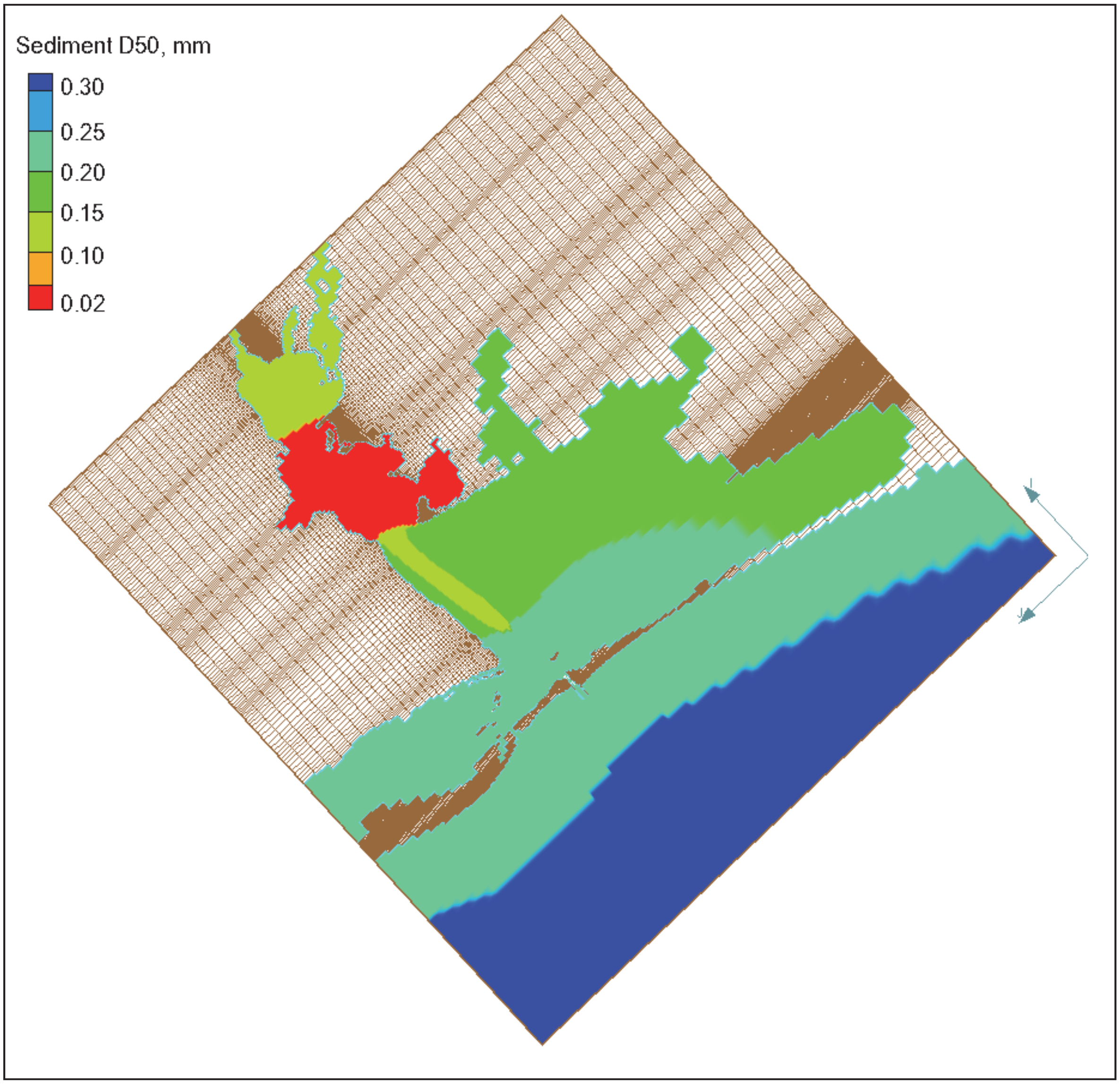
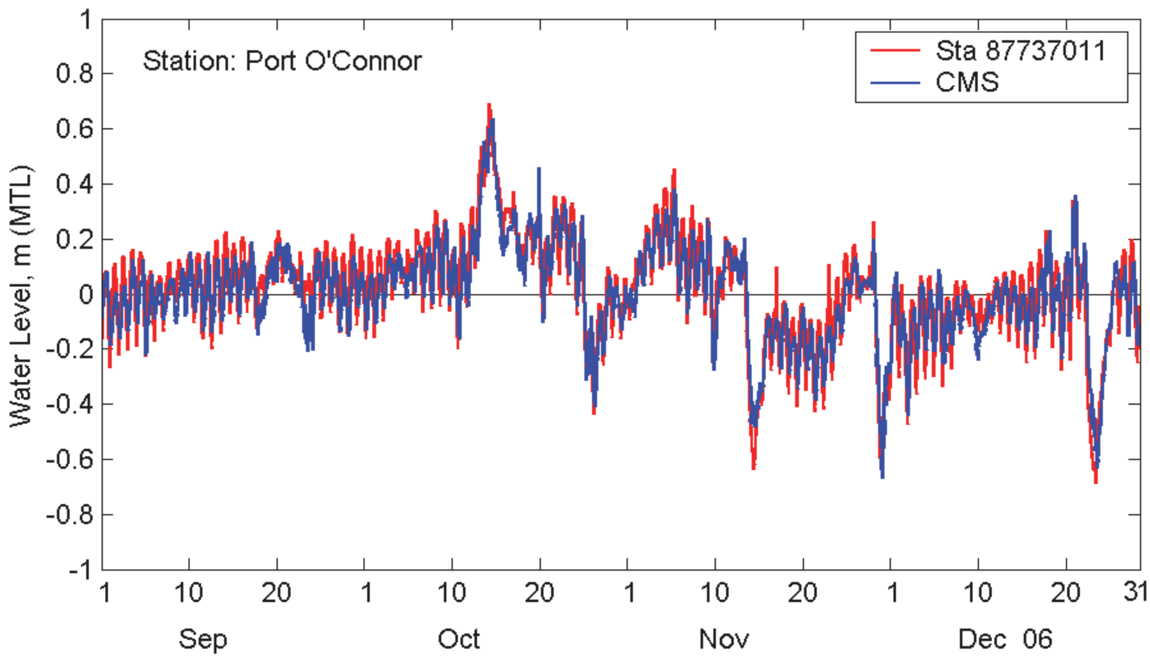
Figure 26. Median Grain Size distribution for Matagorda Bay sediment modeling.



The cohesive sediment transport algorithm in the CMS explicit model assumes sediment transport occurs only as suspended load; thus, no bed load transport is included. The algorithm is based on the scalar transport equation with empirical formulas for erosion, deposition, and settling speed. The scalar transport equation for the cohesive sediment is expressed as (Mehta 1993)

Figure 27. Measured and calculated water levels at NOAA Station 8771431.



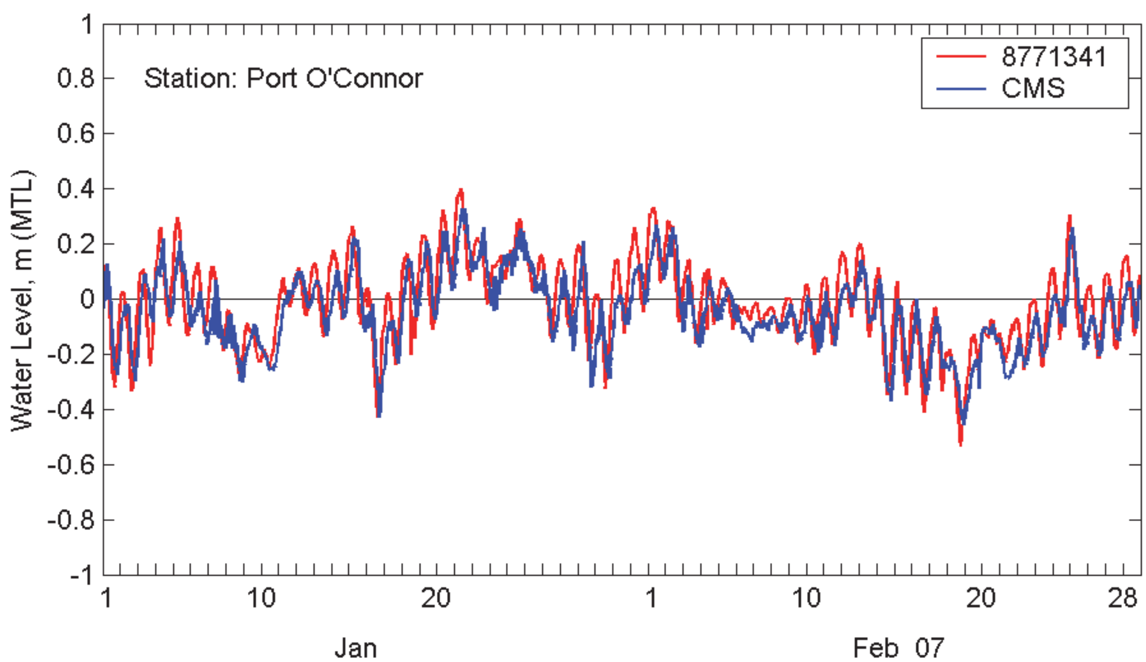
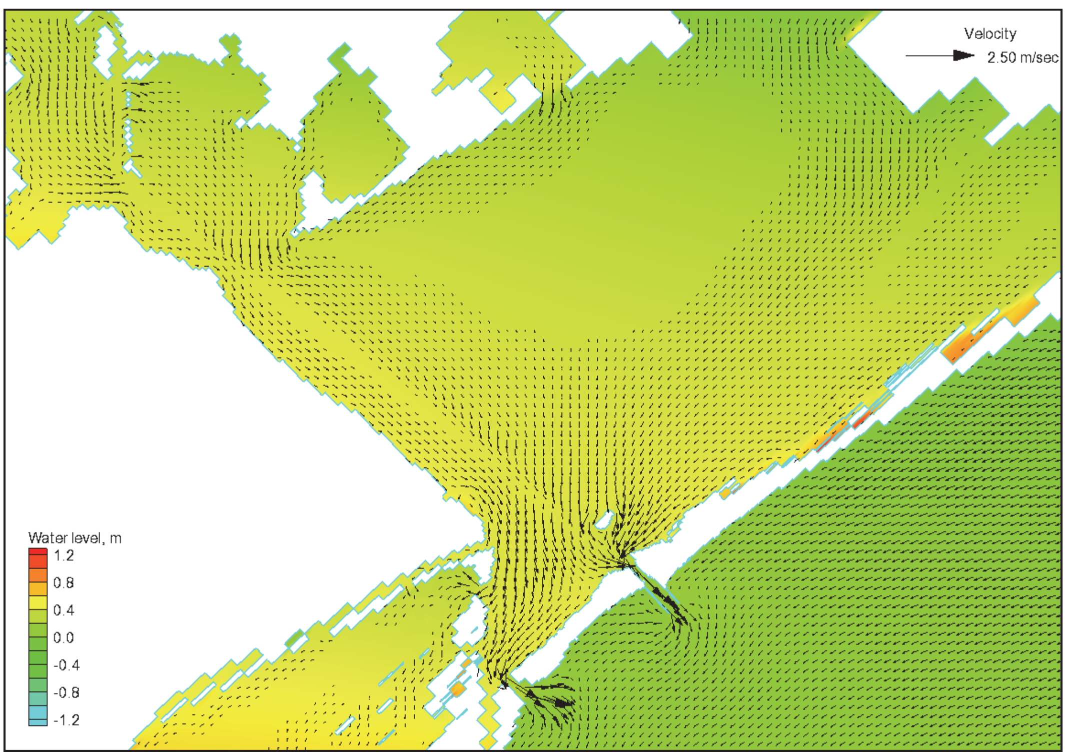


Figure 28. Typical strong flood current field calculated by CMS.

Figure 29. Typical strong ebb current field calculated by CMS.



$$\frac{\partial C}{\partial t}+\frac{\partial q_x C}{\partial x}+\frac{\partial q_y C}{\partial y}=\frac{\partial}{\partial x}(\frac{K_x}{\alpha}\frac{\partial C}{\partial x})+\frac{\partial}{\partial y}(\frac{K_y}{\alpha}\frac{\partial C}{\partial y})+E-D \quad (1)$$

where:

t = time
x,y = horizontal coordinates
C = volume concentration of suspended sediment
K_x = eddy viscosity in x-direction
K_y = eddy viscosity in y-direction
α = scaling coefficient for momentum and sediment dispersion
E = sediment erosion rate
D = sediment deposition rate.

The formulations for E and D are given (Mehta et al. 1989; Parthenaides 1962) as follows:

$$\tau_b \geq \tau_{ce} \; D=0, E=E_r(\tau_b-\tau_{ce})$$

$$\tau_{cd} \leq \tau_b \leq \tau_{ce} \; D=0, E=0$$

$$\tau_b \leq \tau_{cd} \; D=wC, E=0$$

where τ_b is the bottom stress, τ_{ce} is the critical stress for erosion, τ_{cd} is the critical stress for deposition, and w is the sediment settling velocity.

If there are no waves present, the bottoms stress is calculated as

$$\tau_b=\frac{\rho}{8}f_c U^2 \quad (2)$$

where U is the flow speed, ρ is the water density, and f_c is the friction coefficient, defined as follows (van Rijn 1993):

$$f_c=\frac{0.24}{\left(\log_{10}(\frac{12d}{0.0001})\right)^2} \quad (3)$$

where d is the water depth.

If waves are present, the wave contribution is as follows:

$$\tau_w = \frac{\rho}{8} f_w U_w{}^2 \tag{4}$$

where U_w is the wave bottom orbital velocity and f_w is the friction coefficient for wave motion:

$$f_w = \frac{0.0521}{\left(R_e + 100\right)^{0.187}} \tag{5}$$

The combined bottom stress is

$$\tau_b = \sqrt{\tau_c^2 + \tau_w^2} \tag{6}$$

The sediment-settling velocity is specified by parameters C_p and C_m to represent the effects of flocculation and hindered settling, respectively, and w_m for the maximum settling velocity (Van Rijn 1993; Thorn 1981):

$$w_s = w_m \left(1 - | \frac{C - C_p}{C_m - C_p} | \right). \tag{7}$$

Ideally, suspended and bedload sediment measurements throughout the bay would be available to calibrate and validate a mixed-sediment transport model. However, these types of data were not available for this study; thus, anecdotal information based on knowledge of river inflows and the type and magnitude of sediment shoaling in the channel were used as qualitative calibration information. As discussed previously, 3 to 6 feet (1 to 2 m) of fluid mud shoaled in the upper MSC in the 6-month period between September 2006 and February 2007. Figures 30 and 31 show the calculated sediment accretion/erosion fields for cohesive and non-cohesive material, respectively, for this 6-month period of September 2006 to February 2007.

The model calculations agree with observations in that deposition in the upper MSC has more cohesive sediment than non-cohesive sediment, and the magnitude of deposition is comparable to the measurements for this period. Figure 32 shows the calculated sediment accretion/erosion field for the combined (mixed) cohesive and non-cohesive sediment for the period from September 2006 to February 2007.

Figure 30. Calculated cohesive sediment accretion/erosion, September 2006 to February 2007.

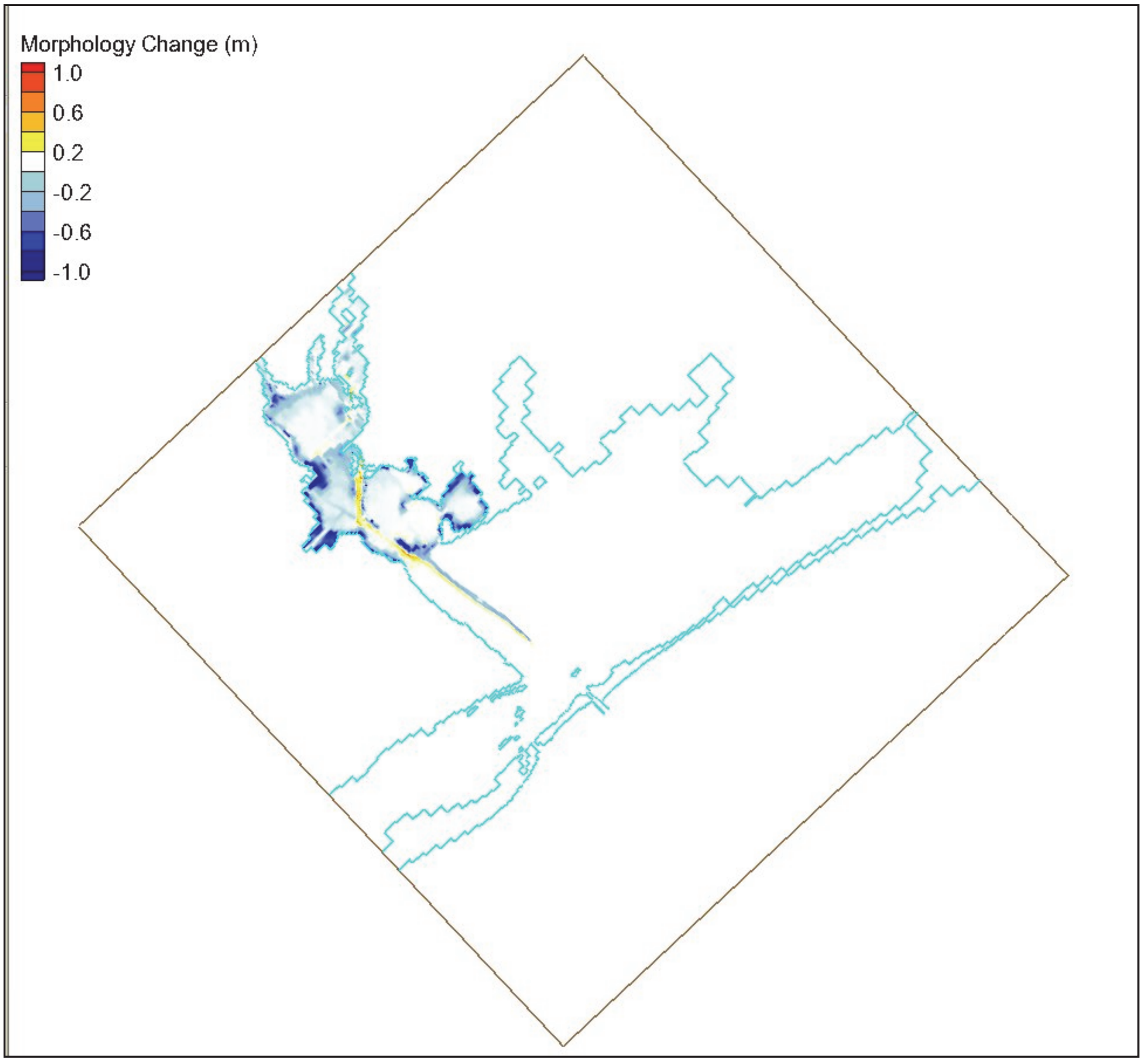


Figure 31. Calculated non-cohesive sediment accretion/erosion, September 2006 to February 2007.

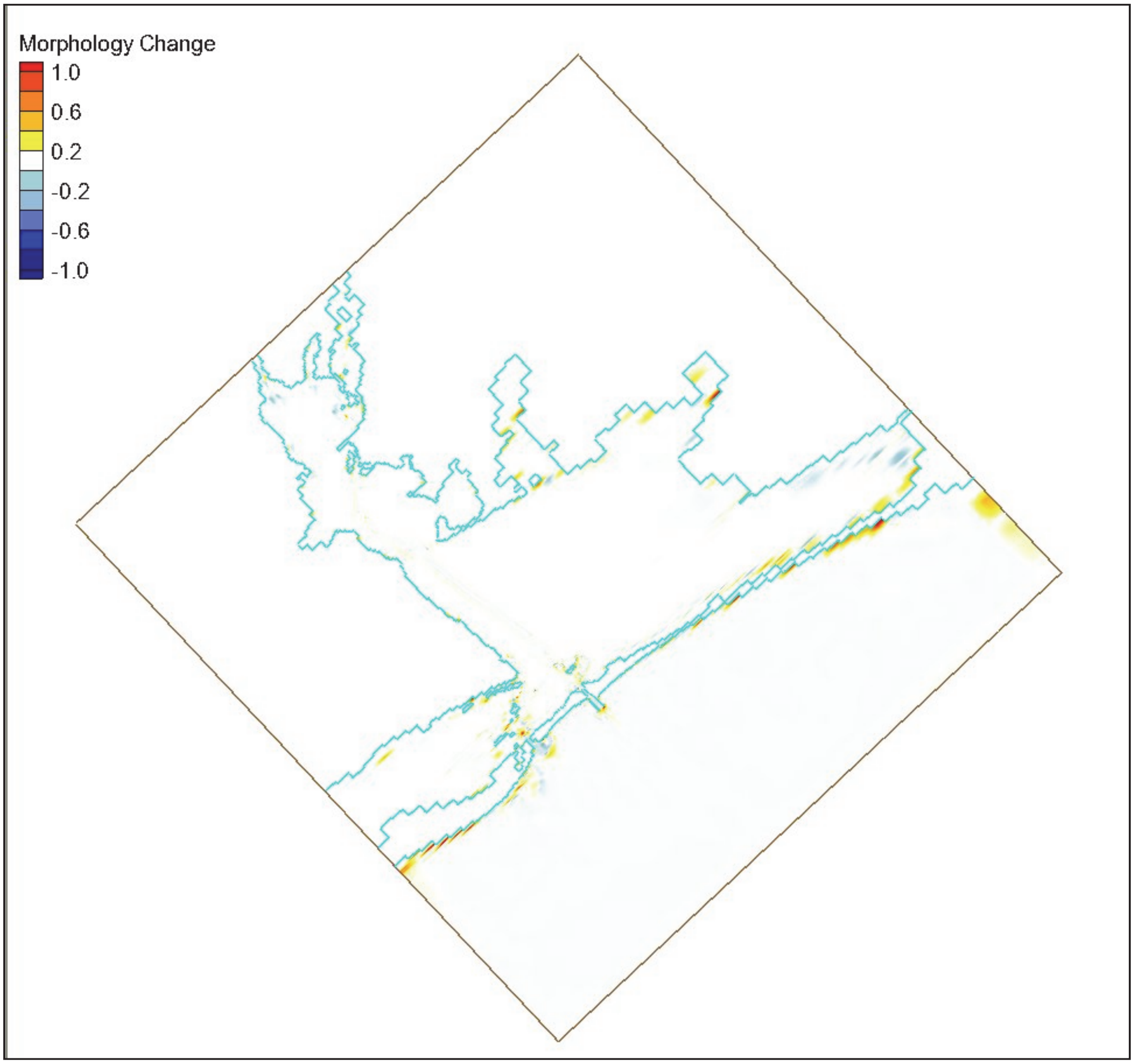
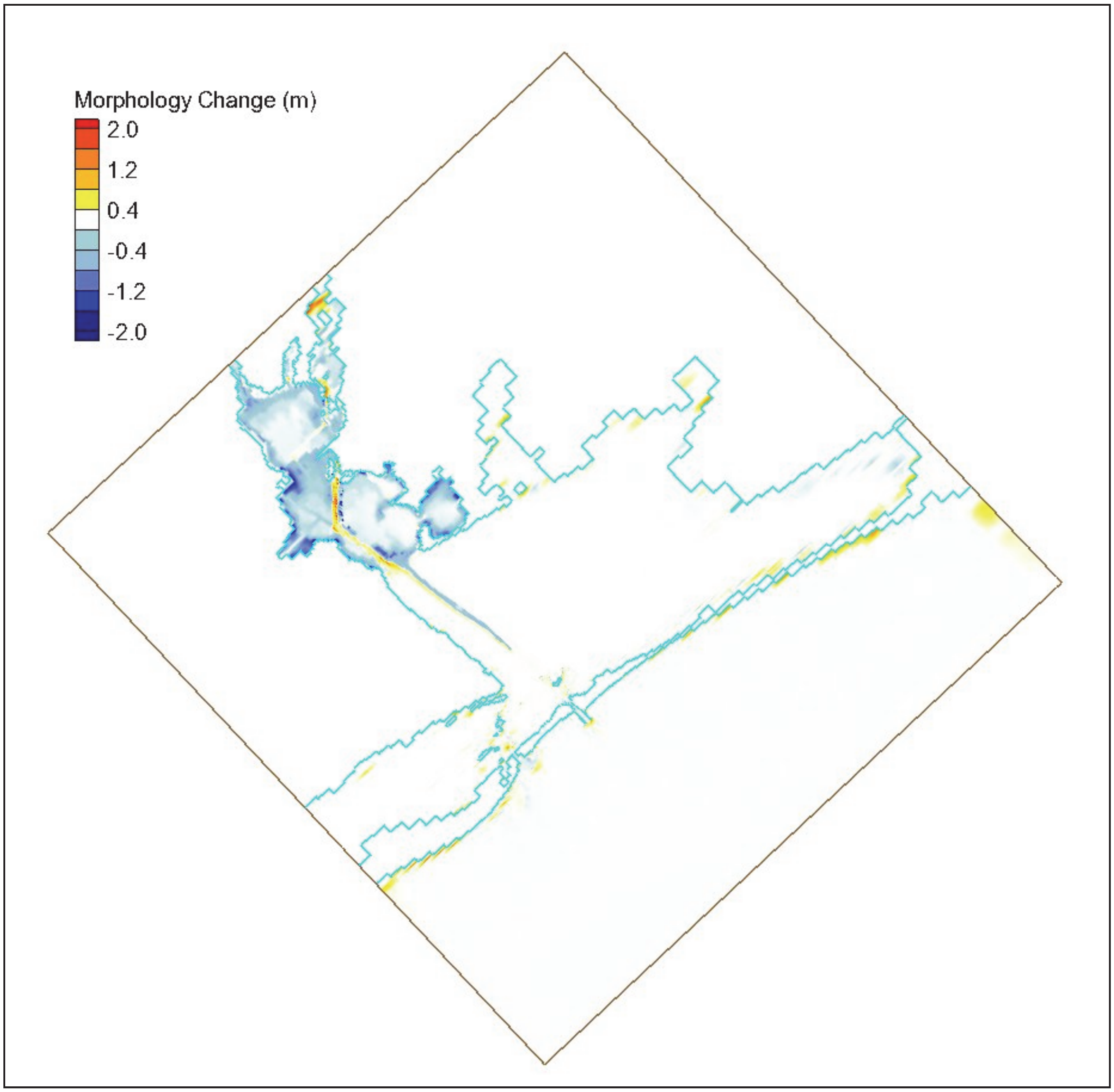


Figure 32. Calculated mixed-sediment accretion/erosion, September 2006 to February 2007.



4 Alternative Formulation and Analysis

Based on channel surveys and field data collection in the past, four alternatives were selected for detailed evaluation through numerical modeling. This Chapter describes the alternatives selected, results of the analyses, and recommendations for each alternative.

4.1 Alternatives Selected for Analysis

Four alternatives were considered to reduce the sediment accretion in the upper MSC:

1. A confined Artificial Island (AI) south of Port Comfort to contain the dredged material from the upper channel
2. Extension of the geotube east of the upper channel to close the gaps between dredged material placement areas; the geotube was assumed to have a diameter of 12 ft (3.7 m)
3. Three new placement areas (New PAs) west of the navigation channel
4. Application of nautical depth concept and higher resolution survey techniques

Figure 33 shows the conceptional layout and configuration of Alternatives 1-3. The confined AI (Alt 1) has approximately 640 acres for the maximum placement of 10 million cy (mcy) of consolidated sediment. The extended geotube (Alt 2) is 2.5 miles (4 km) long with an elevation of 3 ft (1 m) MSL. Each of the three New PAs (Alt 3) is a rectangular area of 0.6 mile (1 km) by 0.2 mile (0.35 km) and is submerged with a minimum depth of 2 ft (0.6 m) MSL.

4.2 Alternative Analysis

Modeling of Alternatives 1-3 was performed by modifying the existing CMS grid for each alternative and running a simulation for the 6-month period from September 2006 to February 2007. The cumulated sediment volume change was compared in three channel sections: Reach 1, Reach 2 and Reach 3 (Figures 34 - 37). Alternative 4, the application of nautical depth concept and higher resolution survey techniques, was not modeled but will be discussed in general terms in this section.

Figure 33. Three alternatives: 1) Artificial Island, 2) Geotube, 3) New Placement Areas.

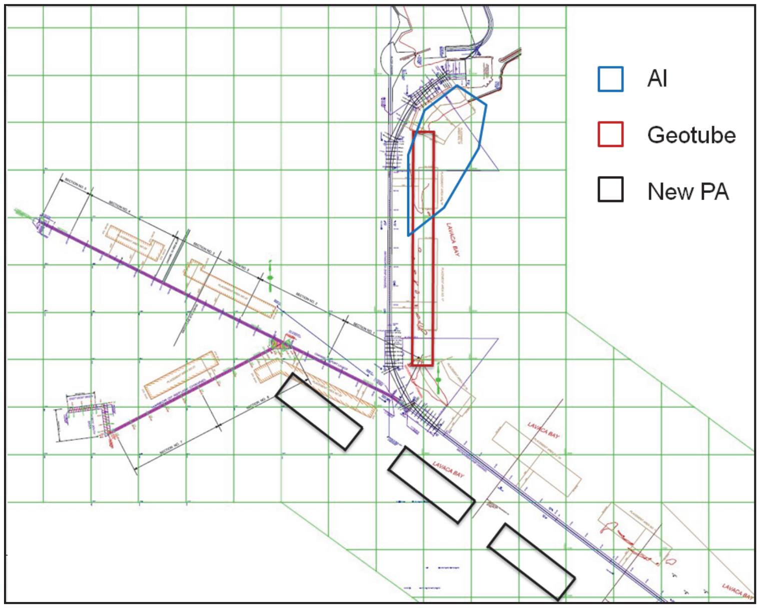


Figure 34. Calculated 6-month morphology change for the existing configuration.

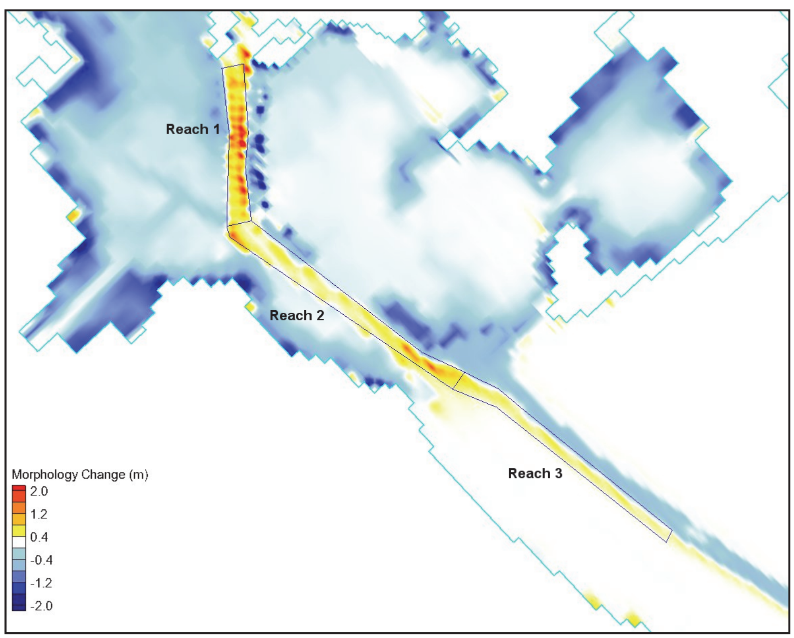


Figure 35. Calculated 6-month morphology change for the AI alternative.

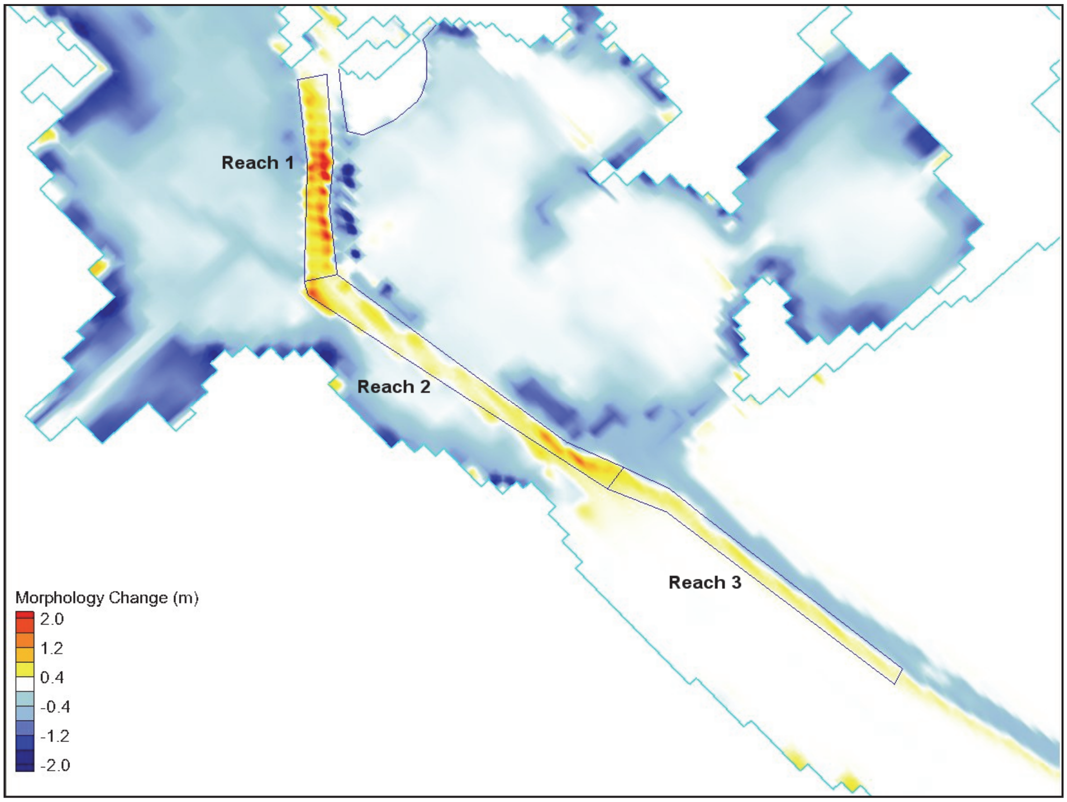


Figure 36. Calculated 6-month morphology change for the Geotube alternative.

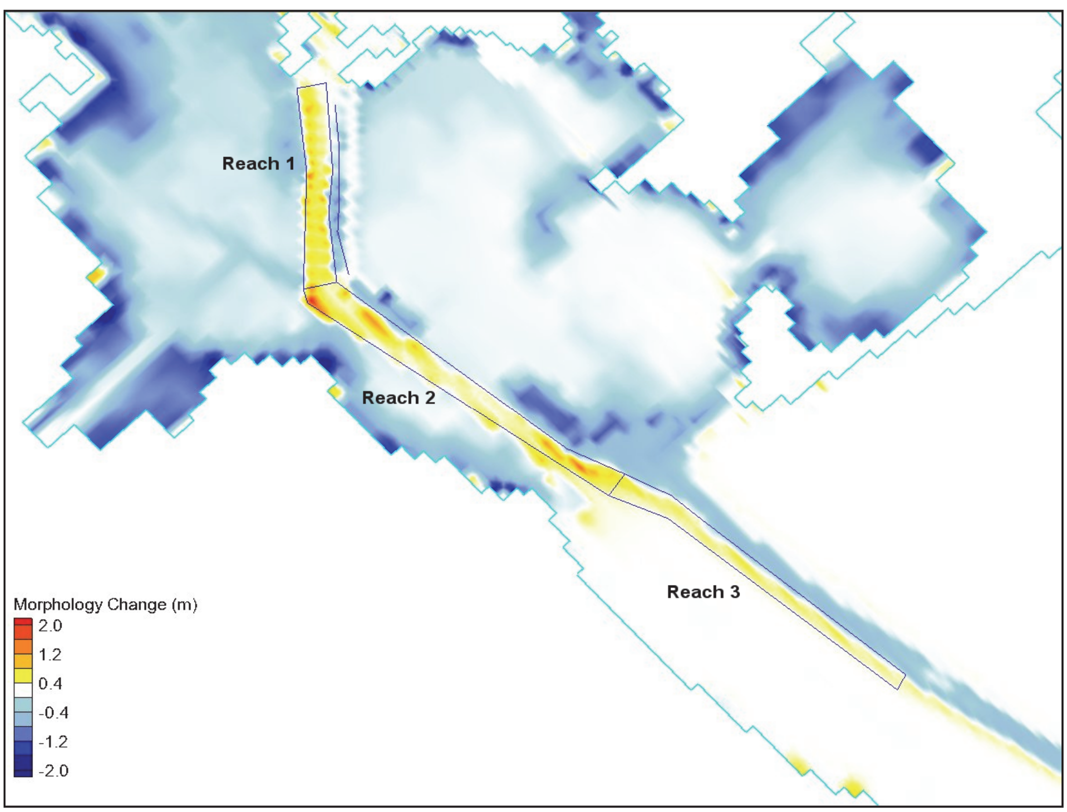


Figure 37. Calculated 6-month morphology change for New PA alternative.

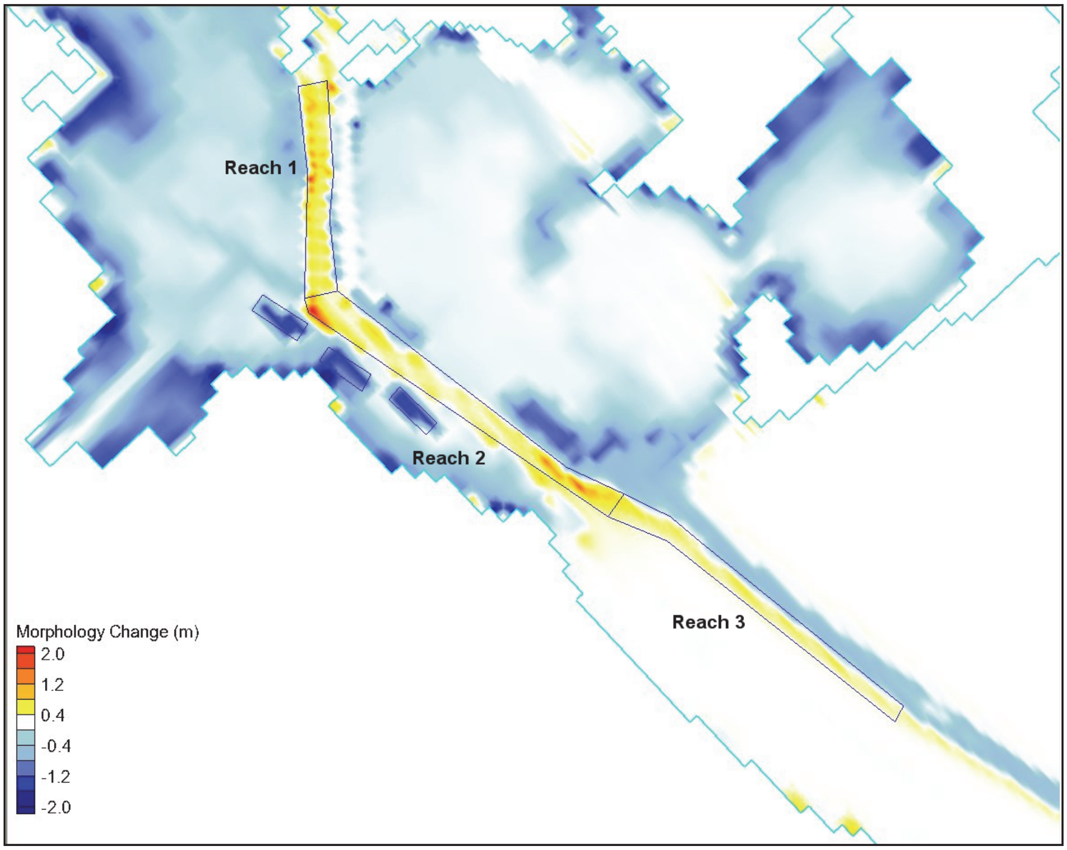


Figure 34 shows the calculated 6-month morphology change fields (September 2006 to February 2007) in the upper channels for the existing configuration. Reach 1 had the largest volume of material movement in the channel with 2.04 mcy (wet volume or wet bulk sediment) being deposited in this 6-month period. The total deposition of material for all three reaches was 3.84 mcy (wet volume).

4.2.1 Analysis of Artificial Island Alternative

Figure 35 shows the calculated 6-month morphology change fields in the upper channel region with the AI alternative (Alt 1) in place. The AI alternative decreased the shoaling in this section of the channel by 7 percent, resulting in the deposition of 3.58 mcy (wet volume) of material during the 6-month period.

4.2.2 Analysis of Geotube Alternative

Figure 36 shows the calculated 6-month morphology change fields in the upper channel region for the Geotube alternative (Alt 2). The Geotube alternative decreased the shoaling by 26 percent, with a total of 2.85 mcy (wet volume) of material during the 6-month period modeled.

4.2.3 Analysis of New PA Alternative

Figure 37 shows the calculated 6-month morphology change fields in the upper channel region for the New PA Alternative (Alt 3). This alternative decreased the shoaling by 25 percent, with 2.89 mcy (wet volume) of material during the 6-month period modeled.

4.3 The Nautical Bottom Approach

Section 2.6 described fluid mud characteristics and respective effects on conventional hydrographic surveying equipment and depth determination. In navigation channels with more consistent bottoms, e.g., sand, an underkeel clearance (distance between the central fore-aft structural member in the bottom of the hull and channel bottom) is used to account for parameters such as ship motion from waves, squat, safety clearance, water density, etc., to avoid contact between ship and bottom. In channels with fluid mud, as per PIANC (1997),

> Although the upper part of the mud layer has a somewhat higher density than water, its rheological properties are comparable with those of water, so that a ship's hull suffers no damage when it penetrates this interface. Even navigation with an under keel clearance which is negative referred to the interface can be considered, which implies that the ship's keel is permanently in contact with the mud. On the other hand, safety of navigation requires that the pilot must always be able to compensate for the effects of mud on ship behavior by means of its own control systems or external assistance (e.g., tugs).
>
> An acceptable compromise between the safety of navigation and the cost of channel maintenance can only be reached by introduction of non-conventional definitions and survey methods and requires additional knowledge about the navigational response of ships in muddy water.

To implement this alternative approach, the terms *bottom* and *depth* can be modified to *nautical bottom* and *nautical depth* where *nautical bottom* is defined (PIANC 1997) as follows:

> the level where physical characteristics of the bottom reach a critical limit beyond which contact with a ship's keel causes either damage or unacceptable effects on controllability and maneuverability

and *nautical depth* as

> the instantaneous and local vertical distance between the nautical bottom and undisturbed free water surface.

To complete the definition of nautical bottom, the physical characteristic(s) on which the *critical limit* criterion is based and the criteria for *acceptable* ship behavior must be provided. Consequently, from a practical and operational perspective, implementation of a nautical bottom concept requires the following:

- a practical criterion, i.e., selection of the physical mud characteristic acting as a parameter for the nautical bottom approach and its critical value;
- a practical survey method for continuous determination of the accepted level;
- a minimum value for the required underkeel clearance with reference to this nautical bottom, ensuring a minimal risk for contact with the latter and acceptable ship behavior;
- the knowledge of ship behavior, i.e., measures to compensate adverse effects on controllability and maneuverability (PIANC 1997).

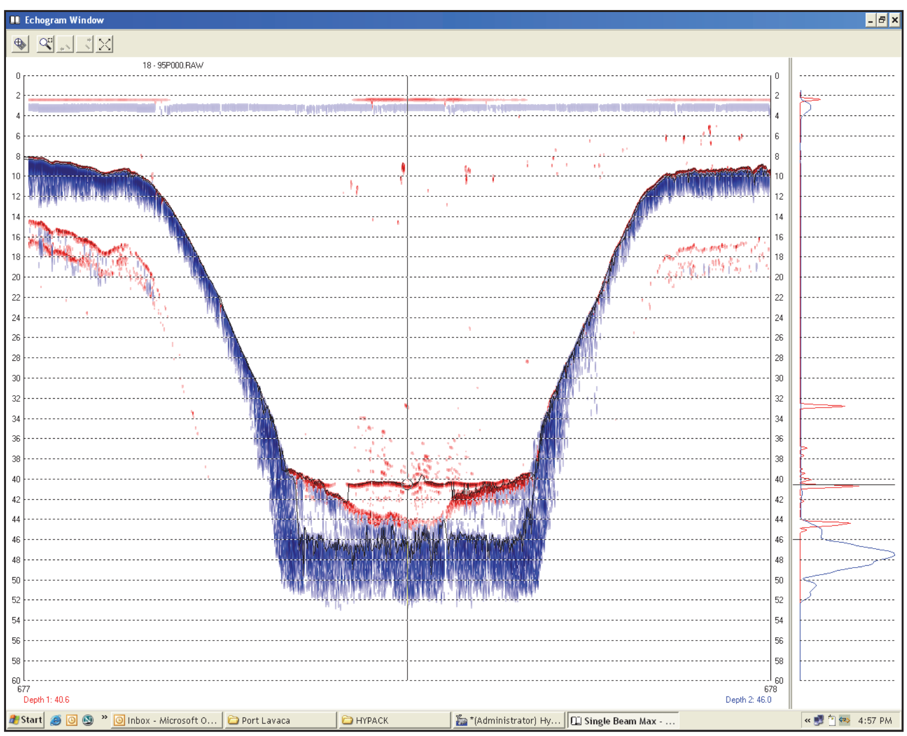
Under the DOER Program and the Monitoring Completed Navigation Projects Program, the ERDC is currently working with the USACE Mobile District to incorporate the four implementation requirements above.

4.3.1 SILAS/RHEOTUNE Survey System demonstration

The SILAS and RHEOTUNE are components of a hydrographic survey system for operation in fluid mud conditions. During 7-8 September 2008, this system was demonstrated at the upper MSC. This section summarizes why the demonstration was conducted and describes the demonstration activities and types of data collected.

As previously described, acoustic hydrographic surveys are usually conducted with either high frequency (approximately >200 kHz) or low frequency (approximately < 30 kHz) transducers, or a combination of both frequencies (a dual-frequency system). The depth in the fluid mud column that an acoustic pulse reflects from is a function of the *sharpness* of fluid mud density gradient (or rate of change in density), not a specific density value itself (USACE 1954). Attenuation of acoustic energy is directly proportional to its frequency. The net result is that the high frequency energy will normally reflect from the upper layer of the reflective material, even a very low density one, and the lower frequency transducer will reflect from a lower layer if that layer has a higher acoustic reflectivity than the upper one. These reflections are illustrated in Figure 38 (uncorrected for tides) showing a dual frequency echogram of Station 95+00 cross-section transect in the MSC, in which red can be interpreted as the upper fluid mud layer and blue as the channel bed. These interactions between reflected acoustic energy and fluid mud physical characteristics can result in ambiguous depth determinations. If depth is determined from the first reflections from the upper fluid mud layer, the physical characteristics of this fluid mud may be similar to *muddy water*. This condition would not pose a hazard to navigation and would lead to inefficient dredging.

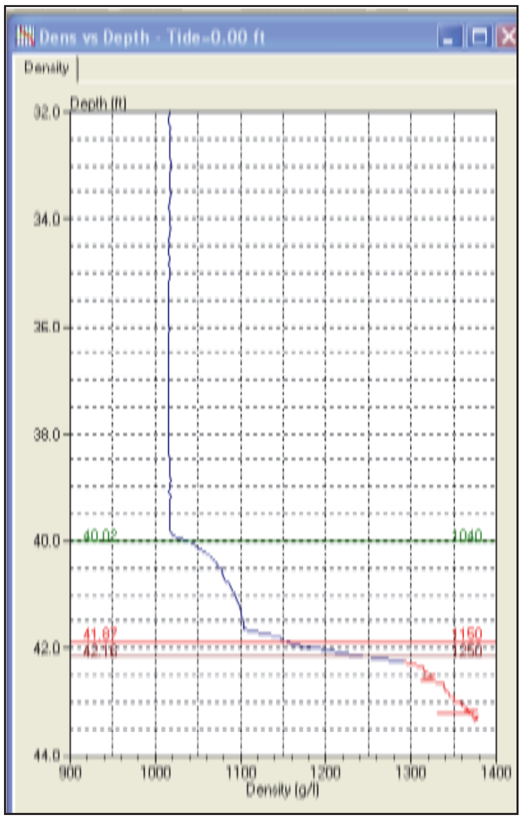
Figure 38. Dual-frequency echogram of Matagorda Ship Channel Station 95+00.



The SILAS/RHEOTUNE system was demonstrated in the upper MSC in conjunction with a conventional duo-frequency echosounder to determine the presence of fluid mud, train ERDC personnel on the use of the survey system, and also fundamentally demonstrate the respective field data collection capabilities in the system.

The RHEOTUNE Silt Density Probe is used to measure density and yield strength of fluid mud in dredged and disposal areas and to determine nautical depth in navigation channels. The probe is lowered from the survey vessel and measures the density of the water and fluid mud profile as a function of depth (Figure 39).

Figure 39. RHEOTUNE density vs. depth profile (Matagorda Ship Channel Station 97+00).



The SILAS software was developed for the acquisition and processing of acoustic subbottom reflection signals operating in the low frequency range of 3.5 to 33 kHz to map sediment distribution and sediment characteristics. By calibrating reflection signals with input from the RHEOTUNE density probe, SILAS can be used to acoustically measure density in the fluid mud column.

4.3.2 Data Collection

Figure 40 shows the RHEOTUNE profiling locations. SILAS transects were run (example shown in Figure 41), but the data was not analyzed to determine specific density horizons. An example of SILAS data analyzed for Gulfport (Mississippi) Ship Channel is illustrated in Figure 42. The most commonly used definition of nautical depth world-wide is 1.20 g/cc (1.20 g/cm^3).

These improved technologies, such as SILAS/RHEOTUNE Survey System, would better classify the dredged material sediment types within the channel and give a more accurate identification of the channel material such as fluid mud. Identification of fluid mud could result in fewer vessel draft restrictions allowing continued vessel movement that historically had been restricted. These changes in the operation of the channel with the SILAS/RHEOTUNE surveying system could result in an increase of several feet of useable channel depth. Additionally, a reduction in the quantity of dredged material may occur. Note that a small reduction in dredged material along the entire length of channel would translate into a significant decrease in dredged material requirements for the project.

Figure 40. RHEOTUNE profile stations in the Matagorda Ship Channel.

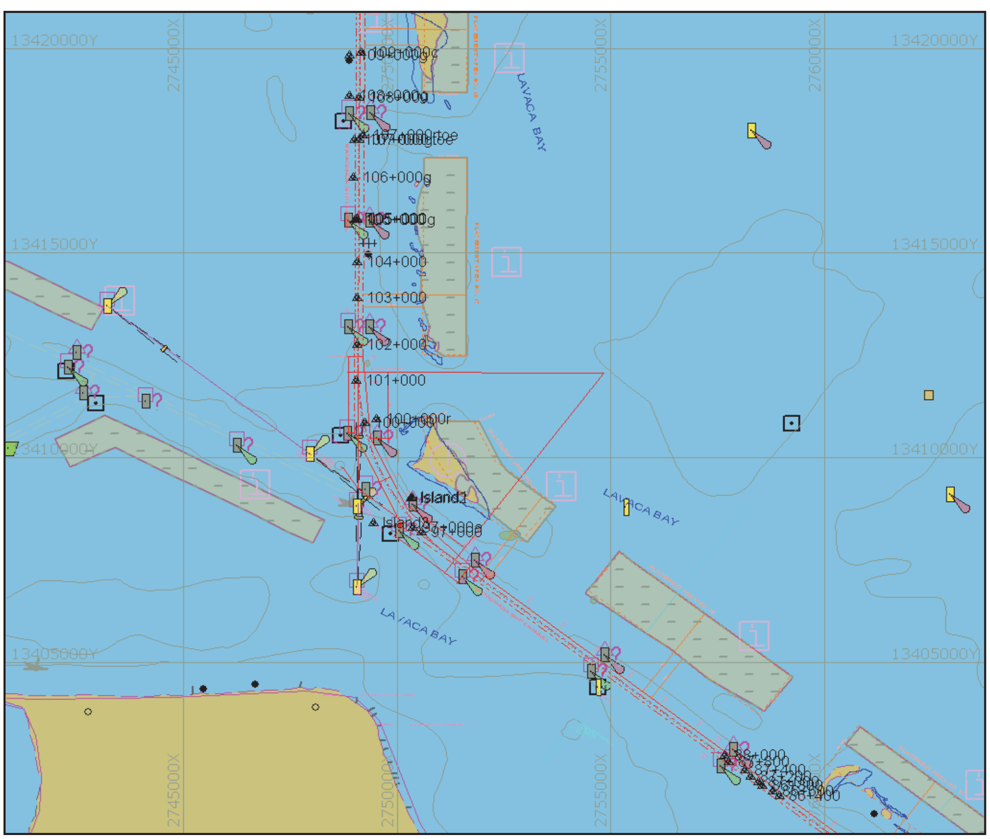


Figure 41. SILAS collected echogram from Station 96+00 Matagorda Ship Channel.

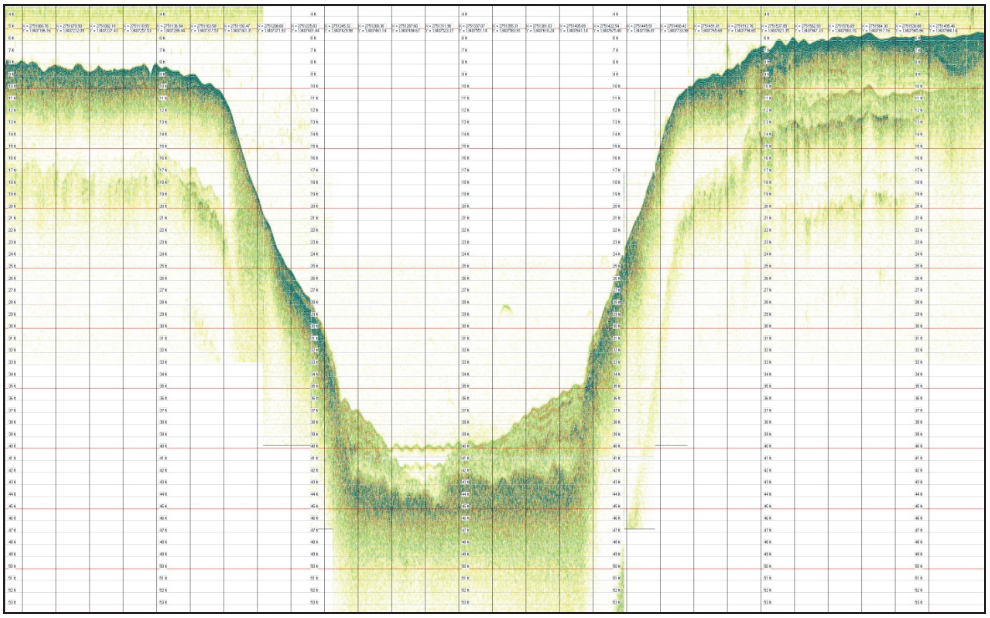
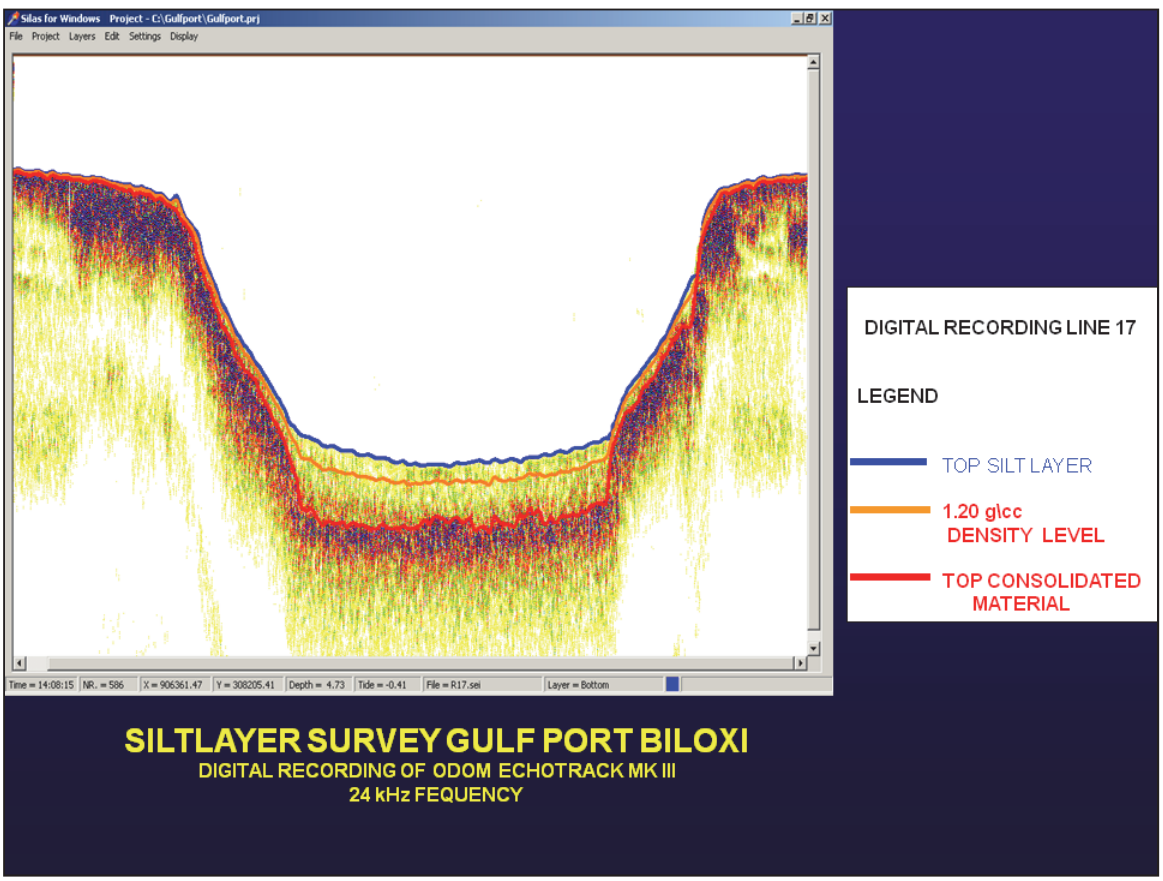


Figure 42. SILAS data analyzed for cross section in the Gulfport Mississippi Ship Channel.



4.4 Comparison of Alternatives

Among the three alternatives modeled, the Geotube and New PA alternatives (Alts 2 and 3) work better to reduce the sediment deposition rate in the upper channel, resulting in about a 25 percent reduction in material deposition in the reaches in the upper bay. The AI alternative (Alt 1) did not significantly reduce the sediment deposition in the channel reaches.

The Geotube alternative could require maintenance over time if the geotube were damaged. Additionally, there could be issues with water circulation and the possibility of water quality problems with the use of geotubes or the AI because the existing water circulation may be blocked by these alternatives.

Modeling shows that relocating the placement areas to the west side of the channel reduces the deposition rate in the upper channel. In this modeling, the new PAs were considered erodible while the existing PAs were not erodible. Unless the existing PAs were armored or the existing material was moved to another location, it is expected that the existing PAs would affect the channel shoaling in the short term as they continued to erode. This impact was not captured in the modeling. However, in the long term, since no additional material would be added to these existing PAs, it is expected that they would eventually stabilize, and the channel shoaling would decrease. Additionally, this new configuration is not expected to significantly change the circulation in this area of the bay because the PAs are submerged.

4.5 Conclusion

Table 15 presents the summary of the calculated cumulated sediment volume change for the existing configuration and three alternatives in the period of September 2006 to February 2007.

The model results show more sediment accretion in Reach 1 and 2 than Reach 3. The Geotube and New PA alternatives have smaller sediment accumulation than AI and the 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.

Table 15. Cumulated sediment volume change (mcy, wet volume).

Configuration	Reach 1	Reach 2	Reach 3	Reach 1-3	% Reduction
Existing Condition	2.04	1.33	0.47	3.84	
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

The demonstration project for the use of nautical depth and surveying changes in Matagorda Bay identified the possibility of altering the operation and maintenance procedures for this channel to allow for additional channel draft when there is a constraint to dredging.

5 Recommendations

5.1 Alternative Selection

Based on the field data investigation and numerical modeling of alternatives, the RSM Team from SWG and CHL developed a plan for implementation of recommendations. Of the three alternatives, the Geotube alternative and the relocation of the placement areas to the west side of the channel significantly reduced channel shoaling in the upper reaches of the bay. 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 after storm events or if it is damaged. The relocation of the placement areas should not cause circulation issues in that they are submerged. Therefore, the RSM Team recommended the relocation of the placement areas as the plan to continue into the implementation phase.

Improved surveying technologies such as SILAS/RHEOTUNE Survey System, described in Chapter 4, could also be utilized to better classify the dredged material sediment types within the channel. These technologies would allow a more accurate identification of the channel material such as fluid mud. If the material is fluid mud, there could be fewer vessel draft restrictions than have been in the past. Using the SILAS/RHEOTUNE surveying system could result in an increase of several feet of useable channel depth. Additionally, a small reduction in the depth of material dredged from the channel could result in a significant decrease in dredged material placement requirements when translated along the entire length of channel.

Another technology that could be used is RoxAnn GD-A, an acoustic ground discrimination system for use by the hydrographic survey industry and scientific community (www.seafloorsystems.com/roxann.htm). It determines the material on the surface of the seabed by analyzing the echo signals from the transducer of a conventional sounder, measuring both a roughness and hardness coefficient which, when combined, uniquely identify the type of seabed material beneath the vessel. Analysis is carried out in real time. It has been used extensively for bathymetric and bottom type classification.

5.2 Plan Implementation

To implement the recommendations to relocate the placement areas to the west side of the channel in the upper reach of the MSC, additional studies are necessary. The current MSC dredging plan was identified in the latest Dredged Material Management Plan (DMMP) and the environmental impacts of the plan were coordinated through the National Environmental Policy Act (NEPA) process. Changes to any of the components of the DMMP, including relocation of the placement areas, would require a new DMMP and environmental coordination and could result in a new Environmental Assessment of the dredging plan changes.

The procedure for updating a DMMP is to analyze the existing dredging plan in a Preliminary Assessment report, which identifies whether the current dredged material plan adequately covers the needs for the channel. However, due to the nature of the placement areas for the MSC being open-water disposal, the placement areas have nearly unlimited capacity. Therefore, the current disposal plan adequately covers the channel needs for the 20-year period of analysis required with a Preliminary Assessment and a Preliminary Assessment is not needed. It is recommended that a DMMP study be initiated to further investigate and incorporate the recommended alternatives for MSC presented in this report. This is the route required to allow the relocation of the placement areas to the western side of the channel. Any changes in surveying techniques can be pursued under the current authority to maintain the channel and would not require additional study.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
August 2013	Final	

4. TITLE AND SUBTITLE
Regional Sediment Management Studies of Matagorda Ship Channel and Matagorda Bay System, Texas

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Coastal and Hydraulics Laboratory
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CHL TR-13-10

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Engineer District, Galveston
2000 Fort Point Road
Galveston, TX 77550

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Three research and development programs within the US Army Engineer Research and Development Center (ERDC) have collaborated to investigate regional sediment management strategies within the Matagorda Bay system, emphasizing the excessive shoaling in the upper reach of the Matagorda Ship Channel (MSC). These three R&D programs were the Regional Sediment Management (RSM) Program, Coastal Inlets Research Program (CIRP), and Dredging Operations and Environmental Research (DOER) Program.

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

Numerical simulations were conducted to investigate the existing Matagorda Bay conditions and three alternatives as proof-of-concept to reduce sediment deposition in the upper MSC: 1) a confined artificial island south of Port Comfort, located in the northeast portion of the bay to contain the dredged material from the upper channel, 2) extension of an existing geotube east of the upper channel to close the gaps between dredged material placement areas, and 3) three new placement areas west of the navigation channel. The present study showed these alternatives could effectively reduce the channel shoaling rate. Options to reduce maintenance dredging by surveying the channel such that the fluid mud interface could be defined are also discussed.

15. SUBJECT TERMS

Regional sediment management	Mixed sediment transport	Matagorda Bay
sediment budget	Fluid mud	Lavaca Bay
	Matagorda Ship channel	Coastal Modeling System

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	Unclassified	74	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18