Mixed Sediment Modeling for Matagorda Ship Channel, Texas

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ABSTRACT

Critical shoaling in the upper reach of Matagorda Ship Channel, Texas, in recent years has resulted in the need for annual dredging. The channel shoaling in the Ship channel is complicated as it involves the mixed sediment in the surrounding area. The US Army Engineer Regional Sediment Management Program and Coastal Inlets Research Program have teamed in 2012 to investigate and perform numerical modeling of sediment transport for the Ship Channel in Matagorda Bay. A Coastal Modeling System with fully integrated wind, wave, current, and sedimentation models is selected to simulate the sediment transport and channel shoaling. The channel surveys completed in September 2006 and February 2007 were used to validate the models. Numerical simulations were also conducted for three new sites to place the dredged materials west of the Channel and a Geotube installation east of the Channel. The model results showed these alternatives could effectively reduce the channel shoaling rate.

INTRODUCTION

The Matagorda Ship Channel (MSC) is a deep draft navigation channel that runs through a jettied entrance at the northwest corner of Gulf of Mexico and extends 38 km (24 mile) into Matagorda Bay and Lavaca Bay, Texas (Figure1). The navigation channel terminates at a wide turning basin at Port Lavaca - Point Comfort in Calhoun County that serves as a gateway to world market for the Texas mid-coast region. The Ship Channel intercepts the Gulf Intracoastal Waterway (GIWW) in the lower Matagorda Bay provides pathways to Port O'Connor and to Port Palacios through Palacios Boat Channel on Tres Palacios Bay. The Federal navigation project in Matagorda Bay maintains both MSC and GIWW in the vicinities of Port O'Connor, Port Palacios, and Port Lavaca - Point Comfort in Matagorda and Calhoun Counties.

Extensive shoaling in the upper reach of the MSC in recent years has resulted in the need for annual dredging. The increasing channel shoaling rate is likely due to the displacement of dredged material into adjacent open water sites west of the channel and the migration of the disposed material back into the channel. It is suspected that active sedimentation in the upper Lavaca Bay also contributes to the high shoaling rate in the Ship Channel. Stronger wave action in Lavaca Bay and Matagorda Bay during fall and winter seasons evidently increases the amount of suspended sediment, especially cohesive sediment, and promotes more sediment deposition in the Ship Channel.

To reduce the channel infilling rate and provide a remedial solution in the upper reach of MSC, the US Army Corps of Engineers Regional Sediment Management Program and Coastal Inlets Research Program have teamed to investigate and perform numerical modeling of sediment transport for the Ship Channel in Matagorda Bay. The modeling effort is focused on evaluating the MSC, GIWW, Matagorda Bay, and Lavaca Bay as a system for hydrodynamics and sediment transport interacting with river influxes and Gulf of Mexico (GOM). The main challenge is to model the mixed sediment, as there is more cohesive material in the Lavaca Bay and upper Matagorda Bay and non-cohesive material in the lower Matagorda Bay, which is the primary sand. This also presents a challenge for modeling of the sedimentation under combined wave and current conditions.

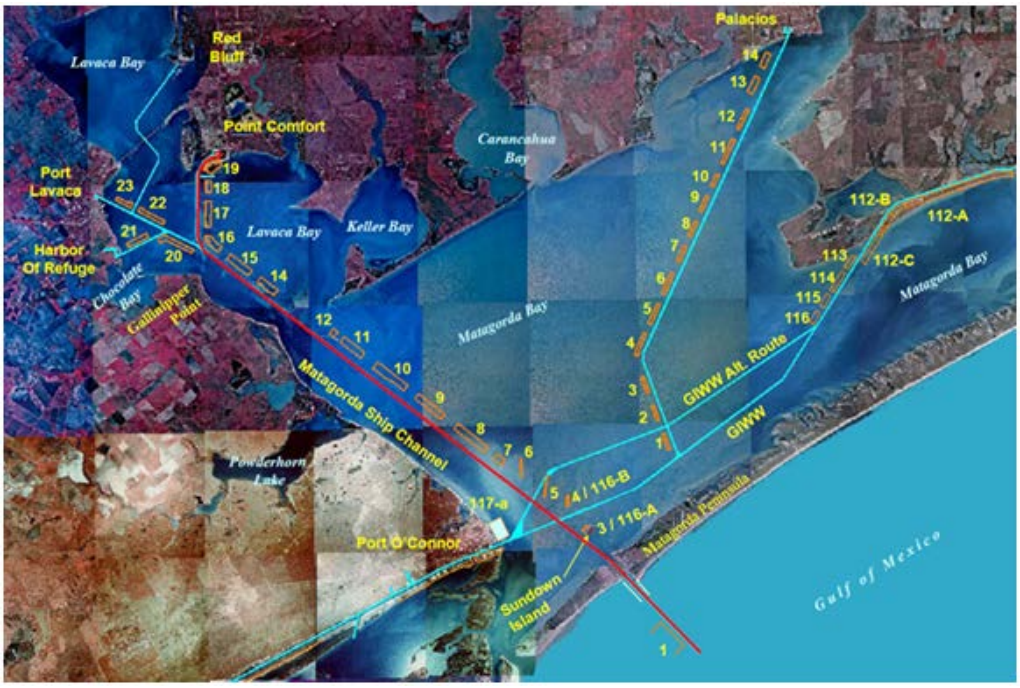

Figure 1. MSC location map with open water placement sites.

A hydrodynamic and sediment transport Coastal Modeling System with fully integrated nearshore wave, current, and sedimentation models is selected to simulate the mixed sediment transport. Numerical simulations were conducted for a 6-month period from September 2006 to February 2007 that represents a typical fall to winter condition. The channel surveys completed (by the US Army Corps of Engineers Galveston District) in September 2006 and February 2007, which showed a rapid increase of sediment accumulation in the upper Ship Channel, were used to validate the models.

Numerical simulations were conducted to investigate the existing bay condition and three alternatives for approval of concept to reduce the sediment accretion in the upper ship channel: 1) a confined artificial island south of Port Comfort to contain the dredged material from the upper channel, 2) extension of an existing Geotube east of the upper channel to close the gaps among dredged material placement areas, 3) three new placement areas west of the navigation channel.

MATAGORDA BAY SEDIMENT CHARACTERISTICS

The sediment in the Matagorda Bay is mixed. More silt and clay are found in the northern and eastern bay as fine sediment was supplied from Palacio Bay, Carancahua Bay, and the Colorado River. The sediment in Lavaca Bay is primarily cohesive material that comes from Lavaca River and Garcitas Creek. Because Lavaca Bay is more geologically isolated in the northwestern corner of Matagorda Bay, the cohesive sediment inside Lavaca Bay is basically trapped that it hardly migrates to Matagorda Bay. During fall and winter time, fluid mud is often observed in the upper Ship Channel as induced by strong wind and wave motion in the Lavaca Bay. The rapid accumulation of hazardous fluid mud in the Ship Channel has required more frequent dredging cycles in recent years.

More sand is found south of GIWW and in the southern bay near the Gulf entrance. Outside Matagorda Bay along the Gulf coast of Matagorda Peninsula and barrier islands, the sediment content is primarily fine sand with a median grain size range from 0.15 mm to 0.22 mm. At the Ship Channel Gulf entrance, because of the narrow inlet constraint the channel bottom has been self-scouring and characterized by gravels and small rocks as a result of strong current in the channel. Figure 2 shows the sediment distribution in the Matagorda Bay system, with more silt and clay in the upper bays and sandy material in the lower bay areas.

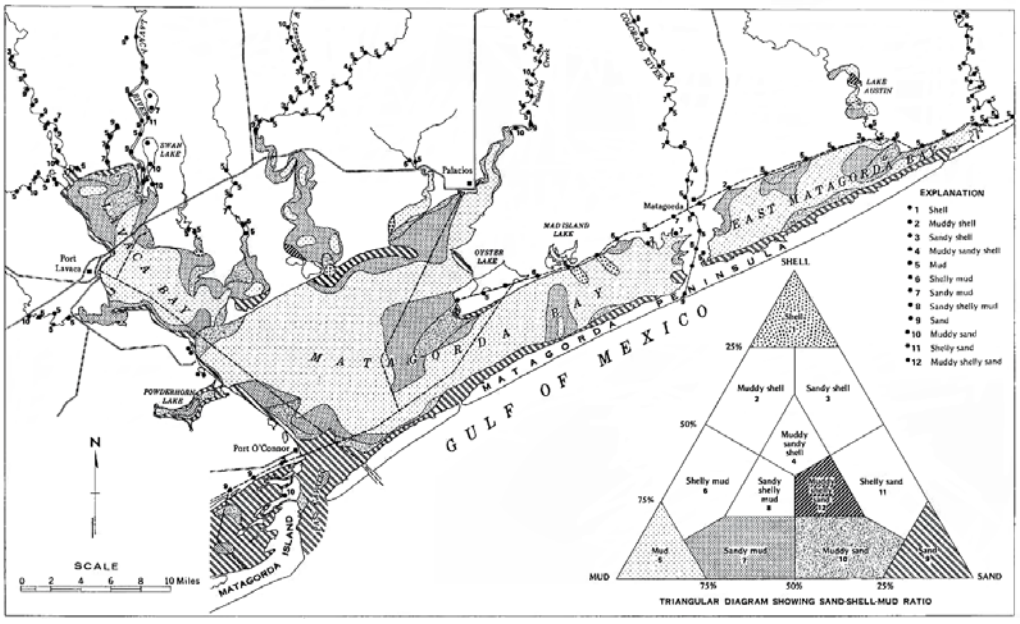

Figure 2. Sediment distribution (McGowen, Byrne, Wilkinson 1979).

COASTAL MODELING SYSTEM

The Coastal Modeling System (CMS) developed under the Coastal Inlets Research Program (CIRP) at the US Army Engineer Research and Development Center was applied to simulate sediment transport in the Matagorda Bay, Texas. The CMS calculates sediment transport and morphology change under combined current and wave

condition by coupling a hydrodynamic model CMS-Flow (Demirbilek and Rosati, 2011) and a wave transformation model CMS-Wave (Lin et al. 2008) through a Steering Module operated within the Surface-water Modeling System (Zundel, 2006).

CMS-Flow solves the flow mass conservation and hydrodynamics based on the continuity and momentum equations. The model is forced by changes in water levels along the seaward boundaries, flow discharge at the river boundaries, wind input field, and wave stresses on the water surface. Physical processes pertinent to the present study calculated by the flow model are current, water surface elevation, sediment transport, and morphology change. The CMS has the option of calculating sediment transport for cohesive (silt and clay) and non-cohesive (quartz sand) material separately or for mixed (combined) cohesive and non-cohesive materials.

CMS-Wave is a full-plane steady-state wave spectral transformation model that solves the wave energy balance equation to calculate wave field properties. It contains theoretically derived formulations for combined wave diffraction, refraction, reflection, and wave-current interaction. In the coastal inlet applications, it is more efficient to run CMS-Wave on the optional half-plane mode such that primary waves can propagate only from the seaward boundary toward shore.

CMS-Wave and CMS-Flow have been validated in many coastal projects and studies. A more comprehensive collection of CMS validation and verification cases is available in recent CMS reports (Demirbilek and Rosati, 2011). The influence of surface-waves to flow and sediment transport is calculated through coupling CMS-Flow and CMS-Wave. The calculated currents, water levels, and morphology change by CMS-Flow are returned to CMS-Wave to increase the accuracy of wave transformation simulation. The sediment transport is calculated in CMS-Flow under the fluid motion with the option to include the wave forcing. Because waves play a major role in the littoral processes of the Matagorda Bay system, CMS-Flow and CMS-Wave are coupled to calculate the sediment transport and morphology change.

MODEL DOMAIN

A CMS rectangular grid with variable cell-spacing has been developed for the sediment transport modeling of Matagorda Bay. The model domain covers the entire bay with navigation channels connecting GIWW and GOM. It extends 70 km (43 mile) alongshore and 72 km (45 mile) cross-shore approximately parallel to the ship channel with the offshore boundary reaching to the 21-m isobath. Figure 3 shows the model domain consisting of 153 × 324 cells with variable cell spacing of 25 m at the bay entrance and 1,600 m at the corner of offshore boundary. In general, CMS-Flow and CMS-Wave are not required to run on the same grid. However, in many applications, it is convenient to maintain just one model grid. In the present modeling of Matagorda Bay, both CMS-Flow and CMS-Wave are run using the same rectangular grid. Figure 4 shows different median grain size used in the present sediment modeling in the Matagorda Bay.

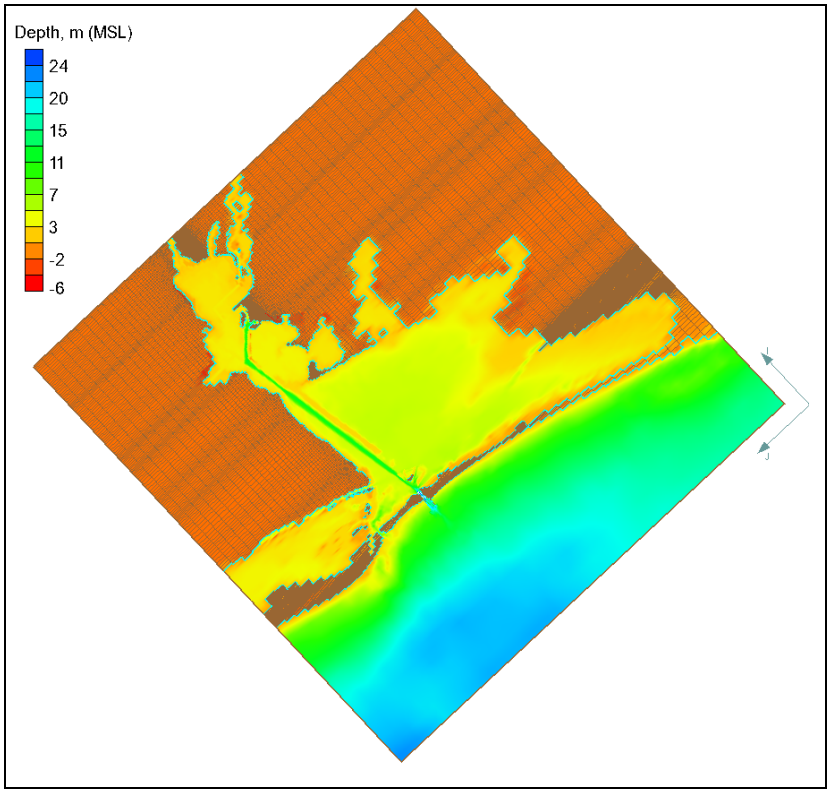

Figure 3. CMS bathymetric grid.

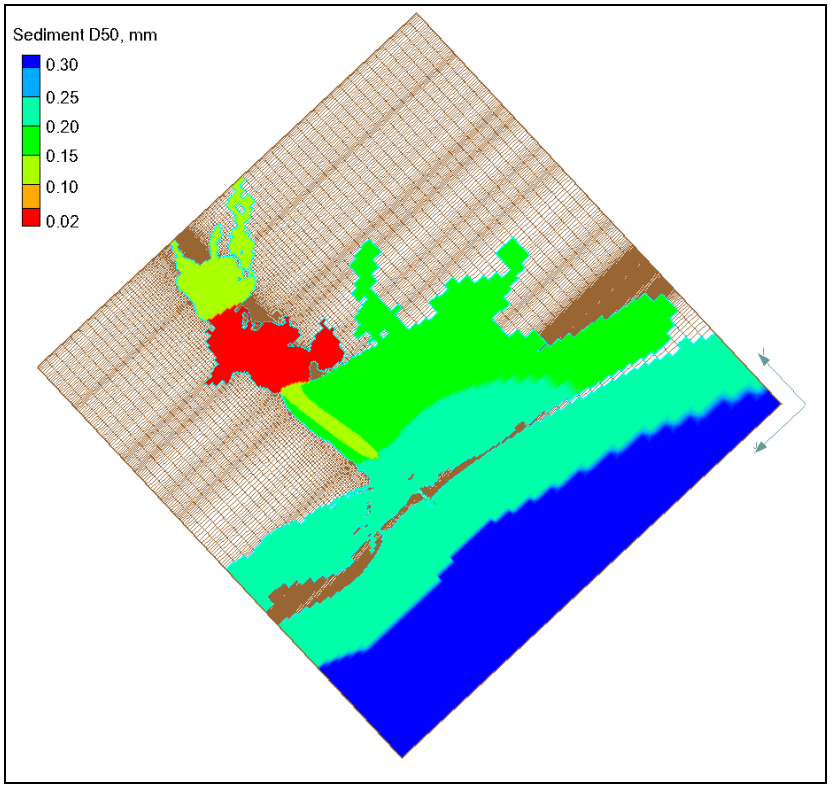

Figure 4. Median grain size distribution in the CMS grid.

SIMULATION PERIOD AND MODEL FORCING

The model simulations were conducted for a 6-month period from September 2006 to February 2007 that represents a typical fall to winter condition. The channel surveys conducted in September 2006 and February 2007 showed a rapid accumulation of fluid mud, on average 1 to 2-m buildup, in the upper ship channel between two surveys.

The water levels specified along the offshore boundary are interpolated from two NOAA coastal Stations: 8771510 at Galveston Pleasure Pier (29° 17.1' N, 94° 47.3 W) and 8775870 at Bob Hall Pier, Corpus Christi (27° 34.8' N, 97° 13' W). Figure 5 shows the hourly water level measurements from September 2006 to February 2007 at two NOAA stations. The water level data shows stronger variation at the Galveston Pleasure Pier than at Bob Hall Pier as the open coast water levels at Galveston Pleasure Pier has more influence by stronger winds or stronger metrological tides in the fall and winter seasons. Figure 6 shows the wind information collected from September 2006 to February 2007 at two NDBC (www.ndbc.noaa.gov) coastal buoys 42019 offshore Galveston (27° 54.8' N, 95° 21.1' W) and 42020 offshore Corpus Christi (26° 58' N, 96° 41.7' W). These wind data clearly show stronger coastal wind at offshore Galveston than Corpus Christi in the fall and winter seasons.

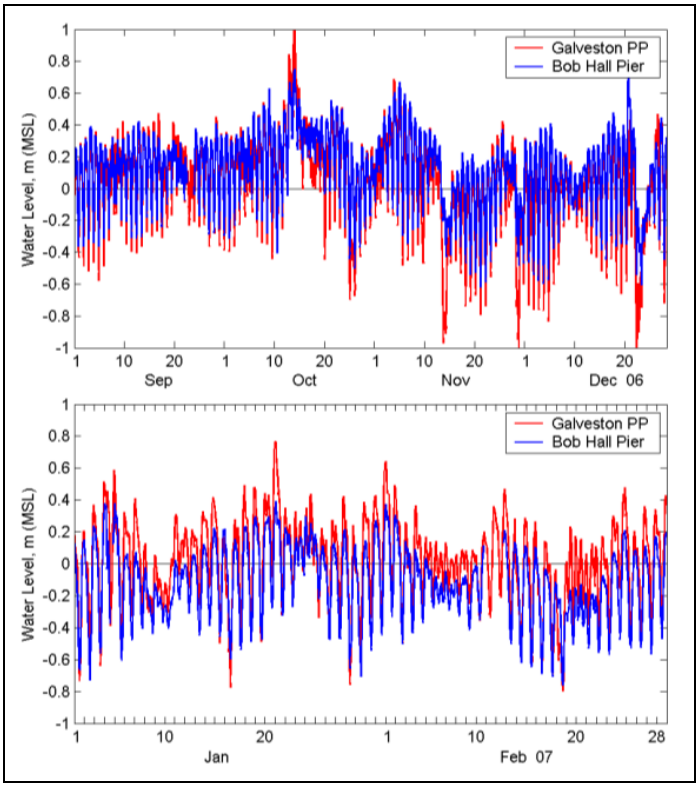

Figure 5. Water level data at NOAA Stations at Galveston PP and Bob Hall Pier.

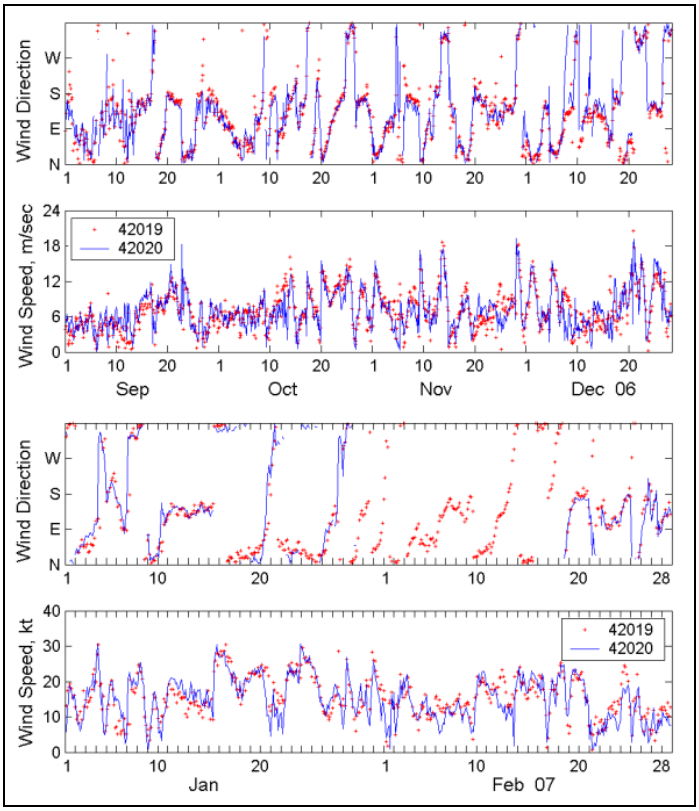

Figure 6. Wind data at NDBC Buoys 42019 (Freeport, TX) and 42020 (Corpus Christi).

Local wind data are available from a NOAA Station 87737011 at Port O'Connor (28° 26.8' N, 96° 23.8' W) in the southwest corner of the bay. Figure 7 shows the wind information collected from September 2006 to February 2007 at Station 87737011 and NDBC Buoy 42019. The wind direction is similar between Station 87737011 and Buoy 42019. The wind magnitude at Station 87737011 is overall smaller than Buoy 42019 as the wind at NOAA Station 87737011 has more influenced by the land and bay effects.

River discharge daily data for Lavaca River are available from USGS Station 8164000 at Edna (28° 55' N, 96° 46' W) approximately 24 km (14 mile) north of Lavaca Bay (http://waterdata.usgs.gov/nwis). The Station 8164000 flow rate data are applied as the river boundary conditions for Lavaca River and Garcitas Creek discharge into the upper Lavaca Bay. The river flow data for Colorado River are obtained from Station 08162500 (28° 58' N, 96° 01' W) near Bay City. Figure 8 shows the river flow data collected at two USGS Stations from September 2006 to February 2007. Because the Colorado River has a much larger watershed area than the Lavaca River, the flow discharge at the Colorado River is usually much greater than at the Lavaca River.

Figure 9 shows the time series of wave data collected at Buoy 42019 offshore of Galveston from September 2006 to February 2007. There are apparently more and higher storm waves in the winter months corresponding to cold fronts passing through the area. The directional wave data collected at Buoy 42019 are used as the input of incident wave conditions along the CMS-Wave offshore boundary.

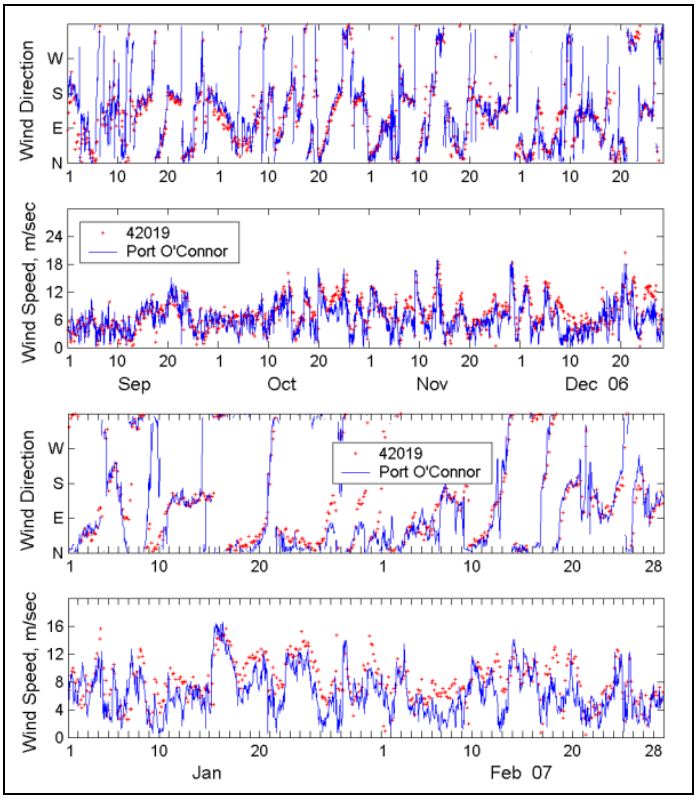

Figure 7. Wind data at NDBC Buoy 42019 and NOAA Station at Port O'Connor.

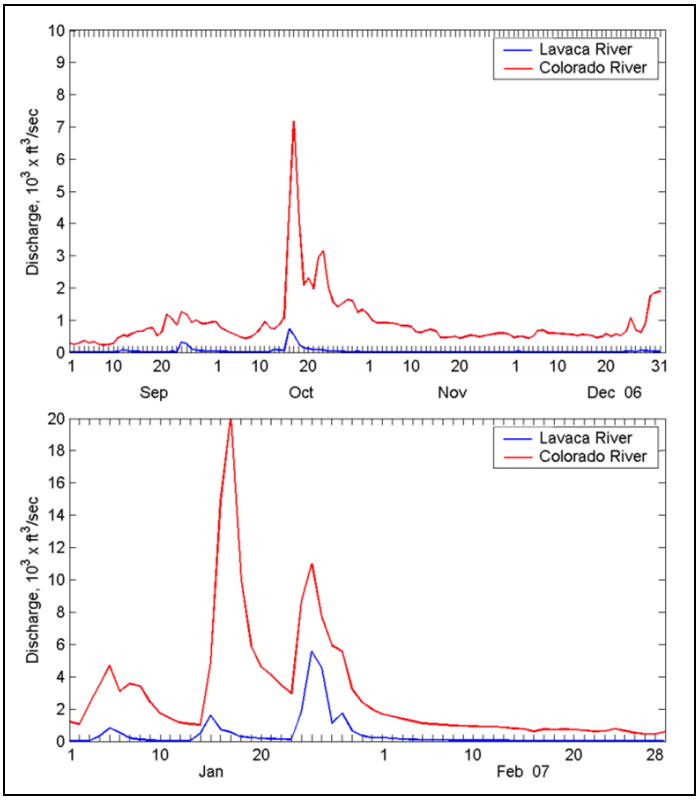

Figure 8. Lavaca River flow data at USGS Station 8164000 (Edna, TX).

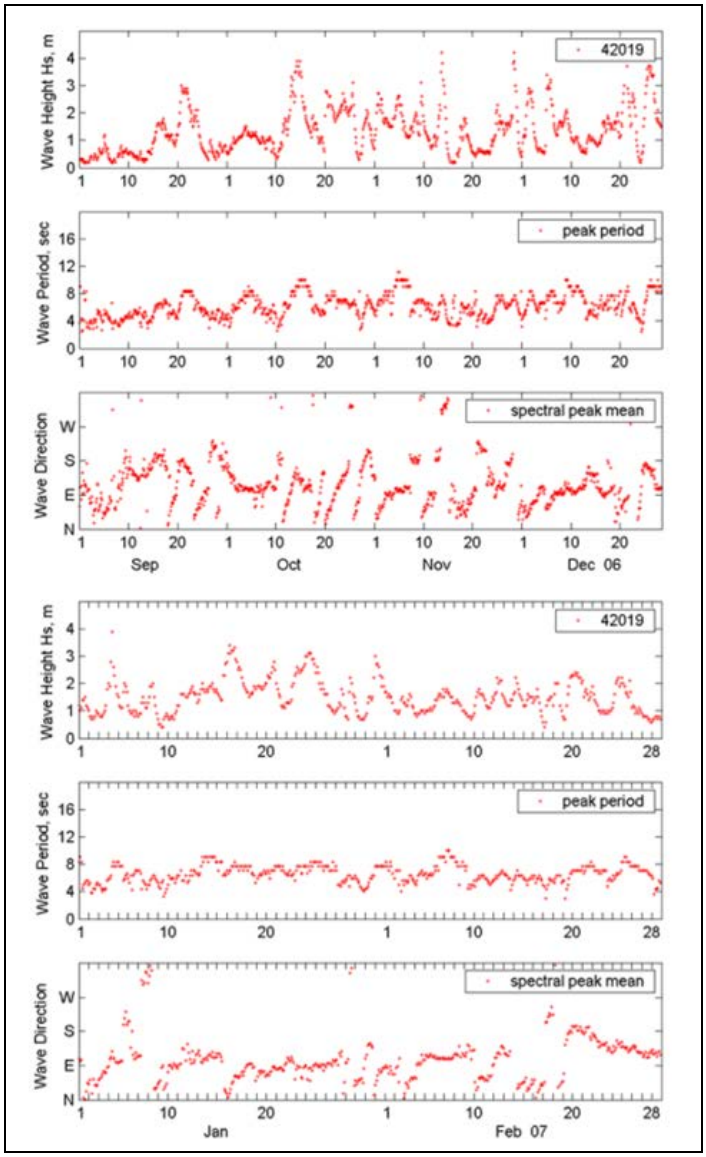

Figure 9. Wave data at NDBC Buoys 42019 (Freeport, TX).

MODEL RESULTS

The model simulations were conducted for a 6-month period from September 2006 to February 2007. Figure 10 shows the comparison of calculated and measured water levels at Port O'Connor (NOAA Station 87737011) for September 2006 to February 2007. Figures 11 and 12 show typical strong current fields calculated by CMS for flood and ebb conditions, respectively. Figure 13 shows the model result of accumulated sediment accretion/erosion for mixed sediment in the period of September 2006 to February 2007. Because the calculation of morphology change includes both suspended and bed loads, and converts the sediment concentration into a solid deposition, the fluid mud that is frequently observed in the upper Ship Channel is interpreted as a portion of the calculated deposition. The calculated sediment deposition in the upper channel agrees with field survey data collected in September 2006 and February 2007.

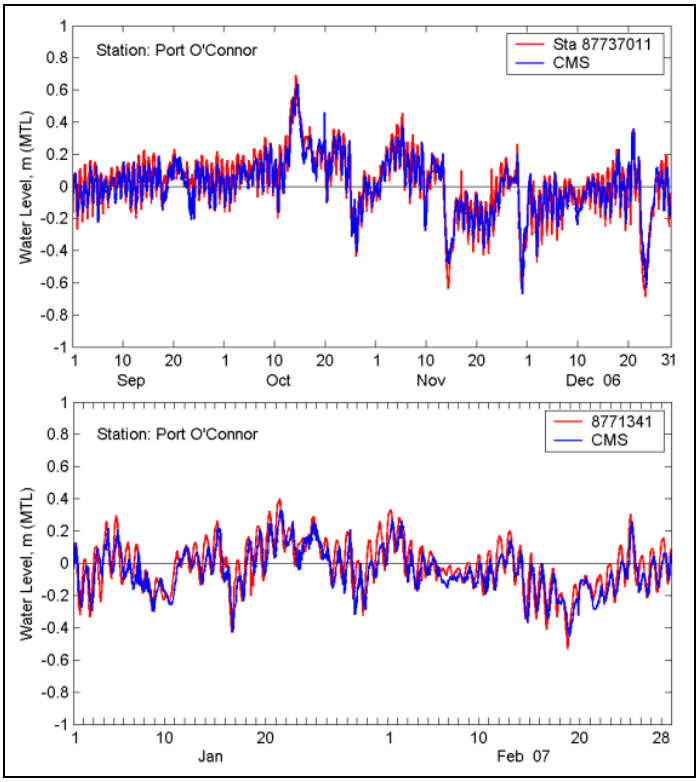

Figure 10. Calculated and measured water levels at NOAA Station 87714311.

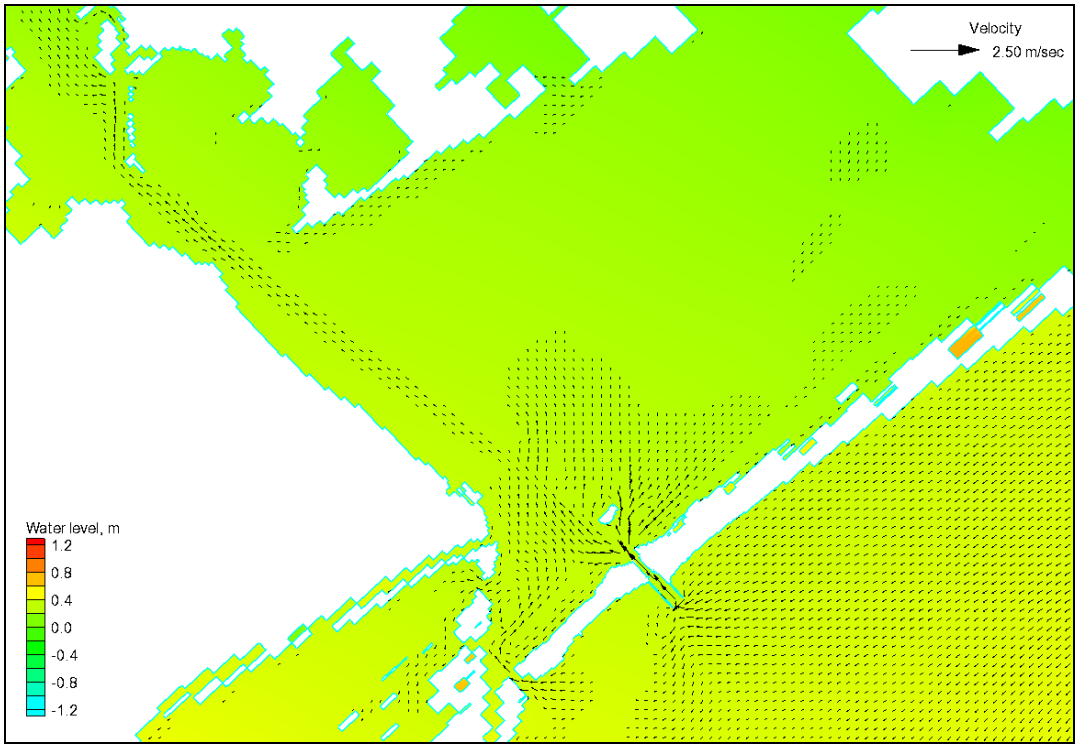

Figure 11. Typical strong flood current field calculated by CMS.

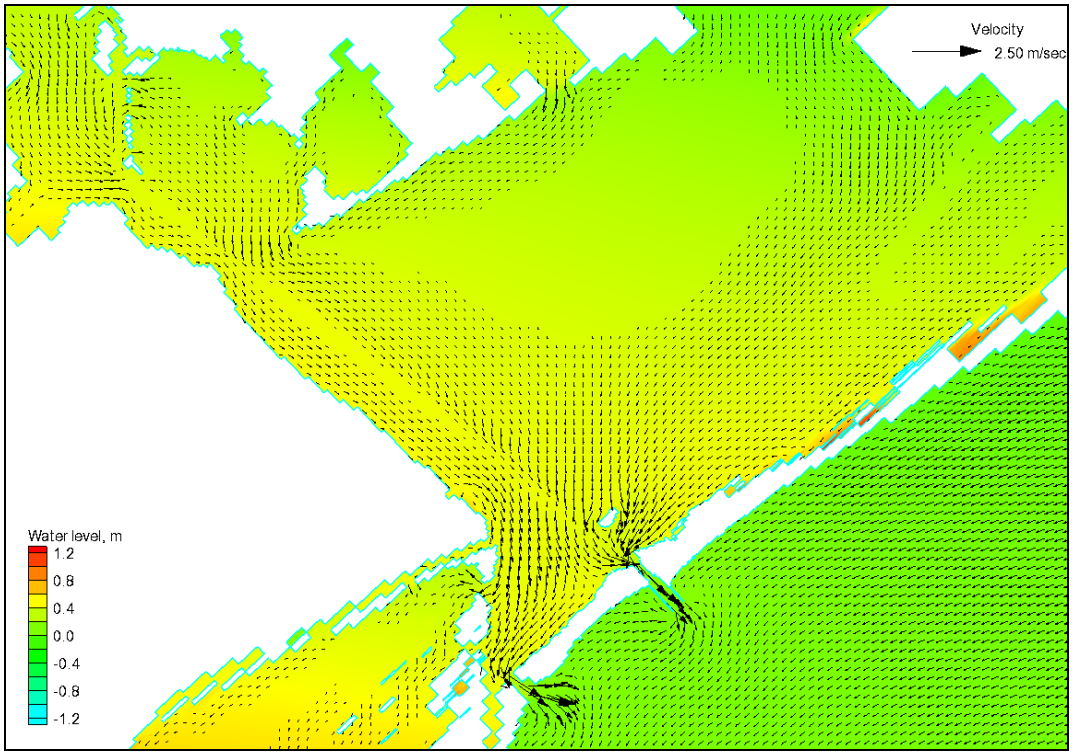

Figure 12. Typical strong ebb current field calculated by CMS.

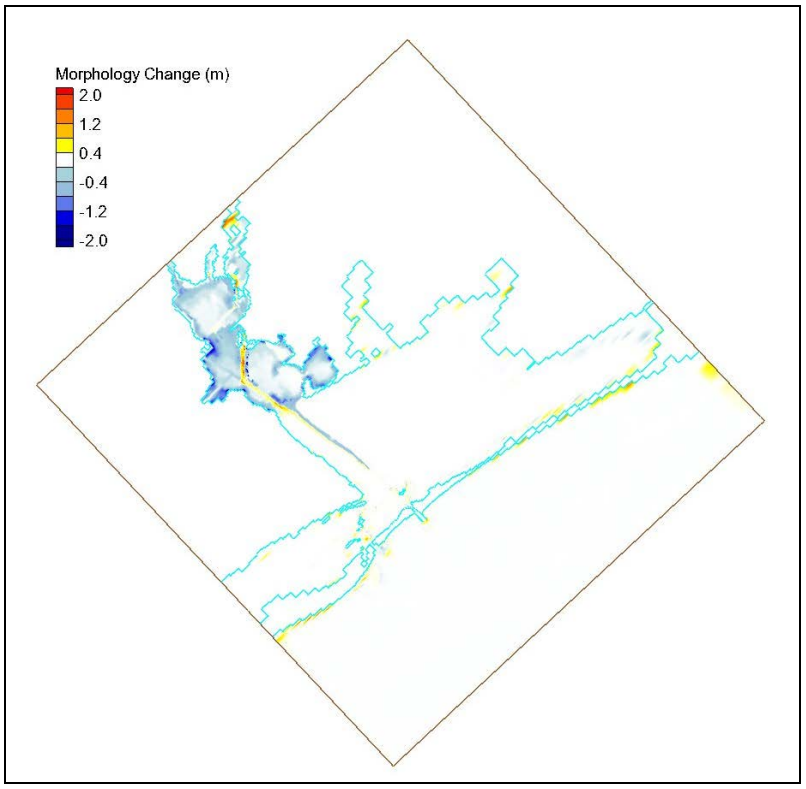

Figure 13. Calculated mixed sediment accretion/erosion, September 2006 to February 2007.

ALTERNATIVES

Three alternatives are selected and considered for a proof of concept to reduce the sediment accretion in the upper ship channel: 1) a confined Artificial Island (AI) south of Port Comfort to contain the dredged material from the upper channel, 2) extension of Geotube east of the upper channel to close the gaps among dredged material placement areas, 3) three New Placement Areas (New PA) west of the navigation channel. Figure 14 shows the layout and configuration of three alternatives. The confined AI has approximately 640 acres for the maximum placement of 10 million cubic yards of consolidated sediment. The extended Geotube is 4-km long with the elevation of 1 m, MSL. Three New Placement Areas, each is a rectangular area of 1 km x 0.35 km, are submerged with the minimum depth of 0.6 m, MSL. The existing CMS grid was modified for each alternative and simulation was run for the 6-month period from September 2006 to February 2007.

Figures 15 to 16 show the calculated 6-month morphology change fields in the upper channel region for the existing configuration and new PA alternative. Based on the CMS model results, the extension of Geotube and new PA alternatives are more effective than the confined AI to reduce the sediment deposition rate in the upper channel.

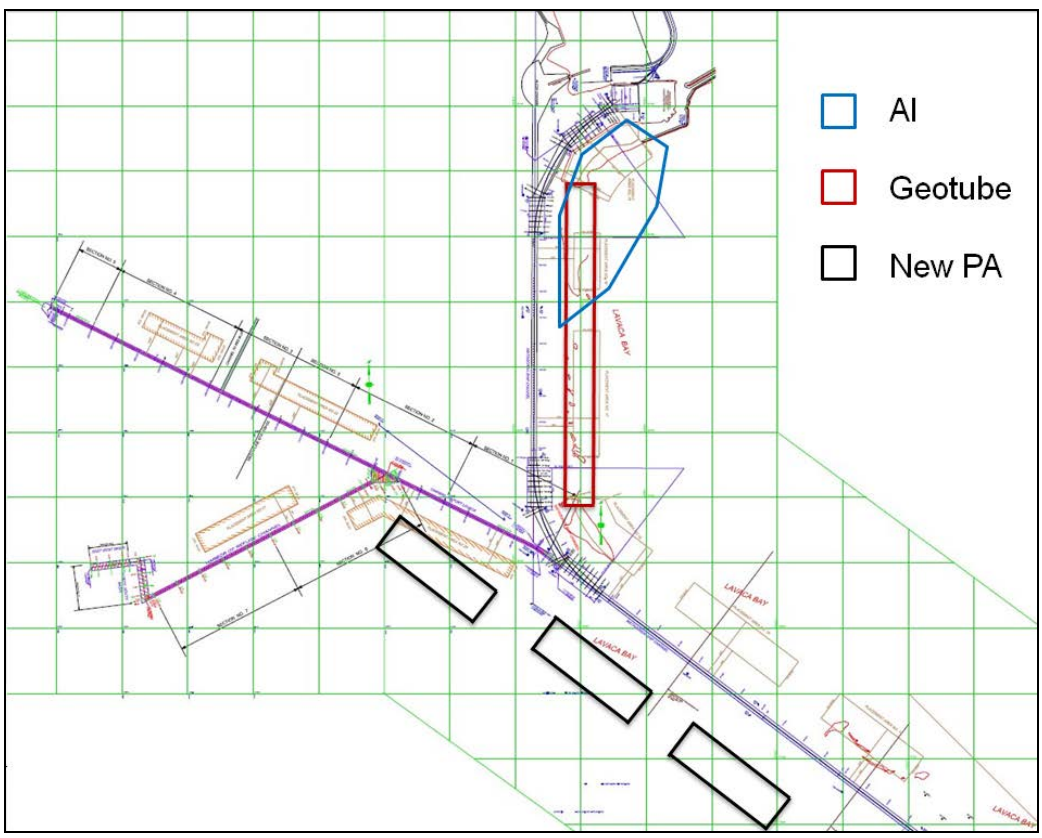

Figure 14. Three alternatives: 1) Artificial Isalnd, 2) Geotube, 3) New Placement Areas.

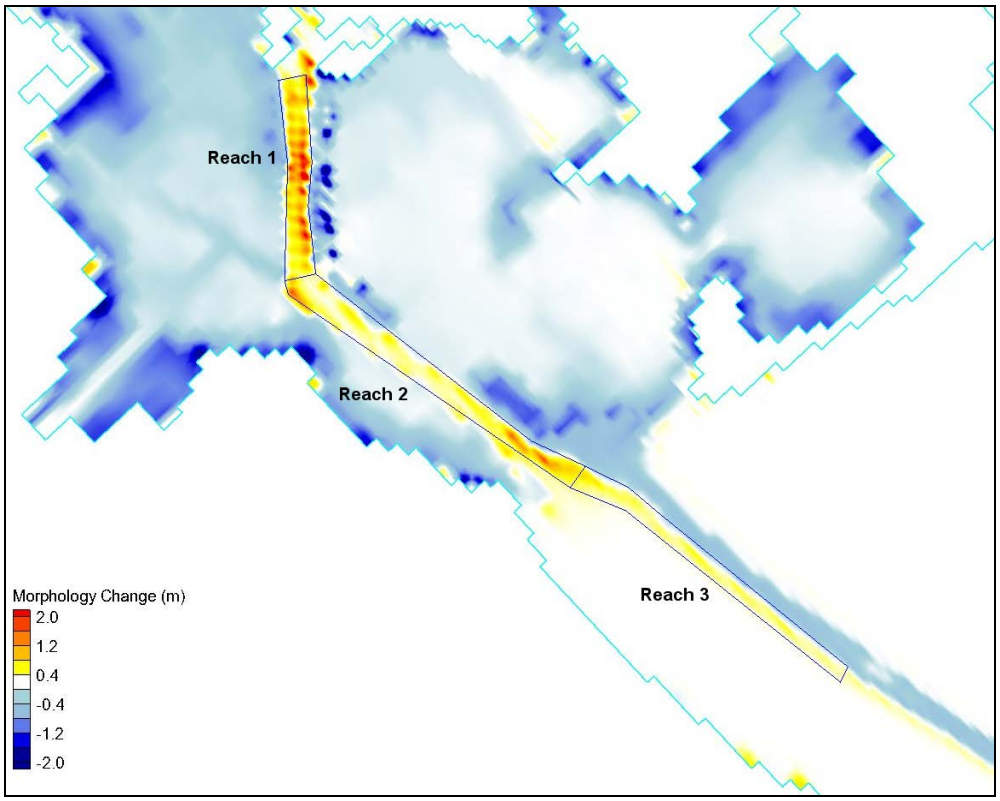

Figure 15. Calculated 6-month morphology change for the existing configuration.

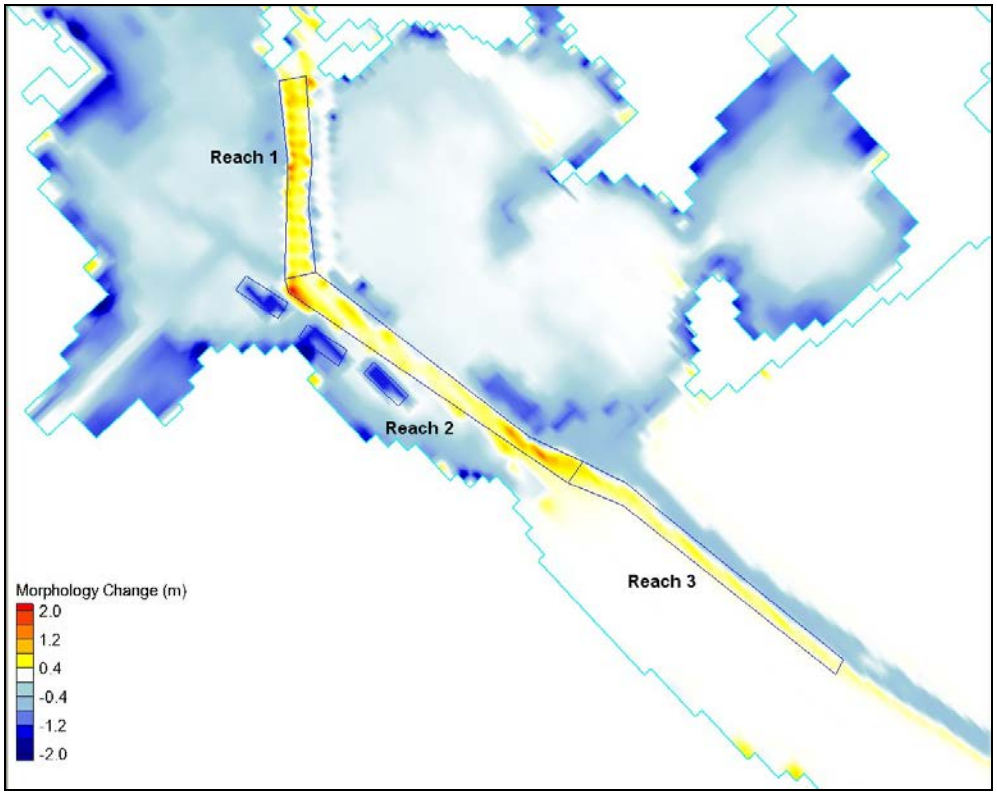

Figure 16. Calculated 6-month morphology change for New PA alternative.

Table 1 presents the model results of accumulated sediment volume change for the existing configuration and three alternatives in the period of September 2006 to February 2007. The accumulated sediment volume change was compared in three sections in the upper channel: Reach 1, Reach 2 and Reach 3 (Figures 16-19). The model simulation shows more sediment accretion in Reach 1 and 2 than Reach 3. The Geotube and New PA alternatives have smaller sediment accumulation than AI and existing configuration. Comparing to the existing configuration, the total percent reduction in Reach 1-3 for AI, Geotube, and New PA alternatives is -7, -26, and -25%, respectively. A combination of AI or Geotube with New PA alternatives may further reduce the sediment accumulation rate in the upper channel. These and other alternatives including different AI and New PA design, with channel deepening and widening projects, are recommended in future studies.

Table 1. Calculated accumulation of sediment volume (mil CY), September 2006 to February 2007.

Configuration	Reach 1	Reach 2	Reach 3	Reach 1-3	% Reduction
Existing Condition	2.04	1.33	0.47	3.84	0
Artificial Island	1.90	1.24	0.44	3.58	-7
Geotube	1.00	1.44	0.41	2.85	-26
New PA	1.10	1.35	0.44	2.89	-25

CONCLUSIONS

A hydrodynamic and sediment transport Coastal Modeling System (CMS) with fully integrated nearshore wave, current, and sedimentation models is used to simulate the mixed sediment transport in Matagorda Bay, Texas. The focus area is in the upper reach of the deep-draft Matagorda Ship Channel that runs through a jettied entrance connecting to the Gulf of Mexico and extends 38 km (24 mile) to Port of Lavaca - Point Comfort in Lavaca Bay. Excessive shoaling at the upper channel in recent years has caused annual draft restrictions resulting in the need for more frequent dredging cycles. It is suspected that the critical shoaling in the upper channel is mainly the migration of the disposed materials back into the channel from open water placement sites adjacent to the channel. Mud fluid and silty sediment from the upper Lavaca Bay also contributes to the high shoaling rate in the Ship Channel.

Numerical simulations were conducted for a 6-month period from September 2006 to February 2007 that represents a typical fall to winter condition. The channel surveys completed in September 2006 and February 2007 that showed rapid accumulation of sediment in the upper Ship Channel were used to validate the models. The model results agree well to the observed channel shoaling of cohesive sediment in the upper channel and increased deposition of non-cohesive sediment at the MSC and GIWW junction.

The CMS is also used to simulate three alternatives for a proof of concept to reduce the sediment shoaling rate in the upper channel. Among the three alternatives, the Geotube extension and relocation of the PAs to the west side of the channel can

effectively reduce channel shoaling in the upper channel. This reduction for either alternative was about 25 percent which is enough to possibly lengthen the time between dredging cycles in this area.

The Geotube alternative may affect the bay circulation which could pose environmental issues. Additionally, it could require maintenance if damaged by storms. The relocation of the PAs should not cause circulation issues in that they are submerged and would be the same as the existing PA conditions but just relocated to the other side of the channel. Therefore, the alternative to relocate PA sites is recommended to continue into the implementation phase.

ACKNOWLEDGMENT

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