ERDC/CHL TR-13-10

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Regional Sediment Management Studies of Matagorda Ship Channel and Matagorda Bay System, Texas

Samantha S. Lambert, Sheridan S. Willey, Tricia Campbell,
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Final report

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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.

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Preface

The field data analysis and numerical modeling studies presented in this report were authorized by the US Army Corps of Engineers (USACE) and the US Army Engineer District, Galveston (SWG), to investigate the increased channel shoaling rate and remedial methods for the Federal Navigation Project at Matagorda Bay system, Texas. Sheridan S. Willey was the project study manager. The technical work was performed by Dr. Lihwa Lin, Dr. Honghai Li, Robert C. Thomas, and Timothy L. Welp at Coastal and Hydraulics Laboratory (CHL), and Samantha S. Lambert and Tricia Campbell at SWG. This study was supported by the Regional Sediment Management (RSM) Program, Coastal Inlets Research Program (CIRP), and Dredging Operations and Environmental Research (DOER) Program, all funded by the US Army Corps of Engineers, Headquarters (HQUSACE). These programs are administered for Headquarters at the US Army Engineer Research and Development Center (ERDC), under the HQUSACE Navigation Business Line. James E. Walker (retired) was HQUSACE Navigation Business Line Manager during the time of this study. W. Jeff Lillycrop, ERDC-CHL, is the Technical Director of the ERDC Navigation Research and Development Program. Program Managers of RSM, CIRP, and DOER are as follows: Linda S. Lillycrop, Dr. Julie Dean Rosati, and Dr. Todd S. Bridges, respectively.

This work was performed at the SWG and CHL during the period October 2011 to September 2012. The report was prepared under the direction of Dr. Jeffrey P. Waters, Chief of the Coastal Engineering Branch; Dr. Rose M. Kress, Chief of the Navigation Division; Jose E. Sanchez, Deputy Director; and Dr. William D. Martin, Director of CHL.

COL Kevin J. Wilson was Commander and Executive Director, and Dr. Jeffery P. Holland was Director of ERDC.

Unit Conversion Factors

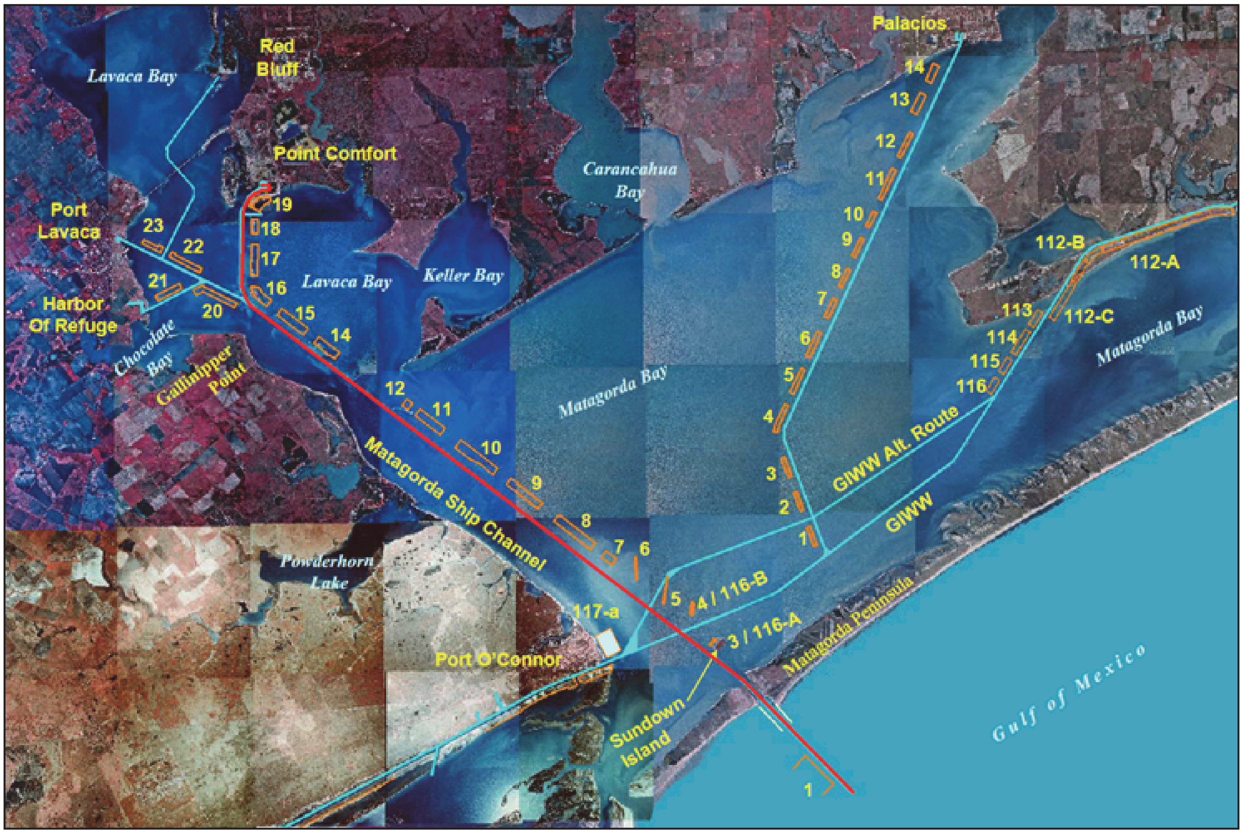
Multiply	By	To Obtain
cubic yards	0.7646	cubic meters
feet	0.3048	meters
inches	0.3937	centimeters
miles (US statute)	1,609.3470	meters

1 Introduction

The Matagorda Ship Channel (MSC) is a deep-draft Federal navigation channel that extends 25 miles (40 km) into Matagorda Bay, Texas. It consists of a 38-ft deep by 300-ft wide entrance channel extending through a jettied inlet and connecting the Gulf of Mexico and Matagorda Bay. The main channel in the Bay is 36-ft deep by 200-ft wide which terminates at a 1,000-ft by 1,000-ft wide turning basin at Point Comfort in Lavaca Bay. The navigation project is located in the vicinities of Port O'Connor, Port Lavaca, and Point Comfort in Matagorda and Calhoun Counties, Texas (Figure 1). Dredged sediments from channel maintenance are disposed in open water placement areas adjacent to the channel (Figure 2).

Figure 1. Location maps of the Matagorda Ship Channel, Texas.

Figure 2. Open water placement areas along the Matagorda Ship Channel.



Critical shoaling in upper reaches of the MSC has caused annual draft restrictions resulting in the need for annual maintenance dredging projects (Figure 1). Project funding is typically limited, and dredging to the authorized depth without advanced maintenance decreases the duration of channel availability to fewer than six months per year. It is suspected that excessive shoaling in the upper reaches of the MSC is mainly due to the disposal of dredged sediments into adjacent open water areas from which the material quickly migrates back into the channel. Additionally, sedimentation from the upper Lavaca Bay contributes to the high shoaling rate in the upper reach; measures to control this shoaling could benefit the project. Other portions of the channel, for example the entrance channel, can experience scour in contrast to the shoaling experienced in the upper reach.

The purpose of the present study is to understand the MSC, Matagorda Bay, and Lavaca Bay as a system and evaluate possible structures or other methods (alternatives) to reduce the shoaling rate in the upper reach of the MSC. Reducing the channel infilling rate would result in providing an adequate level of service and safe deep-draft navigation conditions while conserving valuable funds by increasing the cycle time between dredging events.

To reduce the channel infilling rate and provide a remedial solution in the upper reach of MSC, three Research and Development (R&D) programs at the US Army Engineer Research and Development Center (ERDC) worked together to investigate and perform numerical modeling of sediment transport for the Ship Channel in the Matagorda Bay system. These three R&D programs were as follows: the Regional Sediment Management (RSM) Program, Coastal Inlets Research Program (CIRP), and Dredging Operations and Environmental Research (DOER) Program. The modeling was focused on evaluating the MSC, Gulf Intracoastal Waterway (GIWW), Matagorda Bay, and Lavaca Bay as a system for hydrodynamics and sediment transport as these processes interact with river influxes and tidal forcing from the Gulf of Mexico (GOM). The main challenge was to model mixed-sizes and types of sediment, as there is more silt and clay (cohesive) material in the Lavaca Bay and upper Matagorda Bay and sandy (non-cohesive) sediment in the lower Matagorda Bay. The mixed sediments also present a challenge for investigating and modeling of sedimentation under combined wave and current conditions.

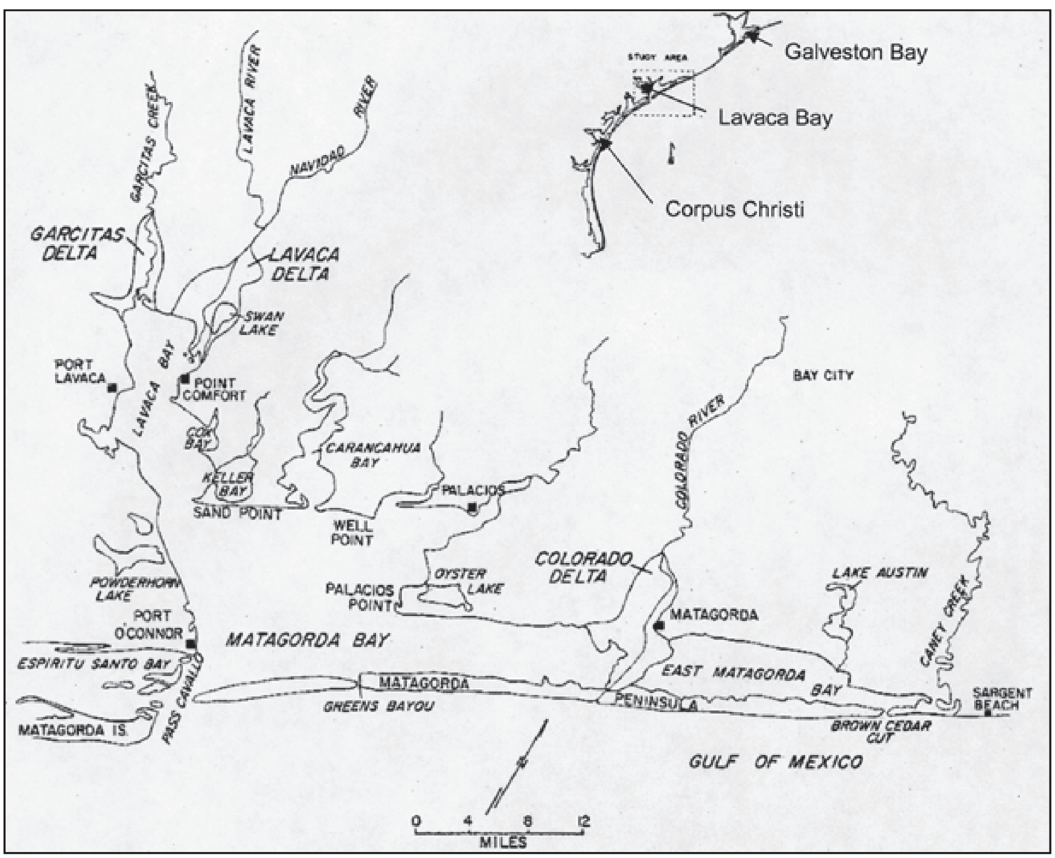
2 Physical Setting and Sediment Budget

This chapter describes geography, physical processes, and engineering activities in the Matagorda Bay region. Information summarized in this chapter should be used in conjunction with an understanding of coastal processes illuminated by numerical modeling discussed in Chapter 3 to inform development of potential solutions to improve the management of sediments.

2.1 Freshwater Flow into Lavaca and Matagorda Bays

Freshwater flow into Matagorda Bay is moderate and consists primarily of discharges from the Colorado River Diversion Channel and the Lavaca and Navidad rivers (Figure 3). The present delta prograding from the Lavaca and Navidad rivers extends approximately 2.7 miles (4.3 km) into Lavaca Bay but has protruded as far as 10.9 miles (17.5 km) in the past (Byrne 1975).

Figure 3. Major bodies of water and rivers in Matagorda Bay system (Byrne 1975).



The ship simulation study discussed in the original design memorandums for the MSC from the 1960s quantified the sediment entering the system from the Lavaca and Navidad Rivers as approximately 700,000 cubic yards per year (cy/yr). Other freshwater contributors include Garcitas Creek, Placedo Creek, East and West Carancahua Creeks, and Palacios Creek. The Garcitas Creek has formed a notable delta, although it has not protruded into Lavaca Bay in recent history. According to sediment studies done in the 1970s, most of the mud that covers the floors of the Matagorda Bay system was transported via these freshwater sources. Figure 4 shows the historical changes of sedimentation in the Lavaca and Matagorda Bays after construction of the MSC.

2.2 Bay Bathymetry

Both Lavaca and Matagorda Bays are shallow with the nominal depths averaging 6.6 to 8 ft (2 to 2.5 m). The entrance to the MSC is 38-ft deep by 300-ft wide, and the main channel is 36-ft deep by 200-ft wide. Placement areas located adjacent to and on the eastern side of the MSC are also shallow at depths less than 6.6 ft (2 m). Figure 5 shows that bathymetry in the area adjacent to the MSC on the east in Lavaca Bay, where channel shoaling and sedimentation are a problem, appears to be shallower than the surrounding areas.

Processes that potentially lead to sediment transport and re-suspension in Matagorda Bay and East Matagorda Bay include wind driven wave re-suspension, storm surges, wind driven blowouts, and river flooding (Bronikowski 2004). According to Pandoe and Edge (2008), the presence of wave action significantly increases the amount of suspended sediment, and consequently, more deposited sediments occur around the ship channel, where shallow shoals are located.

2.3 Placement Areas

Most dredged material placement areas within the MSC are in open water sites east of and adjacent to the main channel. These placement areas are primarily at depths less than 6.6 ft (2 m) with several exposed during low tide. Surveys of these placement areas are not available due to the difficulty to navigate into the shallow depth. The GIWW that intersects the MSC in the lower bay is dredged less frequently with the exception in the vicinity of the junction with the MSC. Historically, material from this segment has been placed on Sundown Island (Figure 2) or in Placement Area 2 (PA 2). More recently dredged material from the GIWW has been placed in Placement Area 6 (PA 6) along the MSC.

Figure 4. Sedimentation increase in Lavaca and Matagorda Bays after construction of the Matagorda Ship Channel (Bronikowski 2004).

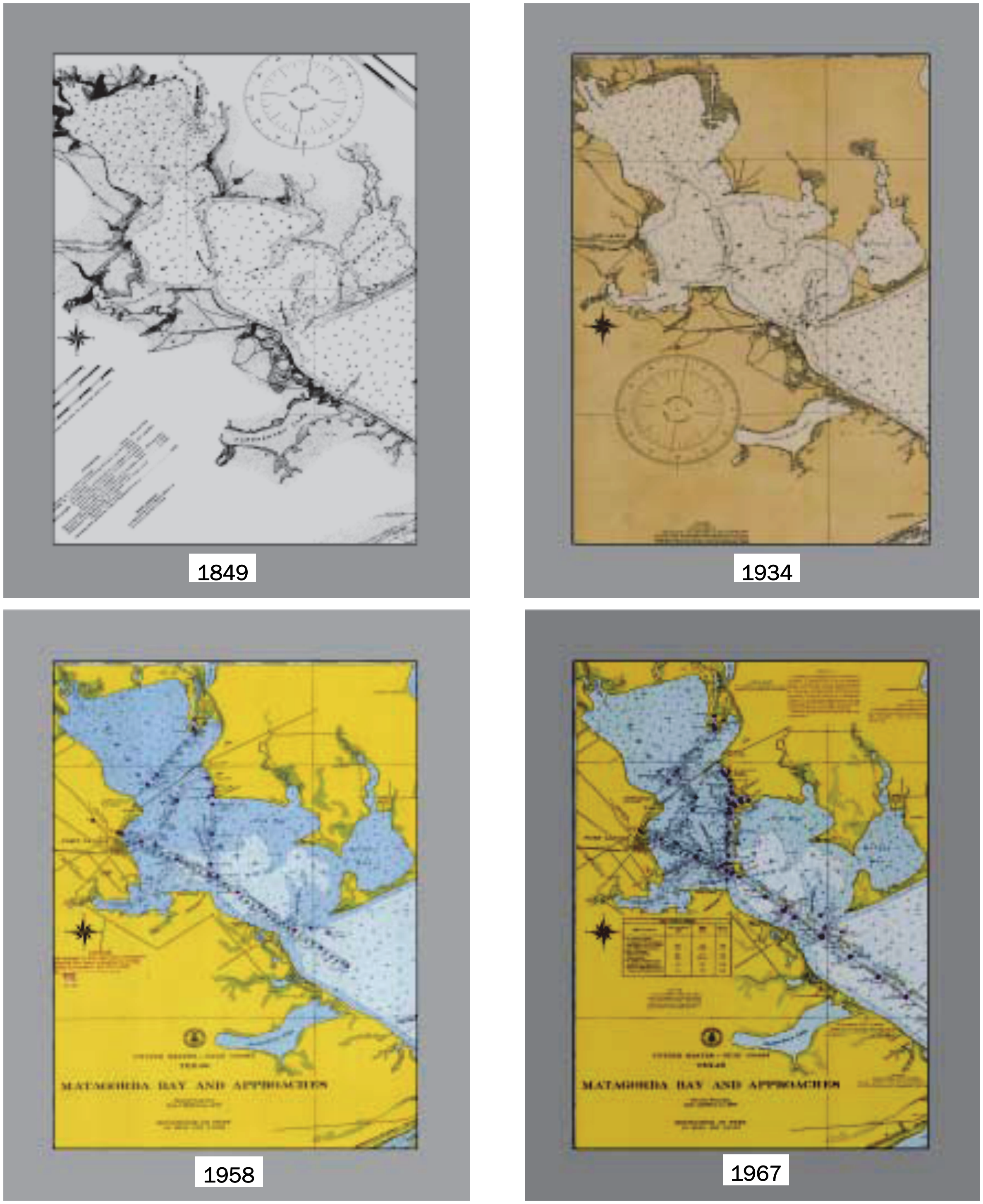
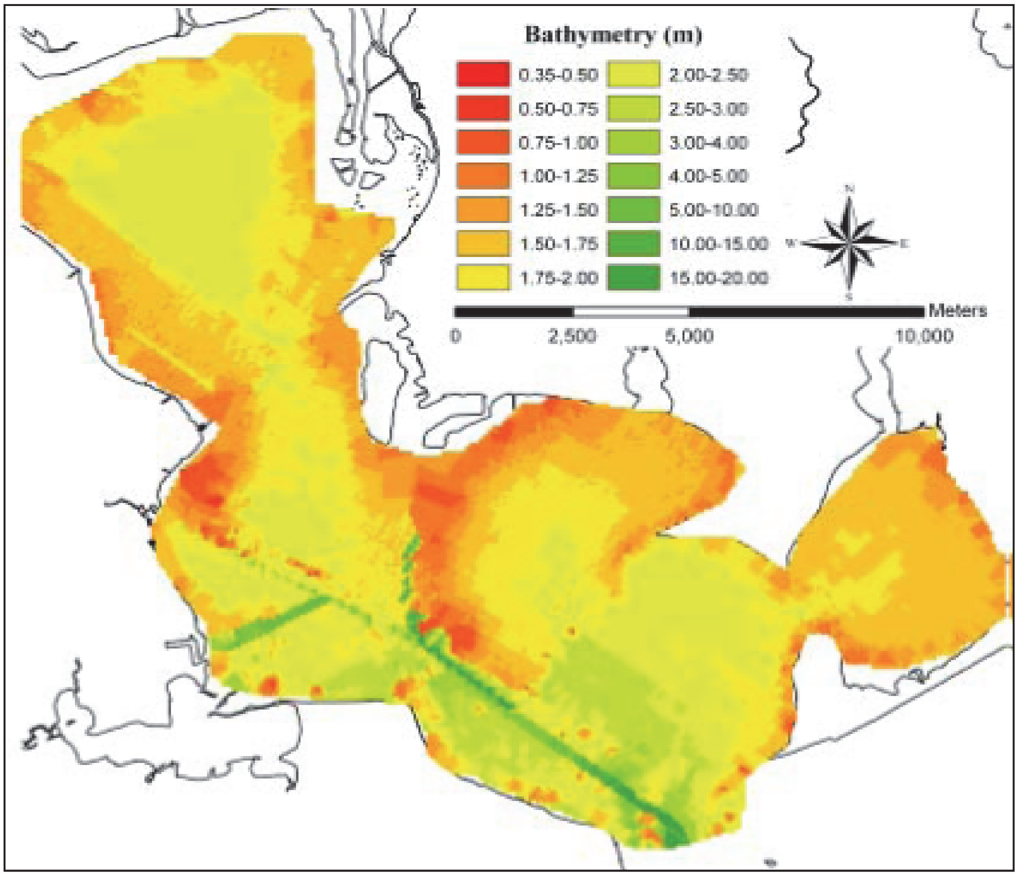


Figure 5. Upper bay bathymetry based on surveys from December 2002 to April 2003 (Bronikowski 2004).



For the channel from the GIWW to Palacios (Figure 2), a shallow draft channel, the open water placement areas are also located adjacent to the channel but on the western side of the channel as opposed to placement areas along the MSC.

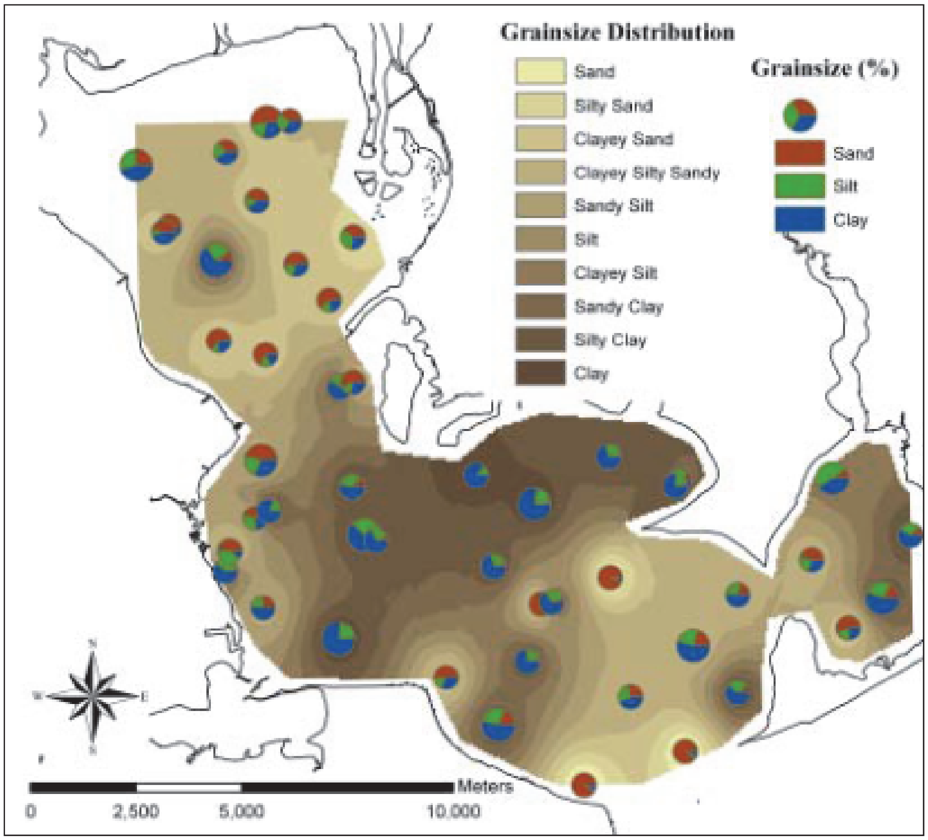
2.4 Sediment Distribution

Figure 6 shows the grain size distribution of the Lavaca Bay. Figure 7 shows the sediment distribution of the Matagorda Bay system. Sediment varies from silt to clay in the upper and mid bays and sandy material in the lower bay.

2.5 Dredging History

The SWG maintains the deep- and shallow-draft navigation channels which transverse Matagorda Bay. These channels include the MSC, the GIWW, the channel to Port Lavaca, and the channel to Palacios. Detailed dredging records were used to quantify the annual shoaling of these channels.

Figure 6. Grain size map showing the distribution of textures in the upper bay - delineation of bottom types based on Shepard's Classification (Brownskowski 2004).



2.5.1 Matagorda Ship Channel – Entrance Channel

For the MSC Entrance Channel, minimal sand is transported from the Gulf to Matagorda Bay. The jettied entrance has been studied recently in great detail by the SWG. At the bottleneck portion (constricted portion through the peninsula) of the Entrance Channel, there has been severe scouring by strong tidal currents. Recent studies indicate that the channel cross section through the bottleneck will likely continue to scour at approximately 1 ft/yr while the width remains constant (Maynord et al. 2011).

Table 1 is a list of dredging information for the Entrance Channel (offshore and jetty channels). The average dredging rate is 346,000 cy/yr from 1971 to 2006, which occurs primarily in the offshore reach; recent studies indicate scouring is evident in the jetty channel (USACE 2012). Moffat and Nichol (2007) estimated an average of 259,000 cy/yr of material dredged from the offshore channel. Material dredged from offshore and jetty channels is placed offshore.

Figure 7. Sediment Distribution of Matagorda Bay System (McGowen et al. 1979).

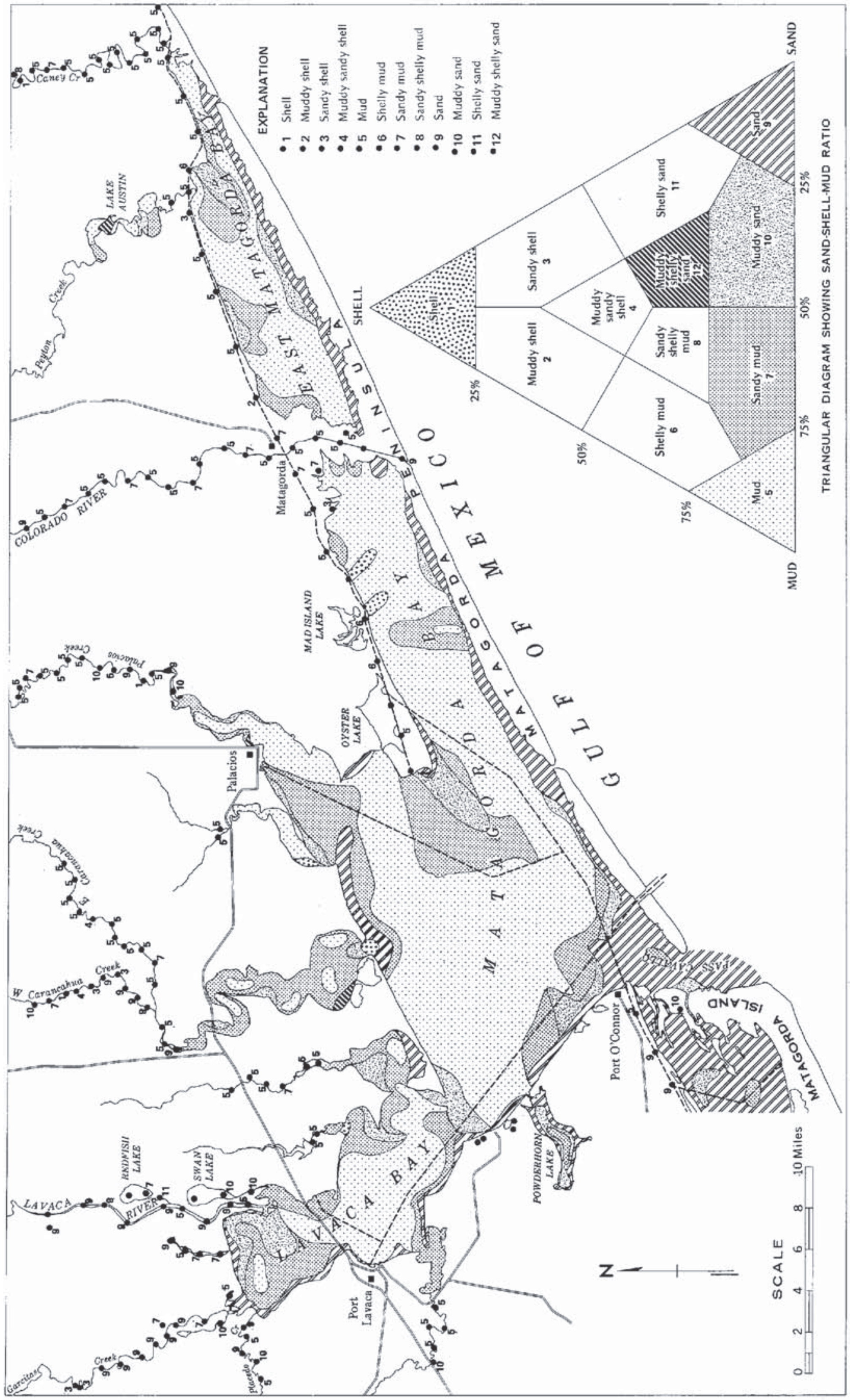


Table 1. Dredging history for MSC Gulf Entrance (Offshore and Jetty) from 1971 to 2006.

Date	Type	Dredged Quantity, (cy)
8/8/1971	Maintenance	1,135,825
4/16/1972	Maintenance	484,560
4/29/1975	Maintenance	547,000
5/6/1975	Maintenance	1,463,473
2/18/1976	Maintenance	943,112
1/31/1978	Maintenance	290,000
8/31/1979	Maintenance	539,891
12/22/1980	Maintenance	1,790,548
3/7/1984	Maintenance	908,933
2/20/1989	Maintenance	498,040
9/7/1993	Maintenance	664,190
10/21/1996	Maintenance	488,383
8/22/1999	Maintenance	590,740
10/29/2001	Maintenance	310,655
2/10/2004	Maintenance	365,226
8/22/2006	Maintenance	1,097,451

2.5.2 Matagorda Ship Channel - Main Channel

The main channel has been dredged on an annual basis in recent years, with the dredging often completed in two sections – Matagorda Peninsula to Galnipper Point (Station 0+000 to 95+000) and Galnipper Point to Point Comfort (Station 95+000 to 117+223). Figure 2 shows the locations of Galnipper Point and Point Comfort. Tables 2 and 3 present the dredging history from 1989 to 2010 for these two sections. Note Table 3 includes the section referred to as Point Comfort Turning Basin or Calhoun Port Authority Docks (Station 116+593 to 118+502) in various contracts. Table 4 lists the placement areas with the dredged material typically placed based on stationing. Based on the dredging history, the average maintenance dredging for the combined main channel (Tables 2 and 3) is approximately 2,319,000 cy/yr. A separate study by Moffat and Nichol (2007) divided the main channel into a Matagorda Bay segment from Station 10+000 to 75+000 and a Lavaca Bay segment from Station 75+000 to 110+000. The shoaling rates were 1,156,000 cy/yr for the Matagorda Bay segment and 1,778,000 cy/yr for the Lavaca Bay segment (USACE 2012).

Table 2. Maintenance dredging records for Matagorda Ship Channel (main channel Station 0+000 to 95+000) from 1991 to 2010.

Start Date	Completion Date	Type	Stations	Dredged Quantity (cy)
11/7/1991	3/17/1992	Maintenance	15+000 to 95+000	2,755,018
10/26/1993	7/7/1994	Maintenance	14+000 to 95+000	4,048,086
3/15/1998	6/12/1999	Maintenance	15+000 to 95+000	3,393,000
1/22/2001	2/25/2002	Maintenance	17+000 to 95+000	2,575,703
12/20/2003	5/17/2004	Maintenance	9+000 to 95+000	3,279,900
3/1/2006	3/28/2007	Maintenance	17+000 to 95+000	4,159,794
3/18/2009	10/1/2009	Maintenance	8+000 to 95000	2,707,866
3/15/2010	8/21/2010	Maintenance	0+000 to 95+000	1,825,000

Table 3. Maintenance dredging records for Matagorda Ship Channel (main channel Station 95+000 to 118+502) from 1989 to 2010.

Start Date	Completion Date	Type	Stations	Dredged Quantity (cy)
12/1/1989	1/23/1990	Maintenance	80+000 to 117+223	2,060,726
11/7/1991	3/17/1992	Maintenance	95+000 to 117+223	2,385,321
10/26/1993	7/7/1994	Maintenance	95+000 to 117+223	2,572,194
3/15/1998	6/12/1999	Maintenance	95+000 to 117+223	3,471,297
1/22/2001	2/25/2002	Maintenance	95+000 to 120+000	2,013,017
1/24/2003	4/11/2003	Maintenance	95+000 to 117+223	1,601,789
12/20/2003	5/17/2004	Maintenance	95+000 to 118+502	1,129,496
1/1/2005	3/12/2005	Maintenance	95+000 to 117+223	1,585,989
3/1/2006	3/28/2007	Maintenance	95+000 to 118+502	1,852,572
4/7/2007	6/6/2007	Maintenance	85+000 to 117+223	1,710,304
6/18/2008	4/4/2009	Maintenance	95+000 to 117+223	1,692,078
3/18/2009	10/1/2009	Maintenance	98+600 to 101+000	14,829
3/15/2010	6/22/2010	Maintenance	95+000 to 118+502	1,868,023

Overall, the dredging records indicate the upper reaches are dredged more frequently, substantiating that the rate of shoaling in the Lavaca Bay reach (the main area of concern for shoaling in this project) is higher than in the Matagorda Bay. The shoaling values estimated from the dredging history are slightly higher than those from Moffat and Nichol (2007), and these values may account for the more recent trend in problematic shoaling within the upper stretches of the channel.

Table 4. Distribution of placement areas for Matagorda Ship Channel.

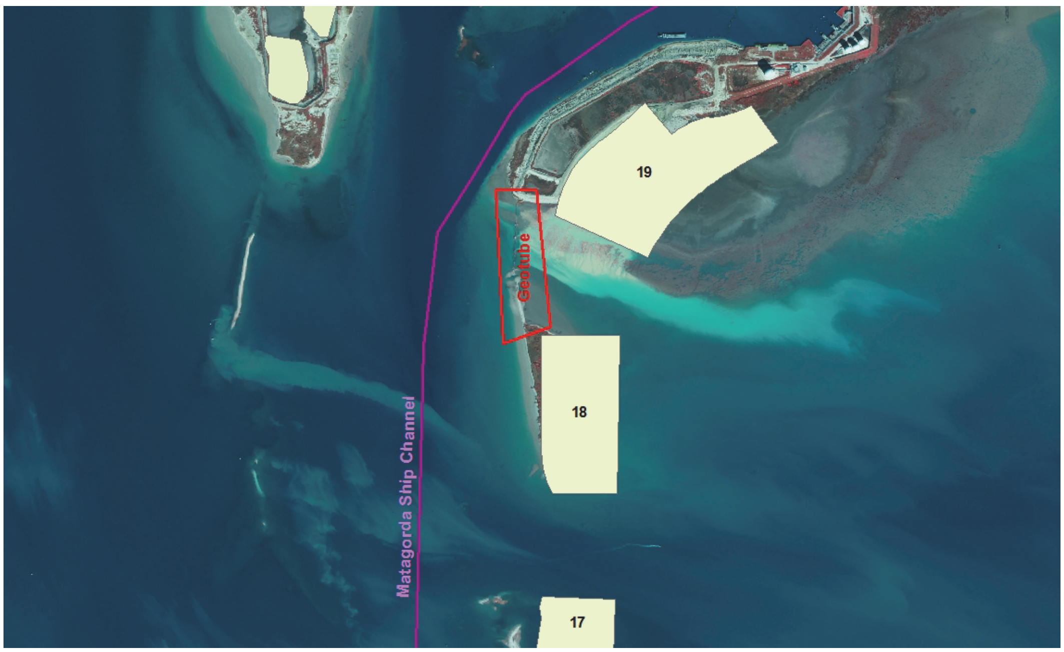
STARTING CHANNEL STATION	ENDING CHANNEL STATION	PLACEMENT AREA NOS.
MATAGORDA SHIP CHANNEL		
MATAGORDA PENINSULA TO POINT COMFORT – SCHEDULE NO. 1		
8+000	15+000	3
15+000	20+000	6
20+000	25+000	6
25+000	30+000	7
30+000	35+000	7
35+000	40+000	8
40+000	45+000	8
45+000	50+000	9
50+000	55+000	10
55+000	60+000	10
60+000	65+000	11
65+000	70+000	11
70+000	75+000	12
75+000	80+000	14
80+000	85+000	14
85+000	90+000	15
90+000	95+000	15
95+000	98+600	16
98+600	105+000	17
105+000	110+000	18
110+000	115+000	19
115+000	118+502	19
GULF INTRACOASTAL WATERWAY		
NATURAL BAY BOTTOM ROUTE – SCHEDULE NO. 1		
615+400	616+600	6
MATAGORDA SHIP CHANNEL		
CALHOUN PORT AUTHORITY DOCKS – OPTION		
116+593	118+502	19

2.5.3 Effects of Geotube Installation in the Upper Matagorda Ship Channel

A geotube was placed in the early 2000s to prevent shoaling in the channel and was re-established in 2008. The geotube and is located adjacent to the

MSC along the eastern side between PA 18 and 19. While the amount of sediment being retained by the geotube has not been quantified, it is apparent from aerials that the geotube has reduced the amount of sediment filtering into the channel (Figure 8). To quantify the material retained by the geotube, the dredging records pre- and post-installation of the geotube (from PA 17 to the turning basin at Point Comfort) would need to be analyzed.

Figure 8. Geotube between PA 18 and PA 19 along the Matagorda Ship Channel.



2.5.4 GIWW Maintenance

The GIWW in Matagorda Bay was originally authorized by Congress in 1939. The GIWW was relocated to the south in 1944 in support of military activities at Camp Hulen near Palacios. This was most likely accomplished with local discretionary authority. Congress authorized the re-establishment of the original authorization in 1962. Most of the GIWW is no longer maintained within the Matagorda Bay system, with the exception of the area that intersects the MSC from Station 600+00 to 615+00, where annual maintenance is required (Table 5). Historically the dredged material was placed into PA 116-B or onto Sundown Island. Recently, the material dredged from the GIWW has been placed in PA 6. From 2005 to 2011, the average amount of material placed in PA 6 from this section of the GIWW was 65,000 cy/yr. The average volume dredged per year from the GIWW historically over a longer trend estimate by Moffat and Nichol (2007) was 88,800 cy/yr.

Table 5. Maintenance dredging of GIWW Station 605+000 to 616+000 (2005 to 2011).

Dredging Date	Stations	Dredged Quantity (cy)
1/16/2005 - 3/25/2005	605+000 to 616+600	109,217
1/10/2006 - 3/19/2006	605+000 to 616+600	229,562
1/27/2008 – 2/5/2008	605+000 to 616+600	10,989
3/16/2009 - 5/26/2009	615+400 to 616+600	14,830
3/15/2010 - 6/22/2010	615+400 to 616+600	10,984
3/15/11 - 8/30/2011	615+400 to 616+600	16,000

2.5.5 Channel to Port Lavaca

The Channel to Port Lavaca has not been dredged as frequently as in recent years. Table 6 presents the dredging volume from 1965 to 2003. The average shoaling quantity excluding new work is 258,500 cy/yr. Table 7 presents the placement areas of dredged material for the Channel to Port Lavaca. PA 22 and PA 23 are located on the northern side of the channel.

Table 6. Maintenance Dredging for Channel to Port Lavaca (1965 – 2003).

Date	Type	Dredged Quantity (cy)
3/20/1965	Maintenance	519,273
6/11/1967	Maintenance	677,057
11/24/1969	Maintenance	523,910
3/26/1972	Maintenance	657,072
11/15/1974	Maintenance	742,531
1/21/1979	Maintenance	805,771
7/8/1982	Maintenance	850,946
3/18/1985	Maintenance	536,518
1/30/1987	Maintenance	553,955
4/16/1989	Maintenance	666,650
2/27/1992	Maintenance	750,426
5/28/1994	Maintenance	796,723
6/24/1996	Maintenance	745,098
4/4/2000	Maintenance	89,931
7/30/2003	Maintenance	882,646

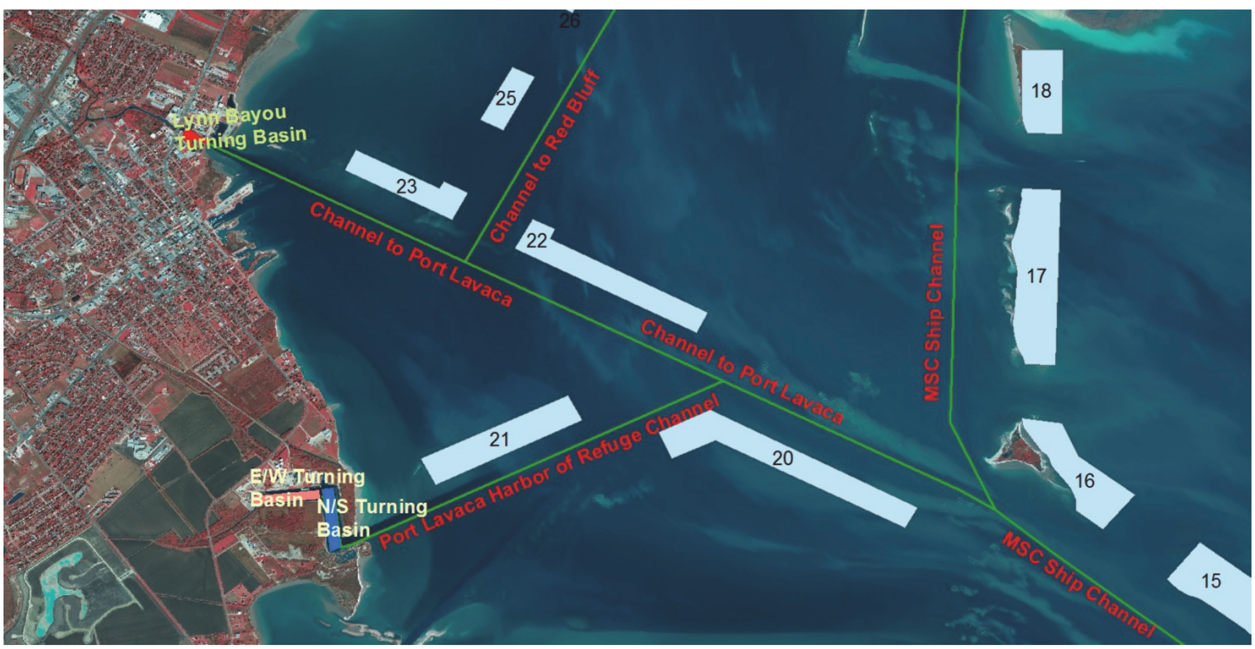
Table 7. Distribution of dredged material for Channel to Port Lavaca.

STARTING CHANNEL STATION	ENDING CHANNEL STATION	PLACEMENT AREA NOS.
6+00	70+00	20
70+00	150+00	22
150+00	217+71	23

2.5.6 Port of Lavaca Harbor of Refuge Channel Including All Turning Basins

This section discusses the USACE maintained channels in the upper Lavaca Bay system including their respective turning basins. Figure 9 shows a close-up view of channels and turning basins and the placement areas that have been typically used for dredging located adjacent to the channels. These are primarily shallow-draft channels, which are dredged less frequently in recent years due to lack of funding or because of the more urgent need to dredge the higher priority (deep-draft channel) shoaling areas. Records from the 1990s until recently for these channels and turning basins lacked needed information making it difficult to understand the recent trends in shoaling. Record keeping has improved since the early 2000s but limited dredging has occurred in these areas to the present day. Improved future data collection is necessary to understand this part of the system.

Figure 9. Upper Lavaca Bay Channels.



2.5.7 Lynn Bayou Turning Basin

This section has not been dredged since 2000. Table 8 presents the dredging history from the SWG Dredging Histories Database. The average yearly dredging rate was 3,700 cy/yr with the channel being dredged approximately every four years. In recent years, dredging has been more infrequent. Sediment from Lynn Bayou Turning Basin is placed into PA 23.

Table 8. Matagorda Ship Channel: Lynn Turning Basin (1982 – 2000).

Date	Type	Dredged Quantity (cy)
7/8/1982	Maintenance	15,704
3/18/1985	Maintenance	8,206
1/30/1987	Maintenance	7,123
4/16/1989	Maintenance	5,910
5/28/1994	Maintenance	13,317
4/4/2000	Maintenance	15,611

2.5.8 Port Lavaca Harbor of Refuge and East–West Turning Basin

This segment has not been dredged in recent years. Table 9 presents the dredging history from 1982 to 2003. Based on dredging history, the average annual shoaling was approximately 8,200 cy/yr.

Table 9. Port of Lavaca Harbor of Refuge and Turning Basin East-West.

Date	Type	Dredged Quantity (cy)
7/8/1982	Maintenance	62,071
5/28/1994	Maintenance	64,607
7/30/2003	Maintenance	45,000

2.5.9 Port of Lavaca Harbor of Refuge and North-South Turning Basin

The North-South Turning Basin has been dredged infrequently in recent years. Table 10 presents the dredging records from 1969 to 2006. The dredging history indicates the average dredged quantity was 114,000 cy/yr. The shoaling rate in this section from 2003 to 2006 is 55,000 cy/yr. In the sediment budget, a combined cell for the two turning basins (East-West and North-South) had an average annual shoaling of 18,400 cy/yr with placement in PA 21 from 1982 to 2006.

Table 10. Port of Lavaca Harbor of Refuge and Turning Basin North-South (1969 to 1994).

Date	Type	Dredged Quantity (cy)
11/24/1969	Maintenance	123,797
7/8/1982	Maintenance	82,287
5/28/1994	Maintenance	86,339
7/30/2003	Maintenance	51,000
8/2006	Maintenance	164,000

2.5.10 Port of Lavaca Harbor of Refuge Channel

Table 11 presents the dredging history for the Port of Lavaca Harbor of Refuge Channel from 1963 to 2003. Excluding new work material, the average annual dredging rate was 192,000 cy/year. The channel had less accumulation in recent years, and the shoaling rate based on more recent surveys (since 2003) is much less than the historical average, approximately 45,000 cy/year. Sediment is placed into PA 20 and 21.

Table 11. Port of Lavaca Harbor of Refuge, Channel (1963 to 2003).

Date	Type	Dredged Quantity (cy)
3/1/1963	New Work	633,860
3/20/1965	Maintenance	351,251
11/6/1967	Maintenance	411,056
11/24/1969	Maintenance	330,505
3/26/1972	Maintenance	447,233
11/151974	Maintenance	455,642
1/21/1979	Maintenance	467,880
7/8/1982	Maintenance	483,069
3/18/1985	Maintenance	377,210
1/30/1987	Maintenance	368,506
4/16/1989	Maintenance	397,105
2/27/1992	Maintenance	506,161
5/28/1994	Maintenance	457,784
6/24/1996	Maintenance	413,050
4/4/2000	Maintenance	1,175,956
7/30/2003	Maintenance	390,767

2.5.11 Channel to Palacios

The Channel to Palacios reach is not dredged as frequently as the MSC. The placement areas are open water placement sites adjacent to the navigation channel. Palacios Creek likely adds some sediment into the system. It is possible that some of the sediment from the re-diverted Colorado River is depositing within this stretch. Most of the bay surrounding the Palacios channel appears to be mud. However, the middle reach of the channel crosses through sandy mud, which may come from the point to the west of Oyster Lake. The portion of the channel close to Palacios is also sandy mud. Table 12 presents the maintenance dredging quantities for this channel from 1946 to 2010. The annual dredging volume is approximately 409,000 cy/yr.

Table 12. Maintenance dredging for Channel to Palacios (1946 to 2010).

Start Date	Completion Date	Dredged Quantity (cy)
2/16/1946	4/14/1946	851,524
5/7/1950	11/25/1950	324,700
4/26/1954	5/29/1954	381,270
10/1/1959	10/18/1959	677,113
12/28/1961	1/15/1962	554,148
11/14/1964	1/7/1965	554,598
4/15/1968	5/4/1968	726,330
1/13/1971	3/22/1971	2,199,740
10/31/1973	5/7/1973	1,078,414
2/27/1977	3/7/1977	2,068,703
10/4/1979	12/11/1979	2,274,094
3/13/1983	6/8/1983	2,315,555
6/23/1986	9/15/1986	2,070,128
10/26/1988	12/13/1988	1,284,247
3/1/1992	6/8/1992	1,799,634
4/20/1995	6/18/1995	1,977,512
12/1/1998	1/27/1999	2,397,471
1/9/2001	1/30/2002	1,828,413
4/27/2010	7/23/2010	787,740

Table 13 presents the placement areas of dredged material for Channel to Palacios. The placement areas adjacent to the channel are indicated in Figure 2.

2.5.12 Pass Cavallo

Pass Cavallo is the natural inlet to the west of the MSC Jetty Entrance Channel (Figure 1). It is a historically unstable inlet that connected the Gulf of Mexico and Matagorda Bay prior to the construction of MSC Entrance channel in 1963 and 1964. After construction of the MSC, tidal hydraulics became much more efficient through the manmade channel than Pass Cavallo. In response, Pass Cavallo experienced significant shoaling and intrusion by growth of barrier spits both from the Matagorda Peninsula to the east and Matagorda Island to the west.

Table 13. Distribution of dredged material for Channel to Palacios.

STARTING CHANNEL STATION	ENDING CHANNEL STATION	PLACEMENT AREA
APPROACH CHANNEL		
0+00	5+01	13
MUNICIPAL BASIN		
0+00	11+30	13
MAIN CHANNEL		
0+65	50+00	13
50+00	100+00	13
100+00	150+00	13
150+00	200+00	12
200+00	250+00	11,12
250+00	300+00	11
300+00	350+00	9,10
350+00	400+00	8,9
400+00	450+00	7,8
450+00	500+00	6,7
500+00	550+00	6
550+00	600+00	5,6
600+00	650+00	4,5
650+00	700+00	3,4
700+00	750+00	3
750+00	800+00	2
800+00	854+60	1

Between 1964 and 1995, the inlet width decreased by approximately 9,500 ft. Since then, the inlet has been relatively stable. It may have reached a semi-equilibrium state in which the inlet width changes with seasonal fluctuation and widens slightly in winter.

Sediment in and around the pass is primarily sand and muddy sand associated with the flood-tidal delta and grades bayward into sandy mud. However, the quantity of material coming into the system or vice versa has not been quantified although several studies have been established to look at the stability of the pass. Historically, the pass has reduced in size dramatically, although it appears to have reached a fairly stable equilibrium in recent years. Recent aerial imagery from 2008 to 2011 (Figures 10 to 12) indicates there is an area of accretion just inside the pass to east side, a flood shoal. It also appears that the shoreline front of the peninsula is accreting.

Figure 10. Pass Cavallo in 2008.

Figure 11. Pass Cavallo in 2009.

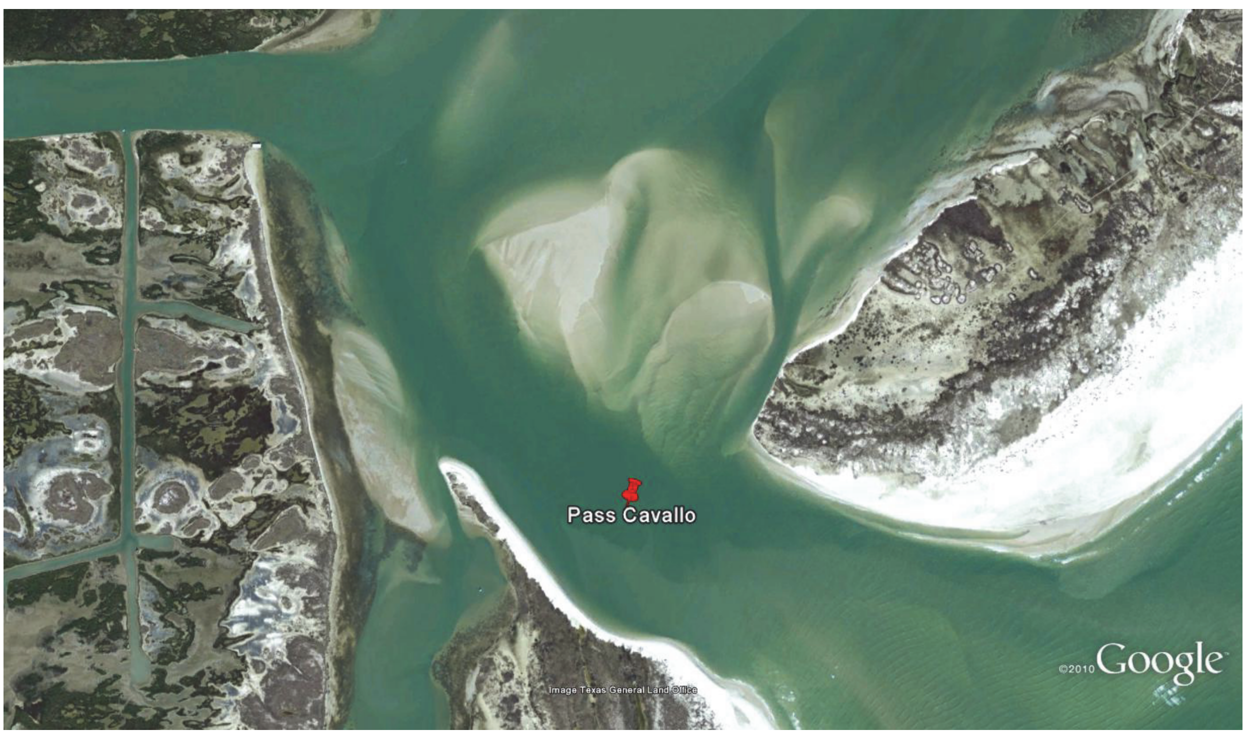


Figure 12. Pass Cavallo in 2011.

2.5.13 Greens Bayou

Greens Bayou, located across the Matagorda Peninsula, is a storm channel that opens only during hurricanes. The approximate location of Greens Bayou is shown previously in Figure 3. It typically functions as an inlet for a few months following the storm and then recloses.

2.5.14 Sediment Accretion on the Bay Side of Matagorda Peninsula

From historic aerials, the bay shores of Matagorda Peninsula have been accreting at a significant rate. The sediment source is unknown; likely candidates include placement areas contingent to the GIWW and sediment from the re-diverted Colorado River delta, which has prograded across Matagorda Bay. The sediment on the Bayside of the barrier island is primarily sand with some deposits of mud (McGowen et al. 1979). If the accreted sediment on the Bayside of the island is in fact primarily sand, then the source may be from overwash from the Gulf of Mexico, or the accreted sediment could have been transported from Pass Cavallo or the MSC entrance. Because both MSC entrance and Pass Cavallo are now more stable, the rate of Bayshore accretion could decrease.

2.5.15 Mouth of the Colorado River

The Colorado River was rerouted to Matagorda Bay by the SWG in 1992 to supply fresh water to the Bay. The rerouted river is one of the primary sources of fresh water flow and sediment into the Matagorda Bay system. Aerials indicate that a delta began forming almost immediately in Matagorda Bay after the diversion occurred (Figures 13 to 15). The delta is likely a significant source of muddy material into the system. The amount of sediment contributed to the system is unknown but significant.

2.6 Matagorda Nautical Depth

2.6.1 Background

Fluid mud flow up the MSC was observed from survey data. Hydrographic surveying on waterways containing fluid mud, a.k.a. fluff, compared to more consolidated bottom materials like sand can pose difficulties in determining where the channel bottom actually lies. The acoustic reflection of conventional hydrographic surveying equipment used to measure water depth may not necessarily identify a depth within the fluid mud column that characterizes a nautical bottom. The term nautical bottom is defined by the

Figure 13. Pre re-route in 1990.

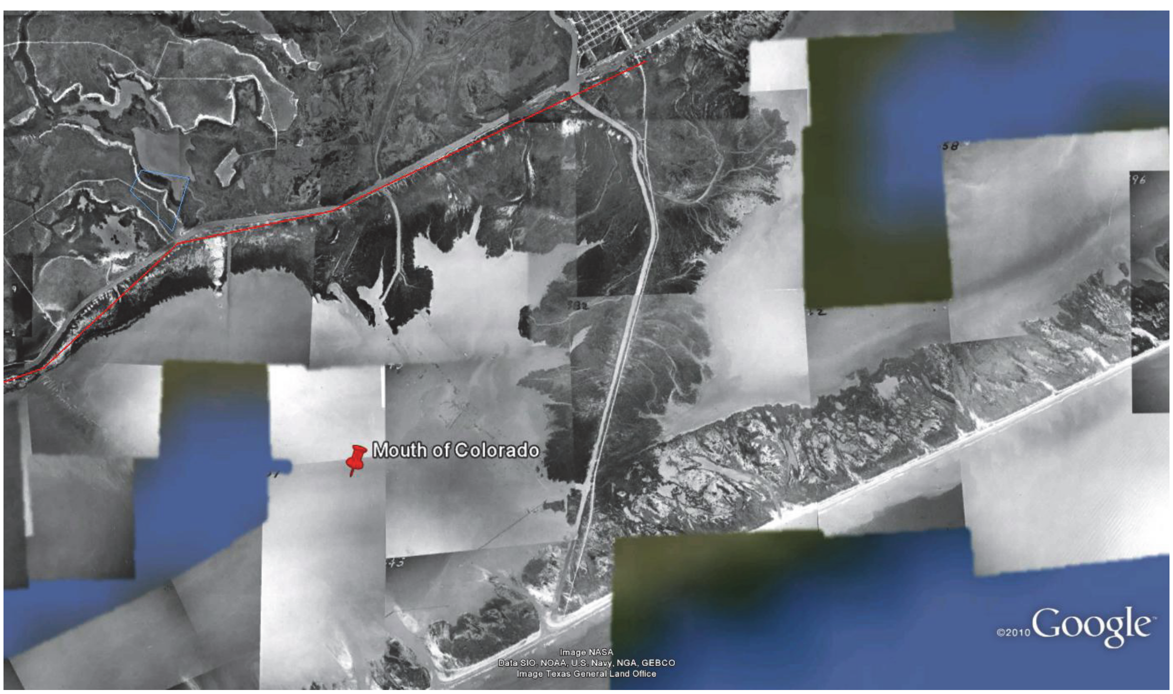


Figure 14. Post re-route in 1995 – formation of delta evident in Matagorda Bay.

Figure 15. Re-routed Mouth of the Colorado River in 2011.

Permanent International Association of Navigation Congresses (PIANC 1997) as "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." With nautical bottom defined as such, the term nautical depth (PIANC 1997) is defined as "the instantaneous and local vertical distance between the nautical bottom and undisturbed free water surface."

The USACE presently has no standardized method to measure the fluid mud to determine nautical depth. The Engineer Manual 1110-2-1003 Hydrographic Surveying (USACE 2003) states "when the upper sediment layer is not well consolidated, the three major depth measurement methods used in the Corps (sounding pole, lead line, and acoustic echo sounding) will generally not correlate with one another, or perhaps not even give consistent readings from one time to the next when the same type of instrument or technique is used." This ambiguity in determining depth has hindered the USACE optimization of maintenance dredging in navigation channels with significant amounts of fluid mud.

An operational definition of nautical bottom in areas of fluid mud based on density or other rheological parameters has reduced maintenance dredging costs in Europe (De Meyer and Malherbe 1987; Herbich et al. 1989; Teeter 1991) and allowed the use of innovative dredging techniques such as sediment conditioning where the fluid mud is pumped into a modified hopper, conditioned (oxygenated and mixed to reduce viscosity and yield strength), then returned to the bottom (Wurpts 2005; PIANC 2008).

2.6.2 Physical Characteristics of Fluid Mud

As defined by McAnally et al. (2007) "fluid mud is a high concentration aqueous suspension of fine grained sediment in which settling is substantially hindered by the proximity of sediment grains and flocs, but which has not formed an interconnected matrix of bonds strong enough to eliminate the potential for mobility, leading to a persistent suspension." Therefore, the fluid mud can be characterized as suspensions with density gradations that are slightly greater than that of the overlying water in its upper layers. To set a frame of reference of density values, work conducted by Krone (1963) was modified to illustrate the relation of bulk density and solids concentration relative to concepts such as turbidity, fluid mud (high and low density), and typical bottom sediments in Table 14.

Table 14. Ranges of bulk densities and solids concentrations (modified after Krone 1963).

Average Bulk Density (g/cm^3) to Solids Concentration (g/l)

Qualitative Descriptor	Solids Concentration (g/l)	Bulk Density (g/cm^3)
TURBIDITY	0 - 5	1.000 - 1.003
Low Density	5 - 225	1.003 - 1.140
FLUID MUD		
High Density	225 - 500	1.140 - 1.311
"TYPICAL" BOTTOM SEDIMENT	> 500	> 1.311

Assumes Solids - 2.65 g/cm^3
Water - 1.000 g/cm^3

While density and viscosity are related, that relationship can be complicated by other factors (Teeter 1992). The factors include (PIANC 1997) the following:

- stress history
- sand content
- particle diameter
- clay mineralogy
- rate of deformation (shear rate)
- percentage of organic material
- water chemistry (especially pH, salinity, etc.)

Because of the variability in these factors from site to site, fluid mud rheological properties can vary significantly in different locations. Herbich et al. (1989) conducted a survey of US ports and USACE Districts to evaluate the number of harbors and channels experiencing fluid mud conditions and determined that "a high percentage of responses clearly indicated that many US ports experience fluid mud problems and presently no uniform procedure to accurately define the channel depth is practiced."

2.7 Dredging Project Challenges with Fluid Mud

The presence of fluid mud in the navigation channel can present challenges to conventional hydrographic surveying methods and equipment in accurately and precisely determining where the channel bottom is. As indicated by Kirby et al. (1980), the static suspension time-dependant properties control their respective detection by echo sounding and affect the following critical dredging project management aspects:

- measurement of navigable depths
- measurement of dredging required
- increases in depth achieved by dredging
- timing of dredging

This ambiguity in determining depth has hindered the USACE optimization of maintenance dredging in fluid mud areas. An operational definition of the nautical channel bottom in areas of fluid mud based on density or other rheological parameters could reduce maintenance dredging costs (De Mayer and Malherbe 1986; Herbich et al. 1989, 1991; Teeter 1992). Herbich et al. (1989) report that the *navigable* or *nautical* depth concept is practiced unofficially in many US ports as the pilots guide ships through channels that contain fluid mud layers.

2.7.1 Hydrographic Surveying Challenges

Hydrographic surveying in areas with fluid mud often results in ambiguous depth measurements due to effects on mechanical (lead line) and acoustic measurement techniques. The USACE recognized these effects as early as 1954 and attempted to determine navigable depth by correlating depths measured by lead lining and echosounding.

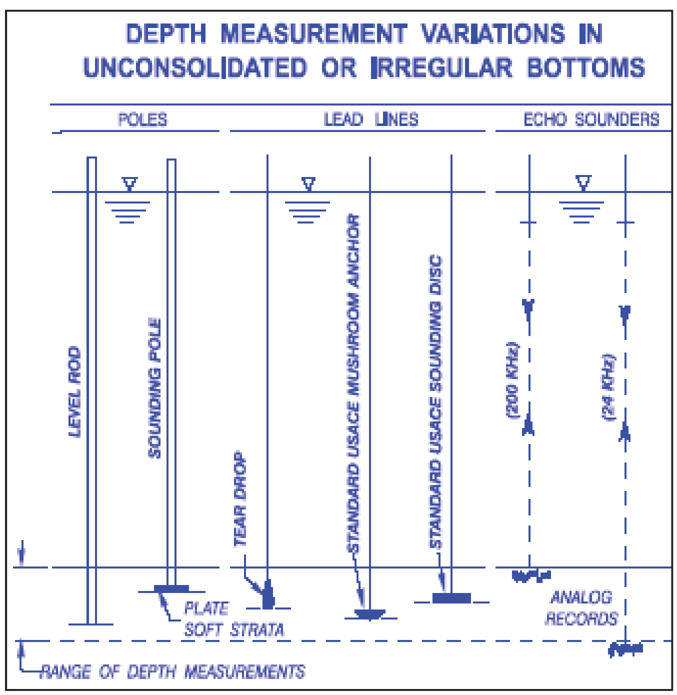
Laboratory and field tests were conducted with variously sized and shaped lead lines in fluid mud and compared to depths recorded by echosounding. The effort focused on attempting to (1) formulate recommendations for better sounding lead shape and procedures, (2) confirm the large range of depth values that can be measured at same station, (3) show range of variables that affect soundings, and (4) indicate the *highly subjective* nature of depth values determined from lead line soundings.

2.7.2 Conventional Acoustic (Echosounding) Depth Measurement

Acoustic echo sounding is the method most commonly used to measure depths in USACE navigation projects. Measurement of water depth was primarily done by lead line until development and implementation of single beam echo sounders in the 1930s, that ultimately became the dominant hydrographic surveying technology used today. However, it is difficult to determine the depth with fluid mud. Depth measurement variations for acoustic echo sounding in fluid mud result from surface reflectivity, density, signal/noise levels, receiver sensitivity, and transducer frequency (USACE 2003).

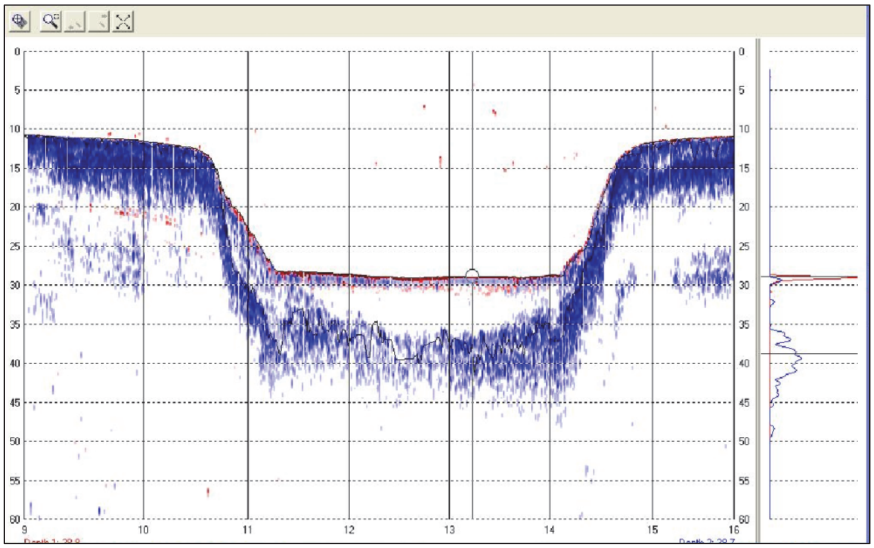
Hydrographic surveys are usually conducted with either a high or low frequency transducer (such as 24 and 200 kHz) or a combination of both frequencies (a duo-frequency system). The depth in fluid mud that an acoustic pulse reflects from is a function of the *sharpness* of fluid mud density gradient (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 high frequency energy will normally reflect from the upper layer of the reflective material, even a very low density one, while the lower frequency depth sounders will penetrate to a lower depth than the higher frequency at the same transmitting power level and receiver sensitivity as shown in Figure 16.

Figure 16. Depth measurement variations over hard and soft bottoms (USACE 2003).



High-frequency echo sounders (200+ kHz) can reflect off the water/muddy water interface, and (given transmit and sensitivity settings are comparable) the lower frequency echo sounders can reflect off a density gradient (or density gradients) deeper in the fluid mud layer. This phenomenon is illustrated in Figure 17 that shows acoustic returns from a dual frequency echo sounder used by the Mobile District (41 and 200 kHz). The high frequency return is being reflected from the water/muddy water interface, and the low frequency return is reflected from a density gradient deeper in the fluid mud layer.

Figure 17. Duo frequency echo sounder returns (black - 41 kHz, red – 200 kHz) in Gulfport Ship Channel.



2.8 Sediment Budget

The sediment budget (Figure 18) investigated in this report focuses on the inner bay system and does not extend beyond the MSC Entrance Jetties. Therefore, shoreline response and longshore sediment transport along the Matagorda Peninsula were not included within this study.

Because of lack of quantified information, many assumptions had to be made which should be researched further to verify and refine the numbers in this sediment budget. The following is a list of the assumptions made to create the sediment budget:

1. Fluid mud flow up the MSC was observed from survey and field data. The actual quantity that fluctuates up and down the navigation channel is unknown. In the present study, numerical modeling was used to provide an indication of the patterns of fluid mud flow but did not quantify the amount of fluid mud that flowed in the channel.
2. Fluid mud appears in the Channel to Palacios. The primary reason for assuming the infilling of fluid mud is the amount of material that accumulates at the upper portion of the channel. It was assumed that 20 percent of fluid mud flow moves from cell to cell.

3. Volumes of fine sediment contributing to the system from the Lavaca River and Garcitas Creek are substantial according to historic documents (including the original design documentation for the MSC). Sediment from Lavaca River is approximately 700,000 cy/yr with approximately 500,000 cy/yr contributing to upper MSC. Because sediment from Garcitas Creek is not quantified, it was assumed to be 250,000 cy/yr with approximately 150,000 cy/yr contributing to the Channel to Port Lavaca.
4. For the MSC, it was known that recirculation from open water placement areas adjacent to the channel was contributing to sedimentation in the channel but the percentage of material recirculating was unknown. In the areas where more recirculation was evident, 20 percent of material placed yearly was assumed to recirculate to the channel. In the areas where less recirculation was evident, it was assumed that 10 percent of the material was recirculated.
5. The amount of sediment infilling the MSC and Palacios Channel from adjacent bays is not quantified. The amount of sediment infilling the channel from the bays was estimated by trial and error and solving the channel cells to determine the amount of fill needed to balance the cell.
6. The sediment budget investigation in this effort involves many uncertainties and unknowns that need to be researched to better estimate sediment movement. It is unclear what the quantity of sediment infilling is in the MSC in terms of fluid mud versus sedimentation from the bay versus recirculation from the placement areas. This sediment budget was intended to evaluate the alternatives to reduce the sediment shoaling in the upper reaches of the MSC.

Figure 18. Matagorda Bay sediment budget movement.

3 Coastal Modeling

A development version of the USACE Coastal Modeling System (CMS) numerical models (Demirbilek and Rosati 2011) was applied in Matagorda Bay. The model results were used to qualitatively illustrate the mixed-size sediment transport driven by waves and currents. This chapter describes the model setup, calibration, and limited results for the existing conditions. Model results were evaluated in detail to help visualize sediment transport sources, sinks, and pathways. Based on these qualitative results, alternatives were developed within the coastal process and engineering activity framework described in Chapter 2.

The CMS was developed under the Coastal Inlets Research Program at ERDC and has been validated and verified for waves, currents, sediment transport, and morphologic change for coastal inlet systems (Demirbilek and Rosati 2011; Sanchez et al. 2011a, 2011b). It can calculate sediment transport and morphology change under combined current and wave condition by coupling a hydrodynamic model, CMS-Flow, and a wave transformation model CMS-Wave through a coupling module operated in the Surface-water Modeling System (Zundel 2006).

3.1 Model description

CMS-Flow is capable of solving the two-dimensional (2D) flow mass conservation and hydrodynamics based on the depth-integrated continuity and momentum equations (Sanchez et al. 2011a, 2011b; Buttolph et al. 2006). The model is forced by changes in water levels (e.g., from tide) along the seaward boundary, flow discharge at the river boundary, wind input field, and wave stresses on the water surface. Physical processes pertinent to the present study calculated by the flow model are the time-dependent current field, water surface elevation, sediment transport, and morphology change.

CMS-Wave is a 2D full-plane, steady-state wave spectral transformation model that solves the wave energy balance equation to calculate wave field properties (Lin et al. 2008). It contains theoretically derived formulations for combined wave diffraction, refraction, reflection, and wave-current interaction. The model is robust and practical for wave simulations at coastal inlets with navigation channels, jetties, and breakwaters. In coastal inlet applications, it is more efficient to run CMS-Wave on a half-plane mode such that primary waves can propagate only from the seaward boundary toward shore.

In the coastal region, where surface waves can play a major role in littoral processes, the influence of waves to flow and sediment transport is calculated through coupling CMS-Flow and CMS-Wave. The CMS-Flow model used in the present study is a development version that includes the cohesive sediment transport for the calculation of mixed sediment transport and pathways. This CMS-Flow developmental model is not available in the public release version.

3.2 Model domain

A CMS rectangular grid with variable cell-spacing was developed for sediment transport modeling of Matagorda Bay. The model domain covers the entire bay with navigation channels connecting the Intercoastal Waterway and the Gulf of Mexico. The CMS grid extends 43 miles (70 km) alongshore and 45 miles (72 km) cross-shore approximately parallel to the ship channel with the southern offshore boundary reaching to the 69-ft (21 m) isobath. Figure 19 shows the model domain which has 153 × 324 cells with variable cell spacing of 82 ft (25 m) at the bay entrance and 5,250 ft (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 use the same rectangular grid.

3.3 Simulation period and model forcing

The model simulations were conducted for a half-year 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 in the upper ship channel, on average 3- to 6-ft (1.0 to 2.0 m) buildup.

The time series of water levels specified along the offshore boundary was 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 20 shows the hourly water level measurements from September 2006 to February 2007 at two NOAA stations, 8775870 and 8771510. The water level data show stronger variation at the Galveston Pleasure Pier than at Bob Hall Pier as the open coast water levels at Galveston Pleasure Pier are influenced by stronger winds or stronger metrological tides in the fall and winter seasons. Figure 21 shows the wind data (magnitude and direction) collected from September 2006 to February 2007 at two NDBC 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 show similar wind magnitude at offshore Galveston and Corpus Christi in the fall and winter seasons.

Figure 19. CMS Bathymetric grid of Matagorda Bay.

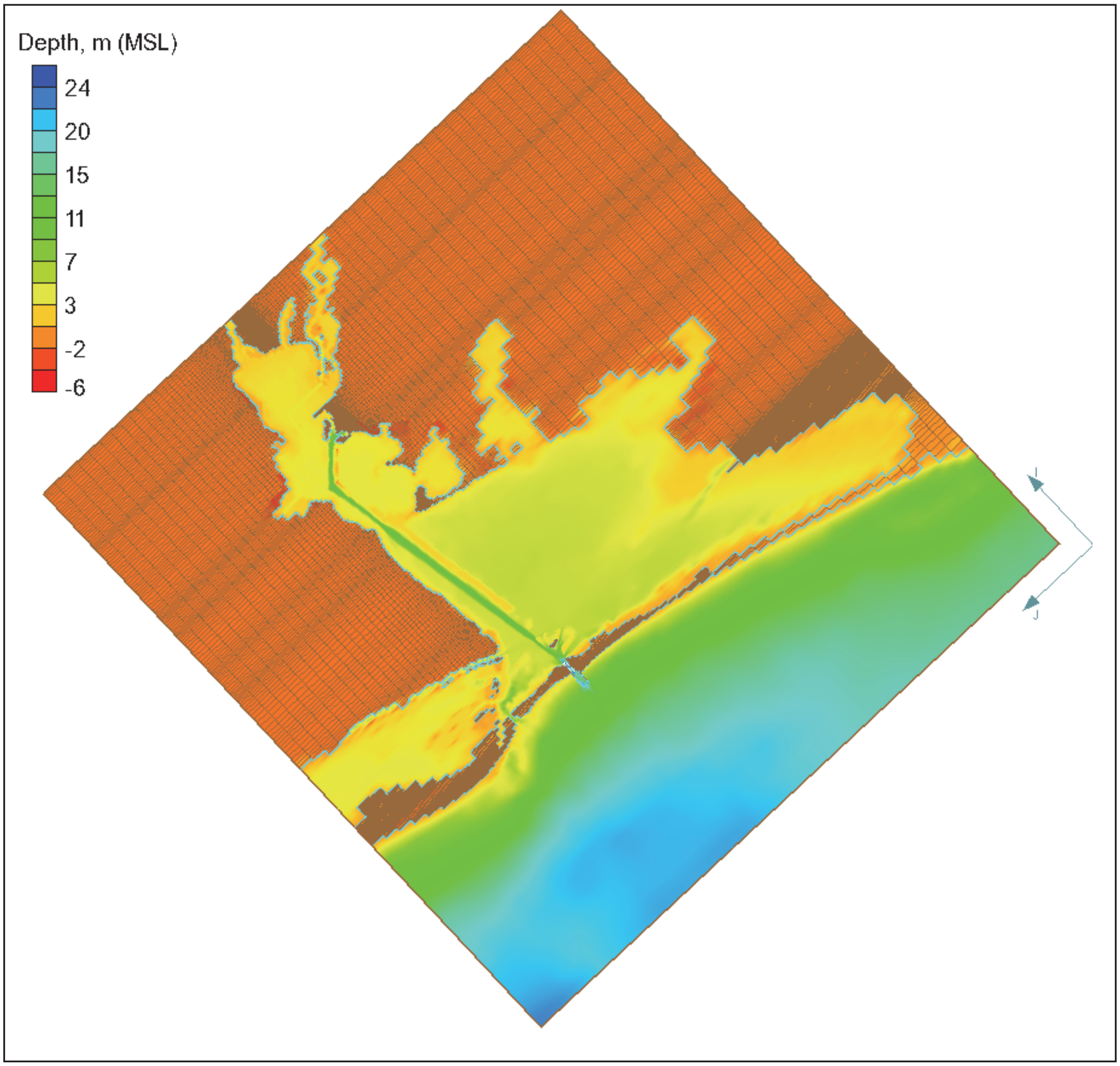


Figure 20. Time series of water levels at NOAA Stations 8771510 (Galveston Pleasure Pier) and 8775870 (Bob Hall Pier) for September 2006 to February 2007.

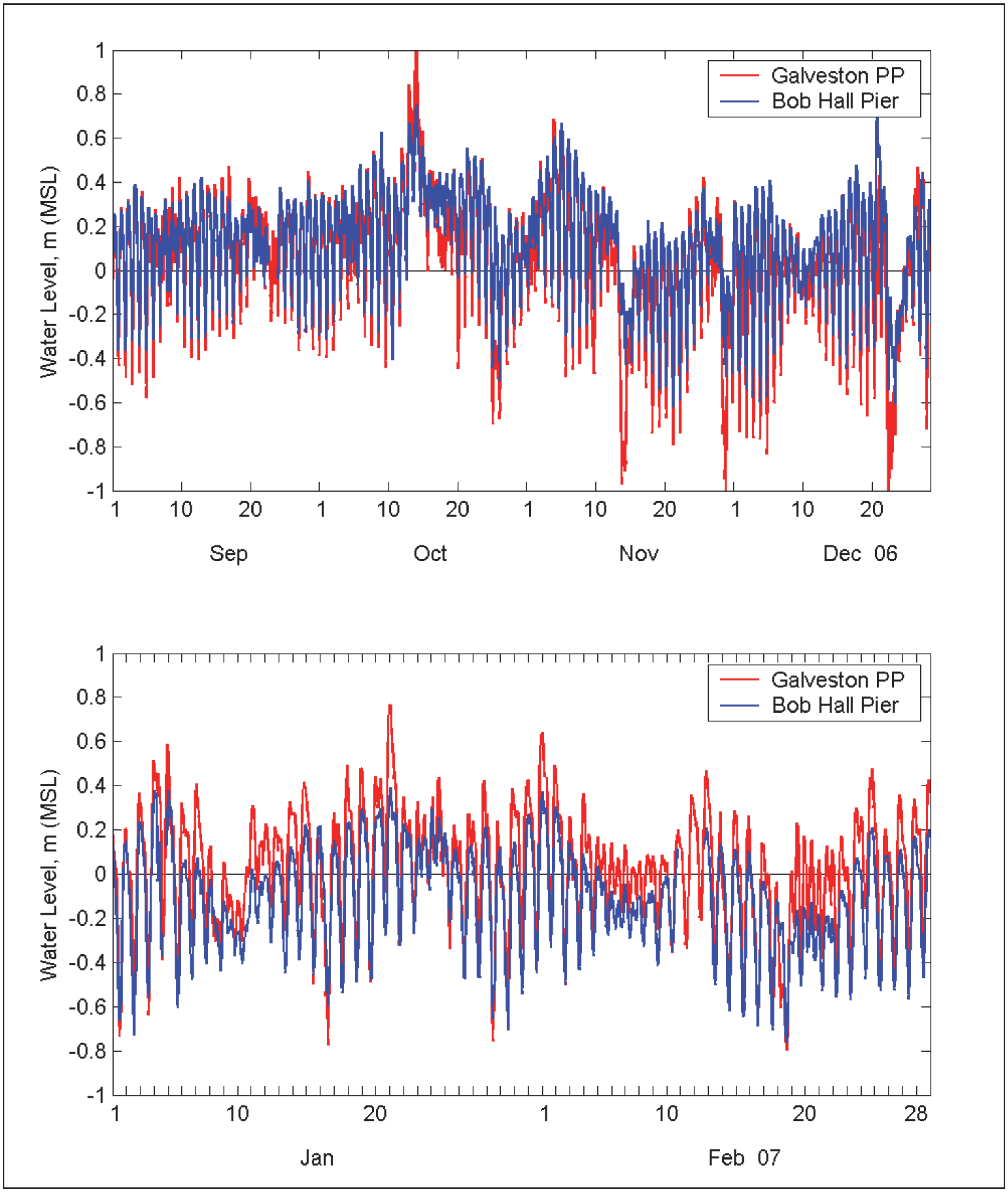
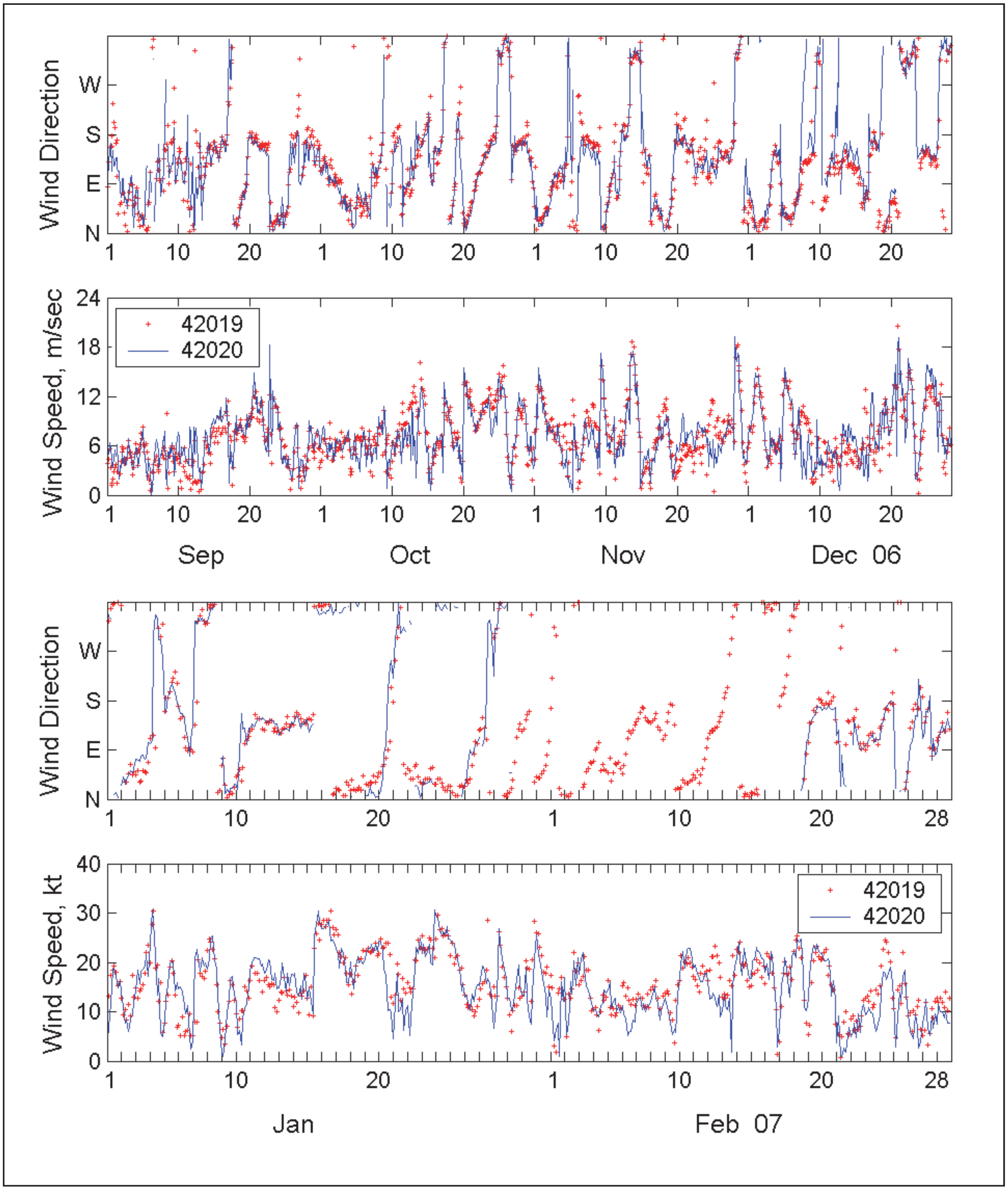


Figure 21. Time series of wind data at NDBC Buoys 42019 (Freeport) and 42020 (Corpus Christi) for September 2006 to February 2007.



Local wind data were available from NOAA Station 87737011 at Port O'Connor (28° 26.8' N; 96° 23.8' W) in the southwest corner of the bay. Figure 22 shows the wind information collected from September 2006 to February 2007 at Station 87737011 and NDBC Buoy 42019. The wind direction is similar at NOAA Station 87737011 and NDBC Buoy 42019. The wind magnitude at NOAA Station 87737011 is overall smaller than at NDBC 42019 as the wind at Station 87737011 is more influenced by land and bay effects than the Buoy 42019 wind in the open coast.

River daily discharge data for Lavaca River were available from USGS Station 8164000 at Edna (28° 55' N; 96° 46' W) approximately 14 mile (24 km) north of Lavaca Bay. The Station 8164000 flow rate data were applied as river boundary conditions for Lavaca River and Garcitas Creek discharge into the upper Lavaca Bay. The river flow data for Colorado River were available from USGS Station 08162500 (28° 58' N; 96° 01' W) near Bay City. Figure 23 shows the river flow data collected at USGS Stations 81625000 and 8164000 from September 2006 to February 2007. Because Colorado River has a much larger watershed area than Lavaca River, the flow discharge at Colorado River is usually much greater than Lavaca River.

Figures 24 and 25 show the time series of wave data collected at Buoy 42019 offshore Galveston from September to December 2006 and January to February 2007, respectively. The directional wave data collected at Buoy 42019 are used for the incident wave conditions along the CMS-Wave offshore boundary.

3.4 Matagorda Bay Sediment Characteristics

In the modeling area 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 MSC Gulf entrance, the narrow inlet constraint has caused the channel to self-scour, and the bed is characterized by gravels and small rocks as a result of strong current in the channel. The sediment at Pass Cavallo is overall coarser than the average sediment on the neighboring beaches because of stronger current through the inlet.

Sediment in Matagorda Bay is mixed, having more sand near the MSC Gulf entrance, Pass Cavallo, and south of GIWW. More silt and clay are found in the northern and eastern bay as fine sediment was supplied from Palacio Bay, Carancahua Bay, and Colorado River. The sediment in

Figure 22. Time series of wind data at NDBC Buoy 42019 (Freeport) and NOAA Station 87737011 (Port O'Connor) for September 2006 to February 2007.

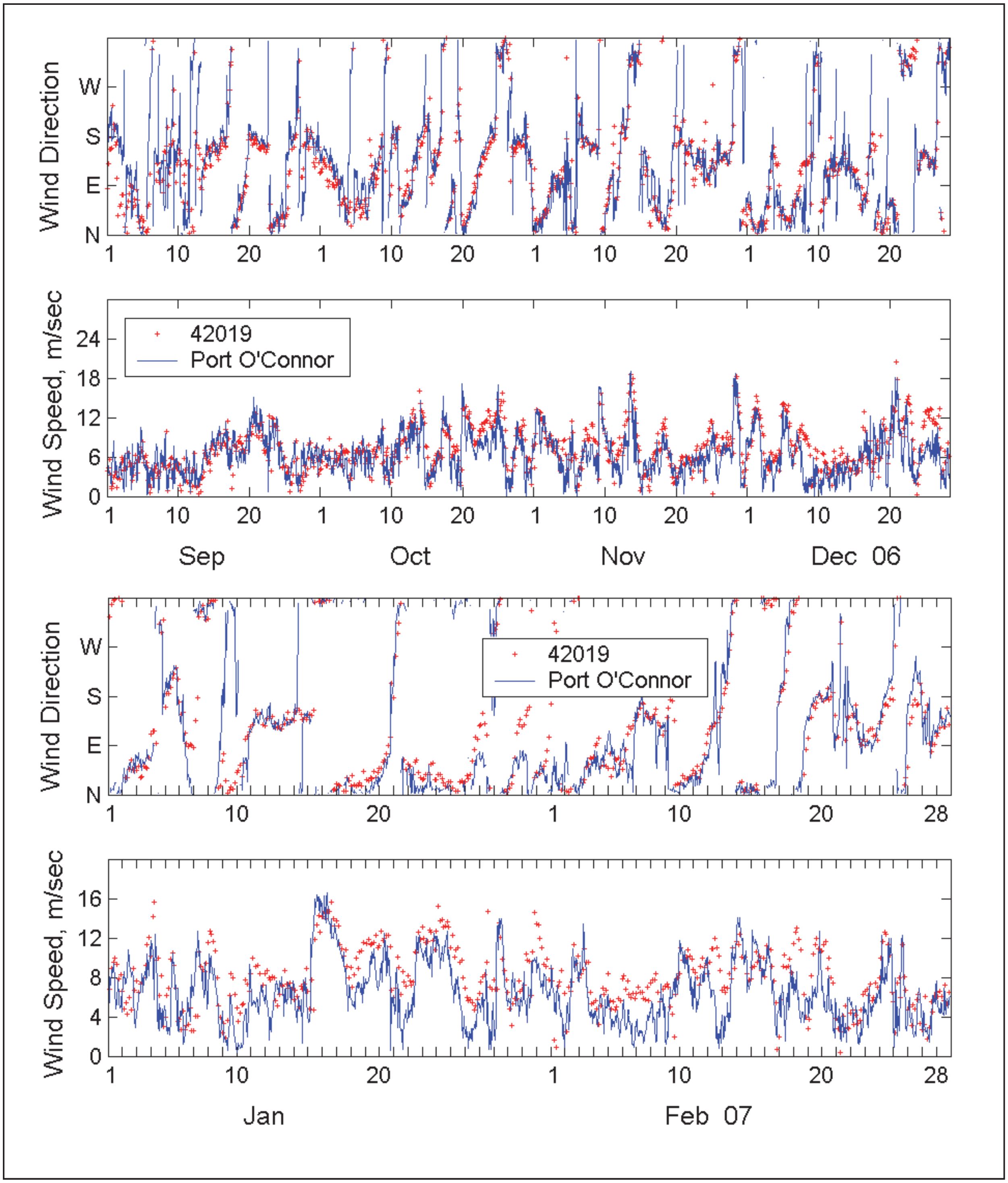


Figure 23. Time series of Lavaca River flow rate data collected at USGS Station 8164000 (Edna, Texas) for September 2006 to February 2007.

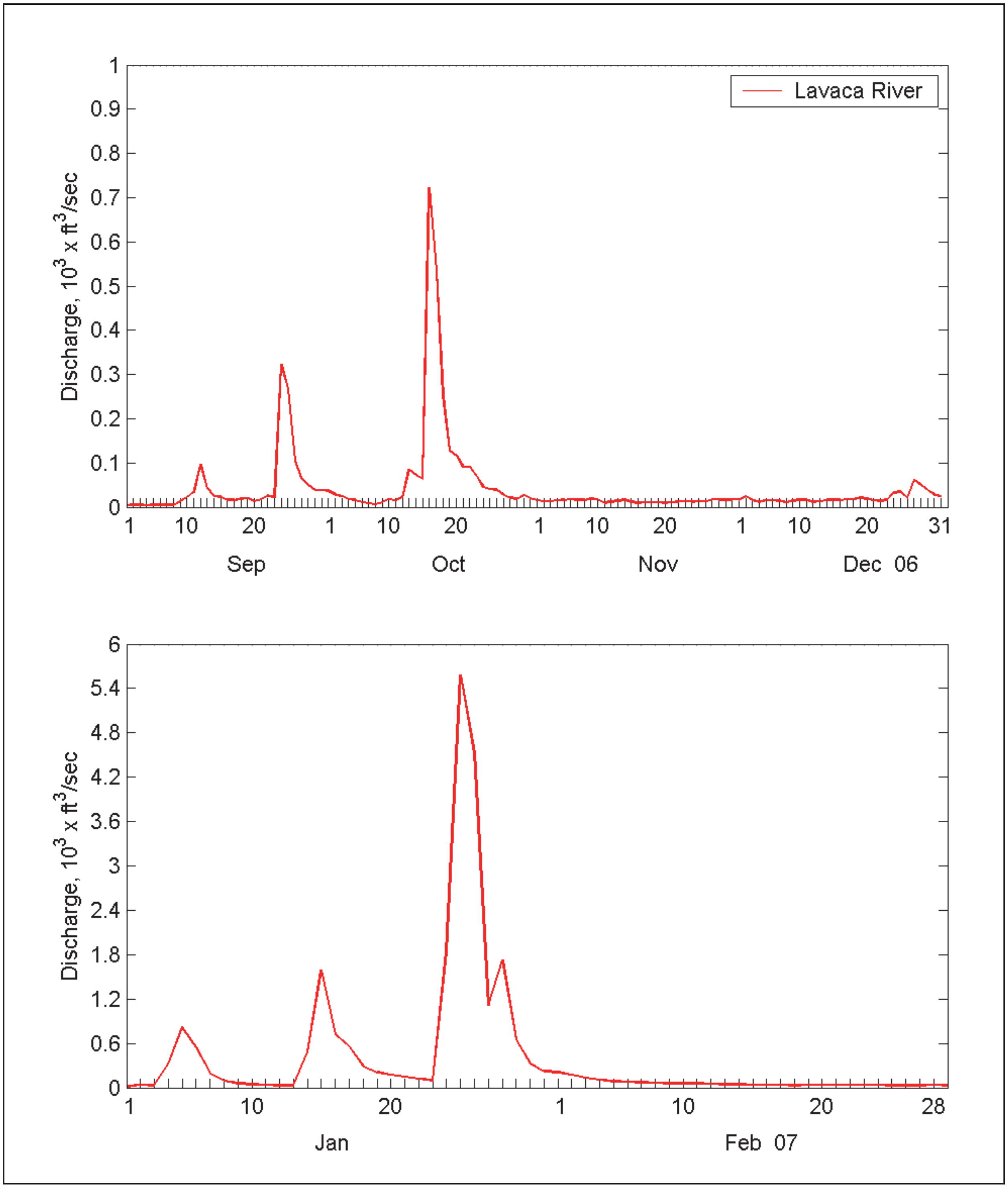
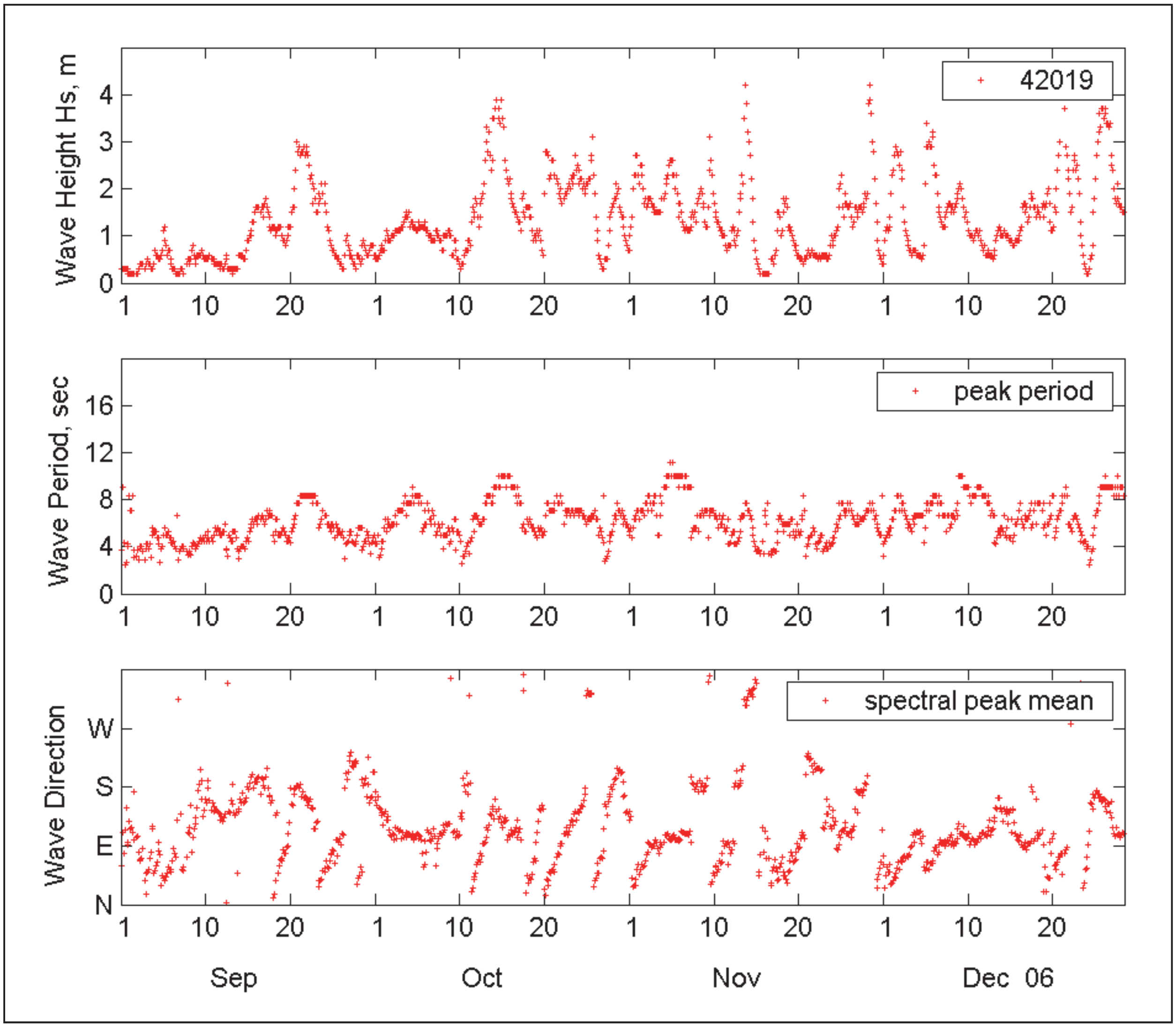
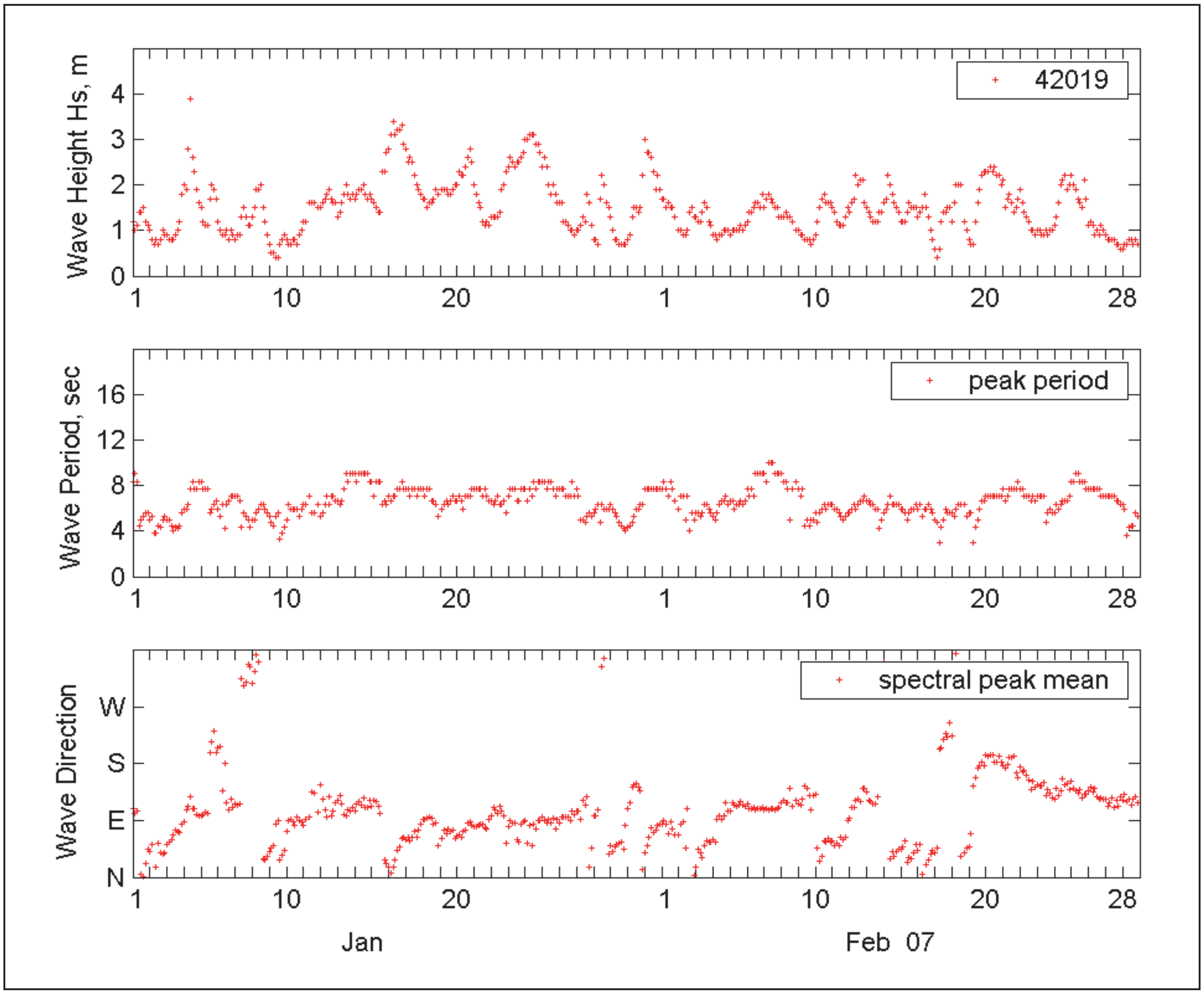


Figure 24. Time series of significant wave height, peak wave period, and spectral peak mean direction from Buoy 42019, September to December 2006.



Lavaca Bay is primarily cohesive material that comes from Lavaca River and Garcitas Creek. Because Lavaca Bay is geologically isolated in the northwestern corner of Matagorda Bay, the fine sediment inside Lavaca Bay is basically trapped and rarely is transported to Matagorda Bay. During fall and winter months, fluid mud is often observed in the upper MSC as induced by strong wind and wave motion in the Lavaca Bay. The rapid accumulation of fluid mud in the MSC has required more frequent dredging cycles in recent years. Figure 26 shows the different median grain size used in the present sediment modeling in Matagorda Bay.

Figure 25. Time series of significant wave height, peak wave period, and spectral peak mean direction from Buoy 42019, January to February 2007.



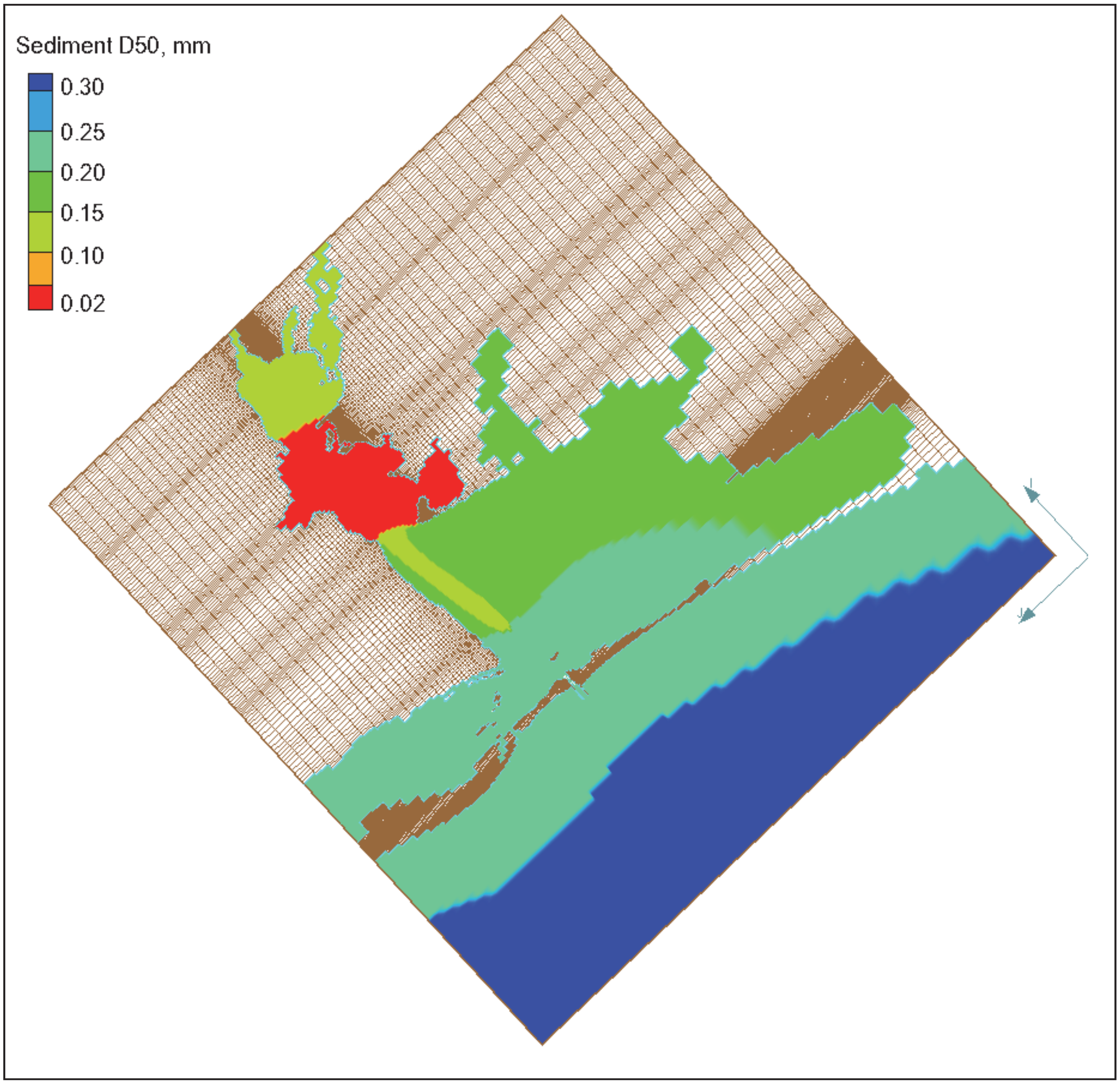
3.5 Modeling Results

The model simulations were conducted for a half-year period from September 2006 to February 2007. Figure 27 shows the comparison of calculated and measured water levels at Port O'Connor, NOAA Station 87737011, for September 2006 to February 2007.

Figures 28 and 29 show typical strong current fields calculated by coupling CMS-Flow and CMS-Wave for flood and ebb conditions, respectively.

The development version of the CMS used includes the option to calculate sediment transport for cohesive (silt and clay) and non-cohesive (quartz sand) sediments individually or for combined cohesive and non-cohesive sediments. The detail of method and equations for sand transport in CMS is provided in the report by Buttolph et al. (2006).

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.

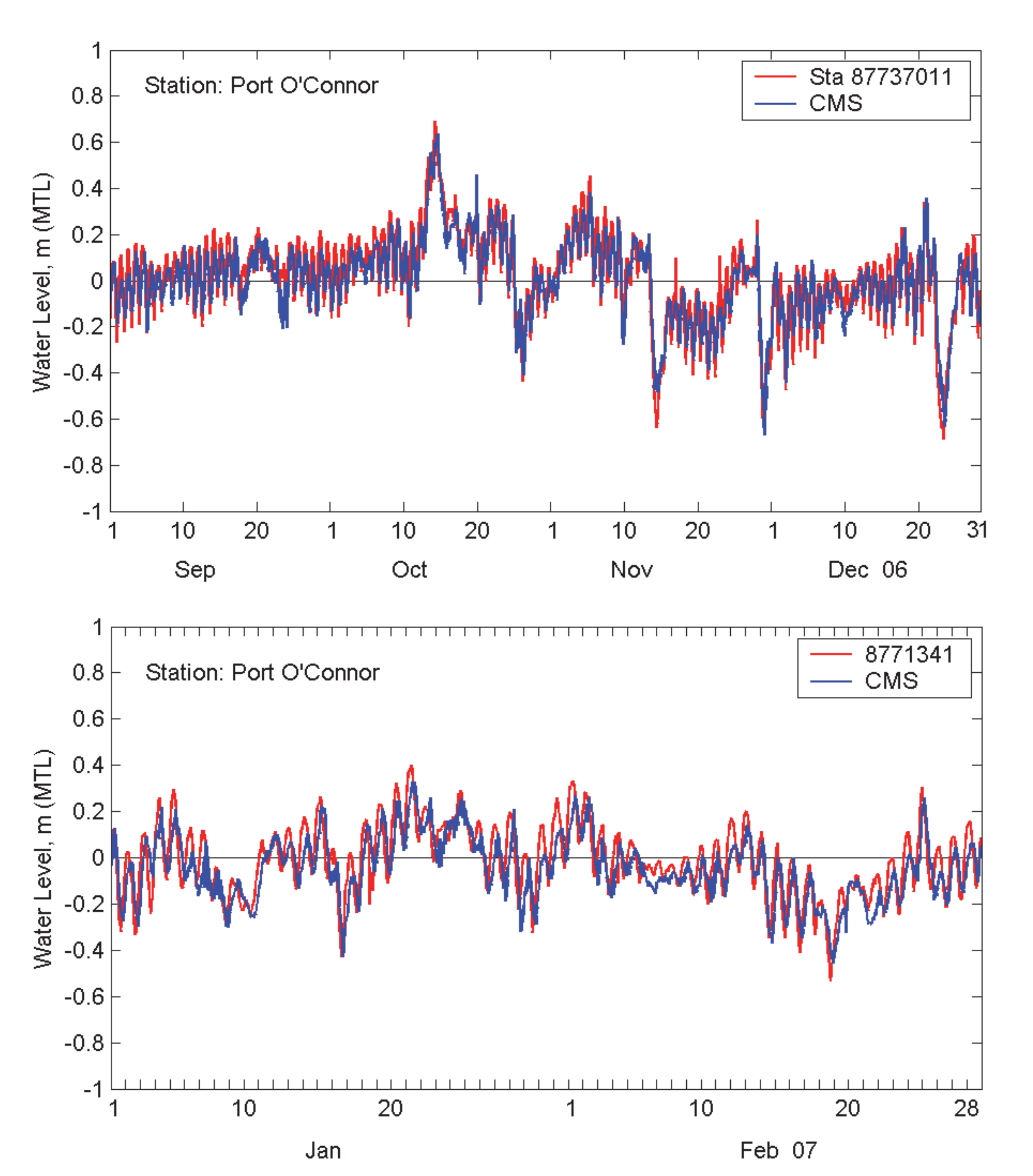
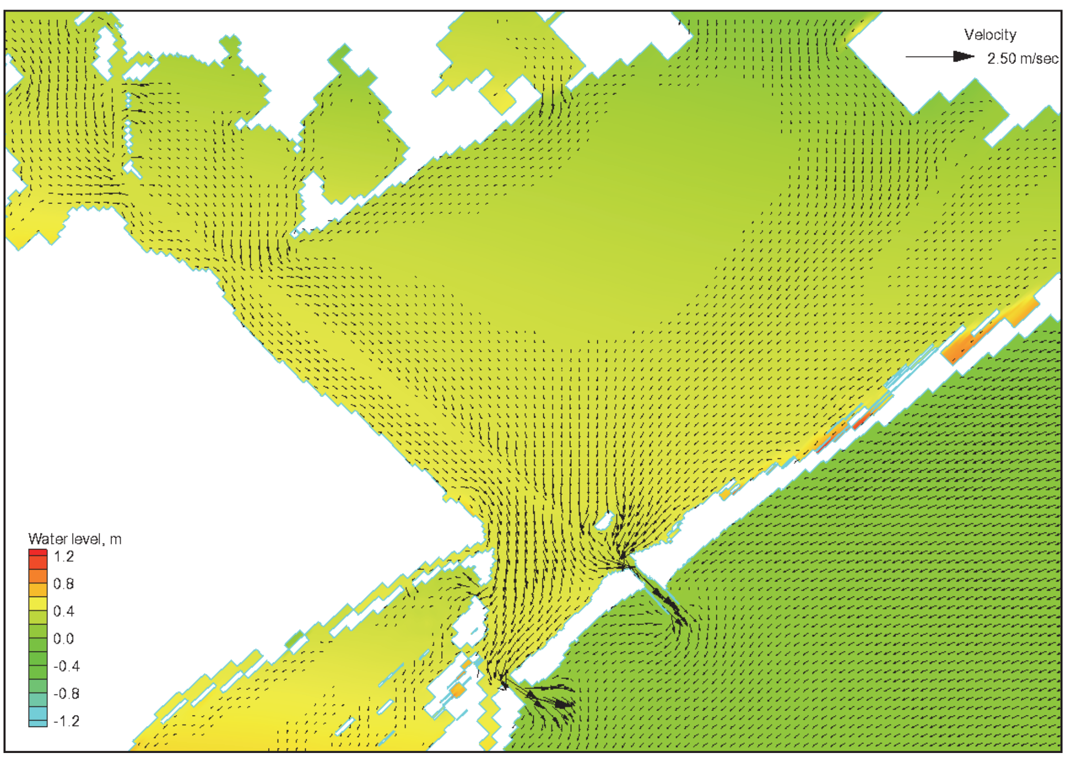


Figure 28. Typical strong flood current field calculated by CMS.

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:

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

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

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

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):

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

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.

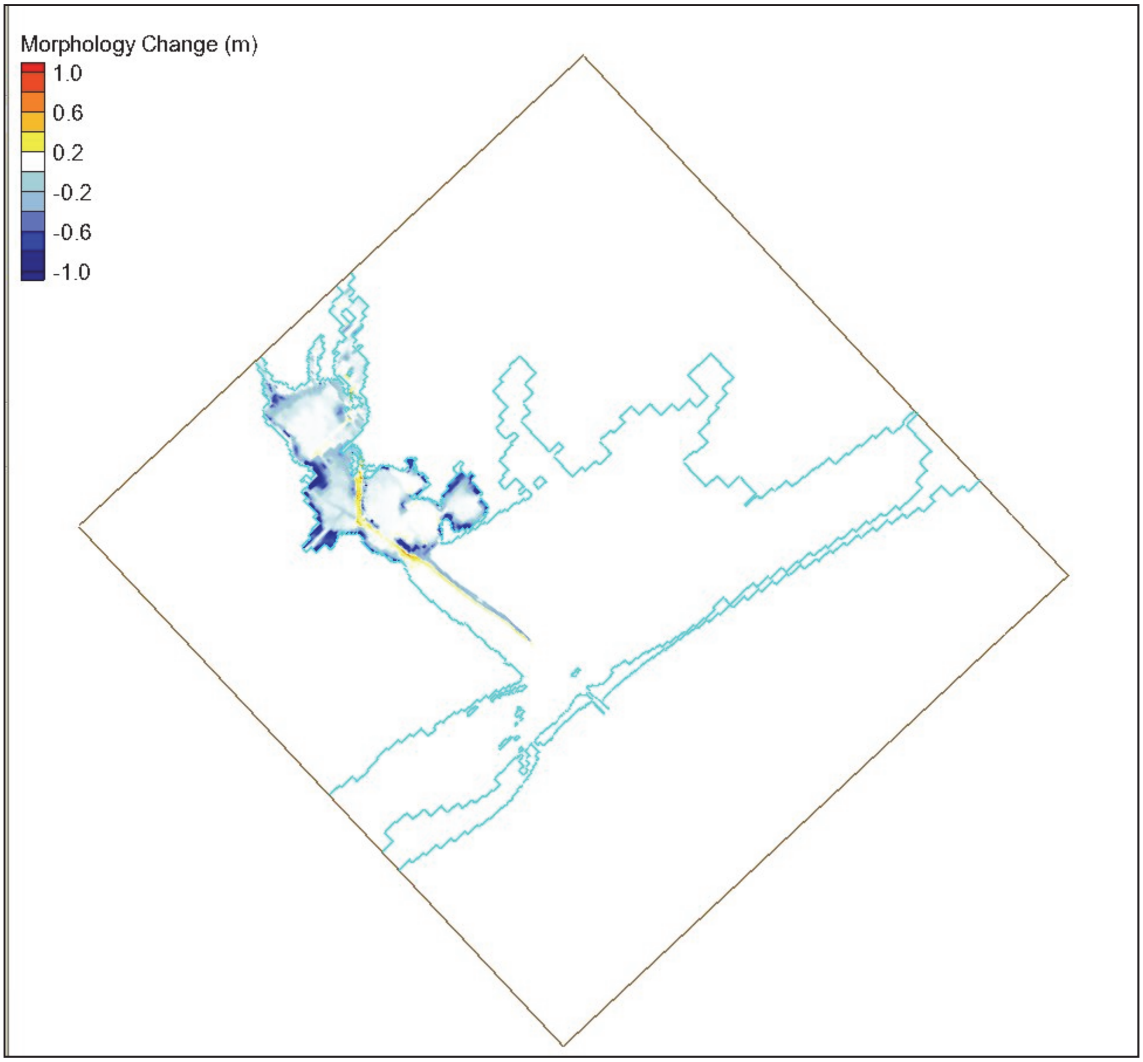


Figure 31. Calculated non-cohesive sediment accretion/erosion, September 2006 to February 2007.

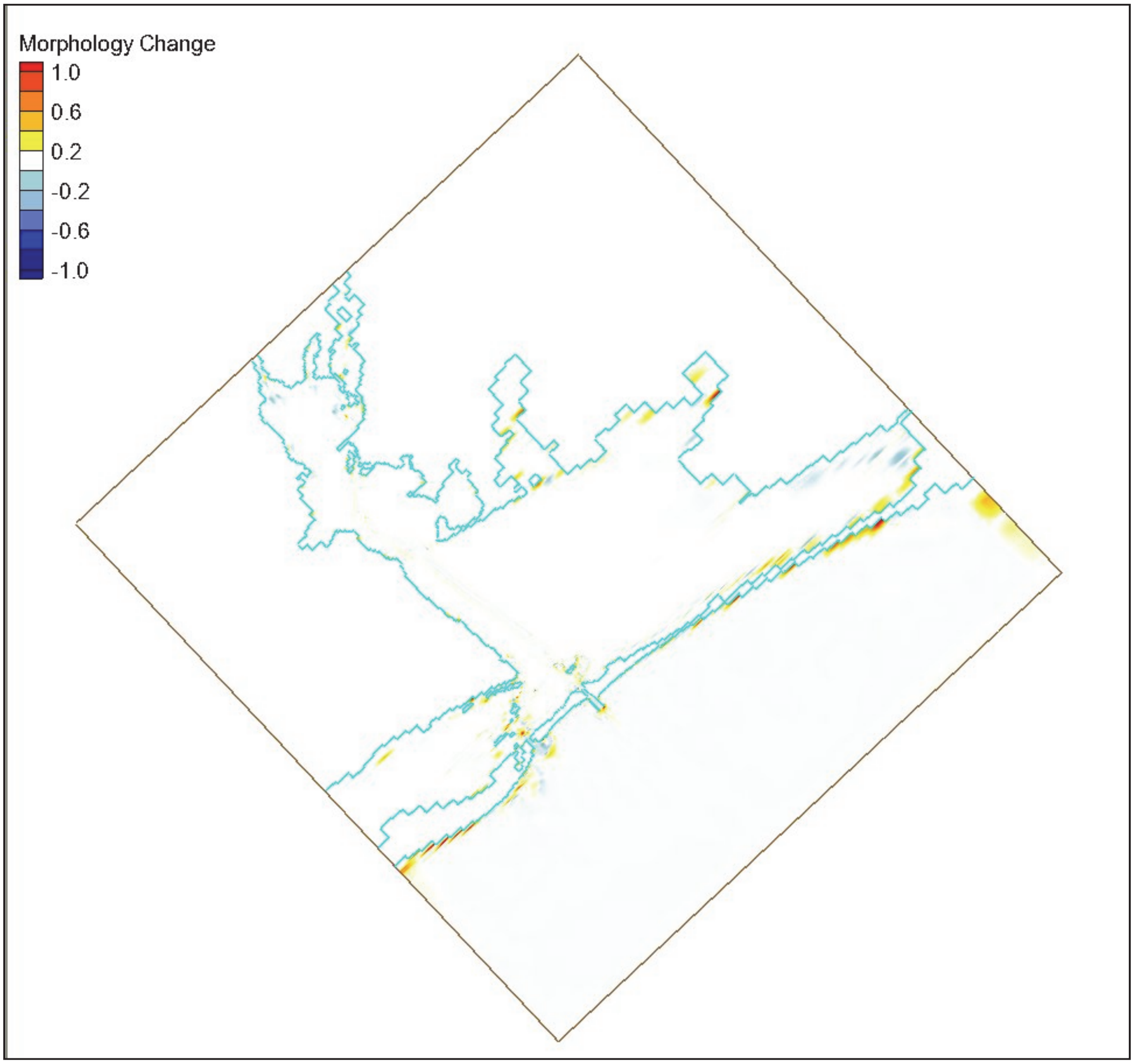
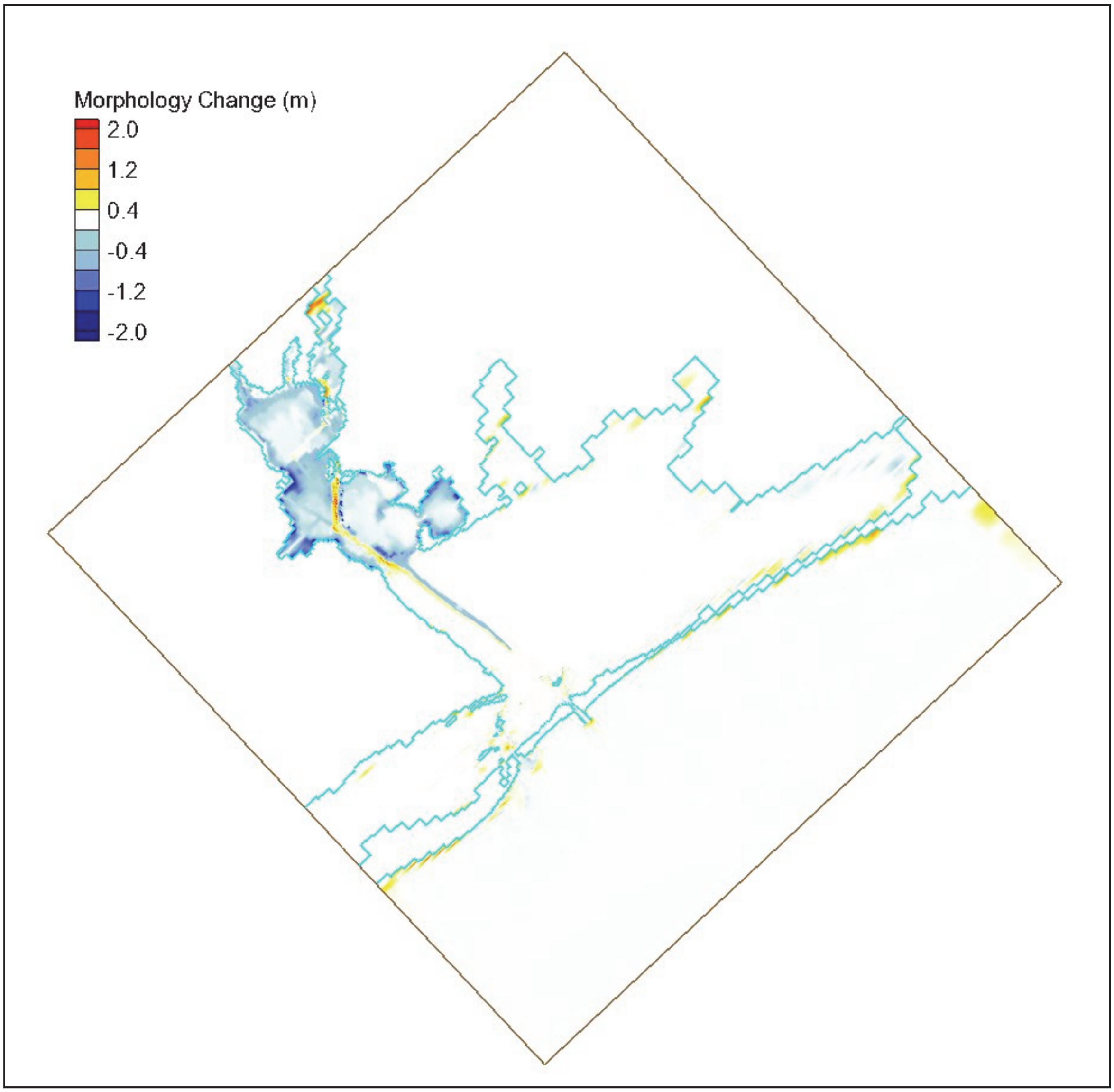


Figure 32. Calculated mixed-sediment accretion/erosion, September 2006 to February 2007.



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.

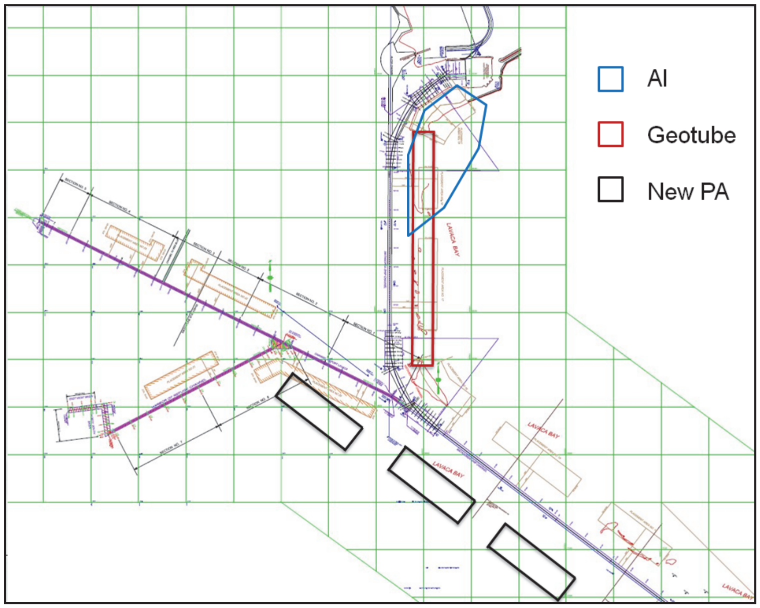


Figure 34. Calculated 6-month morphology change for the existing configuration.

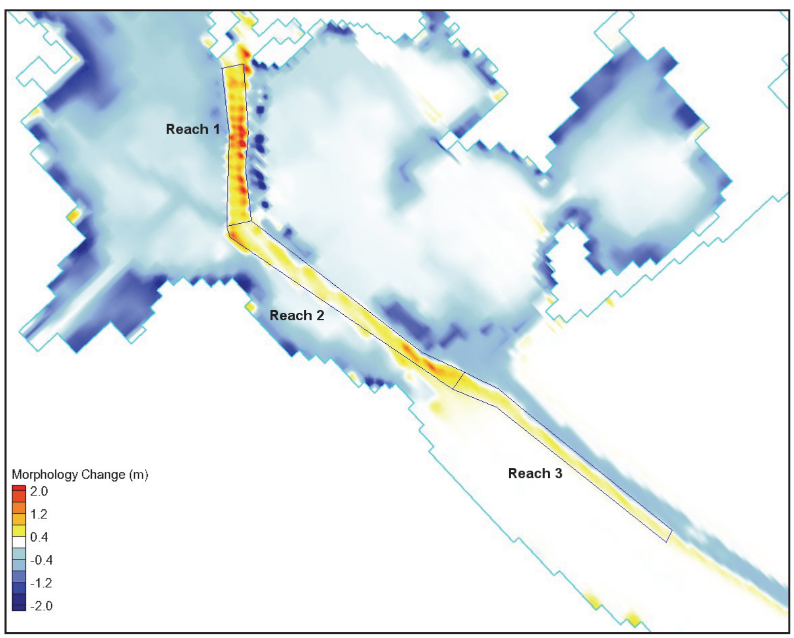


Figure 35. Calculated 6-month morphology change for the AI alternative.

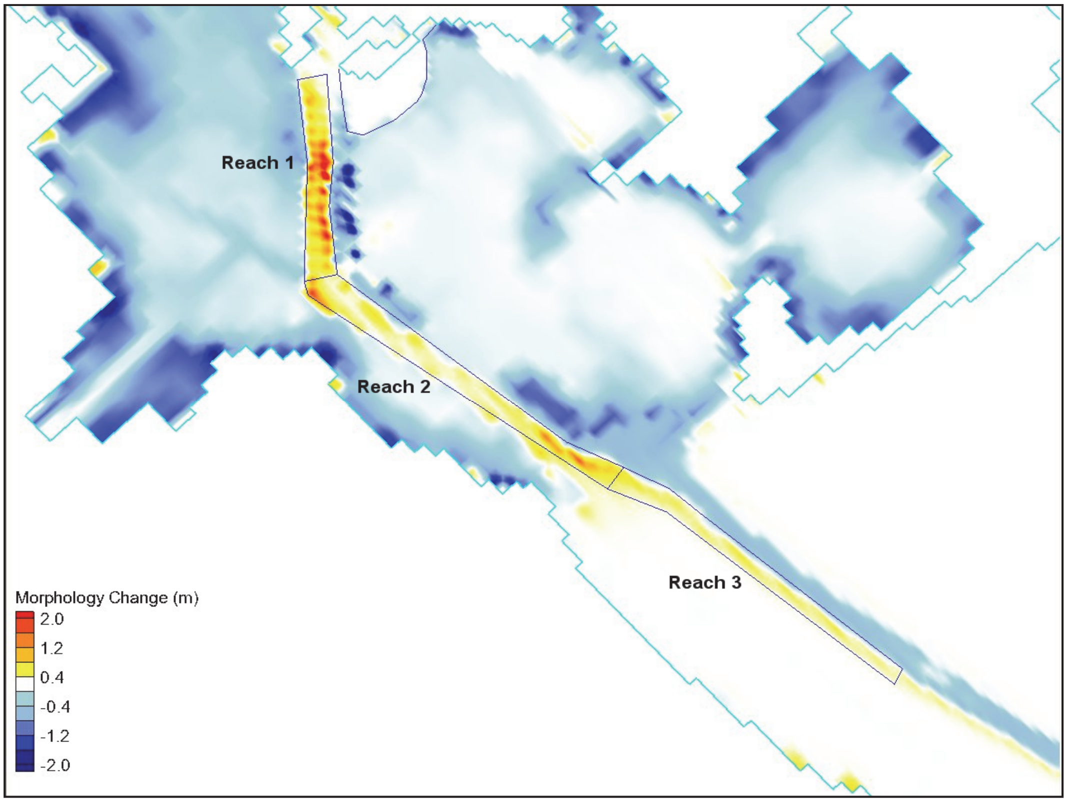


Figure 36. Calculated 6-month morphology change for the Geotube alternative.

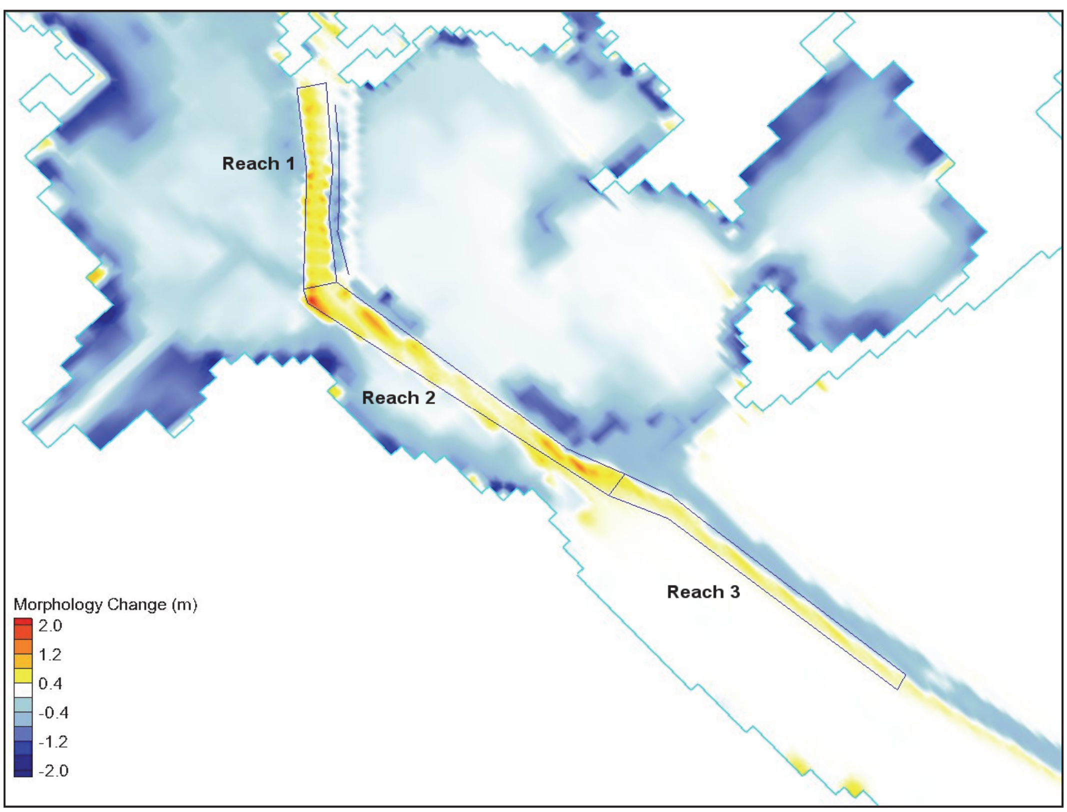


Figure 37. Calculated 6-month morphology change for New PA alternative.

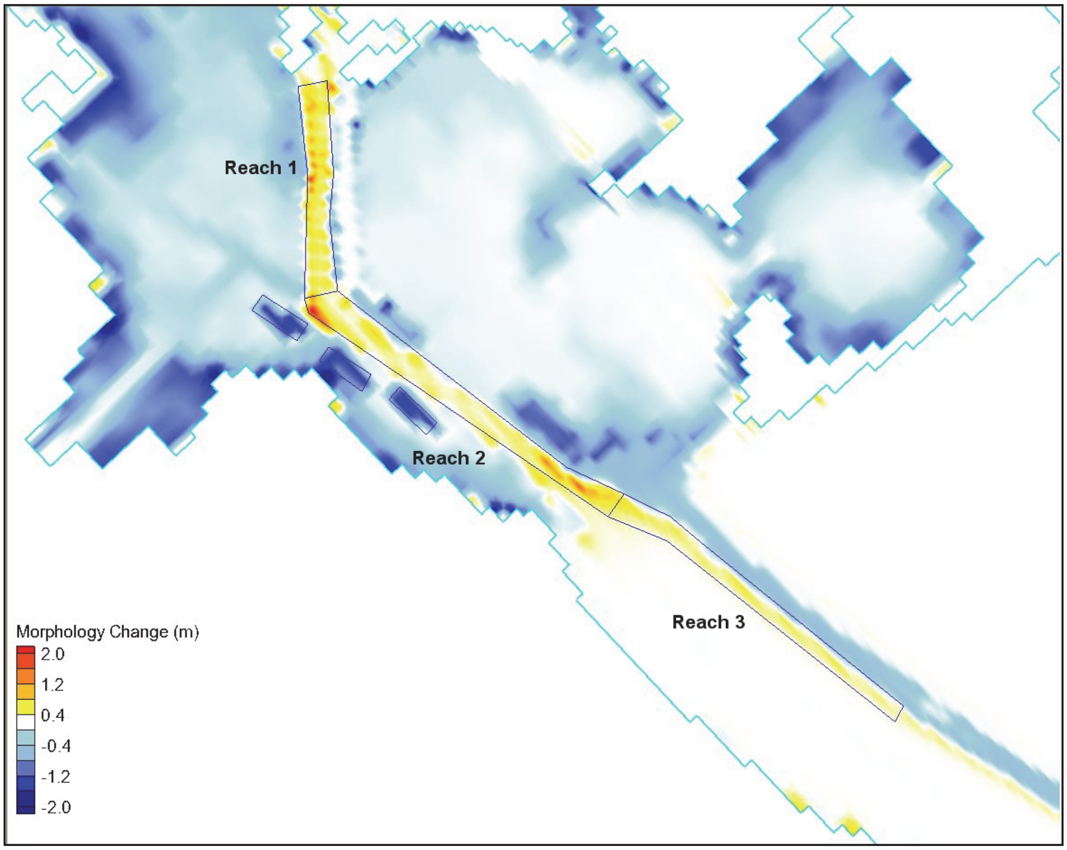


Figure 34 shows the calculated 6-month morphology change fields (September 2006 to February 2007) in the upper channels for the existing configuration. Reach 1 had the largest volume of material movement in the channel with 2.04 mcy (wet volume or wet bulk sediment) being deposited in this 6-month period.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

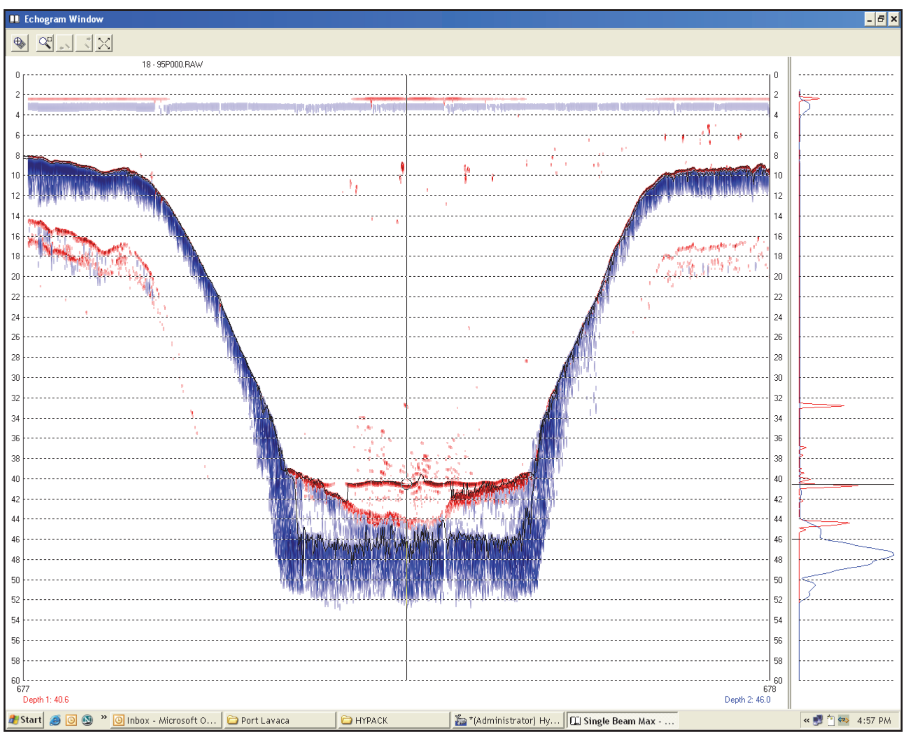
Under the DOER Program and the Monitoring Completed Navigation Projects Program, the ERDC is currently working with the USACE Mobile District to incorporate the four implementation requirements above.

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.

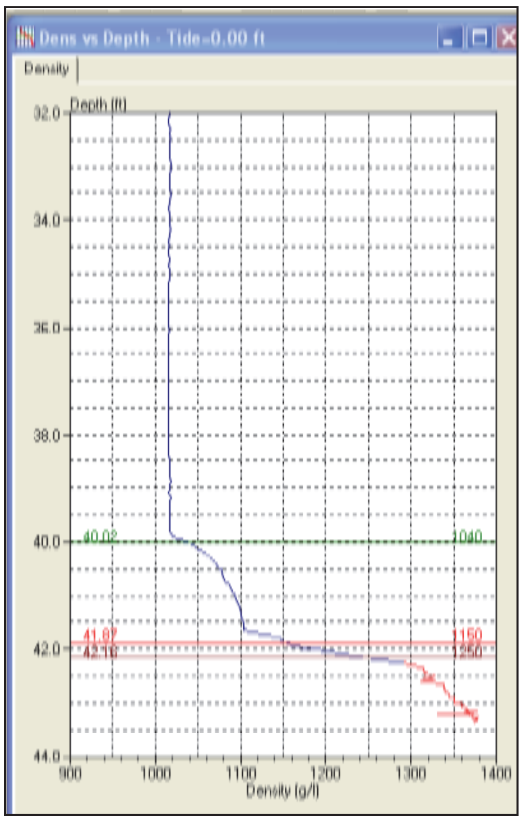
Figure 38. Dual-frequency echogram of Matagorda Ship Channel Station 95+00.



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.

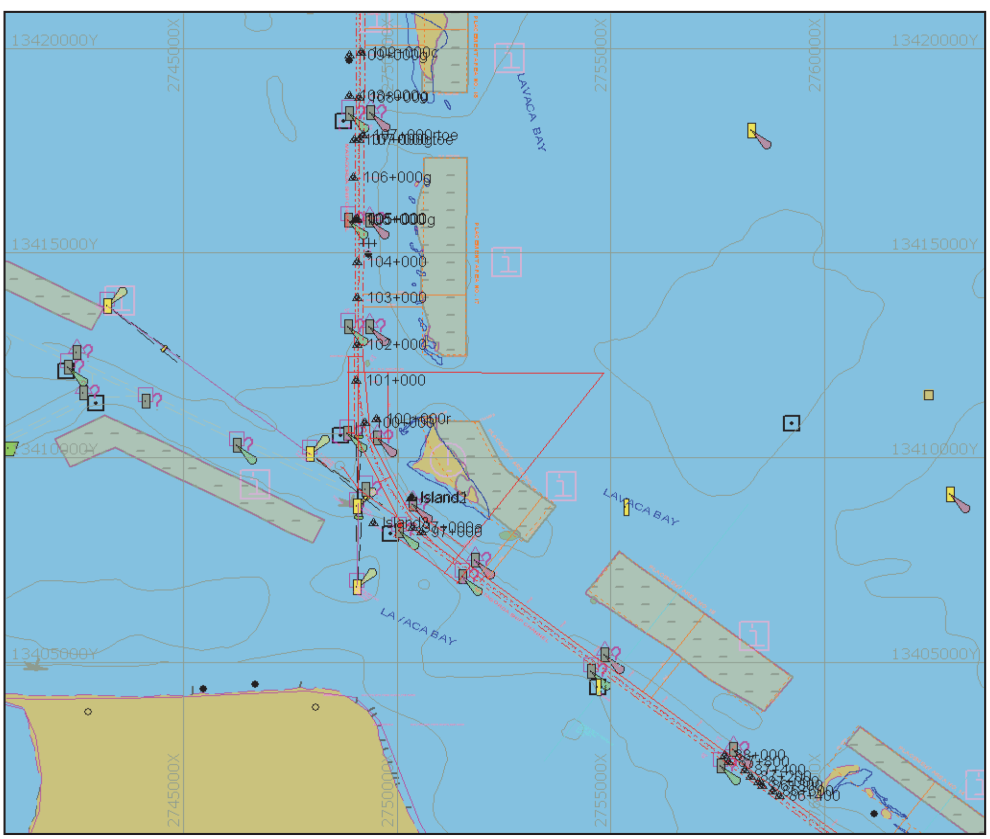


Figure 41. SILAS collected echogram from Station 96+00 Matagorda Ship Channel.

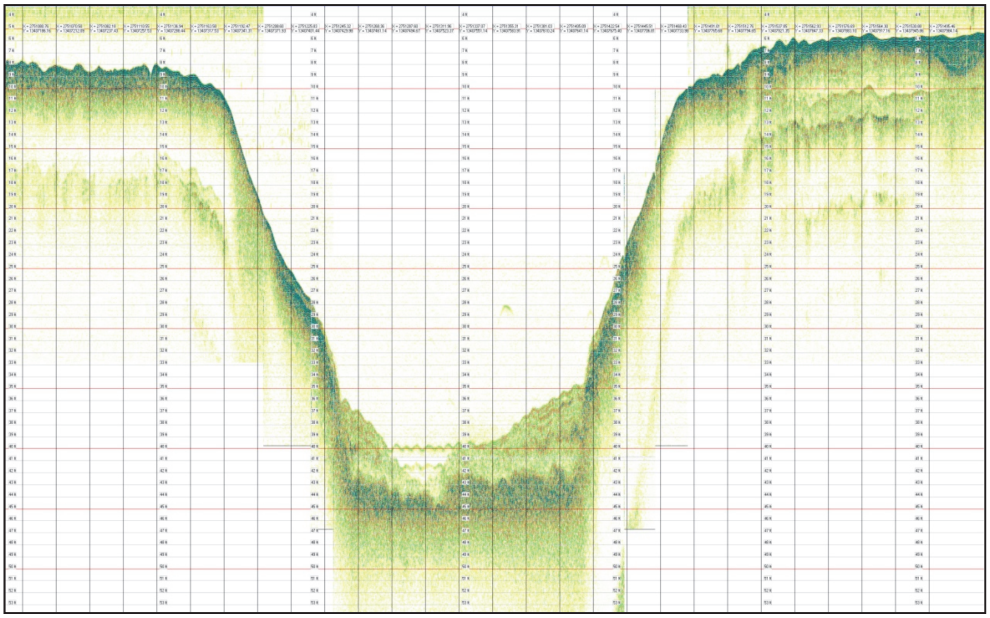
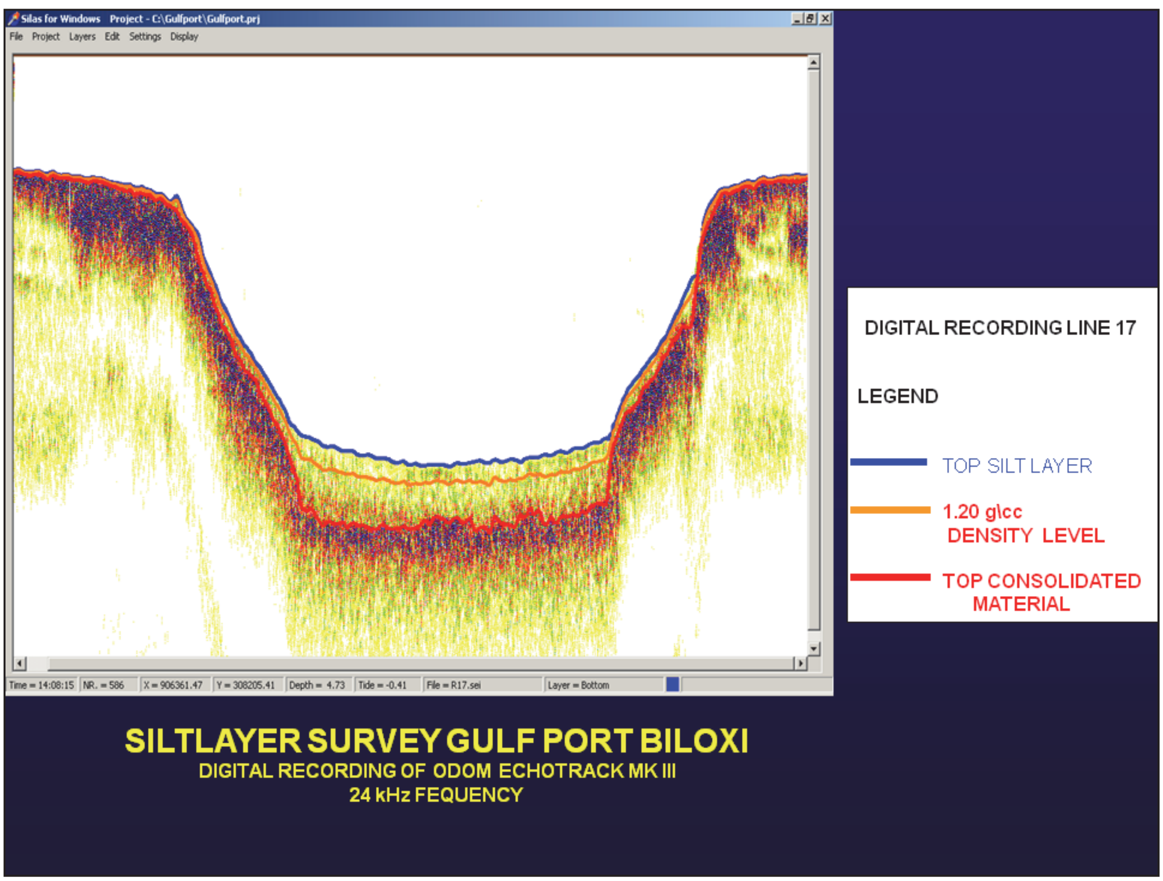


Figure 42. SILAS data analyzed for cross section in the Gulfport Mississippi Ship Channel.



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

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