interests along 2.4 miles.

Beach restoration projects have been conducted along Longboat Key and Lido Key and maintenance dredging material has been obtained from the New Pass Federal Navigation Channel and nearshore borrow areas at New Pass. However, Big Sarasota Pass has never been dredged or altered. Numerical modeling is an inexpensive and efficient tool for predicting potential impacts caused by bathymetric changes due to nearshore sand mining and channel alteration. In order to predict the impacts on sediment transport and inlet morphology within the Big Pass/New Pass system, Sarasota County contracted with Coastal Technology Corporation (CTC) and Coastal Engineering Consultants (CEC) to develop a morphology change model to simulate potential alternative inlet and beach management strategies. These strategies included modifications to the bathymetric surface due to relocation of the Big Sarasota Pass navigation channel and dredging of the Big Sarasota Pass ebb shoal in a depth contour manner. Morphologic changes predicted for the existing conditions and the two inlet management strategies were evaluated to assess potential impacts to the natural morphologic regime. The CMS-M2D coupled with WABED were used in this Study.

2.0 The Model

2.1 Model Description

The CMS-M2D (Coastal Modeling System-M2D) (Militello et al., 2004) model, currently known as CMS-Flow2D, was developed under the Coastal Inlets Research Program (CIRP) conducted at the U.S. Army Engineer Research and Development Center (ERDC) to calculate combined circulation (current and water surface elevation), waves, and morphology change at inlets and nearby areas through the Surface-water Modeling System (SMS) interface. The model contains integrated representation of sediment transport and morphology change through transport rate formulations, the advection-diffusion equation, and sediment continuity equation for updating change in the sea bottom. Morphology change is computed by means of two time steps, a transport rate time step and a morphology change time step. Instantaneous transport rates are computed at the transport rate time step and averaged over the morphology change time step. Averaged transport rates are then applied in the sediment continuity equation. Coupled with a wave model, CMS-M2D accounts for wave-driven currents and wave-induced sediment transport. The wave model used in the Study was WABED (Wave-Action Balance Equation Diffraction), currently known as CMS-Wave, which is a steady-state finite difference model (Mase, 2000; Mase and Kitano, 2000). It simulates depth-induced refraction which transforms the direction of wave crests approaching a shoreline, and depth-induced shoaling which steepens waves propagating over shallow water prior to breaking. The model also accounts for current-induced refraction and shoaling, depth and steepness induced wave breaking, diffraction, and wind driven wave growth.

2.2 Grid Design

Two computational grids were implemented: one for the M2D model and one for the WABED model. Both grids covered the New Pass and Big Sarasota Pass inlet systems including the navigation channels, shoals, interior bays and adjacent beaches. The grids extended seaward of depth of closure beyond which no measurable sediment movement occurs. The M2D grid presented in Figure 2 had varying grid spacing ranging from 25 m inside New Pass and Big Pass to 100 m offshore. Having the fine grid spacing over the ebb shoals and inside the channels enabled capturing the sediment transport and morphologic change processes where they mainly occurred. The larger offshore grid spacing sped up the computational process. Varying grid spacing in WABED was not an option; therefore, the WABED grid spacing was constant throughout the domain at 75 m. This grid spacing was considered optimal: it was small enough to allow wave propagation over the ebb shoals and through the inlets and large enough not to slow down the computational process. Reducing the WABED grid spacing would result in an increase in computational time. For the same reason, the WABED grid did not extend all the way to the mainland. Littoral transport was not anticipated to occur landward of the flood shoal, thus, not having computational cells there helped reduce the computational burden. The WABED grid is presented in Figure 3.

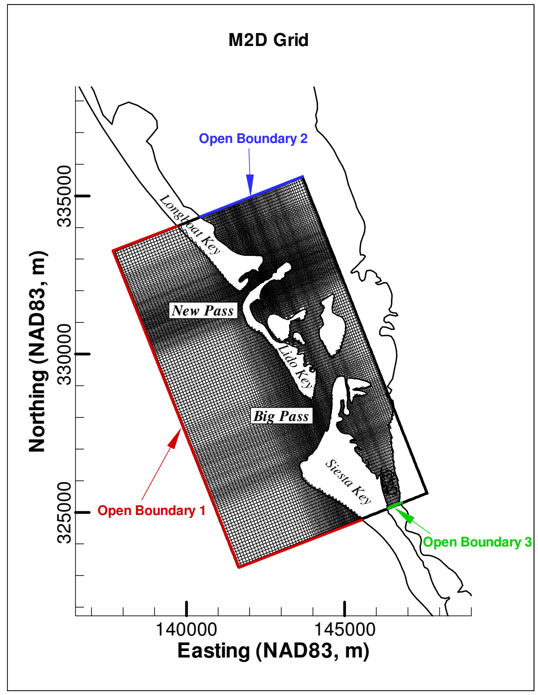

Figure 2. M2D Grid.

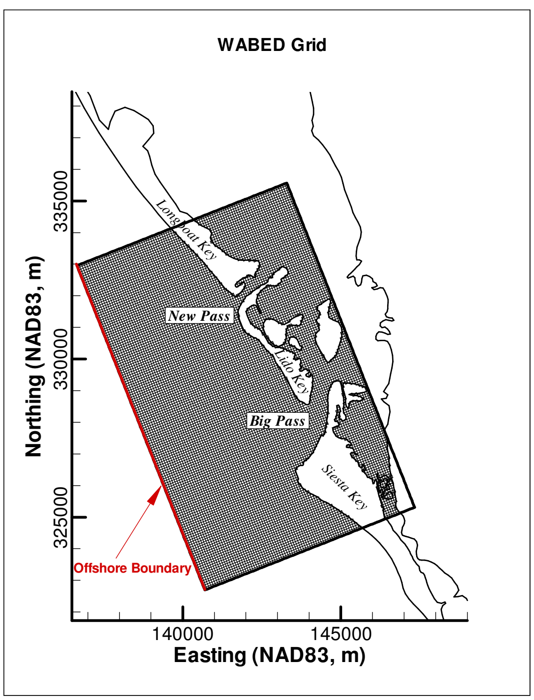

Figure 3. WABED Grid.

CEC survey data (CEC and CTC, 2006a) were used in the nearshore including New Pass and Big Pass channels, ebb and flood shoals. NOAA GEODAS (Sharman et al., 1999) data were used for offshore bathymetry interpolation within the computational domain (http://www.ngdc.noaa.gov/mgg/geodas/geodas.html). In addition to that, the USACE high resolution LIDAR data were incorporated inside Sarasota Bay. The interpolated bathymetry is shown in Figures 4 (M2D grid) and 5 (WABED grid). High resolution (1:70,000) NDGC/NOAA shoreline was utilized to distinguish between land and water (http://rimmer.ngdc.noaa.gov/coast/getcoast.html).

2.3 Simulation Scenarios

Littoral drift varies seasonally and the majority of it that causes morphologic changes occurs during storm events. Therefore, it was of a particular interest to perform a 1-year simulation to look at seasonal variation in sediment transport and morphology change patterns, and choose a highly energetic year in recent history to assess what the worst case scenario may result in.

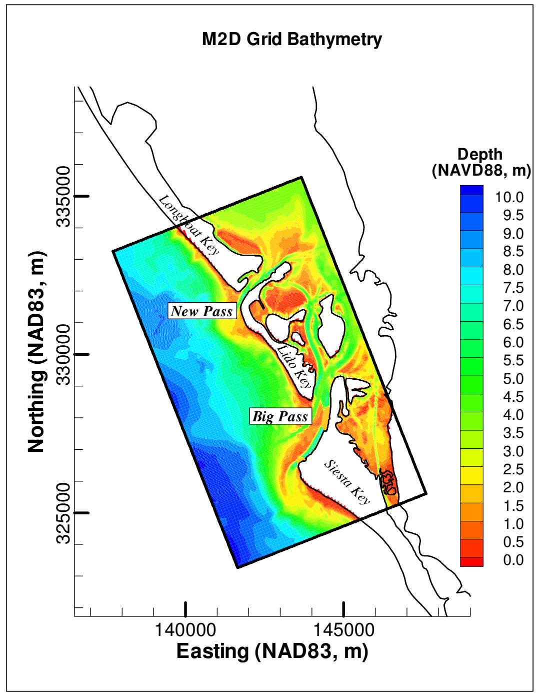

Figure 4. M2D Bathymetry.

The Wave Information Studies (WIS) database was utilized to analyze wave conditions that occurred in the area in recent history. The WIS project (Hubertz, 1992) produced a high-quality online database of hindcast, nearshore wave conditions covering U.S. coastlines (http://chl.erdc.usace.army.mil/). The data cover a 20-year period from January 1, 1980 through December 31, 1999. The time interval of the data is one hour. WIS data used in the analysis were obtained at Station 274 (WIS-274), the closest WIS station to New Pass and Big Pass located in 18-m depth at (LAT=27.25N, LON=82.83W) approximately 16 miles seaward of Lido Key. Based on the wave height analysis, it was determined that the most energetic year between 1980 and 1999 was the year 1998. Figure 6 presents wave height data at WIS-274 during 1998. The figure shows that the wave height exceeded 3 m five times that year with the largest storm occurring on February 5, 1998 when the wave height reached approximately 4.3 m. Figure 7 presents wave and wind roses based on the 1998 WIS data at Station 274. The dominant wave direction was from the Northwest which, considering the shoreline orientation, would cause the littoral transport to the South. The dominant wind direction was from the East which corresponds to the wind blowing offshore.

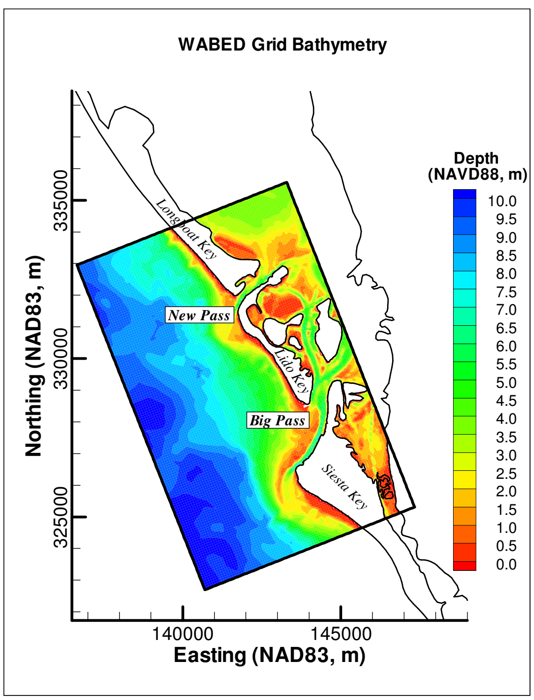

Figure 5. WABED Bathymetry.

Three simulation strategies were performed:

1) Existing bathymetry based on the 2006 survey (CEC and CTC, 2006a), which was designed to allow for existing conditions to remain in their current state without any dredging of Big Pass;
2) Big Pass – Alternative C, which was designed to provide dredging of a new channel alignment through Big Pass and its ebb shoal (CEC and CTC, 2006b). The cut depth was set equal to 12 ft MLW. The Alternative would provide approximately 748,000 yd^3 of fill material which by placing it in the existing channel would block the existing channel leading to its eventual abandonment.
3) Big Pass – Alternative D3, which was designed to provide mining of the ebb shoal in a contour line manner (CEC and CTC, 2006b). The ebb shoal mining was designed between the 7-ft MLW and 12-ft MLW depth contour lines. The cut depth was set equal to 12 ft MLW. The Alternative would provide approximately 836,000 yd^3 of beach fill material.

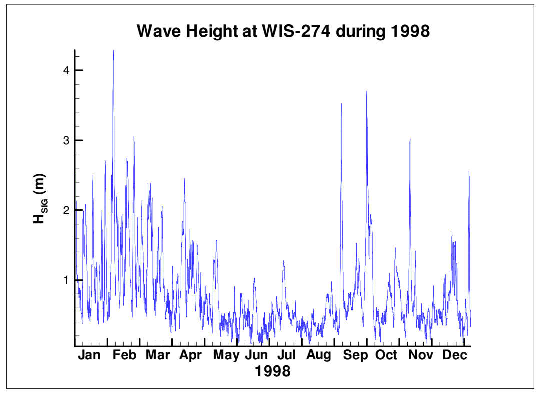

Figure 6. Wave Height at WIS-274 during 1998.

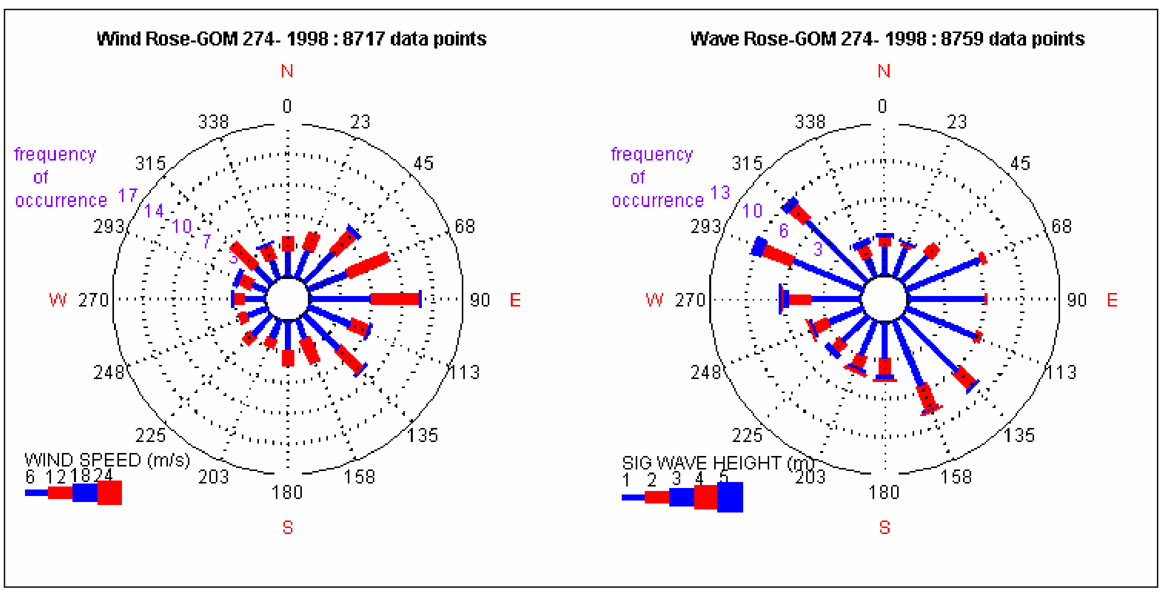

Figure 7. Wave and Wind Roses at WIS-274 during 1998.

Alternatives C and D3 were chosen over the other alternatives evaluated in CEC and CTC (2006b) as they were anticipated to have the most and least significant influence on morphologic changes, respectively, compared to the other alternatives. Further, they represent management strategies for navigation (channel dredging) and for beach nourishment (borrow area mining).

Figures 8 and 9 present comparisons between the existing bathymetry and Alternatives C and D3, respectively, in the vicinity of Big Pass.

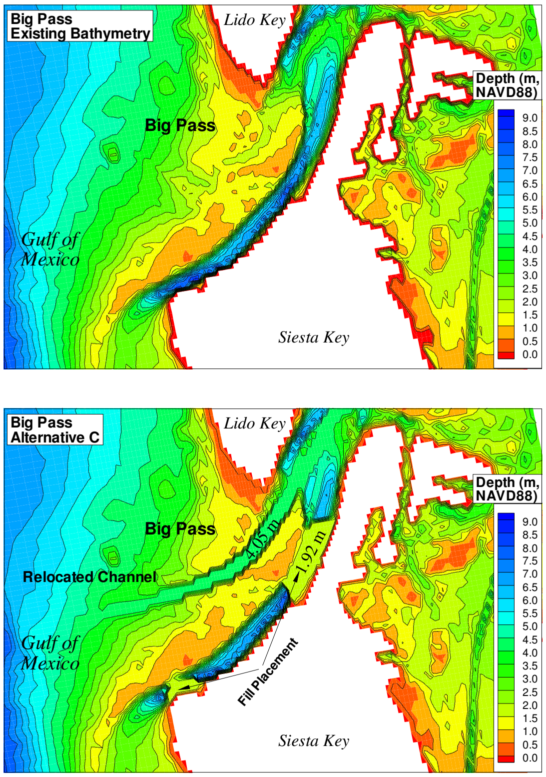

Figure 8. Existing vs. Alternative C Bathymetry.

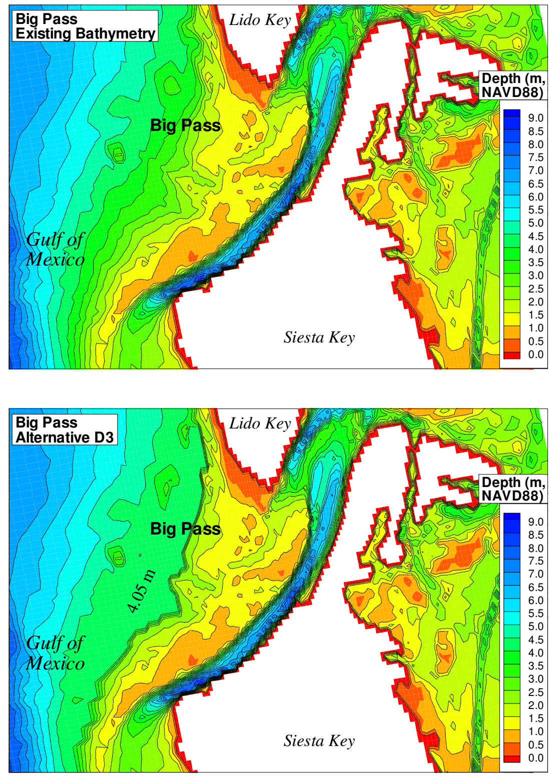

Figure 9. Existing vs. Alternative D3 Bathymetry.

2.4 Boundary Conditions

In order to simulate physical processes close to reality, the M2D and WABED models require the imposition of realistic boundary conditions including 1) offshore wave height, period and direction (WABED), 2) water levels along the open boundaries (M2D), and 3) wind speed and direction over the computational domain (both models). The WABED offshore boundary (refer to Figure 3) where wave boundary conditions were imposed was located closer to the shore compared to the WIS-274 location, in approximately 10-m depth, therefore, the WIS-274 data could not be used directly and WABED boundary conditions had to be calculated by propagating the WIS-274 data to the WABED offshore boundary. This propagation was performed by applying the wave model to a larger domain whose boundary matched the WIS-274 location. Seven storm events with wave heights exceeding 2 m occurred during the winter and early spring months of 1998; wave conditions were mild during the summer months; and there were four storm events with wave heights exceeding 2 m between September and the end of December. Boundary conditions applied along three M2D open boundaries, shown in Figure 2, were calculated using the ADCIRC model. The model was successfully calibrated under this Study's Hydrodynamic Modeling Task (CEC and CTC, 2006c).

2.5 Sediment Transport Parameters

The M2D model contains the integrated representation of sediment transport and morphology change through transport rate formulations, advection-diffusion equation, and sediment continuity equation for updating change in the sea bottom. The Lund-CIRP sediment transport formulation was adopted in this Study. This formulation computes both bedload and suspended load transport rates, which are combined to obtain a total load transport rate. Table 1 presents a summary of sediment transport parameters used in the Lund-CIRP formulation.

Table 1. Sediment Transport Parameters Used in the Lund-CIRP Formulation.

Parameter	Value
Particle Size (d_{50})	0.2 mm
Sediment Density	2650 kg/m^3
Water Density	1025 kg/m^3
Water Temperature	15 ºC
Transport Slope Coefficient	0.25
Sediment Porosity	0.4
Scale Bed Load	0.5*
Scale Suspended Load	0.5*

*Greater values led to numerical instability of the model

It should be pointed out that M2D can only allow constant sediment size throughout the computational domain. The sediment analysis portion of this Study (USF, 2007) showed that sediments found in the New Pass and Big Sarasota Pass inlet systems vary significantly. The mean grain size values ranged from -3.13 Φ (= 8.8 mm), well into the gravel range, to 2.93 Φ (= 0.13 mm). The average mean grain size found on the ebb shoals was approximately 0.2 mm, thus, this value was adopted as sediment size in the Lund sediment transport formulation. Preliminary results, however, showed that using such fine material within New Pass and Big Pass channels in M2D resulted in an increased infilling rate of the channels. In reality, this does not occur due to predominantly coarse sediments that form the channels' bottom which are more resistive to coastal processes causing sediment transport. To account for variability in sediment transport properties, varying bottom roughness was implemented through Manning's n parameter. Manning's n was calculated using the Chow (1959) formula: $n = 0.034 \cdot d_{50}^{1/6}$ where d_{50} is the median grain size in mm. Average grain sizes of 2.5 mm and 5.5 mm within New Pass channel and Big Pass channel, respectively, yield Manning's n of 0.040 and 0.045. For the rest of the computational domain, Manning's n of 0.025 was used.

2.6 WABED and M2D Time Control Parameters

When coupled, the M2D and WABED models interact at a specified steering interval. The steering interval used in this Study was 6 hours and it matched the frequency at which the WABED model computed wave fields. Running WABED at 6-hour intervals allowed to capture the storm events and, at the same time, it allowed to complete the 1-year simulation (January 1 through December 31, 1998) in a reasonable time frame of seven days. Increasing the frequency of WABED simulations resulted in increased simulation time. The M2D model has two time steps, a hydrodynamic time step and a sediment transport time step, both of which were set to 90 s. Reducing these time steps resulted in increased simulation time. The computed morphology change results were output every 24 hr. Table 2 summarizes the time control parameters used in this Study.

Table 2. Summary of Time Control Parameters Used in M2D and WABED.

Time Control Parameter	Value
Simulation Start Time	January 1, 1998
Simulation End Time	December 31, 1998
WABED Simulation Interval	6 hr
M2D Hydrodynamic Time Step	90 s
M2D Sediment Transport Time Step	90 s
WABED/M2D Steering Interval	6 hr
Morphology Change Output Interval	24 hr

During the WABED/M2D coupling, WABED passes wave information to M2D. The hydrodynamic module of the M2D model passes current velocities to WABED, and the sediment transport module of M2D passes updated total depth to WABED. The process repeats itself until the simulation completes.

3.0 Model Results

In this Section, morphologic changes predicted for Alternatives C and D3 were compared to the baseline case, i.e. existing conditions, predictions. Snapshots of morphologic changes calculated for the existing bathymetry (Strategy 1), Big Pass Alternative C (Strategy 2), and Big Pass Alternative D3 (Strategy 3) were compared at 4-month intervals. Bathymetric differences between the existing conditions simulation and the two alternative simulations were computed and cumulative changes were presented at the end of each 4-month period. Wave conditions (wave height and direction) that occurred during each period were also examined.

3.1 January 1 through April 30, 1998

Figure 10 presents a time series of wave conditions that occurred between January 1 and April 30, 1998. The length of each vector is referenced to the wave height and its direction represents the wave direction at the WABED offshore boundary. The three colors represent wave condition ranges: green – mild conditions with wave heights less than 0.75 m, orange – moderate conditions with wave heights greater than 0.75 m and less than 1.5 m, and red – severe conditions with wave heights exceeding 1.5 m. As depicted in the figure, wave conditions during this period were highly energetic with several storm events including the biggest storm of 1998.

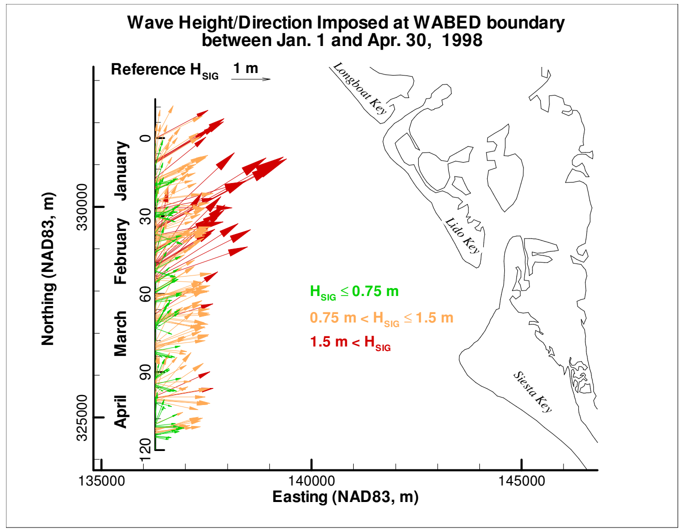

Figure 10. Wave Conditions between Jan. 1 and Apr. 30, 1998.

Figure 11 presents the calculated morphologic changes for Strategies 1 and 2 accumulated during the period. Similarly, Figure 12 presents morphologic changes computed between Strategies 1 and 3. As depicted in Figure 13, the winter storms resulted in well pronounced morphologic changes near both inlets. New Pass was impacted as some infilling and deepening were observed inside the channel. The changes at New Pass computed for Strategy 1 (Figure 11A) were comparable to those computed for Strategy 2 (Figure 11B). Near Big Pass, the differences in morphologic changes between the two strategies were distinct. For Strategy 2, the new channel experienced erosive and accretional changes. Erosion at the midpoint of the channel reached 1.5 m and accretion on the north side of the midpoint reached 0.7 m.

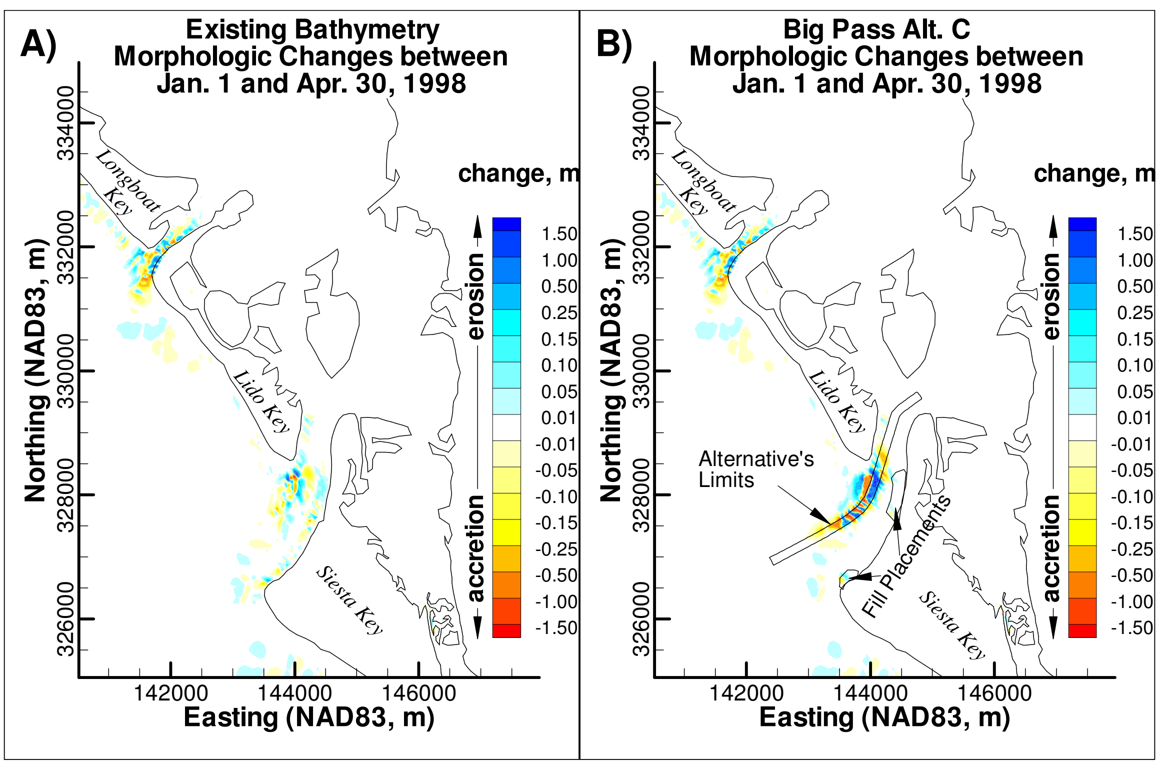

Figure 11. Cumulative Morphologic Changes for Strategies 1 (Pane A) and 2 (Pane B).

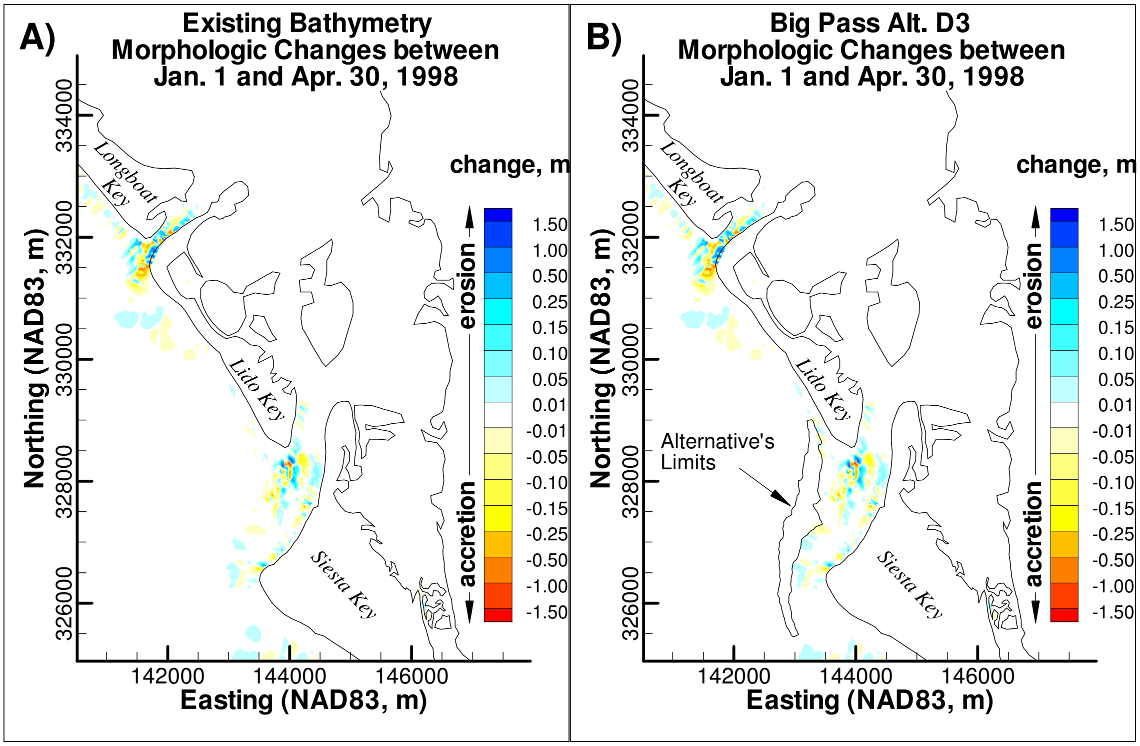

Figure 12. Cumulative Morphologic Changes for Strategies 1 (Pane A) and 3 (Pane B).

Contrary to the Strategy 2 morphologic changes predicted at Big Pass, the Strategy 3 results presented in Figure 12 were very similar to those of Strategy 1. Morphologic changes for Strategies 1 and 3 at New Pass were also comparable, which suggests that Alternative D3 did not cause any effect on the existing sediment patterns at New Pass and Big Pass during the first four months of simulation.

3.2 May 1 through August 31, 1998

Figure 13 presents a time series of wave conditions that occurred between May 1 and August 31, 1998. As depicted in the figure, wave conditions during this period were mildly energetic. Figure 14 presents the calculated morphologic changes for Strategies 1 and 2 accumulated during the period between May 1 and August 31, 1998. Similarly, Figure 15 presents morphologic changes computed between Strategies 1 and 3.

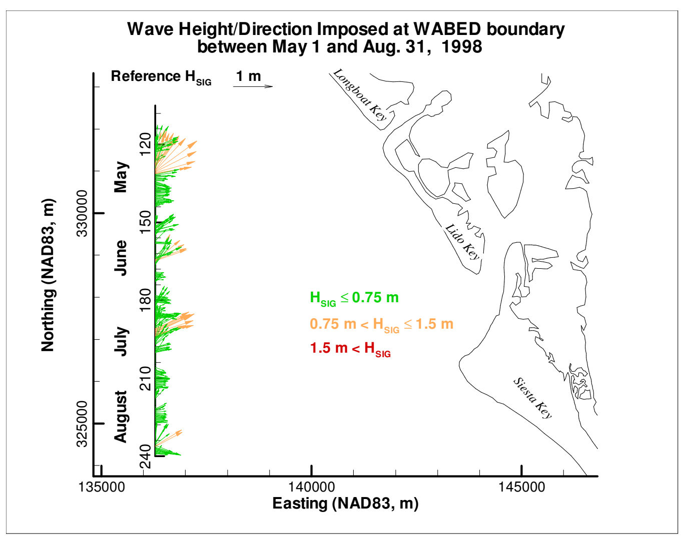

Figure 13. Wave Conditions between May 1 and Aug. 31, 1998.

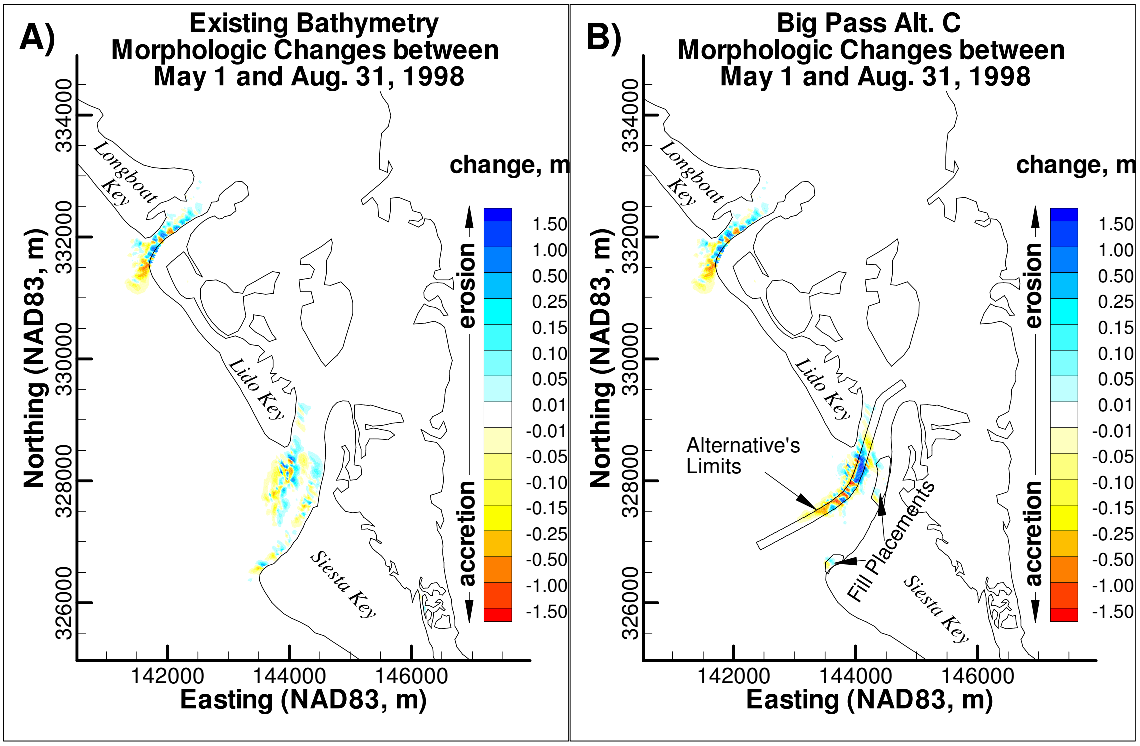

Figure 14. Cumulative Morphologic Changes for Strategies 1 (Pane A) and 2 (Pane B).

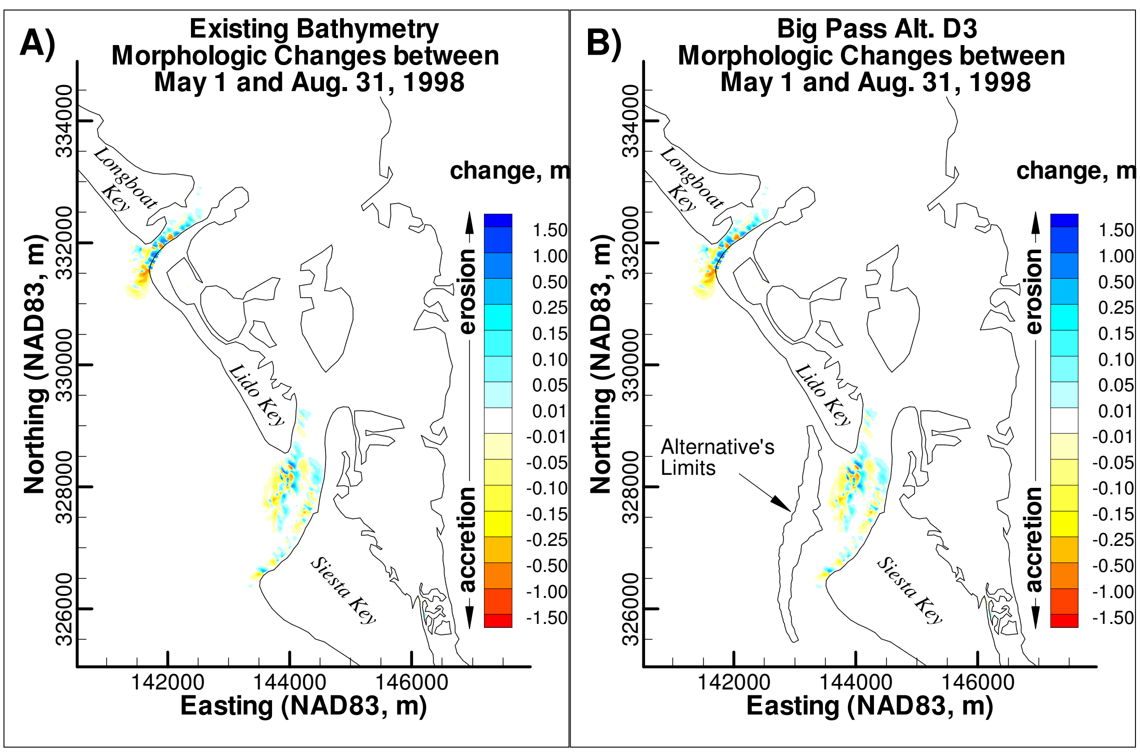

Figure 15. Cumulative Morphologic Changes for Strategies 1 (Pane A) and 3 (Pane B).

The Alternative C simulation results (Figure 14B) continued the trend showing erosion at the midpoint of the new channel and accretion to the north and seaward of the midpoint, however, at lesser rates due to mild wave conditions. The changes computed for Strategy 3 (Figure 15B) closely resemble those of Strategy 1, which indicates that Big Pass Alternative D3 had insignificant effect on the existing sediment patterns at New Pass and Big Pass during the summer months.

3.3 September 1 through December 31, 1998

Figure 16 presents a time series of wave conditions that occurred between September 1 and December 31, 1998. As depicted in the figure, wave conditions during this period were moderately energetic with four storm events. Figure 17 presents the calculated morphologic changes for Strategies 1 and 2 accumulated during this period. Similarly, Figure 18 presents morphologic changes computed between Strategies 1 and 3.

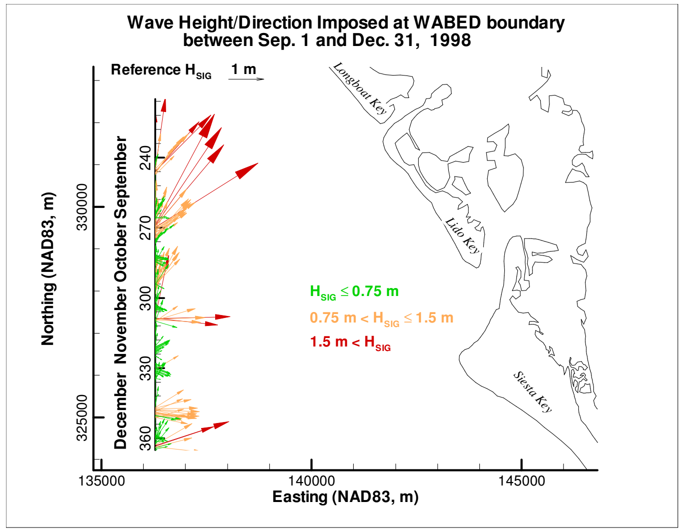

Figure 16. Wave Conditions between Sep. 1 and Dec. 31, 1998.

As depicted in Figure 17, morphology change trends continued for both strategies, the Existing Conditions and Alternative C. However, the changes that occurred between September 1 and December 31, 1998 were more significant compared to those computed during the summer months due to stormy conditions that occurred during this period. The changes computed for Strategy 3 (Figure 18B) are comparable to those of Strategy 1, which suggests that Alternative D3 had minor effect on the existing sediment patterns at New Pass and Big Pass during this period.

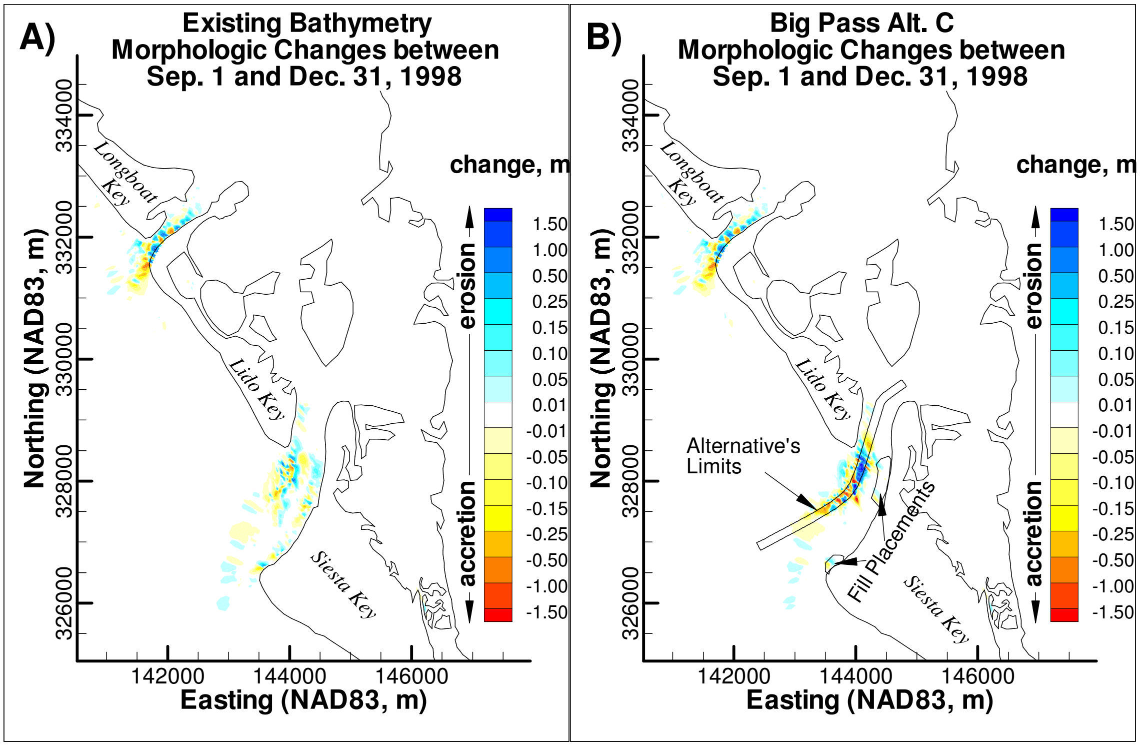

Figure 17. Cumulative Morphologic Changes for Strategies 1 (Pane A) and 2 (Pane B).

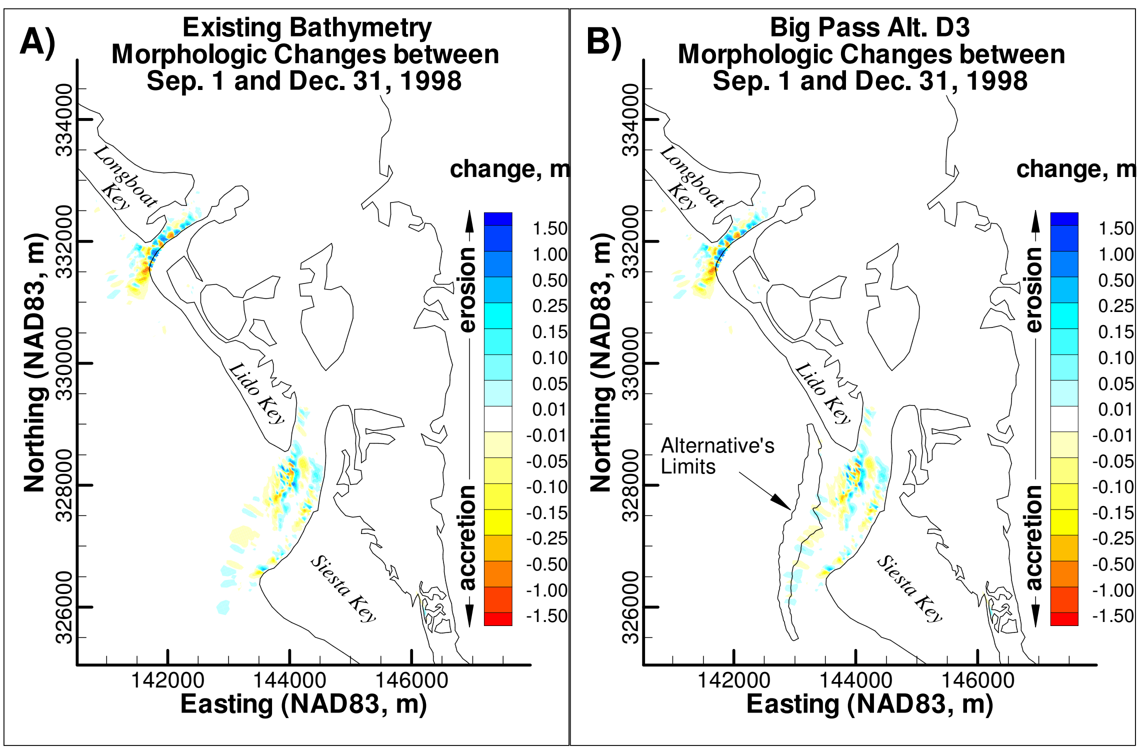

Figure 18. Cumulative Morphologic Changes for Strategies 1 (Pane A) and 3 (Pane B).

4.0 Conclusions

The CMS-M2D hydrodynamic model coupled with the WABED wave model was used to simulate the effects of relocating the Big Sarasota Pass channel off Siesta Key (Alternative C) and dredging the Big Pass ebb shoal in a depth contour line manner (Alternative D3) on the New Pass/Big Pass inlet system's morphology. The predicted morphologic changes of these strategies were compared to the baseline case, i.e. Existing Conditions, to assess potential impacts to the existing morphologic regime. Two computational grids, one for each model, were implemented. Both grids covered the New Pass and Big Sarasota Pass inlet systems including the navigation channels, shoals, interior bays and adjacent beaches. The grids extended seaward of depth of closure beyond which no measurable sediment movement occurs. The 1980 through 1999 WIS database was analyzed to determine the most highly energetic in recent history year impacting the area, which was 1998. Three 1-year simulations, one for each strategy, were performed to look at seasonal variation in sediment transport and morphology change patterns.

The comparison analyses showed that Alternative C's relocated channel impacted the inlet system as the existing flow patterns adjusted and modified the new channel. Figure 19A presents the extent of Alternative C's impact after 12 months of simulation. The figure illustrates the end-of-simulation difference of the predicted morphologic changes between Alternative C and Existing Conditions. Similarly, Figure 19B presents the limits of Alternative D3's impact after 12 months. Table 3 quantifies impacts of Alternatives C and D3 expressed in terms of predicted erosional, accretional, and net volumes computed based on Figures 19A and 19B. The volumes were computed for New Pass, Big Pass – inside Alternative's limits, and Big Pass – outside Alternative's limits.

Table 3. Volumetric Impacts of Alternatives C and D3 after 12 Months.

	Area	Erosion (m^3)	Accretion (m^3)	Net (m^3)
Alt. C	New Pass	-5,000	+5,500	+500
	Big Pass – inside Alt. C limits	-173,900	+154,300	-19,600
	Big Pass – outside Alt. C limits	-133,000	+153,200	+20,200
Alt. D3	New Pass	-1,900	+2,000	+100
	Big Pass – inside Alt. D3 limits	-2,100	+3,000	+900
	Big Pass – outside Alt. D3 limits	-8,400	+8,900	+500

Note: volumes are based on M2D sediment transport parameters presented in Table 1

Figure 19A and Table 3 demonstrate that the predicted morphologic changes for Alternative C had an insignificant effect on New Pass but significantly impacted the existing sediment transport patterns at Big Pass. The extent of the impacts, however, was confined within the mid-section of the relocated channel's limits, just north of the mid-section, and along the north side of Siesta Key. Sections of the channel, seaward of its midpoint, completely filled in via sand deposition by the end of the 1-year simulation. Therefore, it is predicted that Alternative C, if implemented, will affect the existing flow and sediment transport patterns at Big Pass which may result in adverse impacts on south Lido Key and north Siesta Key's shorelines within the area of inlet influence.

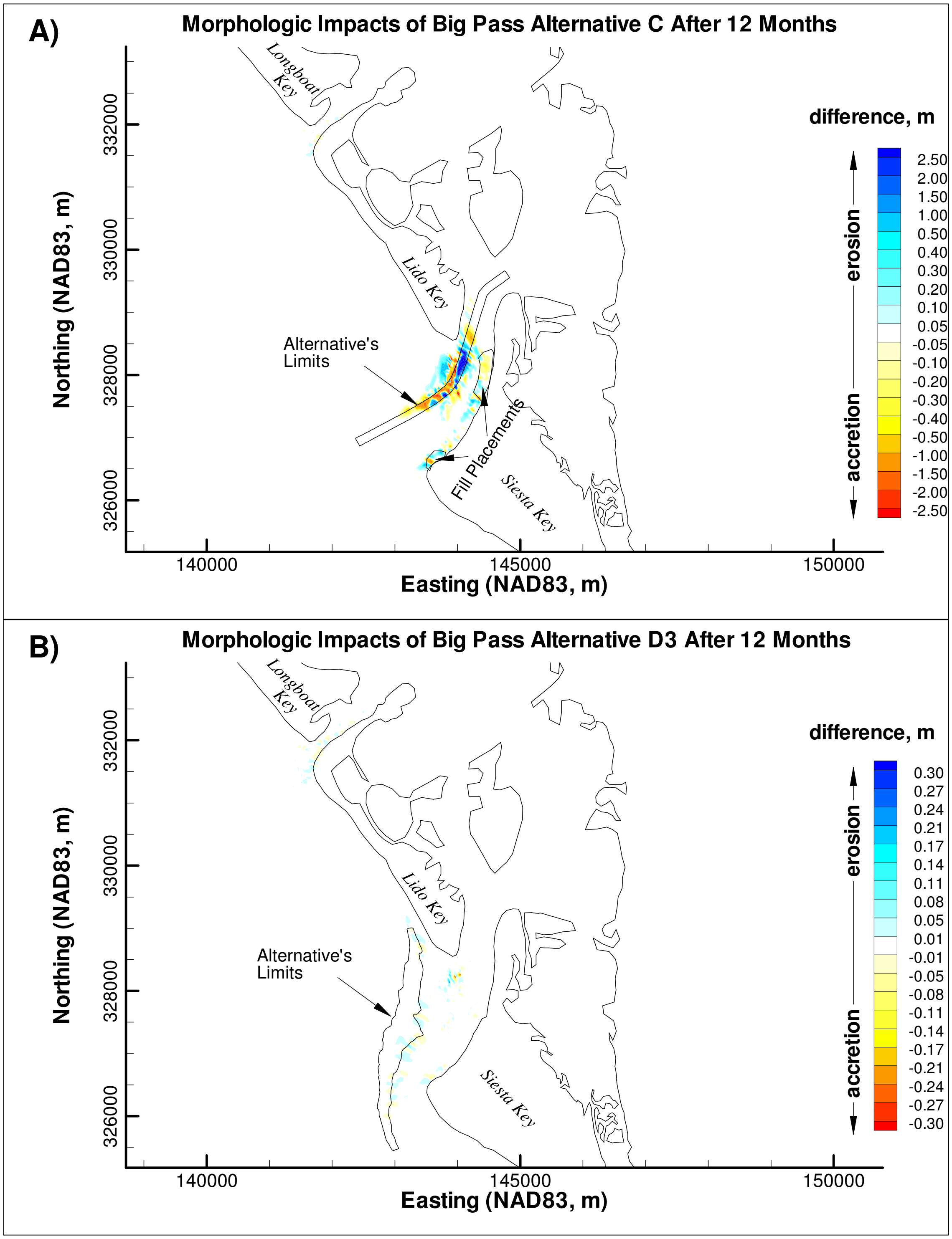

Figure 19. Morphologic Impacts of Strategies 2 (Pane A) and 3 (Pane B) after 12 Months.

The computed morphology changes for Alternative D3 were comparable to those of the Existing Conditions during the 1-year simulation. Figure 19B and Alternative D3's predicted volumetric impacts presented in Table 3 illustrate that dredging the ebb shoal at Big Pass in the proposed manner, if implemented, will not affect the existing sediment transport patterns and will cause insignificant impacts on the inlet system including the shoals and adjacent shorelines within the area of inlet influence.

Acknowledgements

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