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TEXAS COASTAL SEDIMENT SOURCES
GENERAL EVALUATION STUDY

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Executive summary

This report presents a desktop inventory of the Texas coastal soft sediments available through a compilation of engineering and geoscientific reports, peer reviewed publications, and sediment databases in state and federal programs. The objective was to compile and interpret important datasets focused on the potential availability of sediments for coastal restoration and storm protection. The analysis included the availability of sediments within dredging activities and the geological and geomorphological environments across Texas. Limited information on several aspects of the sediment inventories within the coastal system left several gaps that will need to be covered with future investigations.

Geological Deposits.

The beginning sections of this report review the sediment resources potentially available in the geologic record for the last 140,000 years. Sections 2 to 5 present the general geological information that followed sea level rise changes and the sedimentary processes generated by its fluctuations. These changes produced specific deposition (Anderson, et al. 2016) directly connected to fluvial, coastal, and estuarine environments, including paleo river valleys, valley-filled deposits, river deltas, bayhead deltas, barrier islands, former inlets, etc. These depositional processes resulted in a diverse set of soft sediments of varying grain sizes and geographical locations throughout different periods of time.

The coastal landscape as we observe it today is different from the one that existed before sea level inundation. It is assumed that the sedimentary models connected to sea level rises and drops allowed specific deposition for the Texas coastal shoreface and bays, generating cycles of erosion or deposition (Anderson et al. 2016). These sections covered the geological deposition from the Late Pleistocene, including: the paleo-incised river channels and valley-filled fluvial deposits developed on the continental shelf; deposits formed in the last 6,000 years on the Gulf Shoreface; and, bay and estuarine deposits as part of the new coastal environments or on top of Pleistocene deposits.

The report identifies the geological records for several former river valleys that exist below bays and barrier islands (offshore and inland) with the potential to contain sediments compatible with present coastal environments. The geologic records of the main Texas rivers, including the Sabine, Trinity, San Jacinto, Lavaca-Navidad, and Nueces Rivers, show these fluvial environments containing paleo-incised valleys up to 40 meters deep (~120 feet). These were first cut on Pleistocene deposits and then filled to the point where the landscape was leveled. The data available provided limited descriptions on the grain sizes of the valley-fill deposits.

Due to the fact that their watersheds and sediment supplies were extensive, the Brazos, Colorado, and Rio Grande Rivers created several significant and thick deltas during the last 140,000 years. Geological reports show that some of the sea level jumps forced these deltas to migrate to different vertical levels in such a way that they became vertically incised by the response to sea level drops. They were then re-created with a new delta establishing above its former position as result of sea level rise. As an example, the Colorado River delta appears to have significant amounts of sand through its different stages of evolution (Anderson et al., 2016). The analysis of these Colorado River delta systems should be considered a priority for future investigations for their promising location and thickness. For the Brazos River delta, there is some information on the distribution of the former deltas, but the limited data has generated some questions in terms of their specific locations (geo-references) and composition. More data is needed to determine their potential sediment availability. Finally, similar to the Brazos River delta, the Rio Grande River delta has limited information on its paleo-deltas in terms of thickness, distribution, and composition. Additional data will be needed to generate a comprehensive analysis for these paleo-deltas.

The report also includes information regarding geologic deposits considered “ancient barrier islands” that were partially preserved in the shoreface of the Gulf of Mexico. Specifically for the marine areas, the Sabine and Heald Banks are two important locations where sediments may be available. Although their origin is unknown, these banks contain significant amounts of sediment and geological investigations have shown these sediments to have compatible grainsizes to the present barrier islands. These former barrier islands will require more detailed investigations into the specific composition and grain size of the sediments by location.

Geomorphological Deposits.

The creation of the barrier islands was in response to what is called “the ravinement processes” (Anderson et al, 2016), or the process of coarse sediment being accumulated by the energy of the rising Gulf of Mexico during the last sea level transgression. This hydrodynamic event generated large accumulations of sand on the modern shorelines that was manifested by the formation of the present barrier islands. Barrier islands along the coast of Texas vary in age, thicknesses, width, and length. As a result of the formation of these islands, our estuaries and bays were built with new depths and new connections to rivers and inlets. Sections 6 and 7 present an inventory of the sediments that are presently active in the coastal system. For this report, geomorphological deposits were considered those sediments generated after the formation of the barrier islands that started to circulate in the modern estuaries through deltas, bay bottoms, bay shorelines, and bay and Gulf inlets, etc. These deposits are connected to the readjustment of the coastal estuarine systems and the geomorphologic disintegration of these barrier islands on the bay and Gulf sides, or the disintegration of the inundated bay shorelines.

What is referred to in the report as disintegration of barrier islands, former deltas, river terraces, and natural river levees is the migration of offshore soft sediments in the Gulf of Mexico to areas away from the new bay shorelines. For this reason, the report includes, as geomorphological deposits, the sediments that are moving due to shoreline accretion and erosion, currents in the estuaries or fluvial suspended and bedload sediments coming from the main streams, and sediments that are circulating or are trapped in the inlets and their infrastructure.

The lack of geologic data on the bays related to sediment sources that accumulated after the creation of the barrier islands shows the need for detailed investigations on the bay environments. It is assumed that a large number of estuarine habitat restoration and flood protection projects will need extensive amounts of sediments. The lack of information should be considered as an area of special interest from a geologic, geotechnical, and environmental interest. Specific potential volumes were provided based on a desktop analysis, with large limitations on the type of grainsize and qualities of the sediments referenced.

Sediments from the Major River Watersheds and Bays Sediment Transport Processes.

A compilation of data on suspended and bedload sediments originating from the main Texas rivers is presented in Section 8 and was available only for the Sabine, Trinity, Brazos, and Colorado Rivers. The datasets used for the report showed direct and indirect data generated from several sources through measurable and validated data collection programs. The data may not be consistent from watershed to watershed since the studies originate from different authors and there were different objectives for each river basin. However, the data allowed for analysis on the potential volumes of sediment coming to the coast through these rivers, and provided a general idea of how much sediment is reaching the Texas coast.

In terms of bay sediment transport processes, only one study was available and it solely focused on characterizing sediment transport within Galveston Bay (Moffat and Nichols, 2010). The study quantified the amount of sediment per sediment cell circulating in the bay. The study shows the need for similar studies in Texas bays to understand where the sediment generated by shoreline retreat ends in the coastal system and where the same sediments could be accumulating.

Dredge Material Related Sources.

An analysis of dredge material resulting from projects along the Texas navigation channels was also included and is presented in Section 9. First, the analysis was based on dredging volumes available at the US Army Corps of Engineers (USACE) Galveston District for navigation channels. Second, the data consisted mainly of records of maintenance dredging on these channels. Using these historic dredging records, the report presents the location of past dredging events with their associated volumes and the potential location of these sediments in nearby placement areas. The idea was to present the distribution of critical dredging hot spots along the Texas coast and where the material potentially ended after the dredging events. The data allows the reader to identify potential areas with available dredge material (or sediment). The analysis in the report did not include details on the composition of the dredge material and the volumes and composition of the placement areas.

Sediment Impoundments.

A short section on the areas where shoreline retreat is providing sediment supply and the areas where the sediment may be trapped or impounded is presented in Section 10. The Texas coast contains about 16 inlets, many of them with coastal infrastructure that is retaining or modifying the longshore processes occurring on the Texas coastal shorelines. This section briefly describes the critical areas where sediment is potentially available through sediment impoundment structures.

Potential Contaminants.

Section 11 consists of a short narrative on contaminants and pollutants available in state and federal records as zones of environmental accidents or events connected to contaminants. The section shows maps with areas of high interests located on the bays or on watersheds close to the bays where specific contamination was reported. The section is presented only as a reference for future sediment investigations near those areas.

Conclusion.

Section 12 is a conclusion of the areas identified and the potential volumes estimated in the cited studies and reports by region. The location of the sediment sources and potential volumes should be considered as the first step for future detailed sediment or dredge material investigations identifying specific targets for areas dedicated to supply sediment for coastal restoration and projection projects.

Caution

The reader should be aware of the quality of some figures in this report. The report consisted of a desktop analysis and had to use previously published reports to identify the location of sediment sources. Unfortunately, some figures had low resolution or low quality since, in some cases, the figure came from a previously scanned report. The reader should go directly to the original source of information cited in the report for a better resolution of these mentioned figures.

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Acronyms and Abbreviations

ArcGIS	Arc Geographic Information Systems
BP	Before Present
CERPRA	Coastal Erosion Planning and Response Act
CY or cy^3	Cubic Yards
EDNA	Elevation Derivatives for National Applications
GBEP	Galveston Bay Estuary Program
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
GOMESA	The Gulf of Mexico Energy Security Act of 2006
Km	Kilometers
Km^2	Square kilometers
Cu m or m^3	Cubic Meters
MIS	Marine Oxygen Blanket
NFWF	National Fish and Wildlife Foundation
NOAA	National Oceanographic and Atmospheric Association
NRDA	National Resource Damage Assessment
P3	Public-Private Partnerships
PA	Placement Area
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
RESTORE Act	Revived Economies of the Gulf Coast States Act
RSM	Regional Sediment Management
SMP	Sediment Management Plan
Sq. Mi.	Square Miles
TCEQ	Texas Commission on Environmental Quality
TMB	Texas Mud Blanket
TNRCC	Texas Natural Resource Conservation Commission
TPWD	Texas Parks and Wildlife Department
TxSed	Texas Sediment Database
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USFWS	US Fish & Wildlife Service
USGS	US Geological Survey
WGB RSM	West Galveston Bay Regional Sediment Management

1.0 INTRODUCTION

The Texas Coastal Sediment Sources General Evaluation Study is an initial effort of the Texas General Land Office to identify sediment sources for restoring the natural environment and protecting public infrastructure along the Texas coast. This study presents an inventory of potential sediment sources available for future projects dedicated to coastal restoration and storm protection. Additionally, it serves as the first step toward future-dedicated sediment source investigations and presents various sets of data connected to the identification of potential sediment sources for the development of a Texas Sediment Management Plan (SMP).

The goal of a SMP extends beyond the compilation of existing and available geologic, geomorphologic, geotechnical, and dredging and dredged material disposal sites data. It is also to identify areas of interest for the identification of sediment sources to be used for supporting the development of sustainable coastal programs.

Geologic and geomorphic models evaluated under this study have resulted in the identification of sediment sources that establish Texas coastal sedimentary environments connected to the evolution of fluvial, bay, and estuarine environments and barrier island systems. Further, these models capture the importance of inlets, deltas, and navigation infrastructure and the role that modern fluvial sedimentation plays within the entire sediment system.

Figure 1-1 presents the Sediment Analysis Model used to identify potential sediment sources for beach, dune, marsh, and habitat restoration; including fish and other types of coastal habitats (Reinson, 1992). The model simplifies the analysis and understanding of future sediment source investigations by selecting different available sources of data throughout different coastal-related programs, including federal, state, private, and academic sources.

The description of the geological; geomorphological; and, navigation and coastal shoreline stabilization units reviewed under this study is represented in Figure 1-1.

Figure 1-1 depicts the sediment analysis modeling units, as follows:

> **A.1.** Coastal/marine depositional environments associated with past cycles of sea level rise that occurred from the Middle to Late Pleistocene;
>
> **A.2.** Paleo-incise river channels and valley-filled fluvial deposits developed on the inner shelf;
>
> **A.3.** Holocene deposits formed in the last 10,000 years on the Gulf shoreface;
>
> **B.1.** Bay deposits as part of the new coastal/bay Holocene environments or on top of Pleistocene deposits;

B.2. Ebb Delta deposits located on the Texas Gulf Inlets;

B.3. Flood Delta deposits located on the Texas Bays;

C.1. Suspended and bedload fluvial sediments coming from rivers and watersheds;

C.2. Fluvial-Deltaic deposits;

D.1. Sediments generated by dredging and dredged material management of navigation channels; and

E.1. Sediments impounded by coastal engineering and navigation structures (e.g., jetties, breakwaters).

Evaluation of these units under this study provide the basis for identifying potential sediment source locations for coastal protection and restoration projects, and areas to be considered for future detailed geophysical and geotechnical studies to ascertain extents and volumes of available in-situ and dredged sediment that may be classified as possible sediment source borrow areas.

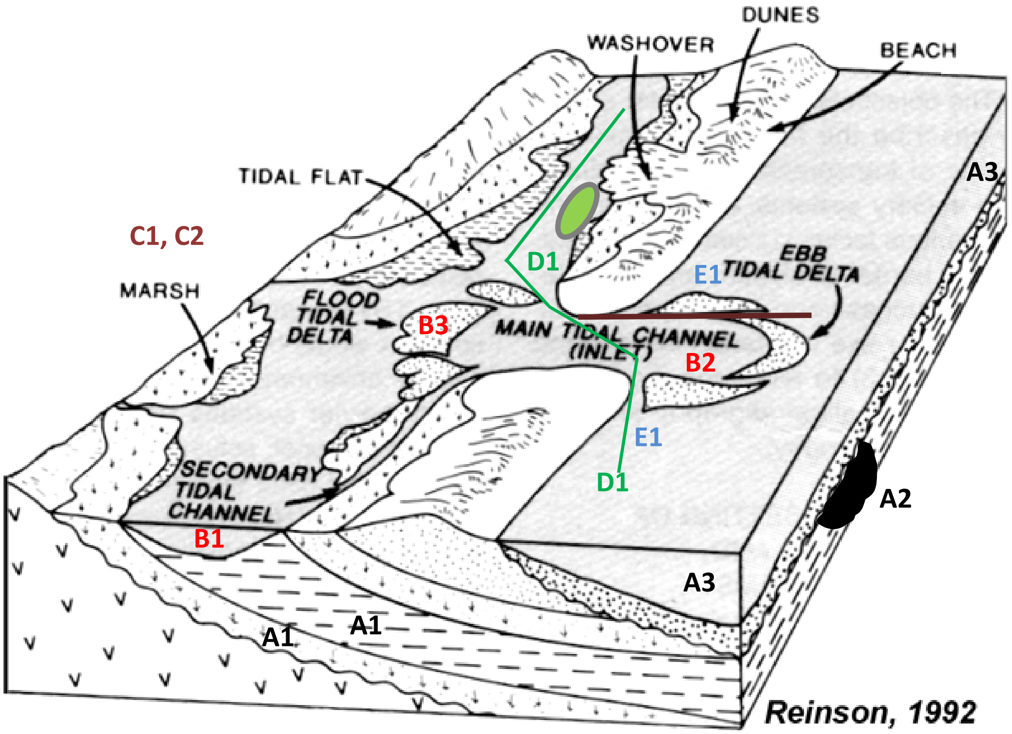


Figure 1-1, Sediment Analysis Model used for the development of this report showing the location of potential sediment source areas for investigation. The model is based on the establishment of the Texas Barrier Islands and headlands and their geologic and geomorphologic environments in the Gulf and bays-estuaries. See the text above for descriptions of the units (Modified from Reinson, 1992).

2.0 COASTAL AND MARINE GEOLOGICAL DEPOSITION FROM THE MIDDLE TO THE LATE PLEISTOCENE

The Texas Coast was developed through a combination of fluvial, coastal, and marine geological and geomorphological processes that occurred within the last 140,000 years connected to the last sea level rise cycles (Anderson et al., 2016). The worldwide sea level regressions and transgressions forced the coast to migrate vertically and horizontally. The most critical changes for the identification of soft sediment sources occurred within the last 17,000 years before present (BP).

Within the last 17,000 years, sea level rose about 300 feet, modifying the morphology of pre-existing river valleys, deposits, and ecosystems in the bays and estuaries (Anderson 2007). These changes involved fluvial, deltaic, coastal, estuarine, barrier island, and bay environments (Fisher et al., 1972). Figure 2-1 shows an adapted sea level curve for the Gulf of Mexico following Anderson (2007). This curve explains the magnitude of the sea level changes in the last 140,000 years and shows how the different stages on the coast, referred to as highstands, lowstands, and transgressive systems, dictated how these global changes locally affected the Texas coast through the rising or dropping of sea level. Although the curve shows transgressions and regressions, the classification of those stages is based on long-term regional trends (Rice University Gulf of Mexico Research Group, 2016).

The precise age of the geological record related to sea level changes along the Texas coast was recently analyzed by Anderson et al., (2016). Using sedimentological work that included detailed lithological descriptions, identification of sedimentary structures, grainsize analysis, seismic stratigraphic analysis, macro-and micro faunal analyses, magnetic susceptibility and clay mineralogy, hundreds of radiocarbon dates, oxygen isotope profiles, and micro paleontological data, the authors were able to provide relative age assignments of sea level transgressions and regressions, and the deposits created during these changes within the last 124,000 years.

Combined with the data described above, the authors used basic sequence stratigraphic techniques and terminology to subdivide the stratigraphic section to the called “systems tracts” that are connected to the sea level curve and associated Marine Oxygen Isotope (MIS) (Anderson et al., 2016). These systems tracts are connected to the type of sediments available in the geologic record and this report follows the ages and events defined by these systems tracks and associated their stages. The suggested ages and names of these geologic events are described in Table 2-1 below (Anderson et al., 2016). The system tracts analysis helped to create a sediment inventory for coastal areas.

Table 2-1
Ages of the Texas Coastal Geological Events During the Last 24,000 Years

Sea Level Event	Approximate Time in Thousands of Years
Highstand Systems Tract (MIS 5e)	~124-119
Falling-Stage Systems Tract (MIS 5-3)	~119-22
Lowstand Systems Tract (MIS 2)	~22-17
Transgressive Systems Tract (MIS 1)	~17-4.0
Current Highstand (MIS 1)	~4.0 - Present

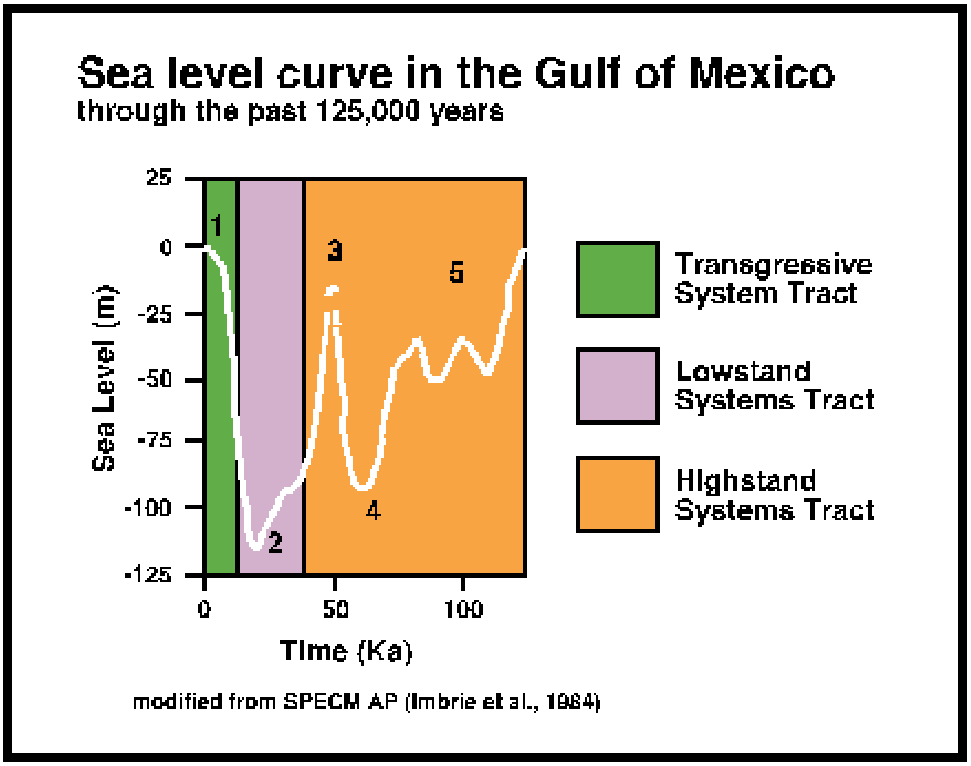


Figure 2-1, Sea Level Rise Curve in the Gulf of Mexico over the past 124,000 years. The curve represents the transgressions (sea level moving up) and regressions (sea level moving down) on the Northern Gulf of Mexico shorelines. The numbers above and below the curve correspond to specific geological stages of erosion and deposition associated with the sea level responses. (Bernard et al., 1970; and Fisher et al. 1972).

As presented in the sea level curve (Figure 2-1), the highstand system track and falling stage system (5e and 5-3) occurred between 124,000 and 22,000 years BP where sea level was regressing, with some fluctuations and jumps. This time represents periods of geologic deposition and erosion on which is now the continental shelf. The curve represents the transgressions and regressions along the Northern Gulf of Mexico shorelines. The numbers above and below the curve correspond to specific geological stages of erosion and deposition associated with the sea level responses (Anderson et al., 2016).

2.1 THE BEAUMONT FORMATION

Before sea level rise Stage 1, coastal-marine and other deposits became consolidated where streams were able to cut (vertically and horizontally) as they were trying to reach the available sea level. Some of the oldest coastal deposits are known as the Beaumont Formation. The Beaumont Formation, or Beaumont clays, is a common Pleistocene formation present across the Texas coast (Figure 2-2). Bernard et al., (1970) and Fisher et al. (1972) originally defined the Beaumont Formation as a fluvial delta with shallow marine deposits and barrier-strand plain-chenier units formed between around 400,000 and 35,000 years BP. The Beaumont Formation is present in large areas of the former coastal plains and continental shelf as presented in Figure 2-2 (Chowdhury and Turco, 2006).

Blum and Price (1998) dated the age of the Beaumont Formation using the nearby Colorado River system, showing that the representative time period of the deltaic and fluvial deposition spanned from around 400,000 - 300,000 to 85,000 years ago. These deposits consisted of multiple fluvial and deltaic cycles of river valley incision and filling (Blum and Price, 1998). The Beaumont Formation, that includes ancient barrier islands and beach deposits created before 35,000 years ago, can be observed in Rockport, Port O'Connor, Ingleside, and on the north shorelines of West and East Galveston Bays (Fisher et al., 1972).

In conclusion, the Beaumont Formation appears to have ended its deposition at the end of Stage 3 as presented in Figure 2-1 (Bernard et al., 1970; and Fisher et al. 1972). At the end of Stage 1, with the slowdown of sea level rise for the last 9,000-2,000 years, the new coast became a mix of sandy barrier island environments, marsh-swamps, bay-estuary-lagoons, and offshore shorefaces and fluvial-deltaic systems that covered the Beaumont Formation. These new environments have a large spectrum of sediments, including sands, silts, and clays. In general, the post-Beaumont Formation coastal deposits correspond to reworked deposits from previously deposited environments placed on the new environments (Anderson et al., 2016).

Figure 2-2 shows the surficial geology of the coastal Texas aquifers illustrating the extension of the Beaumont clay throughout the Texas Coast (Turco, 2006).

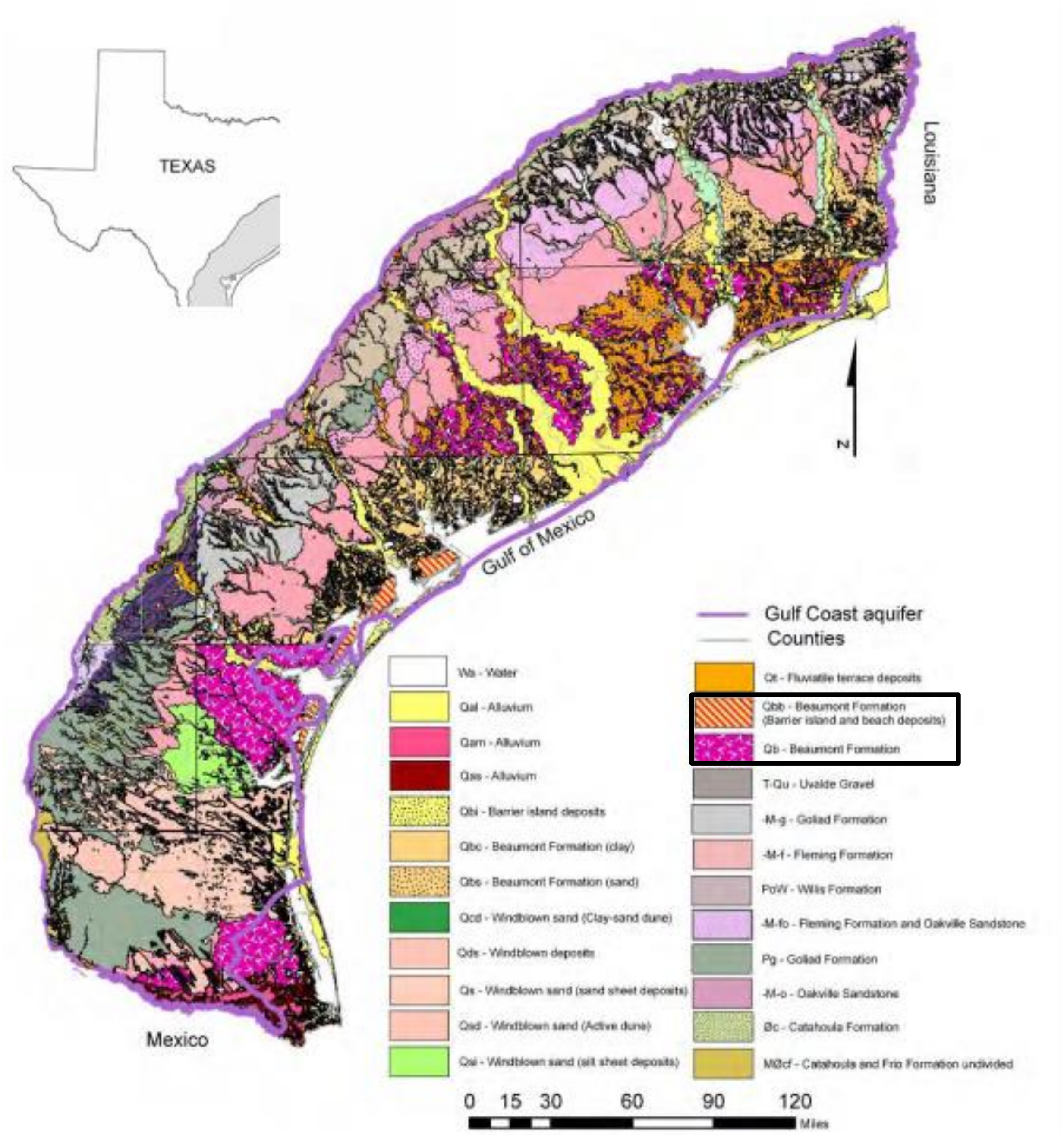


Figure 2-2, Surficial Geology of the Coastal Texas Aquifer showing the extension of the Beaumont clay in the Texas coast. Notice the units of the Beaumont Formation with the Box in the Legend (Source: Chowdhury and Turco, 2006).

3.0 PALEO-INCISED RIVER CHANNELS AND VALLEY-FILLED FLUVIAL DEPOSITS DEVELOPED ON THE CONTINENTAL SHELF

3.1 THE LARGER TEXAS RIVER VALLEYS

From Stages 5 to 2 (as presented in Figure 2-1), incised river valleys and river deltas were created following the migration of the shorelines in the Gulf of Mexico. During this period, large rivers, such as the Brazos, Rio Grande, and Colorado Rivers, deposited a set of large, fluvial-dominated deltas that migrated across the Texas inner shelf responding to changes in sediment supply and climate changes (Anderson et al., 2016) (Figure 3-1). With the drops in sea level, the drainage basins produced large discharges dominated by fine-grained and suspended mud sediments on steep slopes (Abdulah and Anderson 1994, 2004).

Figure 3-1 shows a map of the geological location of the different stages of evolution and accretion of the Brazos and Colorado River Deltas during the last highstand period, including Stages 3 and 5 (Rice University Gulf of Mexico Research Group, 2016).

Similar sedimentation processes occurred (on a different scale) along other Texas rivers during the same time period, leaving a diverse set of geological deposits on the continental shelf. The fluvial sediments were deposited on top of the previous Pleistocene deposits or created new landforms and deposits on the inner shelf during Stages 3 and 5.

As sea level regressed during the last period of lowstand, the Texas rivers developed longer watershed configurations than the ones we see today (Blum et al., 2013) (presented in Figure 3-2). Coastal shorelines and river deltas at one point were located about 300 feet below present levels (Anderson et al., 2016). The length of the Texas rivers on the upper coast were considered “mega rivers” (i.e. Mega Brazos and Mega Colorado) (Blum et al., 2013) with larger watershed and discharges than we see today.

A large distribution of the incised river valleys covered a significant portion of the inner shelf and the areas known today as coastal areas (Blum et al., 2013). The fluvial morphologies observed in Figure 3-2 and Figure 3-3 suggests that around 17,000 years BP, the morphology of Texas’ rivers on the former coastal plain (mainly the Beaumont Formation) consisted of deep channels with steep slopes on the river banks, surrounded by elevated uplands with respect to the river bottoms. Some of the important coastal Texas cities, such as Galveston, Angleton, Lake Jackson, Port Aransas, etc., are located on top of the incised valley zones, as presented in Figure 3-3 (Anderson et al., 2016). Close to the 17,000 years BP mark, the rivers created deep gorge environments and started to receive large sediment discharges that were dominated by fine-grained and suspended mud sediments in contact with sea level (Bernard et al., 1970; Abdulah and Anderson, 1994), which then filled the previously established incised channels.

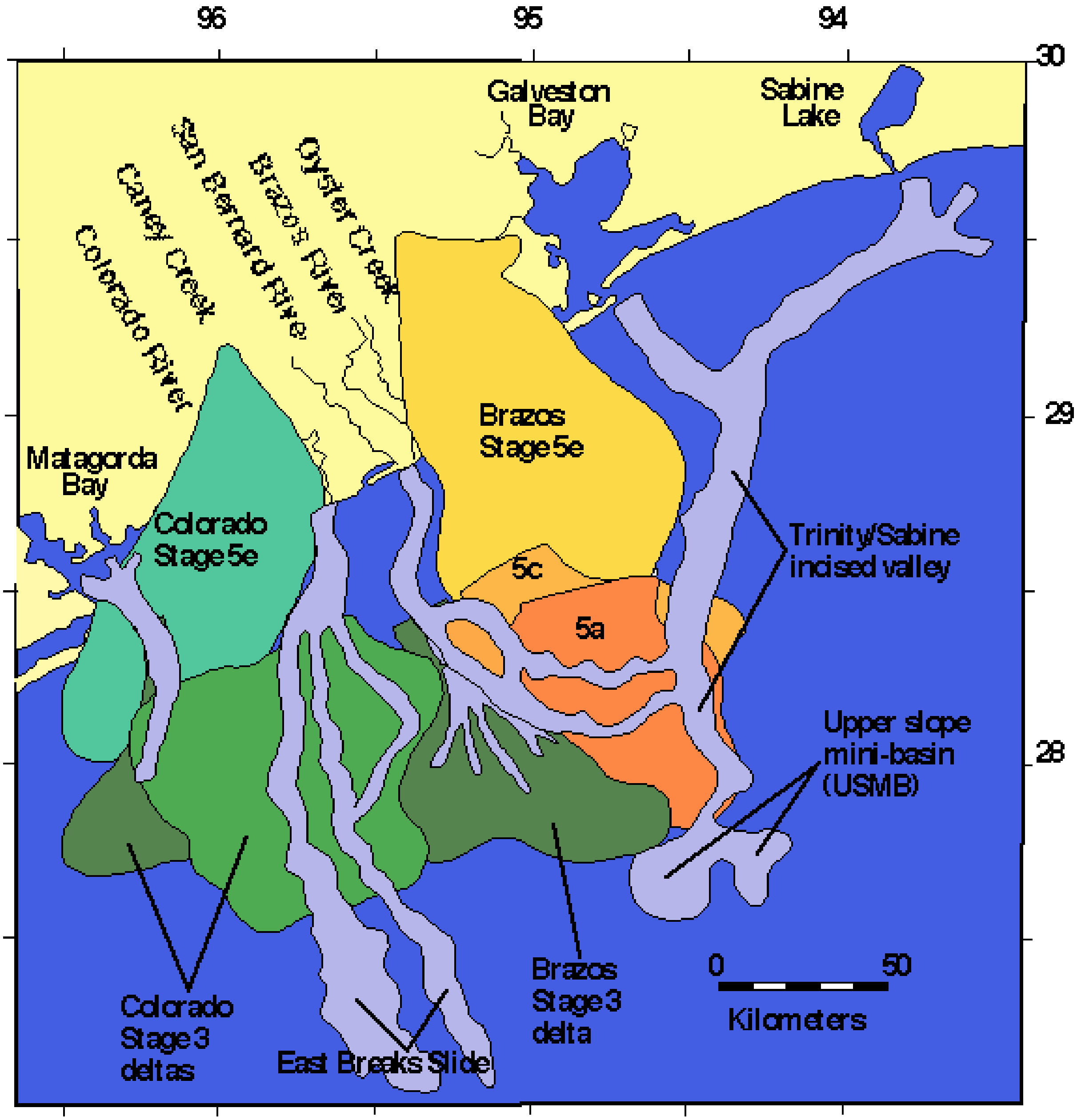


Figure 3-1, Highstand of the Colorado and Brazos River Deltas. Location and distribution of the Colorado and Brazos River Deltas during different stages of sea level ups and downs that occurred during the highstand systems track period presented in Figure 1-1. The numbers in the map correspond to periods of growth of the Colorado and Brazos River Deltas following sea level changes that occurred between 124,000 and 22,000 years BP (Rice University Gulf of Mexico Research Group, 2016).

Figure 3-2 illustrates current Texas river watersheds as we know them today and the distribution of the Mega Rivers and their incised valleys in the upper coast (Blum et al., 2013). Figure 3-3 displays a paleo-geographic map showing major lowstand depositional systems that occurred between 22,000 and 17,000 years ago, (see Figure 2-1) when sea level was located at about 300 feet below its present location. The figure also shows the morphology of the previous incised valley morphologies that were later filled as sea level moved vertically (after Anderson et al., 2016).

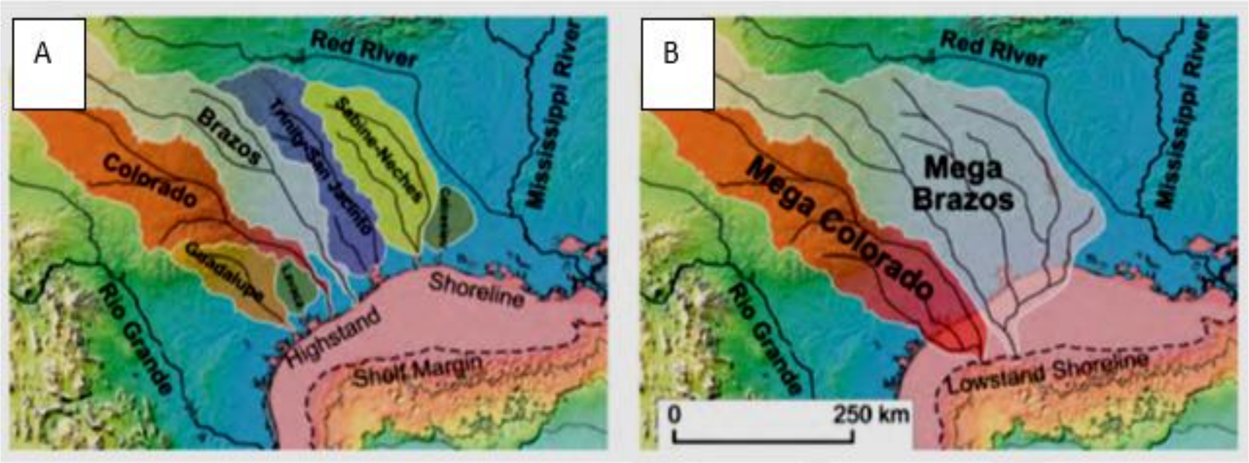


Figure 3-2, (A): Texas river watersheds as we know them today. (B): the distribution of the Mega Rivers in the upper coast as a response to the sea level drop that reached its maximum about 17,000 years ago. The end of Transgressive Shorelines represents the Gulf shoreline as we see it today. Lowstand Shoreline is the location of the Gulf shoreline around 17,000 years ago (Source: Blum et al., 2013 and Anderson et al., 2016).

An example of the morphology of incised channels corresponds to a seismic profile of the Trinity River incised channel underneath the eastern tip of Galveston Island, Bolivar Roads, and the western tip of Bolivar Peninsula (presented in Figure 3-4) (Anderson, 2007), shows the general features developed by the Trinity River vertical incision. The profile shows sedimentary processes associated with sea level rise filled the river incision that was then later covered by the barrier island. The seismic profile shows a vertical incision of at least 150 feet deep, with steep banks on each side (Anderson, 2007). The valley-filled sedimentation that occurred transformed from fluvial deposits to bay and estuarine deposits, ending in barrier island deposits at the top of the sedimentary sequence. Similar incised channels were filled across the coast affecting all major rivers, including the former Lavaca and Nueces Rivers.

Of significant importance is the way rivers with major deltas responded. For example, for Stage 1, the main valleys of the former Mega Colorado and Mega Brazos Rivers became filled and at the end started a period of delta lateral migration and terrestrial avulsion processes, while other river valleys became part of the bay systems as presented in Figure 3-5 (Blum et al., 2013 and Anderson et al., 2016).

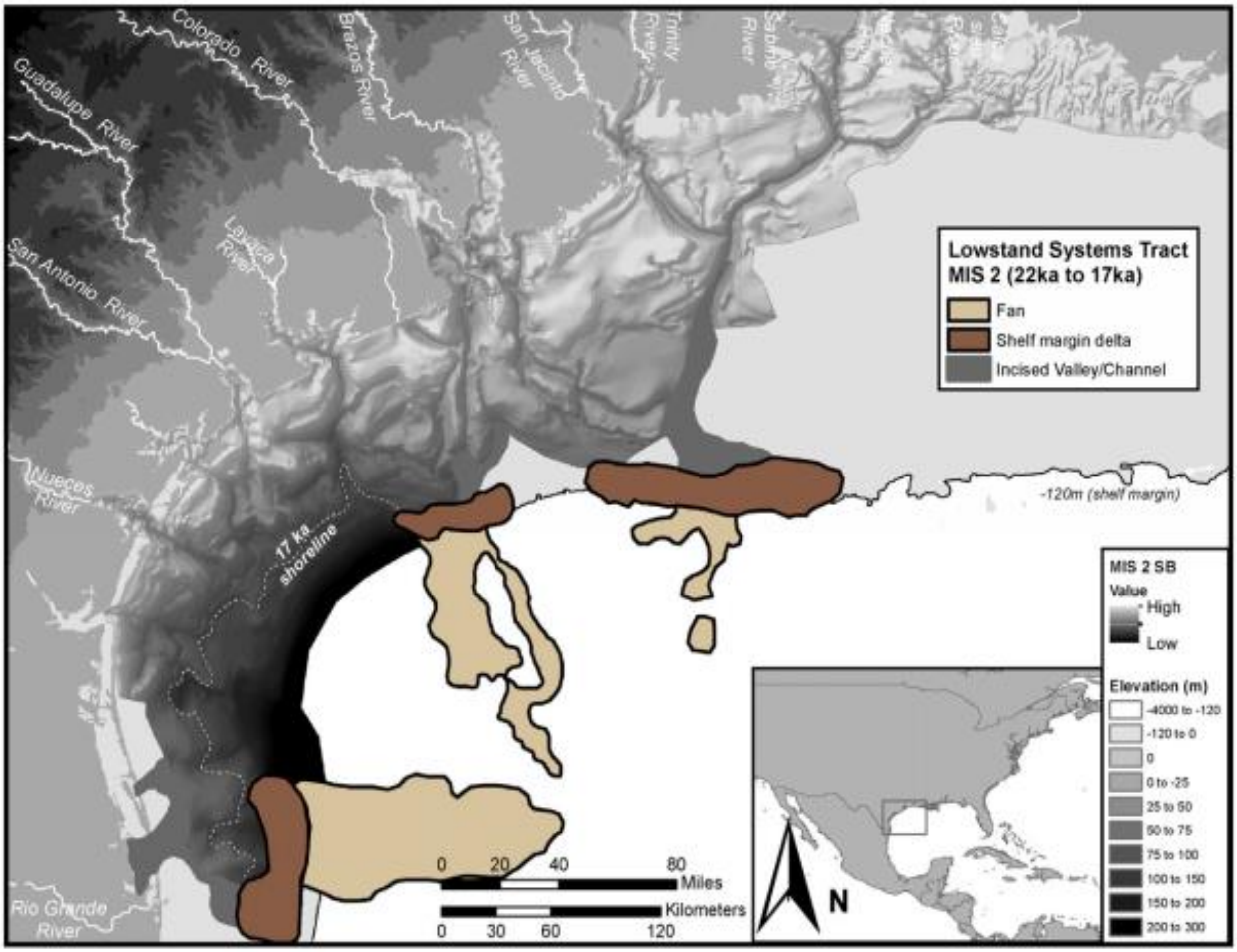


Figure 3-3, Paleo-geographic map showing major lowstand depositional systems that occurred between 22,000 and 17,000 years ago, (See Figure 1-1) when sea level was located about 300 feet below its present location. The figure shows the morphology of the previous incised valley morphologies that were later filled as sea level rise was rising (After Anderson et al., 2016).

These valleys were filled with different types of fluvial deposits, including fines, sands, gravels, and swamp deposits that can be investigated in the future for the identification of sediment sources.

Figure 3-5 illustrates the distribution of the paleo-incised valleys of the Brazos and Colorado Rivers. These deep valleys were filled with alluvial deposits in the last few thousand years as a response to sea level rise creating areas of delta migration and fluvial avulsion (Blum et al., 2013).

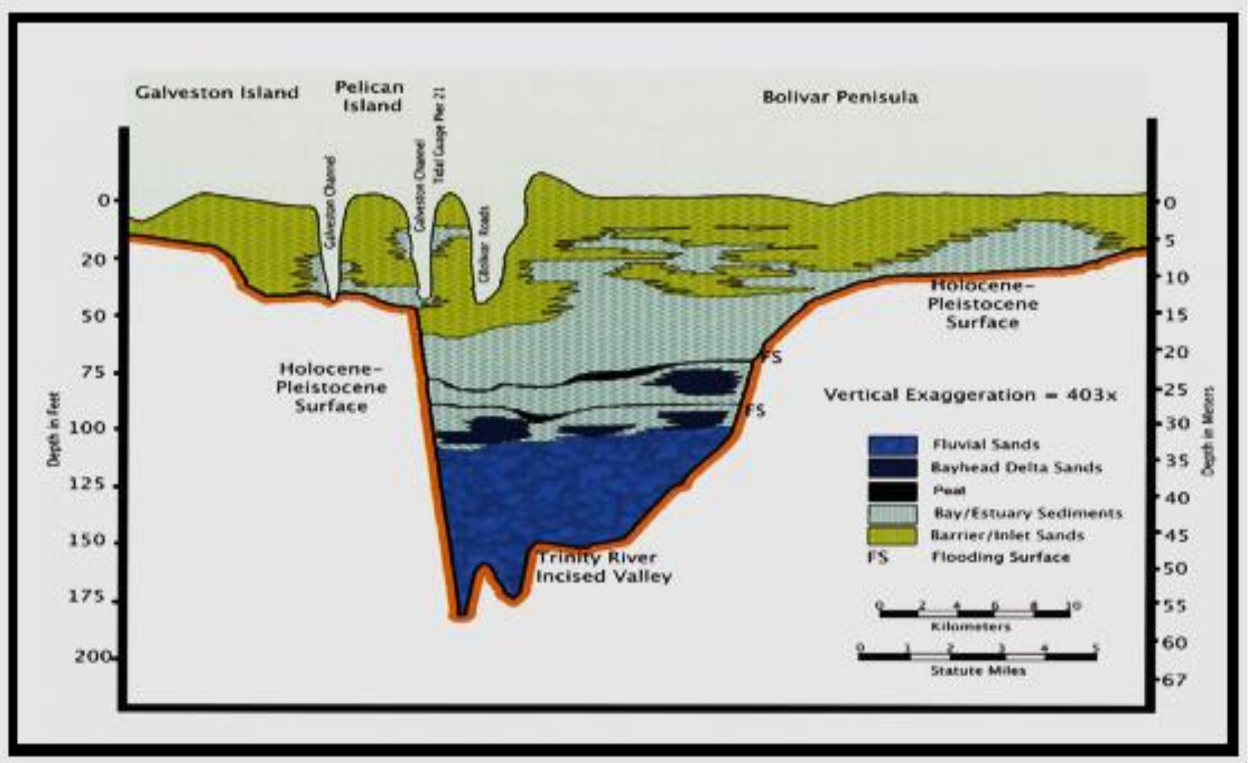


Figure 3-4, Trinity River Valley Cross Section. Geologic cross section of the Trinity River Valley underneath the eastern tip of Galveston Island, Bolivar Roads, and the western tip of Bolivar Peninsula showing the paleo-morphology of the valley, which was created by the incision of the Trinity River, responding to the drop in seal level. The valley was then filled when sea level rose. Details of the ages of these events are on Figure 1-1. (Anderson 2007).

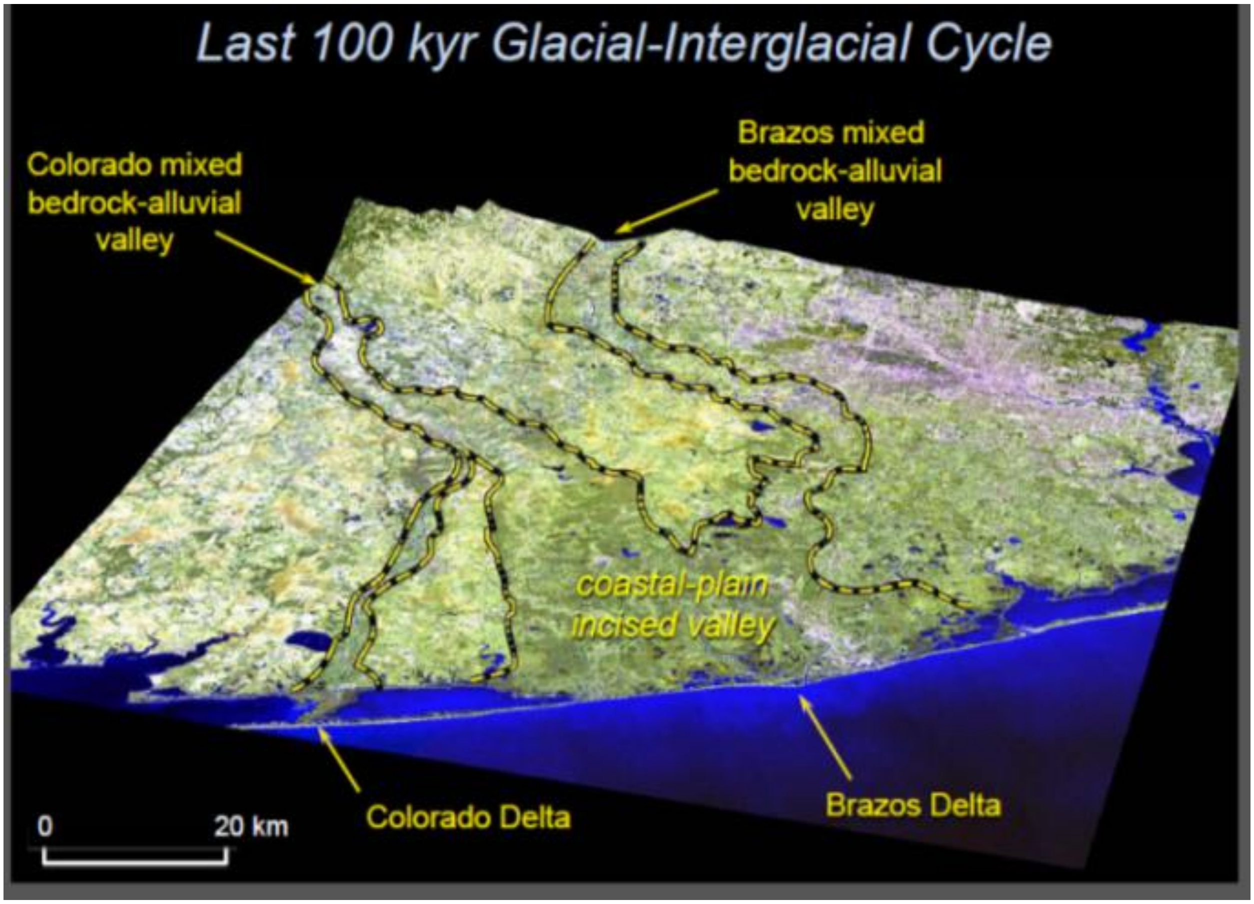


Figure 3-5, Image showing the distribution of the former paleo-incised valleys of the Brazos and Colorado Rivers. These deep valleys were filled with alluvial deposits in the last few thousand years as a response to sea level rise creating areas of delta migration and fluvial avulsion (Blum et al., 2013).

3.2 TRINITY-SABINE INCISED VALLEYS

As part of the Mega Brazos River system, the former Sabine River was previously connected to the Trinity River offshore of Galveston Island. The Sabine River runs parallel to what is today Bolivar Peninsula (Figure 3-6). The position of the Sabine River system has been recently investigated for sediment volumes showing significant amounts of valley-filled deposits (Dellapenna et al., 2009; Anderson et al., 2016). Sediments have been identified as a set of different deposition stages as sea level was rising and filling the valleys.

With a depth of at least 40 meters (average depth suggested by Anderson et al., 2016) (Figure 3-6 and Figure 3-10) and a length of up to 200 kilometers, the paleo valleys of the Trinity and Sabine rivers, formerly part of the Mega Brazos watershed, potentially contain more than 40,000,000,000 cubic meters (52,318,024,772 cubic yards) of soft sediments, mainly fine sediments, (including the secondary channels) in the geologic record (Table 3-1). This assessment includes the first 50 kilometers from the coast and considers all stages of deposition, including fluvial back-stepping deposition, delta head and bay environments, and coastal muds.

Figure 3-6 illustrates the Sabine and Trinity River Valleys as presented by paleo-topography. Due to the complexity of these rivers, data regarding the sediment volumes of these two rivers is presented later in this report.

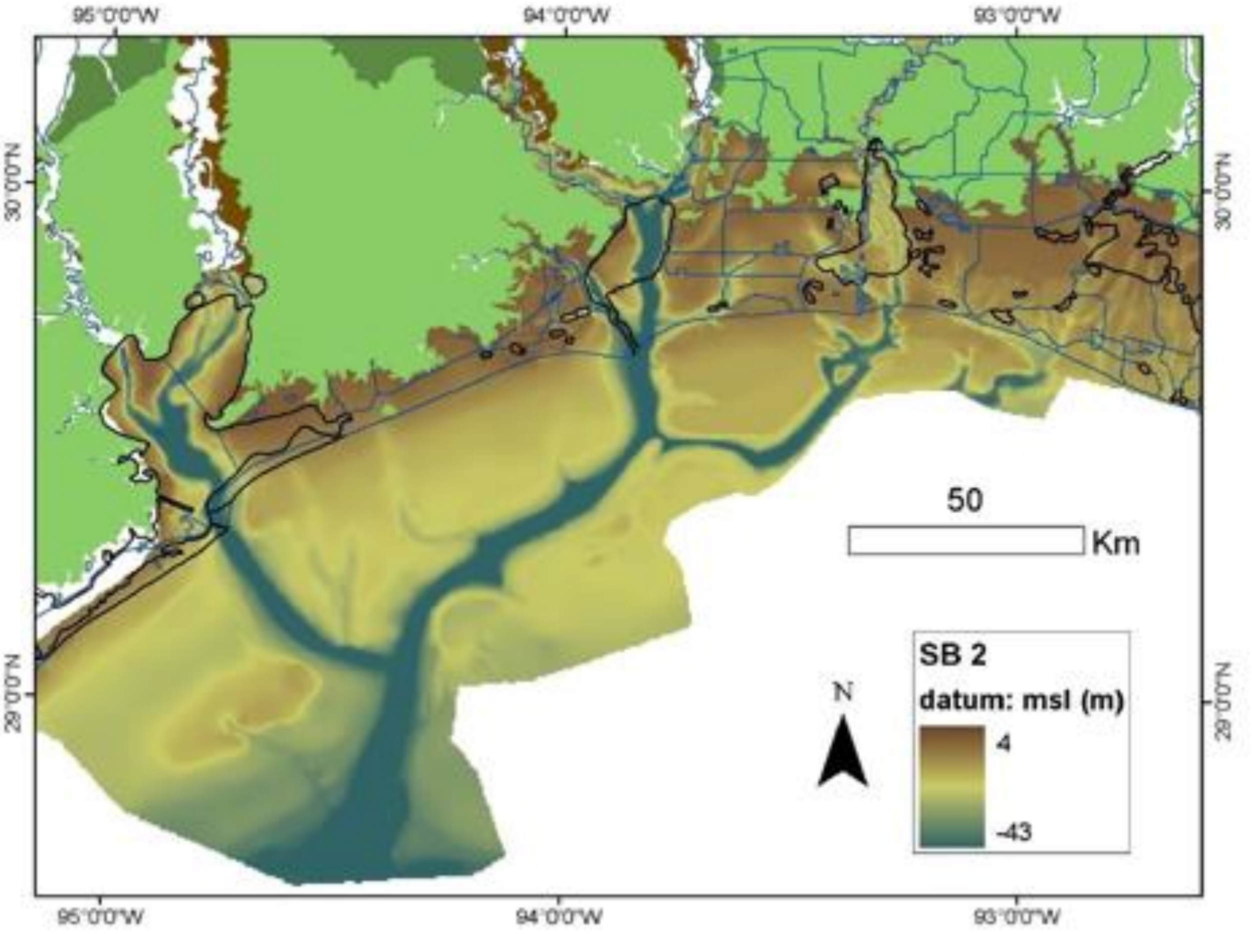


Figure 3-6, Ancestral Calcaseiu, Sabine and Trinity River Valleys as presented by paleo-topography. Notice the parallel location of the Sabine River with respect to the Bolivar Peninsula area (After Milliken et al., 2008).

Table 3-1
Offshore Trinity and Sabine Incised Valleys

Geologic Unit	Potential Sediment Volume
Offshore Trinity and Sabine Incised Valleys	~40,000,000,000 cubic meters

3.3 COLORADO AND BRAZOS RIVERS

The Colorado and Brazos Rivers incised valleys appear to be different because they were developed on previous deltas that were then covered by recent deltaic deposition (Figure 3-7).

The previous river paths of the Colorado River during stages 5a and 3 indicate that the Colorado River delta was formerly located offshore from Matagorda and Espiritu Santo Bays, and then was cut by the incised channels of the Lavaca River during stage 2 (Figure 3-7) (Anderson et al., 2016).

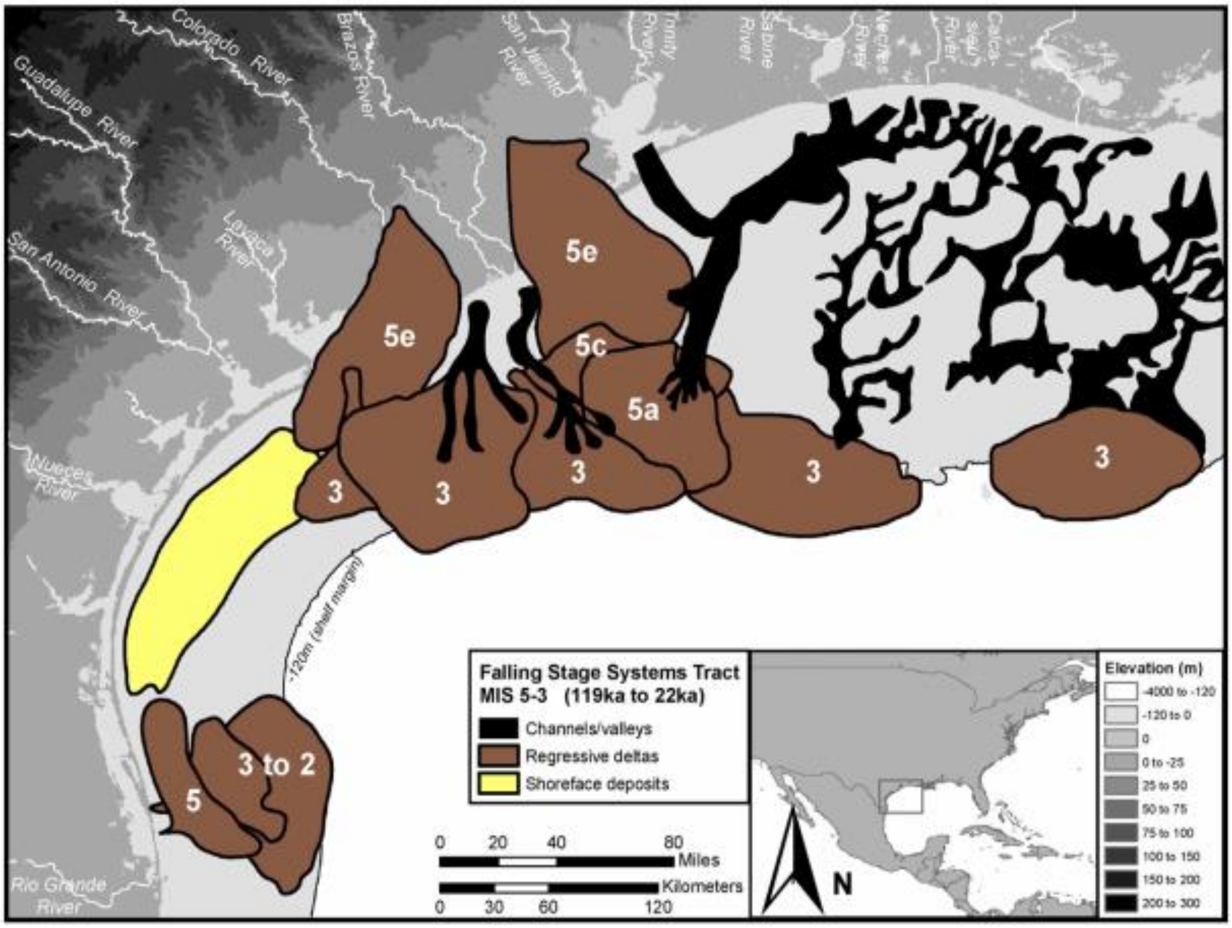
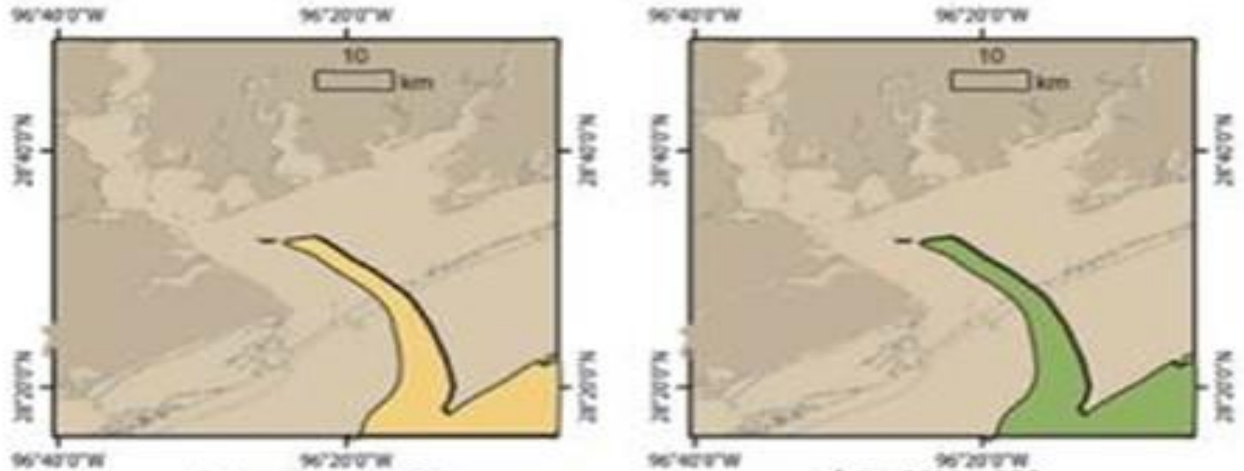
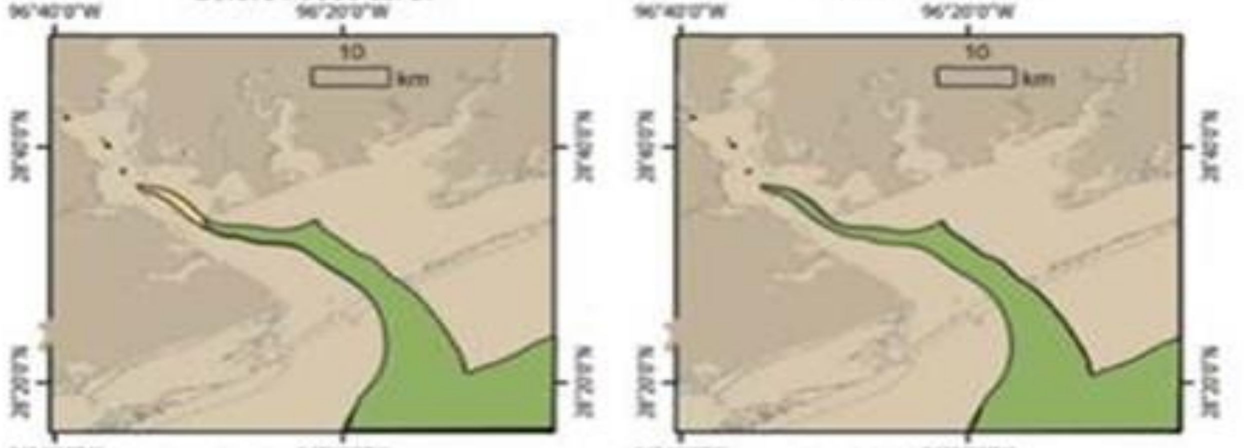


Figure 3-7, Paleo-geographic map showing the major falling-stage depositional systems of the Texas coast showing the repeated cycles of progradation and back-stepping that occurred on the Texas rivers as a response to the sea level curve shown in Figure 1-1 From Stages 5e to 2). (Source: Anderson, et al., 2016).



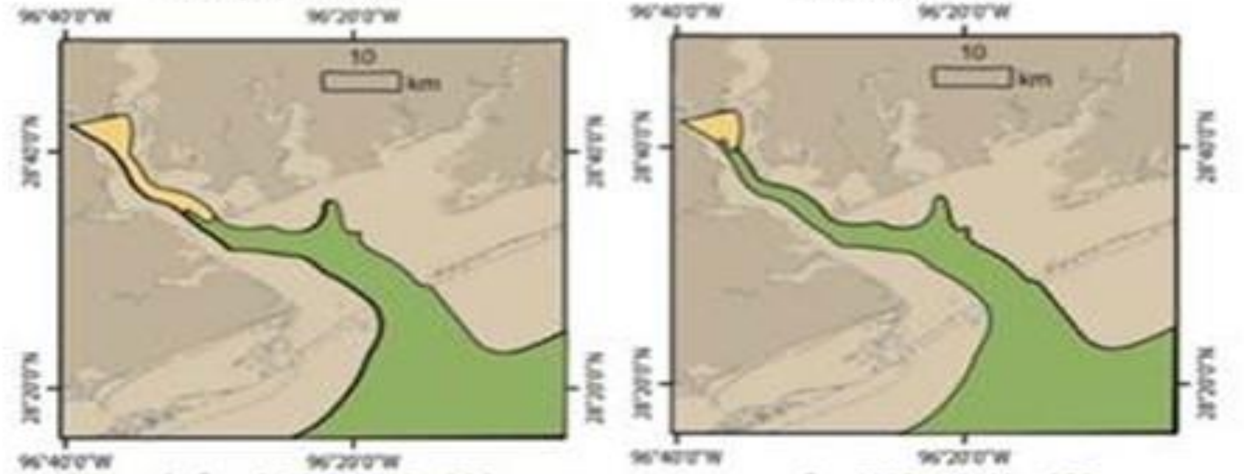
before >9600 cal BP

after >9600 cal BP



before 9500 cal BP

after 9500 cal BP



before 8200 to 8500 cal BP

after 8200 to 8500 cal BP

Figure 3-8, Geological evolution of Matagorda Bay associated with the inundation of the Lavaca River Valley in the last 10,000 years BP before the formation of the Matagorda Peninsula (around 6,000 years BP). After Maddox et al., (2008).

3.4 LAVACA RIVER INCISED VALLEY

The former Lavaca River and Colorado River were once connected as part of the former Mega Colorado River. Data from Maddox et al., (2008) and Anderson et al., (2016) related to the geological changes and sedimentation that occurred in the last 10,000 years indicates that this river contains a young incised channel that cut the former Colorado delta formed during stages 5e, and then started to fill in the last 9,500 years (Figure 3-8). The formation of Matagorda Peninsula was created around 6,500 years BP, closing the bay, by the new barrier island (Maddox, et al., 2008). From the oldest to the youngest sedimentary history starting around 9,500 years BP, the former Lavaca River Valley transformed from Pleistocene clays to fluvial facies, then to bay head delta facies, and finally to bay bottom facies. This sequence is very similar to the sequence for Matagorda Bay as presented in Figure 3-8. Detailed information for the incised Lavaca River channel in the Matagorda Bay area is presented in Chapter 8.0.

3.5 INCISED CHANNELS SOUTH OF THE LAVACA RIVER INCISED VALLEY

South of the Lavaca River valley, data regarding sediment resources connected to other incised valleys on the inner shelf is limited. The Guadalupe, Lavaca, and San Antonio Rivers were previously connected to the former Mega Colorado River (Blum et al., 2013) (Figure 3-2). These former river valleys that run along the continental shelf are open for sediment source investigations.

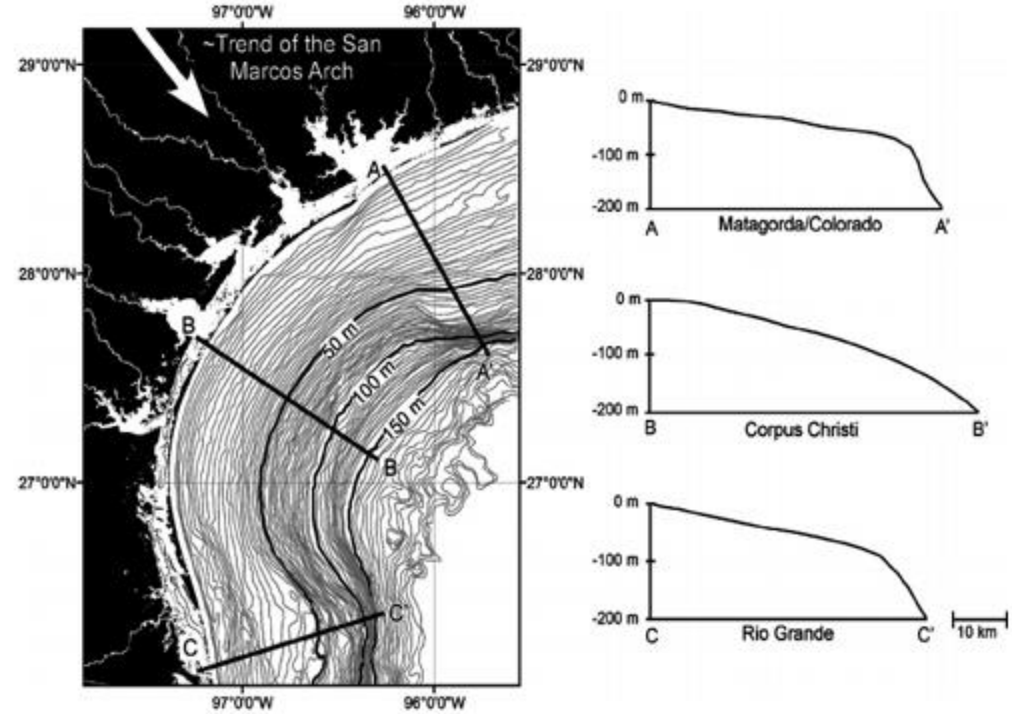


Figure 3-9, Bathymetric profiles of the Texas continental slope and profiles illustrating variation in Texas inner shelf physiography (After Anderson, et al.,2016). Notice the steepness of the inner shelf in Central Texas.

Generally, the Central Texas continental shelf presents steep slopes (Figure 3-9) (Anderson et al.,2016). The bathymetric profile of the inner shelf in central Texas is steeper than the north and south shelfs, limiting the availability of offshore depositional systems. The area offshore Espiritu Santo Bay to Central Padre Island has been classified as a zone of very fine shoreface deposits due to the limited presence of significant Late Pleistocene fluvial bodies (Anderson et al., 2016).

3.6 SMALL FLUVIAL CHANNELS ON THE CONTINENTAL SHELF

Geological information collected by Dellapenna et al., (2009) and Dellapenna (2010) in the Texas upper coast between the Texas shorelines, the Sabine River, and the Sabine Bank shows that several small watershed channels are connected to the former Mega Rivers on the shoreface of the Texas coast. These small channels were part of small watersheds that contain unconsolidated sediments (Figure 3-10) and were formed right before sea level inundated these areas. Although the former channels are not deep, they may contain significant amounts of unconsolidated sediments.

Some investigations conducted on the paleo channels along the shoreface of Jefferson County (Gahagan & Bryant, 2013; McCoy et al., 2015) show that the paleo-streams were once part of the former Sabine watershed adjacent to the former Sabine River path. Sand bodies with more than 3,000,000 cubic meters (3,900,000 cubic yards) were found to be compatible beach sands; however, the sand bodies were overburdened with important clay deposits (Gahagan & Bryant, 2013; McCoy et al., 2015). Clay rich overburden has been mentioned as being an incompatible material for beach projects. Despite this, it may be a good source of sediment for clay core dunes, berms, or for marsh fill material.

For potential medium side channels, specific analysis should be considered for the “Deweyville Terraces” (Blum et al., 1995), referred to as DT in Figure 3-11 (Dellapenna et al., 2009). Figure 3-11 corresponds to a geophysical cross section of a former small river channel located offshore 12 miles southwest of Sabine Pass on the inner shelf (Dellapenna et al., 2009). The Deweyville Terraces correspond to the last fluvial deposition period before fluvial features became inundated by sea level. Some Deweyville Terraces have been dated as young as 4,000 years BP (Phillips, 2008) on the former alluvial alluvial plain of the Sabine River. These terraces tend to contain important amounts of sandy deposits, as confirmed by Dellapenna et al., (2009). For instance, these small fluvial channels can have sediments with up to 5,000,000 cubic meters (6,500,000 cubic yards) on the north side of the former Sabine River path (Dellapenna personal communication), but their distribution may be minimal (Table 3-2).

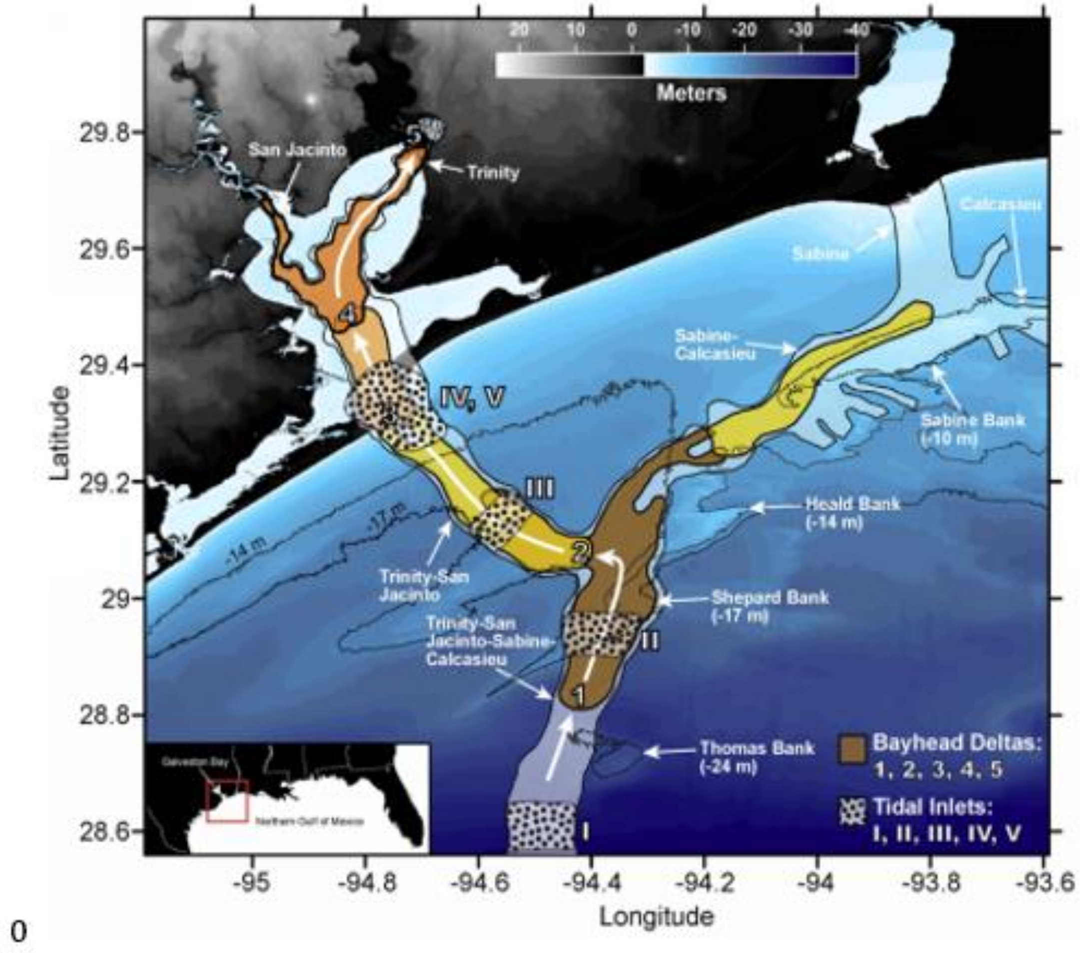


Figure 3-10, Specific sedimentary units associated with sea level rise and valley fill on the Sabine-Trinity River Valleys that were part of the Mega Brazos River. These deposits are considered back-stepping deposits as sea level inundated the previously created valleys with a potential of more than 40,000,000,000 cubic meters (52,300,000,000 cubic yards) of sediments (mainly fines) in the geologic record (After Anderson et al., 2016 and Dellapenna, personal communication).

Table 3-2

Offshore Small Channels of the Trinity and Sabine Incised Valleys

Geologic Unit	Potential Sediment Volume
Offshore Small Channels of the Trinity and Sabine Incised Valleys	~5,000,000 cubic meters (per channel under specific circumstances)

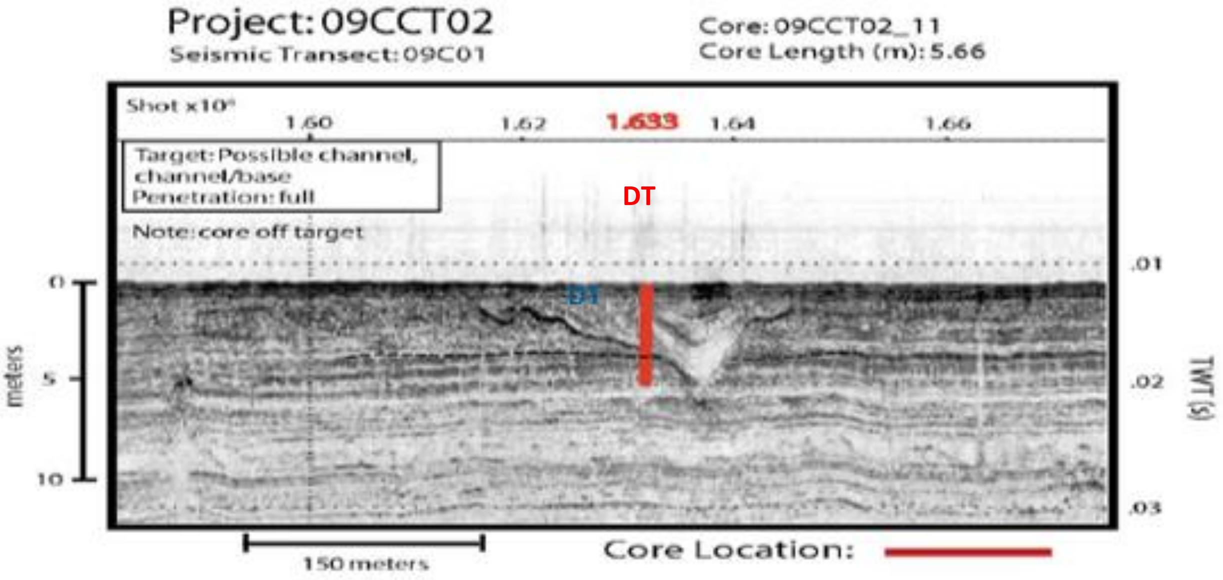


Figure 3-11, Fluvial channels connected to the former Sabine River offshore Sabine Pass. The profile shows an important fluvial feature with unconsolidated sediments (Dellapenna, et al., 2009). DT=Deweyville Terrace.

3.7 MAJOR SUBMERGED DELTAIC DEPOSITS

3.7.1 Colorado River Delta Deposits

The Colorado River Delta is one of the offshore geological features that contains the largest volumes of sand in close proximity to modern shorelines. A few periods of delta deposits were developed during its evolution from Stages 3 to 1 (Anderson et al., 2016). During Stage 3 (between 40,000 and 23,000 years ago), the delta covered a large area of deposition (Figure 3-12) (Rodriguez et al., 2000). According to the authors, an estimate of 21 km^3 (21,000,000,000 cubic meters or 27,466,963,005 cubic yards) of delta sediments accumulated during Stage 3.

The most recent river delta was created during Stage 1 (between around 11,500 and 8,000 years ago) as a back-stepping delta. Geologic analysis indicates that the delta contains high quality sands (Van Heijst et al., 2001). Other geologic deposits associated with back-stepping processes that occurred between the same period (around 11,500 and 8,000 years ago) are presented in Figure 3-13 (Anderson et al., 2016) and in Table 3-3. During the transition from Stage 2 to Stage 1, the delta deposited about 77 km^3 (77,000,000,000 cubic meters or 100,712,197,687 cubic yards) of delta and fluvial deposits, including important volumes of clean sand. During Stage 1, about 10 km^3 (10,000,000,000 cubic meters or 13,079,506,193 cubic yards) of sediments were deposited (Figure 3-12). Based on the geological information available, this is possibly the largest coastal sediment deposit available for restoration purposes within close proximity to the Texas coast. The Colorado River deltas appear to be the best potential source of sand for barrier island restoration projects (John Anderson personal Communication).

Table 3-3
Delta Stages for the Colorado and Brazos Rivers

Geologic Unit	Potential Sediment Volume
Colorado River Delta Stage 3	~21 km^3 (21,000,000,000 cubic meters)
Brazos River Delta Stage 2 to 1	~77 km^3 (77,000,000,000 cubic meters)
Colorado River Delta Stage 1	~10 km^3 (10,000,000,000 cubic meters)

3.7.2 Brazos River Delta Deposits

Data for the Brazos River incised valleys indicates the same problem occurred when the Colorado River channels developed where the valleys were previously cut on delta deposits, and then were filled again with new deltas (Figure 3-7). From the analysis of the Brazos River Delta deposits throughout different stages, several deltas can be recognized over the last 120,000 years (Anderson et al.,2016). Between 120,000 and 90,000 years ago, about 33 km^3 (33,000,000,000 cubic meters or 43,162,370,437 cubic yards) of sediments were deposited during stage 5e to 5b. From 80,000 to 60,000 years ago, an estimated 27 km^3 of sediments (27,000,000,000 cubic meters or 35,314,666,721 cubic yards) were deposited during Stage 5a to 4. Between 55,000 to 23,000 years ago, about 112 km^3 (112,000,000,000 cubic meters or 146,490,469,363 cubic yards) of sediments were deposited during Stage 3.

For the sediments deposited on the paleo river valleys, between 20,000 years ago to the present, an estimated 48 km^3 (48,000,000,000 cubic meters or 62,781,629,727 cubic yards) of sediments were deposited as valley fill during Stages 2 and 1 combined. The identification of specific sand sources for beach restoration is open for the analysis of these delta deposits in the Gulf of Mexico.

The geologic references have limited information on the composition (% of sands) of these deltas. Assuming the modern delta on the present coast has the same composition as the past deltas, a large variety of sediments (from gravels to fine clays) should be available but will require specific studies to identify the areas of clean sand.

Table 3-4
Delta Stages for the Brazos River

Geologic Unit	Potential Sediment Volume
Brazos River Delta Stage 5e to 5b	~33 km^3 (33,000,000,000 cubic meters)
Brazos River Delta Stage 5a to 4	~27 km^3 (27,000,000,000 cubic meters)
Brazos River Delta Stage 3	~112 km^3 (112,000,000,000 cubic meters)
Brazos River Delta Stage 2 to 1	~48 km^3 (48,000,000,000 cubic meters)

3.7.3 THE RIO GRANDE

There is limited data connected to the stages of the Rio Grande recent incised channel as a potential sediment source. Due to the large amounts of sediment supply, this Mega River is one of the largest watersheds in the U.S. and Mexico. The Rio Grande constructed deltas that advanced across the shelf in a step-wise fashion during stages 5 to 2 (Anderson et al., 2016) (Figure 2-8). The incised valleys were created by cutting previous deltas that were then covered by recent deltaic processes. The potential sediment source investigations associated with the last stages of the Rio Grande River delta are open due to the limited data available for the purpose of this report.

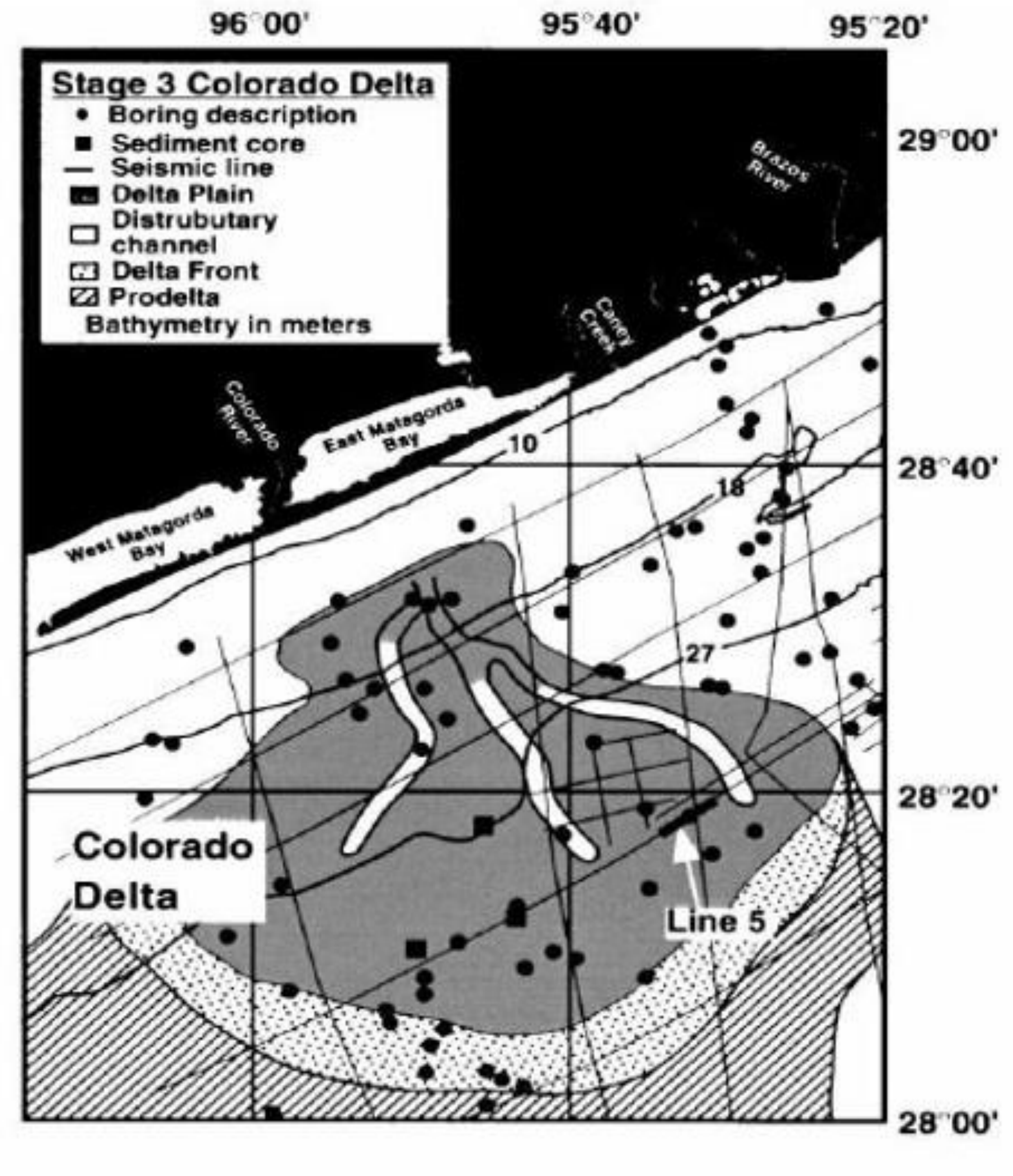


Figure 3-12, Location of Former Colorado River Delta During Stage 3 (From Rodriguez et al., 2000).

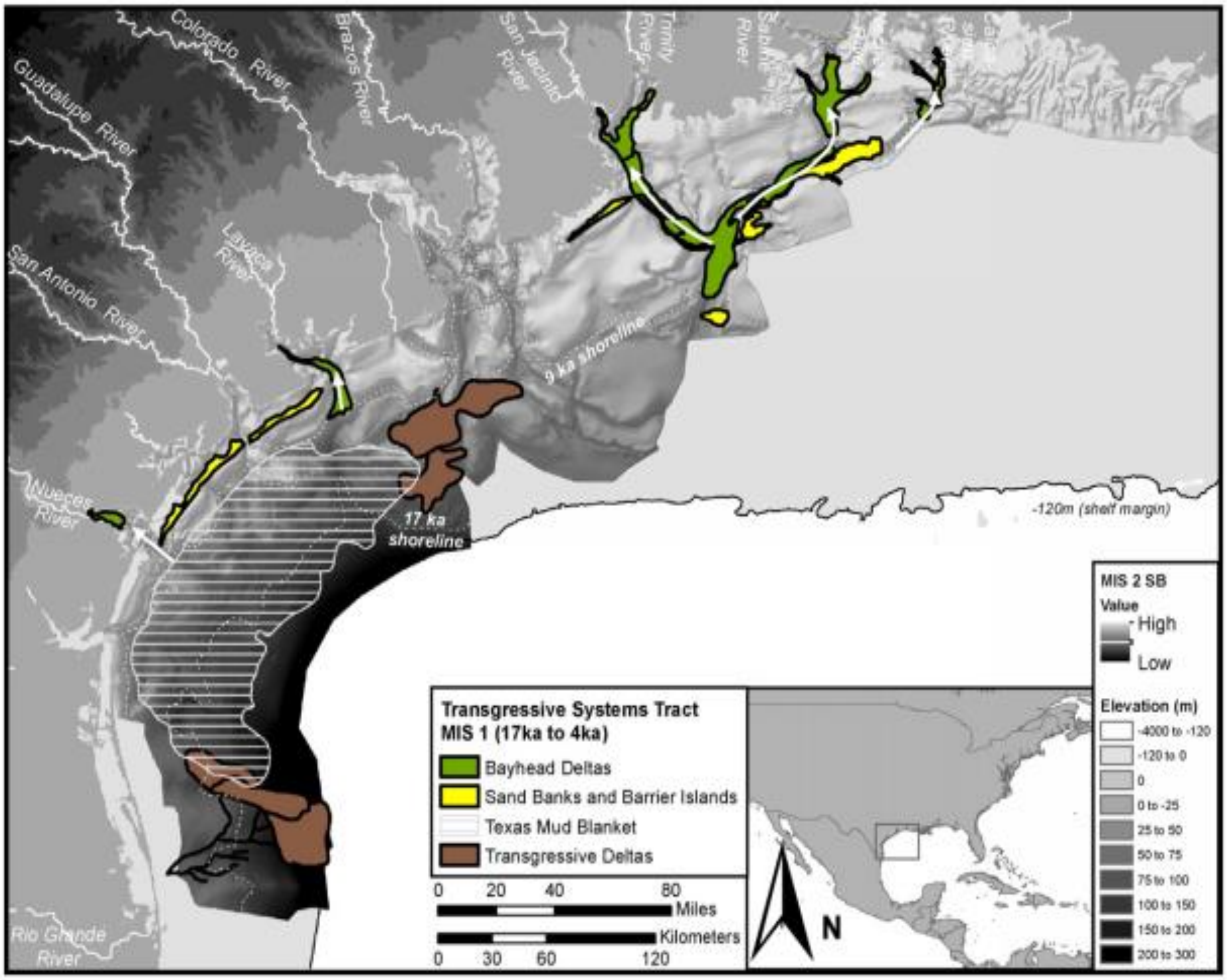


Figure 3-13, Paleo-geographic map showing major depositional systems occurred between 17,000 and 4,000 years ago during the transgression from stages 2 to 1 (After Anderson et al., 2016). Arrows show direction of back-stepping valley fill facies.

4.0 DEPOSITS FORMED IN THE LAST 10,000 YEARS ON THE GULF SHOREFACE

4.1 IMPORTANCE OF RAVINEMENT SURFACE

As sea level was rising in the last 17,000 years, the previously deposited units of the inner shelf and the coastal plains were "scraped" by what is called the ravinement surface. The ravinement surface consisted of erosional processes created by the shoreface "processes" connected to the wave and energy environments of the Gulf of Mexico as sea level was rising. Seismic profiles from the inner shelf exhibit examples of fluvial channels and deltas decapitated by the transgressive ravinement surface (Anderson et al., 2016). The ravinement processes removed between 8 and 10 meters of sediments on the surface of the previously deposited fluvial and coastal units, deleting part of the geologic record previously established.

This is important for sediment source investigations because the morphologic configuration previously developed after the valley fill period, and any morphologies associated with minor features of Pleistocene soft deposits, were practically eroded from the new Gulf of Mexico shoreface. Several remains of previously formed barrier islands, river levees and terraces, and bay head deltas and tidal inlets were removed from the geologic records as sea level was approaching its present configuration. This is critical to identify sedimentary units that are pre- or post- sea level rise ravinement processes and barrier island formation on the Texas shoreface. The processes associated with the ravinement surface are directly connected to the availability of sand for the coastal system. The energy was able to separate the sediments being reworked and accumulate the sand on the barrier islands. Fine sediments were also reworked and redeposited in other lower areas on the shoreface. The general profile of the sediments established on the shoreface before the influence of the ravinement surface and the deposits that occurred after the ravinement processes is discussed later in the chapter.

4.2 THE TEXAS MUD BLANKET ON THE SHOREFACE AND CONTINENTAL SHELF

There is a unique sedimentary (muddy) unit that formed within the last few thousand years on the shoreface of Central Texas (Figure 4-1) as the result of the fine sediments created by the ravinement processes and the post sea level rise coastal/marine processes. The unit is called The Texas Mud Blanket (TMB) (Weight et al., 2011 and Anderson et al., 2016). The TMB consists of a sedimentary unit up to 50 meters thick that covers the entire central Texas shelf. Radiocarbon data shows that TMB accumulated mainly during the Holocene. Its growth began around 9,000 years ago and was derived mainly through transgressive ravinement of shelf strata and coincided with a period of growth of the Brazos, Colorado, and Rio Grande deltas. It was not until about 3,500 years BP that the most rapid phase of TMB deposition occurred (Anderson, et al., 2016). Mineralogical results indicated that the sediment originated mainly from the Colorado, Brazos, and Mississippi Rivers as a result of changed sedimentation rates to the Gulf of Mexico and by an increase in south easterly wind and marine currents. The TMB consists mainly of fluid muds. The TMB resembles the origin of some of the units of the Beaumont Formation.

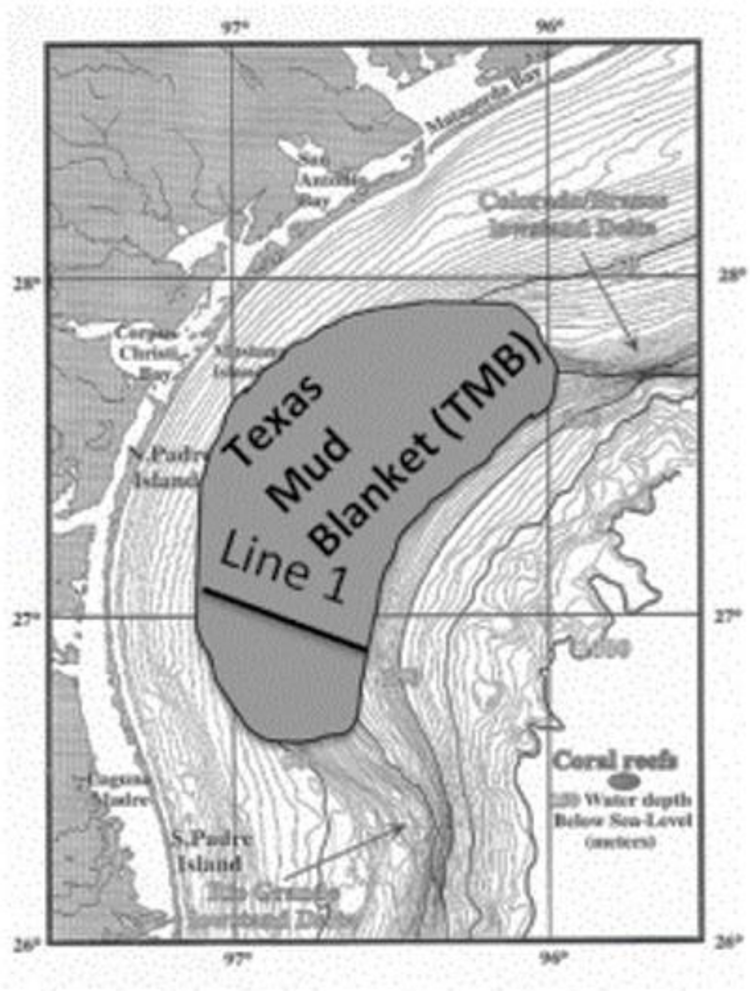


Figure 4-1, Location of the Texas Mud Blanket on the Shoreface of Central Texas (After Weight et. al 2011 and Anderson et al., 2016).

Although far from the Texas shorelines, if considered for fine deposits, the TMB may consist of more than 1,000,000,000 cubic meters (1,300,000,000 cubic yards) of fluid muds that could potentially be used for coastal projects (Table 4-1).

Table 4-1
Texas Mud Blanket

Geologic Unit	Potential Sediment Volume
Texas Mud Blanket	1,000,000,000 cubic meters

4.3 SHOREFACE PROCESSES CLOSE TO BARRIER ISLANDS

As sea level was approaching its present location, some of the transgressive deltas maintained a good record on the shoreface as well as some sand banks considered as former barrier islands, fluvial terraces, fluvial levees, etc., (Anderson et al., 2016). For the Texas upper coast, the remains of these geologic-geomorphologic features have been studied to determine the geologic history and in some cases for their potential as sediment sources (Rodriguez et al., 1999a, 1990b, 2001 and 2004; Morton and Gibeaut, 1995; Dellapenna et al., 2009, Dellapenna et al., 2010; Dellapenna et al., 2012; and Anderson et al., 2016).

Morton et al., (1995) suggested that the inner shelf is an important sink for eroded beach sand that is deposited principally as storm beds that slowly accumulate in water depths of 10 meters or more. The most analyzed areas for the evolution and quantification of sand banks and their composition are the Sabine, Heald, Sheppard, and Thomas banks (Figure 4-2) (http://gulf.rice.edu/ETexas/gulfeTexasS_T_SJ_tst.html) (Morton et al., 1995; Dellapenna et al., 2010; Anderson et al., 2016).

Dellapenna et al., (2009, 2010 and 2012) was able to measure the geometry, sediment volumes, and grain-size distribution of sands on two facies of the Sabine and Heald Banks and was able to compare their composition with the East Texas Gulf Coast beach sands. Dellapenna's conclusion was that some of the sands available within the Sabine and Heald Banks contain areas that could be considered potentially compatible for beach replenishment along the Texas Gulf Coast beaches. Sandy Facies of what was called Sandy Facies A1 on the Sabine Bank and Heald Banks have the potential to contain up to 777,000,000 cubic meters (1,000,000,000 cubic yards) of fine sand. Additionally, Sandy Facies A2 may contain up to 611 million cubic meters (865,000,000 cubic yards) of shelly fine sand (Dellapenna et al., 2010). Together these two sandy facies have the potential to contain up to 818,000,000 cubic meters (1,390,000,000 cubic yards) of fine sand (Table 4-2). The muddy sands of Facies B contain large amounts of silts and clays making them a limited sand source for beach replenishment. The conclusion of the study is that the Facies A1 and A2 sands from the Sabine and Heald Banks are viable sand and fine sediment sources for beach nourishment and coastal restoration for the upper Texas coast.

Table 4-2
Sabine and Heald Bank Facies A1 Potential Sediment Volumes

Geologic Unit	Potential Sediment Volume
Sabine and Heald Bank Facies A1	~777,000,000 cubic meters
Sabine and Heald Bank Facies A1	~661,000,000 cubic meters
Total	~1,390,000,000 cubic meters

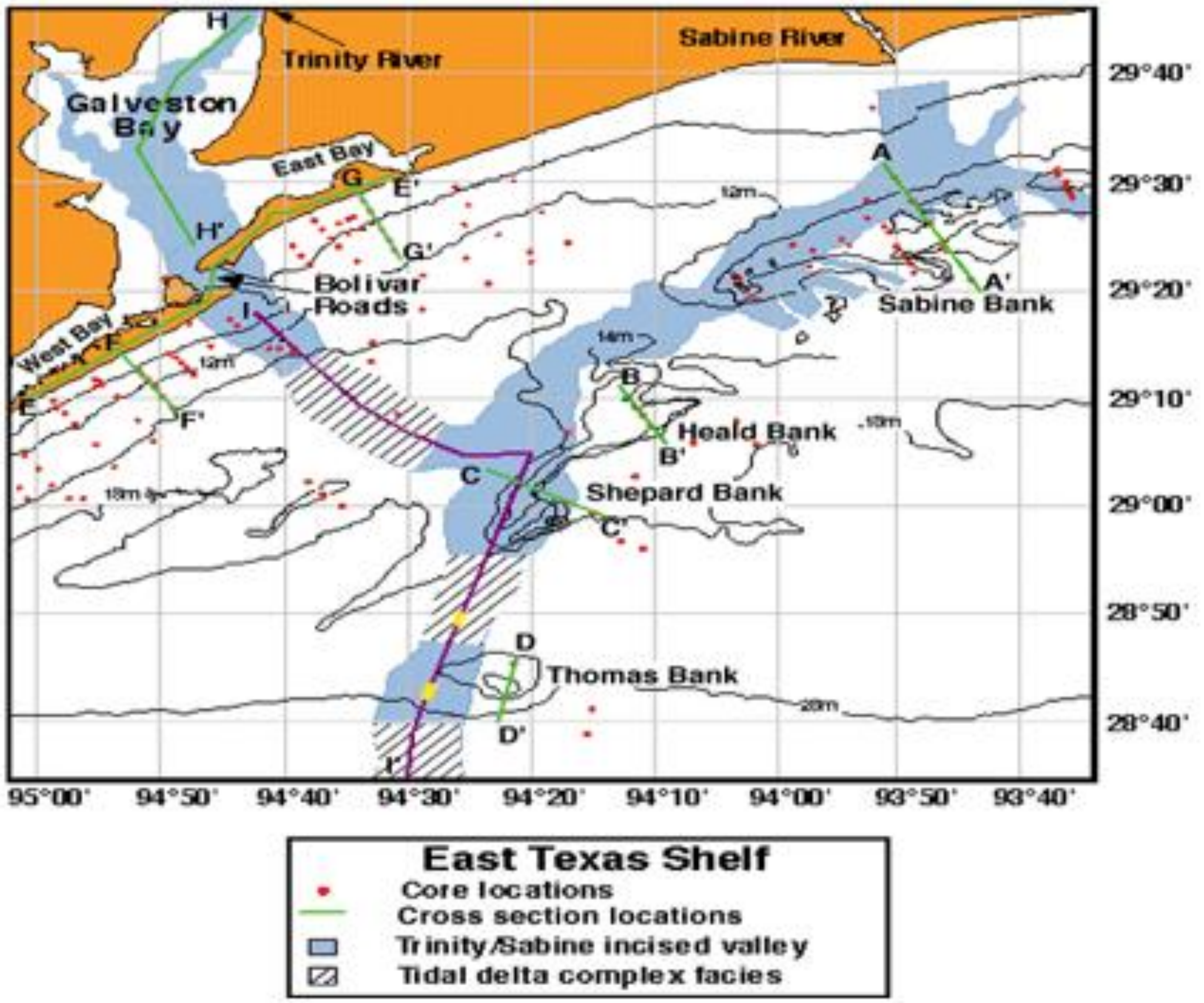


Figure 4-2, Location of the Sabine, Heald, Shepard and Thomas Banks and their connections to the former Sabine and Trinity rivers. (http://gulf.rice.edu/ETexas/gulfeTexasS_T_SJ_tst.html).

Geophysical (sub-bottom profiling) investigations were conducted in 2005 and 2009 on the shoreface of the upper Texas coast, including the Sabine and Heald Banks (Dellapenna et al.,2009). One of the surveys was conducted in January (before Hurricanes Rita and Katrina), a second survey was conducted one-month post-Hurricane Rita, and a third survey seven months after Rita. Since the Sabine Bank was in the path of Hurricane Rita, some sedimentary changes were observed. The results of the investigations were used to map the composition of the Sabine Bank and its relationship with the energy and sedimentary processes on the shoreface. The data suggests that muds migrating on the shoreface tend to cover the former sand bars of the banks.

Figure 4-3 represents the survey images before and after Hurricane Rita showing how the storm uncovered some of the sandy banks by the removal of the fine and soft sediments. Seven months after Hurricane Rita, the average energy and sedimentary conditions on the shoreface brought back fine sediments to cover some of the exposed sandy deposits (Dellapenna et al. 2009). The data suggests that other sand ridges and sand bars that are part of the banks may be covered by the fine sedimentation occurring on the shoreface as the fine deposits move away from the Texas shorelines.

Figures 4-3 and 4-4 show sub-bottom profiling of the Sabine Bank ridges. Figure 4-3 shows the Sabine Bank ridges covered under fine shoreface sedimentation and then exposed in 2006 by Hurricane Rita, then covered again seven months after the storm (Dellapenna et al., 2009). Figure 4-4 shows detailed sub-bottom profiling of the Sabine bank ridges exposed in 2006 by Hurricane Rita.

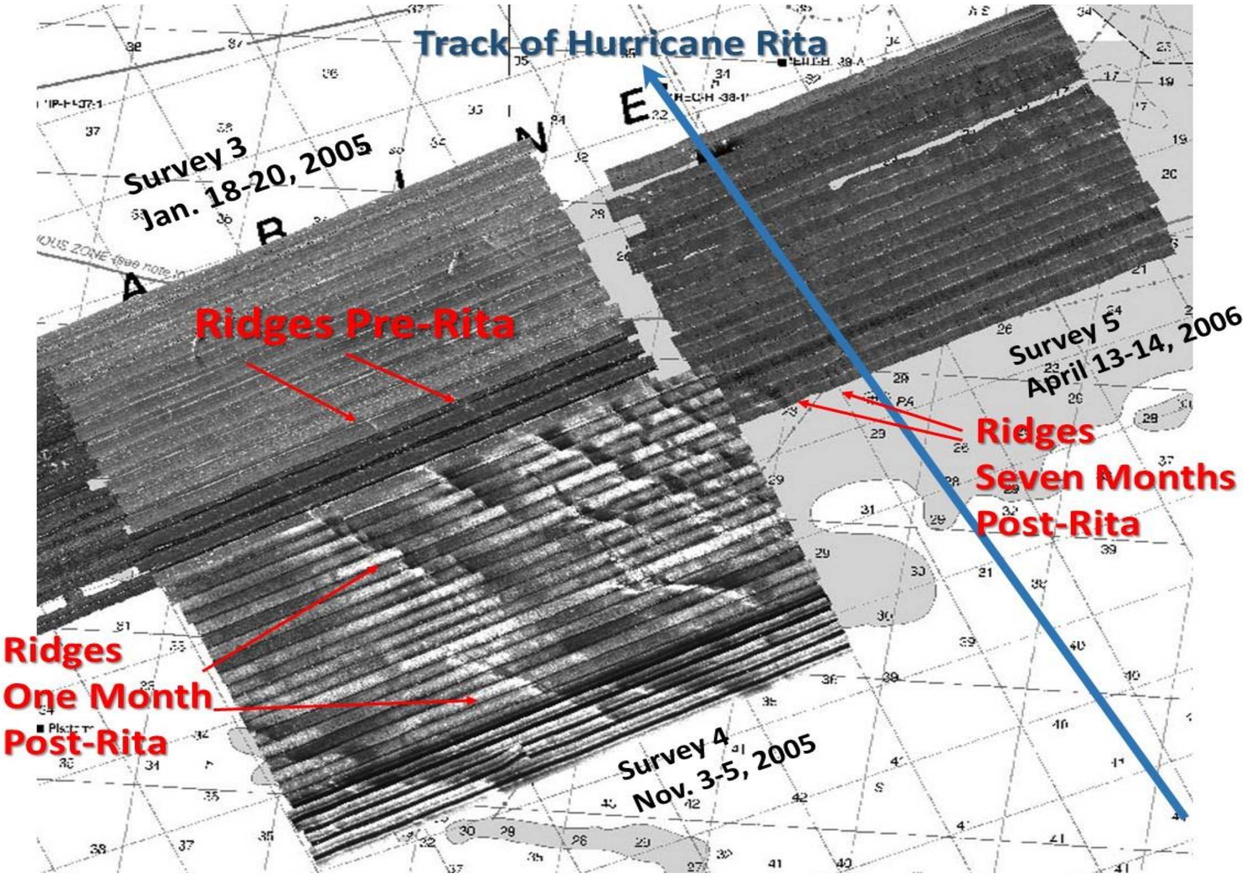


Figure 4-3, Sub-bottom profiling of the Sabine Bank ridges covered under fine shoreface sedimentation and then exposed in 2006 by Hurricane Rita and covered again seven months after the storm (Dellapenna et al., 2009).

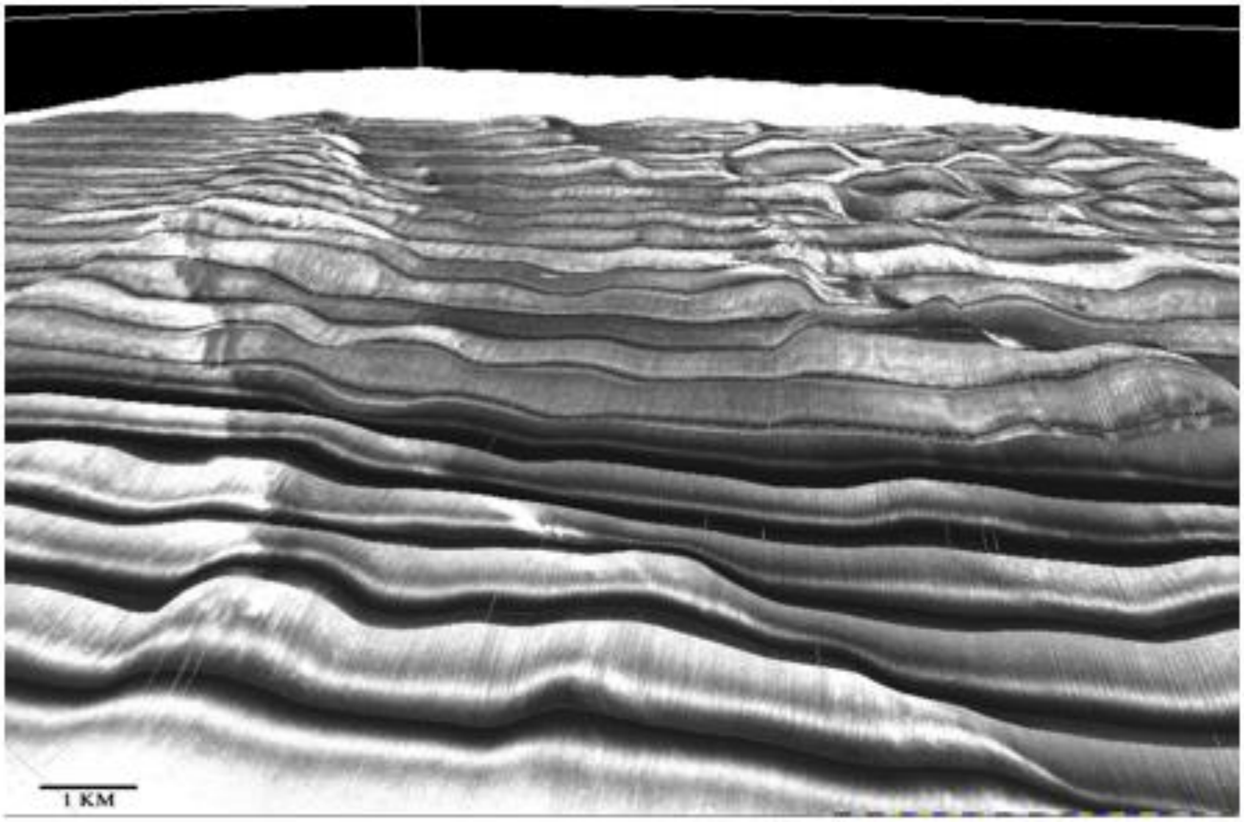


Figure 4-4, Detailed sub-bottom profiling of the Sabine Bank ridges exposed in 2006 by Hurricane Rita (Dellapenna et al., 2009)

The data also suggests that some sandy deposits may exist on the Texas shoreface; however, additional analysis of the shoreface is required. The images suggest that below some of the fine muds on the shoreface, sand ridges left behind by the ravinement surface may exist as potential sand sources for coastal projects.

Additional geological-sediment investigations on the Galveston shoreface were conducted before and after Hurricane Ike starting in 2000 and continuing until today (Robb et al., 2003; Dellapenna et al., 2010; and Dellapenna and Johnson, 2012). A detailed mapping project identified the age and composition of the shoreface in front of Galveston Island (Robb et al., 2003) (Figure 4-5). The mapping included the stratigraphic description, detailed stratigraphy, geophysical profiling, and detail sediment coring with dating and grain size analysis.

Figure 4-5 shows the detailed CHIRP cross-shore profile of a shoreface transect in front of Galveston Island. The image shows the different sedimentary units occurring in the shoreface, including the Beaumont Formation, some former fluvial channels, the flooding surface associated with the ravinement surface, the modern transgressive layer, and the modern mud layer (Robb et al., 2003).

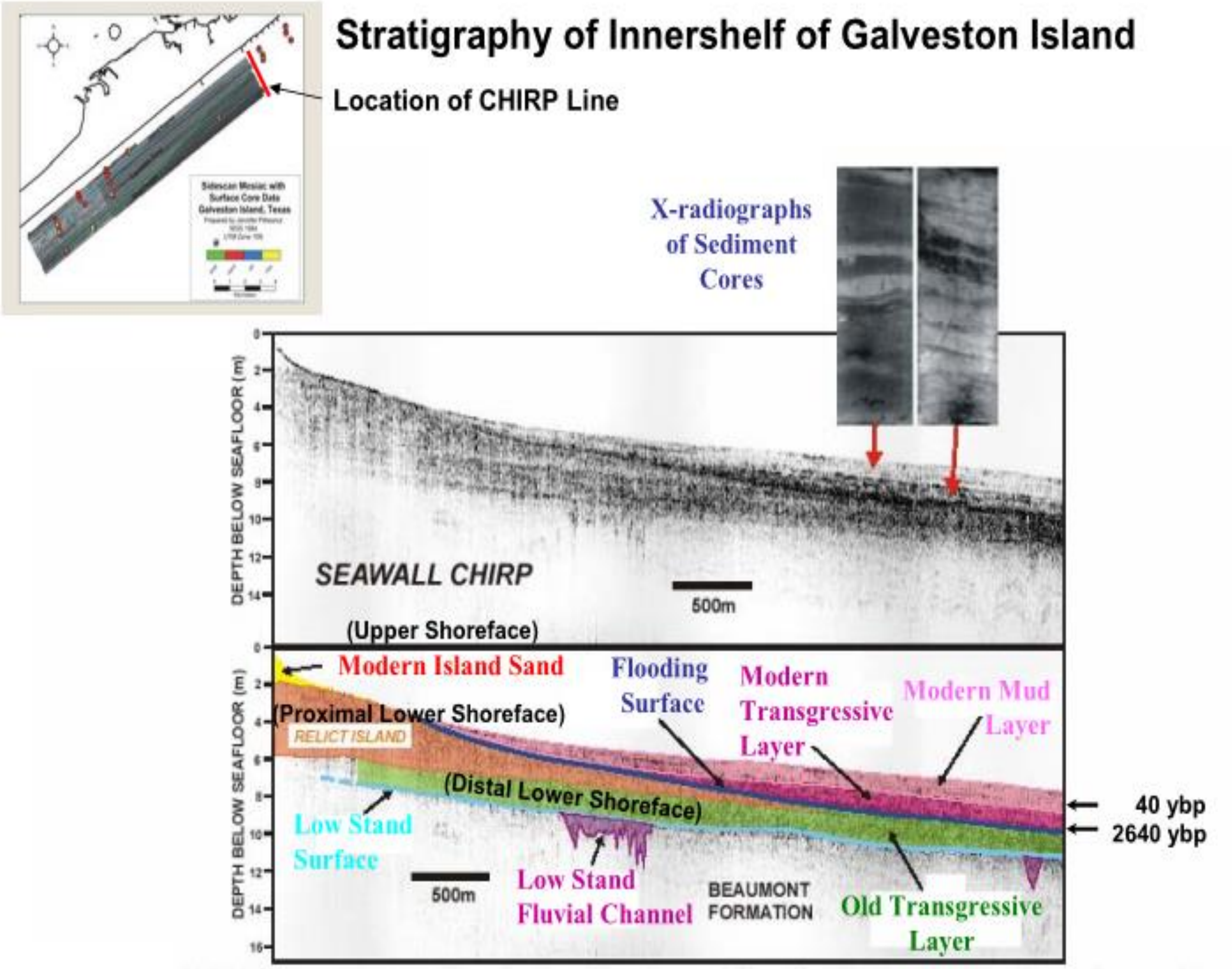


Figure 4-5, Detailed CHIRP cross-shore profile of a shoreface transect in front of Galveston Island. The image shows the different sedimentary units occurring in the shoreface including: The Beaumont Formation, some former fluvial channels, the flooding surface associated with the ravinement surface, the modern transgressive layer, and the modern mud layer (Robb et al., 2003).

Further definition of the geologic units helped to identify the sedimentary layers created before and after the ravinement processes close to Galveston Island. The identification of the small fluvial channels and the modern mud layer on top of the modern transgressive line is important (Figure 4-5). Everything above the flooding surface generated by the ravinement surface should be considered new sedimentation created on the shoreface (Robb et al., 2003).

The mapping of these units may serve as the model for modern shoreface sedimentation and sediment transport models in the same geomorphological setting. New sand bars created after storms or sand bars migrating to the deepest parts of the shoreface located above the flooding surface should be considered recent sediments on a migration path and can be considered potential sediment sources for coastal projects.

4.4 MOVING SEDIMENT ON THE SHOREFACE

The recent investigations regarding shoreface processes included geophysical, sediment, and bathymetric data collected before and after Hurricane Ike (Robb et al., 2003; Dellapenna and Johnson, 2012). The studies were able to collect a sequence of beach and shoreface surveys during years 2006 and 2011. The general conclusions of the surveys conducted for the Galveston Island area show that the shoreface is a very dynamic geomorphologic unit that is always in transition (Robb et al., 2003; Dellapenna and Johnson, 2012).

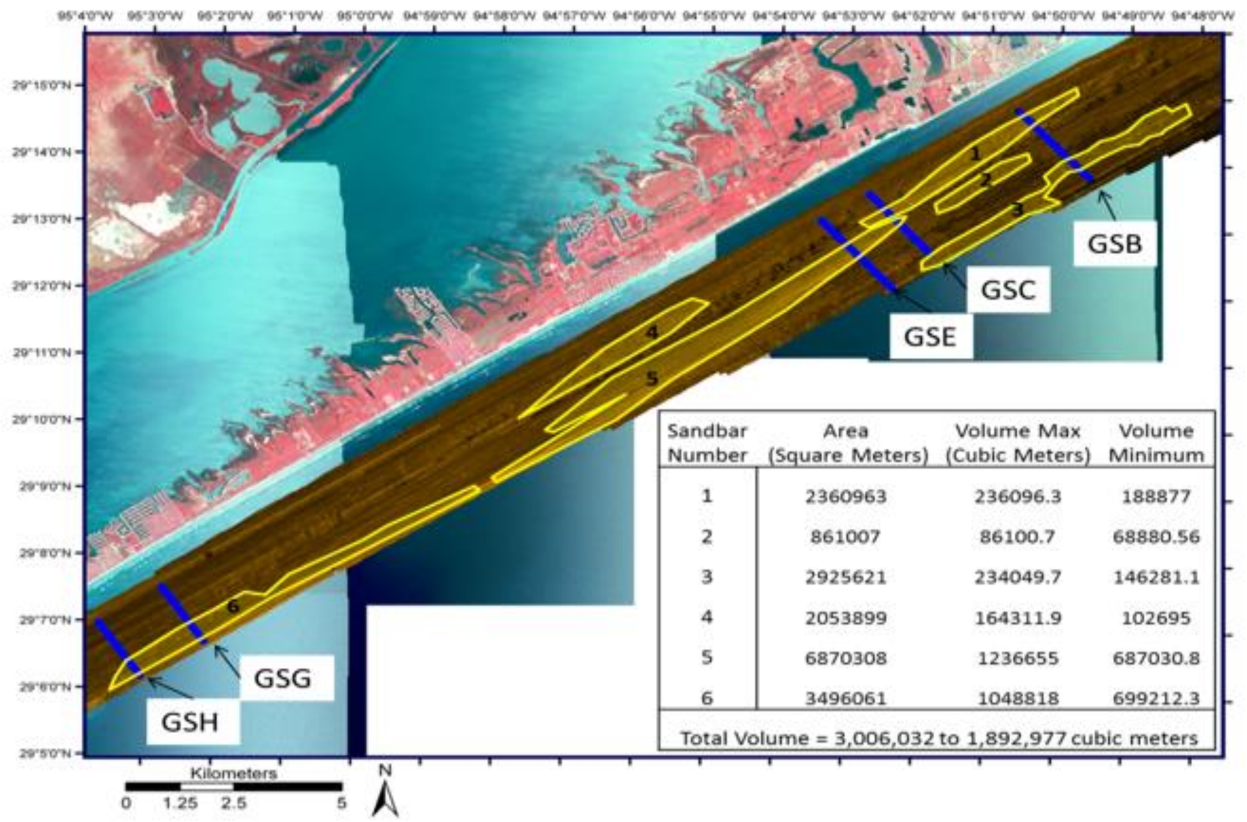
Once the ravinement-flooding surface has been identified, the identification of new or very recent deposits can be defined by the sediment coming from storms or shoreline processes on the shoreface. Dellapenna and Johnson (2012) identified sand bars on the shoreface created as a response to Hurricane Ike. The storm removed sediments from the beach and the surf zone and moved them offshore. Figure 4-6 exhibits the sand bars that were created or expanded following the storm.

Using the bathymetric profiles, patterns in the side scan data, and the depth of sand from the sediment cores, surface sand volume estimates were generated for each distinct sand bar and for the percent of sand in the first 5 kilometers of the shoreface (Figures 4-6 and 4-7) (Dellapenna and Johnson, 2012). As the sand bars migrated away from the beach, the sandy deposits became enriched with fine sediments. The data collected post-Hurricane Ike showed that the percentage of sand varied from 90% (in close proximity to the beach) to less than 20% (3-4 kilometers from the beach). This type of deposition was not observed in surveys prior to Hurricane Ike.

The total amount of the sand in the sand bars a few months following Hurricane Ike were in the approximate order of 1,800,000 to 3,000,000 cubic meters (2,300,000 to 3,900,000 of cubic yards) of sand (Figure 4-6 and Table 4-3). Some of this sand may be recovered for shoreline restoration projects within 6-12 months following storm events. Once the sand leaves the upper portions of the shoreface, it becomes enriched with fine deposits, mainly muds (Figure 4-7).

Table 4-3
Sand Bars on the Shoreface of Galveston Island

Geologic Unit	Potential Sediment Volume
Sand Bars on the Shoreface of Galveston Island	1,800,000 to 3,000,000 cubic meters (depending upon the circumstances)



Sandbar Number	Area (Square Meters)	Volume Max (Cubic Meters)	Volume Minimum
1	2360963	236096.3	188877
2	861007	86100.7	68880.56
3	2925621	234049.7	146281.1
4	2053899	164311.9	102695
5	6870308	1236655	687030.8
6	3496061	1048818	699212.3

Total Volume = 3,006,032 to 1,892,977 cubic meters

Figure 4-6, Detailed distribution of migrating sand bars developed after Hurricane Ike on the shoreface of Galveston Island (Dellapenna and Johnson, 2012).

The study conducted by Dellapenna and Johnson (2012) was also able to compare the changes in the total volume of the beach and shoreface from the surveys conducted in 2006 and 2011. The authors noticed that the shoreface profile also retreated during Hurricane Ike. Sediments removed from the beach and upper shoreface areas ended up beyond the depth of closure deeper in the Gulf of Mexico. The Galveston Island shoreface study suggests that similar processes should be occurring along the shoreface on the Texas coast during storms. Some of the sand bars observed by Dellapenna and Johnson (2012) should be part of the inner shelf sediments suggested by Morton et al., (1995), which consists of inner shelf deposits eroded from the sandy beaches that are deposited principally as storm beds that slowly accumulate in water depths of 10 meters or more.

The total amount of the sand along the Galveston Island beaches and shoreface a few months following Hurricane Ike was approximately 79,000,000 cubic meters (60,400,00 cubic yards) of sand (Table 4-4). Monitoring the sand that is lost during storms on the upper sections of the shoreface should be considered a priority for future identification of sand sources within 6-12 months after the storm event. Areas such as Galveston Island and the west side of Bolivar Peninsula (east of the jetty) have similar shoreface conditions that are ideal for the development of sand bars from erosional processes on the beach.

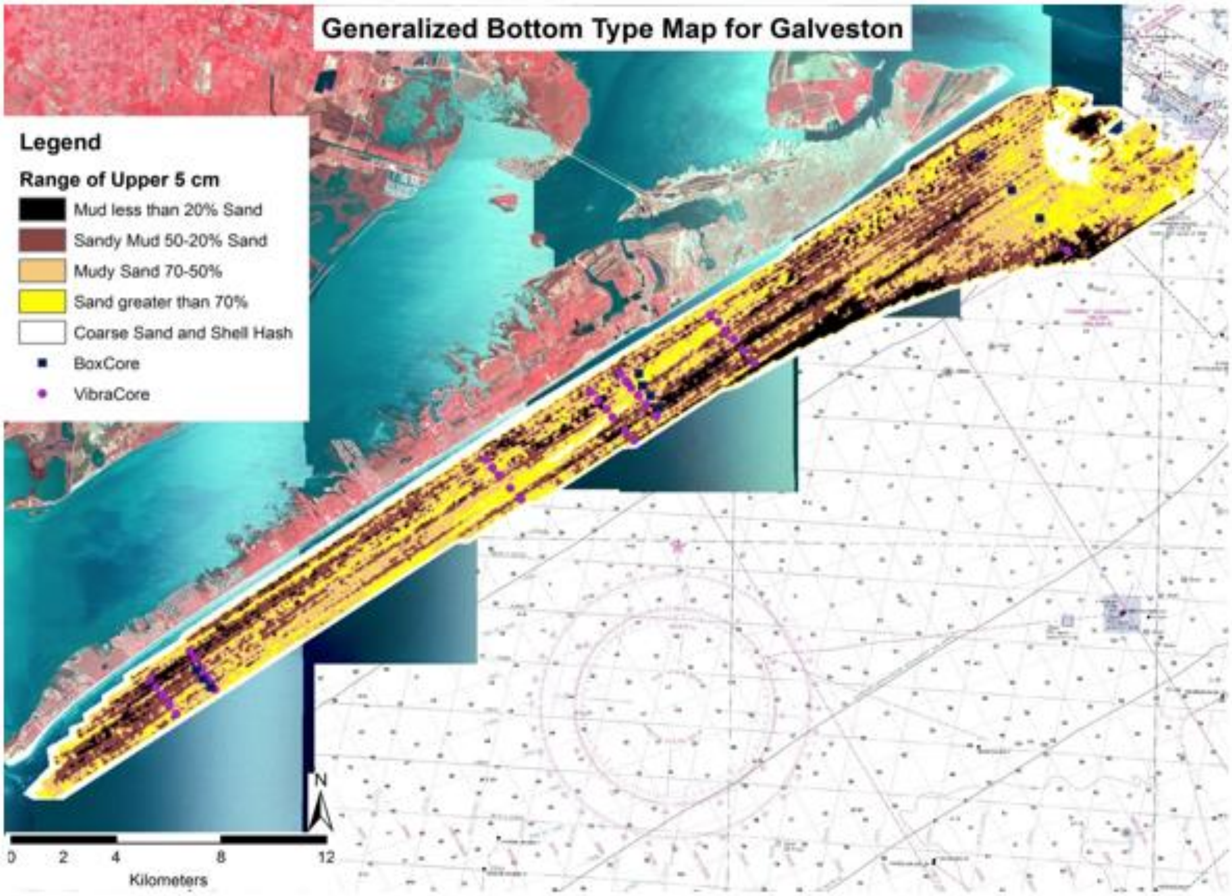


Figure 4-7, Generalized Map of Bottom Types showing the percent sand composition in the surface sediments in front of Galveston Island after Hurricane Ike showing how sands become enriches with muds (Dellapenna and Johnson 2012)

Table 4-4

Sediment Loss on Galveston Island Beaches and Shoreface Post-Ike

Sediment Loss of a Geologic Unit after Ike	Potential Sediment Volume
Galveston Island Beaches and Shoreface	~79,000,000 cubic meters (sediment has not been identified)

5.0 BAY DEPOSITS AS PART OF THE NEW COASTAL AND BAY HOLOCENE ENVIRONMENTS OR ON TOP OF PLEISTOCENE DEPOSITS

This section includes the potential location of bay deposits as a sediment source for coastal projects. Bay deposits will be considered here as the sediments connected to previously created geological deposits and the deposits that have been recycled or re-deposited after the formation of the barrier islands independently of the age (from Late Pleistocene to the present time).

The ages of the barrier islands formation across the Texas coast are not the same, with Mustang Island being the oldest barrier island created almost 10,000 years ago and South Padre, San Jose, Follets Island, and Bolivar Peninsula being the youngest barrier islands with ages close to 2,000 years old (Alderson et al.,2016).

For Galveston Island, radiocarbon dates collected by Rodriguez et al., (2001) on the bay side showed that the island started to build up about 5,300 years BP and ended its accumulation about 1,200 years BP. The geologic data suggests that Bolivar Peninsula did not form until after 2,500 years BP (Abdulah and Anderson 2004). It is possible that Follets Island developed even later. Using the time frame of around 5,300 to 2,000 years BP for the formation of the Texas upper coast barrier islands should be adequate to discuss the age of bay processes. Age may vary with other islands, but this timeframe should be a good generalization of the age of the bay and estuarine erosional and depositional processes for the upper coast.

Figure 1-1 shows a model used in this report for the geomorphological structure of the bays and estuaries and the potential areas to search for sediment sources. In general, bay deposits are a combination of Pleistocene clays and previous inland deposits (mainly on the north side of the bays), sandy barrier islands, estuarine clays, and former fluvial deposits. In general, bay bottom areas closer to the barrier islands tend to be influenced by the sands of these Holocene deposits. Unless influenced by deltas, fluvial features, or former Pleistocene barrier islands, the north side of the bays’ bottoms and shorelines tend to be in clay dominated environments.

5.1 GALVESTON BAY

As discussed in Section 1.0, the large bays of Texas are connected to former fluvial systems. Galveston Bay was developed following the ancestral paths of the Trinity and San Jacinto River Valleys (Figure 5-1). The former Trinity River Valley was deeper and wider between the Trinity North Bay and East Bay in front San Leon and Smith Point.

The evolution within the Trinity River incised valley became filled through episodes of tidal-inlet and tidal delta development within the offshore valley (Anderson and Thomas, 1994). The valleys were filled through episodes of shoreline stability interrupted by landward shifts in bay head delta and bay and tidal deltas that were tens of kilometers in distance (Figure 5-2). The authors documented that with each landward step of the valley fill deposits, a new phase of bay evolution began. Morphologically, as the incised valley evolved, the valley was transformed from a deep, narrow fluvial-bay bottom to the broad, shallow bay as we know it today. The valley fill sedimentation was dominated by cycles of back-steeping deposition (Anderson and Thomas, 1994) with processes that were repeated during the fill processes of other bays, including Calcasieu Lake, Sabine Lake, Matagorda Bay, Corpus Christi Bay, Copano Bay, and Baffin Bay (Anderson et al., 2016). Valley fill sedimentation dominated by cycles of back-stepping deposition in former valleys that became bays should be considered the standard method for deposition in the search for sediment Texas Bays. Exceptions will occur on deltaic, deltaic influenced, or fluvial dominated coastal environments.

Sediments deposited as valley fill material will require detail investigations since deposition included all types of fluvial and estuarine deposits. Changes in composition may vary in time and geographical distribution.

Following the model presented by Anderson et al., (2016) and shown in Figure 5-2, the most dominating sedimentation processes in present times in the upper bay is the deposition of fine materials (mainly muds) along the bay bottoms due to the re-suspension of former deposits as a result of new processes occurring in a shallow bay.

What is known today as Galveston Bay can be considered the combination of three sub-bays: Trinity-Upper Galveston Bay, East Bay, and West Bay. From the geological and geomorphological point of view, these three sub-bays can be identified as unique estuaries, considering their most recent evolution (around the last 5,000 years) and dominating sedimentary processes. Utilizing calculations on the dimension of the incised valley of at least 25 meters deep and a minimum of 6 kilometers wide with a minimum river length of 20 kilometers, (Figures 5-1 and 5-2), it is suggested that at least 3,000,000,000 cubic meters (3,920,000,000 cubic yards) of sediments may be available as valley fill deposits in the paleo-valley of the former Trinity River under Trinity Bay (Table 5-1).

Table 5-1
Trinity River Incised Valley

Geologic Unit	Potential Sediment Volume
Trinity River Incised Valley	3,000,000,000 cubic meters

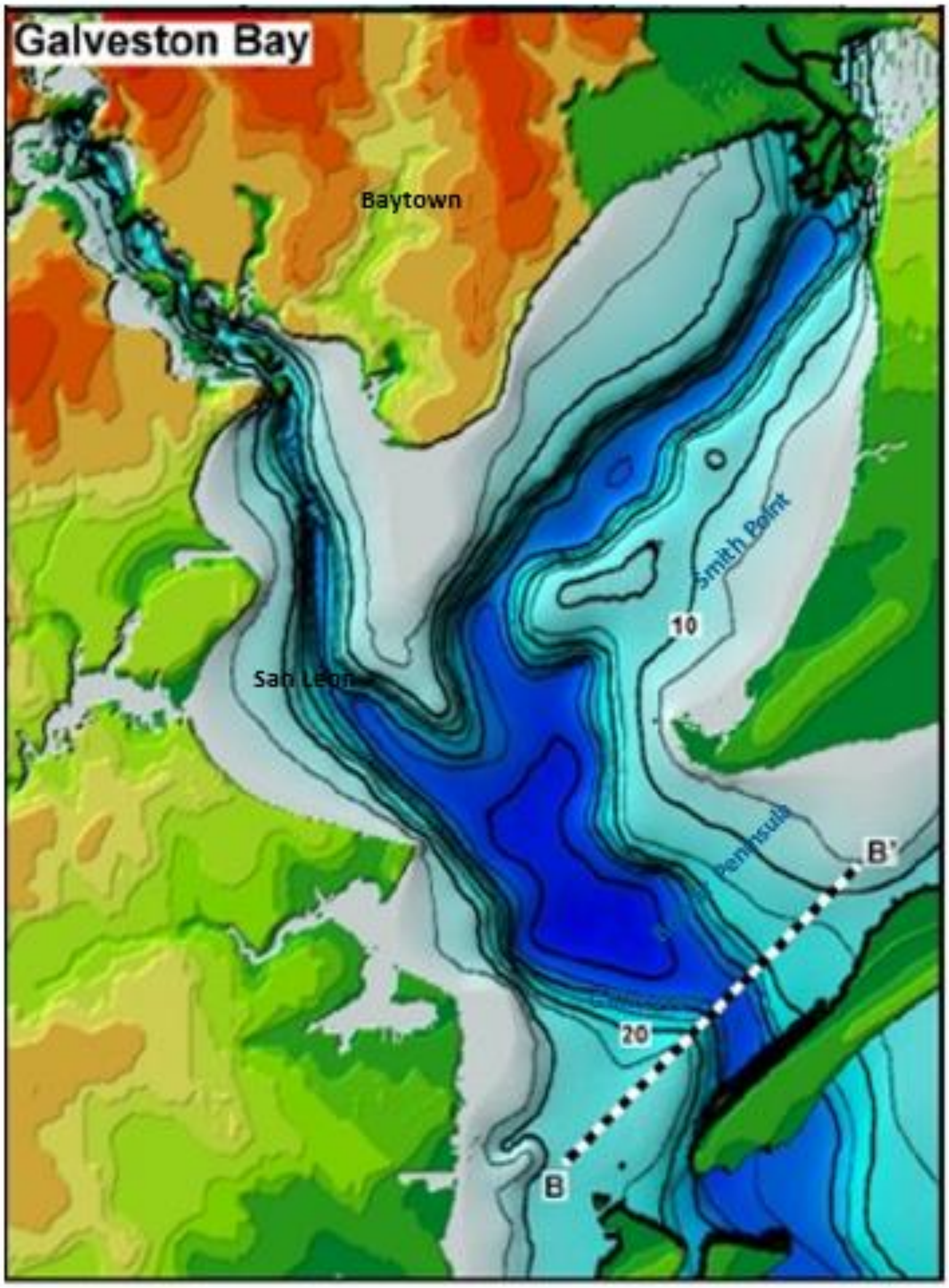


Figure 5-1, Detailed Geomorphic and Topographic Map of the Ancestral Trinity and San Jacinto Rivers Incised Valleys beneath Galveston Bay before the sea level inundation (After Anderson et al., 2016). The deeper and wider section of the valley used to be located between San Leon and Smith Point.

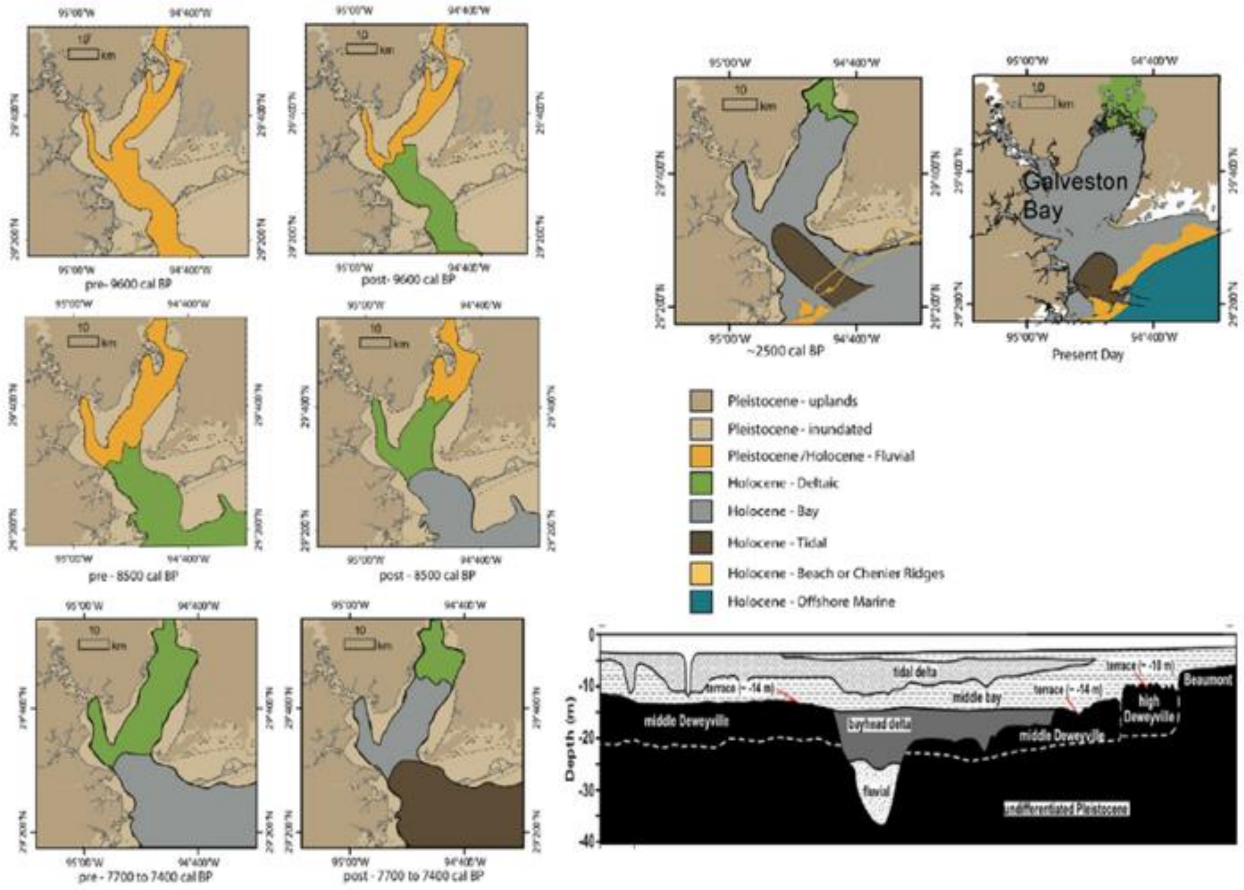


Figure 5-2, Paleo-geographic reconstructions showing the Holocene evolution of Galveston Bay. Note the depositional events on the scale and the type of sedimentation filling of the former valley transitioning from fluvial then deltaic, bay, and tidal. Also, notice the cross section of the sedimentary processes and the type sediments accumulated below the present bay bottom (Anderson et al., 2016).

5.1.1 Trinity-Upper Galveston Bay

For this report, the Trinity-Upper Galveston Bay area includes the region located north of San Leon-Smith Point where fine sedimentation dominates the bay bottom (Fisher et al.,1972; Anderson et al., 2016). The bay bottom consists mainly of bay muds as presented in Figure 5-3 (Fisher et al.,1972). The only active sources of sediment appear to come mainly from the sedimentation generated by bay shoreline retreat and the limited input from the Trinity River, and minor inputs from the San Jacinto River.

Figure 5-3 shows the geologic composition of the bay bottom in the Trinity-Upper Galveston Bay (After Fisher et al., 1972). The map shows the mud-dominated environment of the bay system, with minimum deltaic influence coming from the Trinity River system.

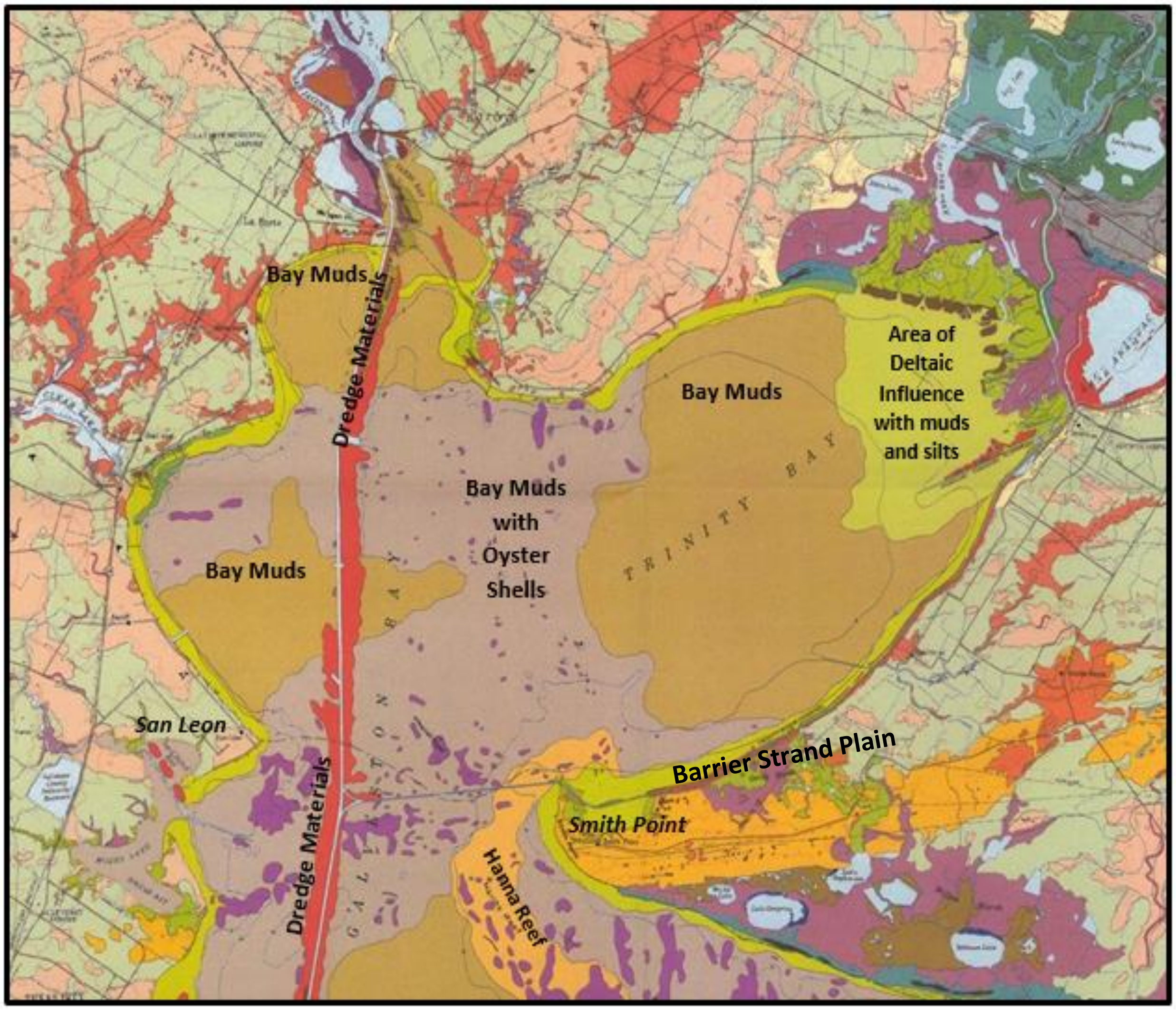


Figure 5-3, Geologic composition of the bay bottom in the Trinity-Upper Galveston Bay (After Fisher et al., 1972). The map shows the mud-dominated environment of the bay system only having minimum deltaic influence coming from the Trinity River system.

On the central and north sides, as shown in the geologic map of the bay bottom by Fisher et al., (1972), except for sediments coming from the dredging activities connected to the Houston Ship Channel and its infrastructures, the availability of coarse sediments in the bay bottom is almost non-existent and has been that way for the last few centuries. However, on the southeastern side of the bay, sandy deposits appear to be connected to the formation of the Hanna Reef and the Pleistocene Barrier-strand plain sand, corresponding to a former barrier island (Pleistocene). The Hanna Reef shows an important percentage of sand in several bay samples (TxSed, 2016).

The reef morphology (orientation and position in the bay) suggests that the feature may correspond to deposits associated with the former entrance from the Gulf of Mexico to Galveston Bay. This sandy body sustains a large area of oyster reefs. The reefs appear to have been developed before the Bolivar Peninsula

Spit was completed. Only a small portion of the sandy reefs are exposed up into the Trinity-Upper Galveston Bay, suggesting that new upper bay deposits have not buried this unit. As a sediment source, this geological unit has a large number of live oysters and oyster beds on top limiting its potential use.

5.2 EAST GALVESTON BAY

Sedimentation in East Bay is very complex. The bay bottom reflects the evolution of an open bay later dominated by the formation of the Bolivar Spit or Bolivar Peninsula. Some of the bay features, such as sand mounds and oyster reefs, appear to have been created by the growth of the spit toward the south (Fisher et al., 1972). The two large fan deltas on the bay side of Bolivar Peninsula at one point corresponded to flood delta inlets (Dellapenna, et al., 2009). Bolivar Peninsula formed after 2,500 years BP (Abdulah and Anderson 2004), which means these inlets were most likely there before the initial formation of Bolivar Peninsula. As the spit was growing and the inlets migrated south, East Bay was registering sedimentary changes due to these morphologic and hydrodynamic changes until the flood deltas became disconnected from the Gulf of Mexico.

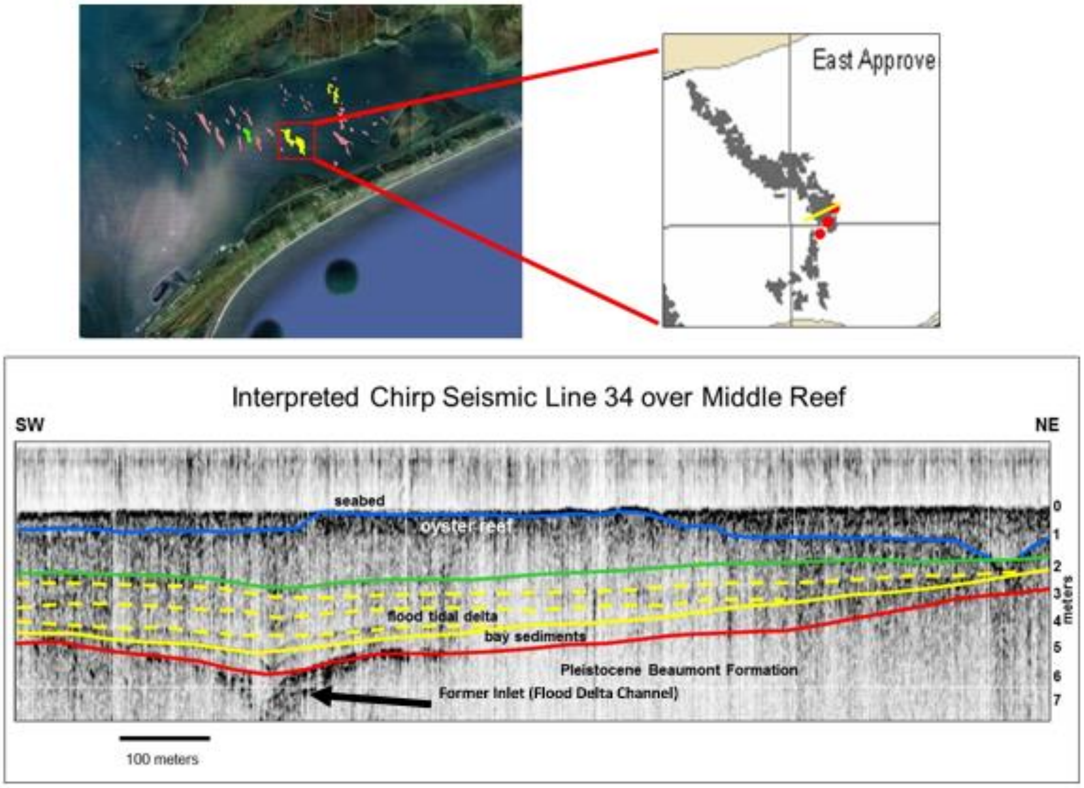


Figure 5-4, Seismic Profile of East Bay and the sedimentation that followed the migration of the former inlets that communicated the bay with the Gulf of Mexico during the evolution of Bolivar Peninsula. The red line corresponds with the contact between Pleistocene and bay and flood delta deposits; the blue line is the boundary between flood delta deposits and oyster beds (After Dellapenna et al., 2009).

Figure 5-4 shows a CHIRP Seismic Profile of East Bay collected by Dellapenna et al., (2009) on the north side of the flood delta inlets showing the morphology of these features before they disappeared as the Bolivar spit continued growing. The figure shows the evolution of the Bolivar area which originally consisted of the Beaumont Formation (Pleistocene) deposits, and then was modified by inlet processes and deposits to become filled by bay deposits and oyster reefs. The former inlet morphologies and deposits are only a few meters thick (sediments between green and red lines in Figure 5-4). The presence of major oyster reefs (these reefs being some of the largest reef areas in Texas) is the limiting factor of the inlet sediments as potential sediment sources. At least 2-3 meters of oyster reef layers (oysters and shells) have been observed via CHIRP profiles on top of these inlet deposits which have significant presence of sands (Figure 5-4) (Dellapenna et al., 2009).

Figure 5-5 corresponds to an inventory of the oyster reefs in East Bay generated by Texas Parks and Wildlife (TPWD, 2011). This figure shows the location of the current oyster reefs that developed on top of former inlet deposits. In some cases, the oysters are on top of sandy mounds associated with former flood deltas. Oyster reefs followed the pre-existing substrates where the former inlet geomorphological features can be reconstructed. These morphologies also appear to follow the original position and migration of the spit. The reefs include the productive reefs and areas where reefs have been dredged to use the oyster beds for construction materials leaving behind depressions on the bay. These depressions are not a good source of sediments since they were filled with liquid muds.

5.2.1 Old Tidal Delta Deposits

Following the final stages of the spit growth on Bolivar Peninsula, the old inlet of Bolivar Roads was formed. It appears that the entrance to Galveston Bay was previously larger and was able to accumulate large amounts of flood delta deposits (Figure 5-6) (Anderson, 2007). Figure 5-6 represents the area of the former flood delta before the inlet became dominated by and controlled by structures creating the modern delta. The figure also shows the general location of the modern flood delta.

Dellapenna et al., (2009) calculated the volume of potential sediments (mainly sands) that accumulated on the old tidal delta and shown in Figure 5-7. Using the Pleistocene clays as the boundary of the flood delta deposits (about 2.5 meters deep), the authors estimated the flood delta to be 14 kilometers x 10 kilometers in area, with an estimate of around 400,000,000 cubic meters (about 520,000,000 cubic yards) of sediments mainly sands deposited in the late Holocene (Table 5-2). Some areas of the old delta are covered by oyster reefs, but the west side should be further analyzed for potential use.

Figure 5-4 shows the CHIRP profile of East Bay and the sedimentation that followed the migration of the former inlets within the Gulf of Mexico during the evolution of Bolivar Peninsula. The red lines correspond with the contact between Pleistocene and bay and flood delta deposits. The blue line indicates the boundary between flood delta deposits and oyster beds (after Dellapenna et al., 2009).

Table 5-2
East Bay Old Tidal Delta

Geologic Unit	Potential Sediment Volume
East Bay Old Tidal Delta	400,000,000 cubic meters

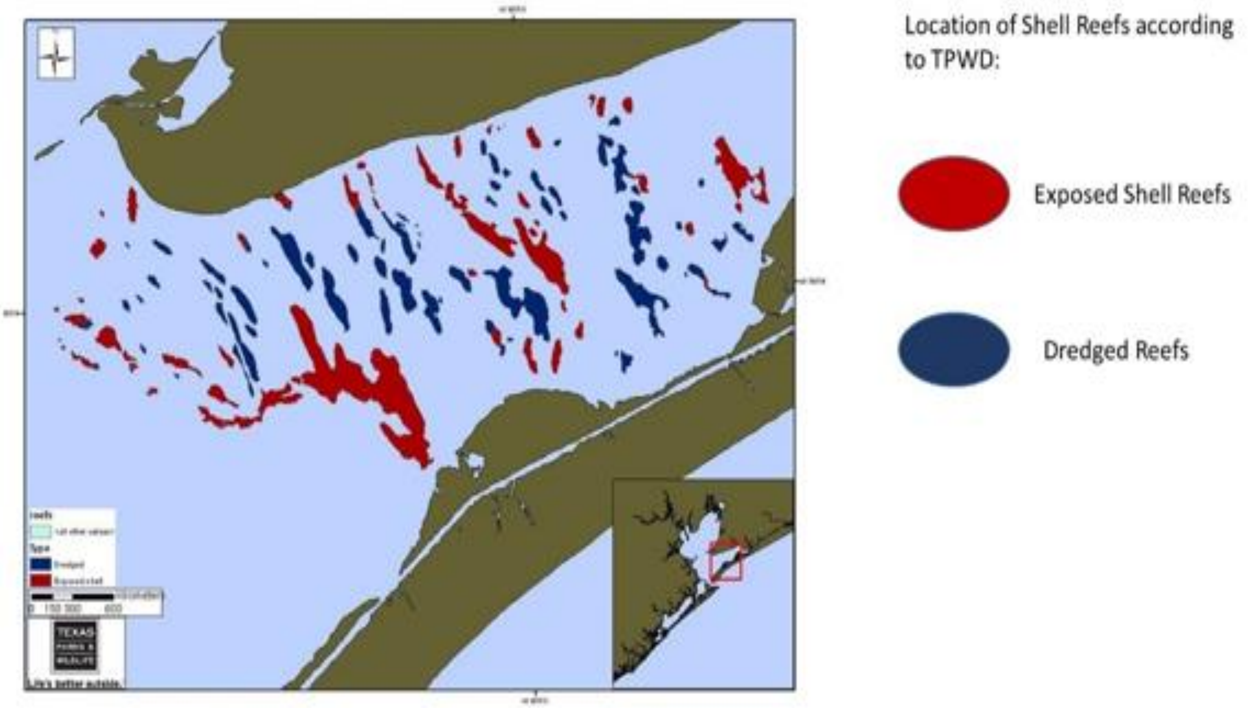


Figure 5-5, Location of the present oyster reefs in East Bay that followed the intertidal features as the Bolivar Peninsula Spit was growing (Source: TPWD, 2014). Due to the abundance of the shells in the reefs within the last decades, some of these areas were dredged for the use of the shells in the construction industry. The depressions are now filed with liquid muds.

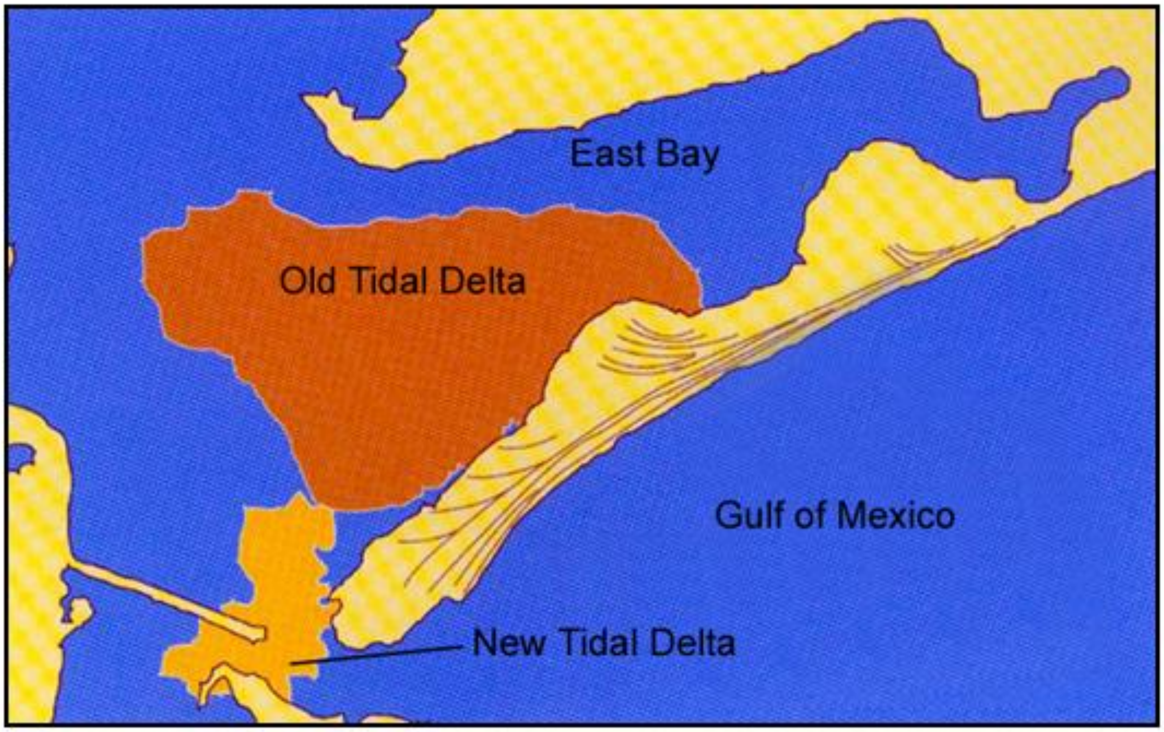


Figure 5-6, Location of the Old Tidal Delta as Bolivar Peninsula was at the last stages of its formation (Anderson, 2007). Estimated volumes for the Old Tidal Delta shows up to 400 million cubic meters (520 million cubic yards) of soft sediments connected to this old tidal delta (Dellapenna et al., 2009).

5.2.2 The Modern Delta

Data regarding the modern tidal delta in Galveston Bay appears to be limited in terms of thickness and total volume. Fisher et al., (1972) limited the area of the modern delta to just north of the GIWW (Figure 5-7). A grab sample shown in the TxSed (2016) Database, sample: BEG1TBEG_GTE36 shows 98% sand just north of the intersection at the GIWW and the Houston Ship Channel. A second core: RU14BRFTD-92-1 shows up to 2.8 meters of sand and mixed sands in the sediment profile. Data from the dredging projects on the GIWW, Galveston Ship Channel, and Houston Ship Channel confirm that the delta is an active area of sedimentation (see Section 9.0). No volumes have been measured for the recent flood tidal delta since a large portion ends on the navigation channels. he following figure (Figure 5-7) shows the area of active deposition occurring on the modern ebb delta of the Bolivar Roads Inlet. The yellow area shows the area of active inlet deposition (Fisher et al., 1972). Details of the sediments available on the ebb delta is present in Section 8.0.

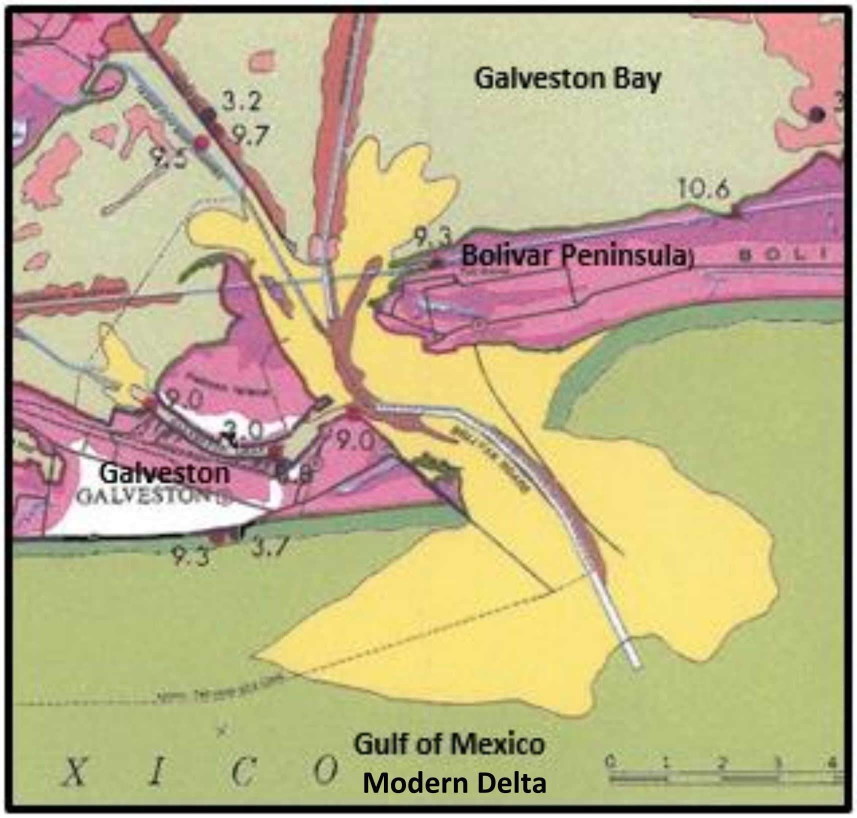


Figure 5-7, Area of active deposition occurring on the modern ebb and flood deltas of the Bolivar Roads Inlet. The yellow area shows the extension of the active inlet deposition (Fisher et al., 1972).

5.2.3 Hurricane Ike Sediment Inputs on East Bay

Hurricane Ike acted as a sediment modifier by bringing large amounts of sediment inputs to East Bay (Dellapenna et al. 2009). The authors measured the sedimentation that resulted from the Gulf of Mexico storm surge into East Bay during Hurricane Ike (Figure 5-8 and Figure 5-9). Storm-related sediments came to the bay in two forms. First, the Gulf of Mexico storm surge brought the sediments from Bolivar Peninsula into the bay system (Figure 5-8). Then, as the storm continued to inundate the north side of the bay, the surge flooded the land. As the surge receded, the waters carried the top soil of the land, mainly composed of fine sediments and organic soils (Dellapenna personal communication) and deposited the fines on top of the sandy materials from the peninsula. This way, two sets of sediment sources were deposited in the bay: first, the sandy materials from the gulf surge as the first event, and second, the fine deposits from the land receding surges on top of the sands (Figure 5-8).

The following figure (Figure 5-8) shows the sedimentation model complied by Dellapenna et al., (2009) after Hurricane Ike in East Galveston Bay. The white arrows crossing Bolivar Peninsula show the source of sandy sediments ending on the bay, they grey arrow shows the source of fine deposits coming from the bay receding waters, and the yellow arrow shows the post-storm sedimentation moving the sediments into the larger bay (after Dellapenna et al. 2009).

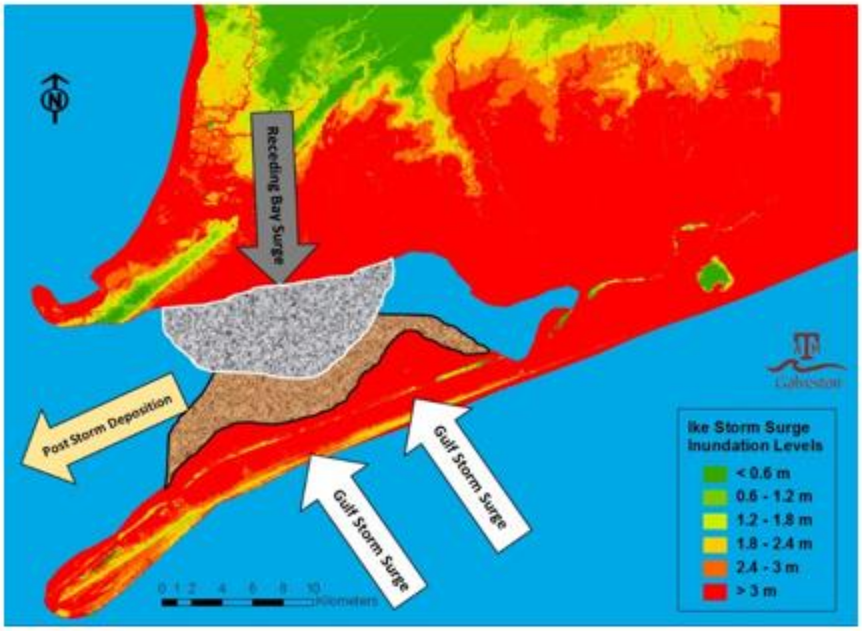


Figure 5-8, Sedimentation model compiled by Dellapenna et al. (2009) after Hurricane Ike in East Galveston Bay. The white arrows crossing Bolivar Peninsula show the source of sandy sediments ending on the bay; the grey arrow shows the source of fine deposits coming from the bay receding waters. The yellow arrow shows the post-storm sedimentation moving the sediments into the larger bay (After Dellapenna et al., 2009).

The data collected immediately after Hurricane Ike shows that the sediments accumulated close to Bolivar Peninsula area contained higher concentrations of sands (Figure 5-9). Likewise, sediments that were closer to the north shorelines contained higher concentrations of fines. The thickness of the new sediment varied, but reached up to 1.40 meters of new sediment close to Rollover Pass and south of Wallis Lake on Smith Point. These post-Hurricane Ike deposits buried large areas of productive oyster reefs with more than a meter of sands and/ormuds.

A rough estimate from Dellapenna (personal communication) on the volumes of post-Hurricane Ike deposition proposed that no less than 160,000,000 cubic meters (about 209,000,000 cubic yards) were deposited into the bay due to Ike surges. The analysis assumed just 1 meter of thick sediment deposit, with the lower 0.5 meters being sand and the upper 0.5 meters being mud, and assuming a length of 20 kilometers, which is about the length of East Bay as measured on Figure 5-9, and an average width of 8 kilometers. Based on those assumed areas, there was approximately 104.6 million yards of mud and 104.6 million yards of sand, for a volume of up to 209.3 million yards of sediment as a result of Hurricane Ike (Figure 5-9). No data has been collected on what happened to these sediments after Ike and how they moved into other portions of the bay. Today, bathymetric profiles on the oyster reefs show that conditions are becoming normalized as pre-Ike conditions. Post-Ike sediment interpretations are suggesting that a large amount of these sediments were transported back to the Gulf of Mexico via Bolivar Roads or were re-distributed through the other areas in Galveston Bay (Dellapenna personal communication).

Table 5-3
Sediments Post-Hurricane Ike

Geologic Unit	Potential Sediment Volume
Sediments After Hurricane Ike (not clear where they ended up)	~159,791,965 cubic meters

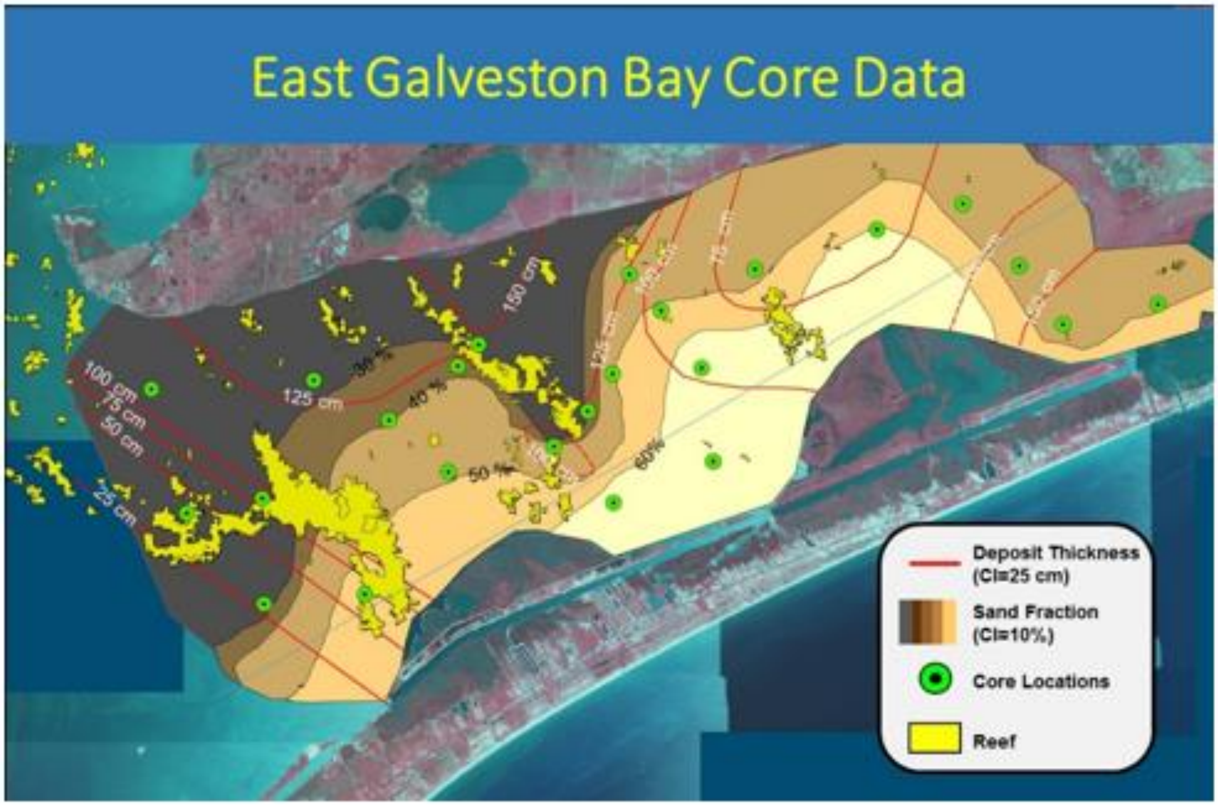


Figure 5-9, Post-Ike sedimentation in East Galveston Bay using cores and post bathymetric surveys (Dellapenna et al.,2009). These new sediments buried large areas of productive oyster reefs. The light color represents a higher percentage of sand; likewise, the dark color represents a higher percentage of fines.

5.3 WEST GALVESTON BAY

Some sediment data inventories for Galveston were compiled under the West Galveston Bay Regional Sediment Management Plan (WGB RSM) (Moya et al.,2012). Under the WGB RSM, a Sediment Availability Model was developed for the potential volumes of sediments available by geologic-geomorphologic units in West Galveston Bay (Moya et al.,2012). The sediment availability was developed based on geologic information of the bay bottom, previous cores collected in the system, new cores collected and geomorphologic observations. First, the geologic mapping of the bay bottom by White et al., (1985) helped establish the base for comparison with the new cores and grab samples collected in 2010 and presented in Figure 5-10 (Moya et al.,2012). The comparison of the 1985 (White et al.,1985) sediment data set with the 2010 data set (Moya et al.,2012), combined with previous studies and the ADCIRC model, helped to develop a sedimentation model. The study suggested that the sediments identified were a combination of fine sediments and sands. An estimated potential maximum volume of 17,500,000 cubic meters (22,800,000 cubic yards) was found to be available in the system, including the geological and the navigational system. The data includes the GIWW and Chocolate Bayou navigation channels (Table 5-4) and is only focused on the sediments available on the surface (first few feet) of the Galveston Bay geologic units.

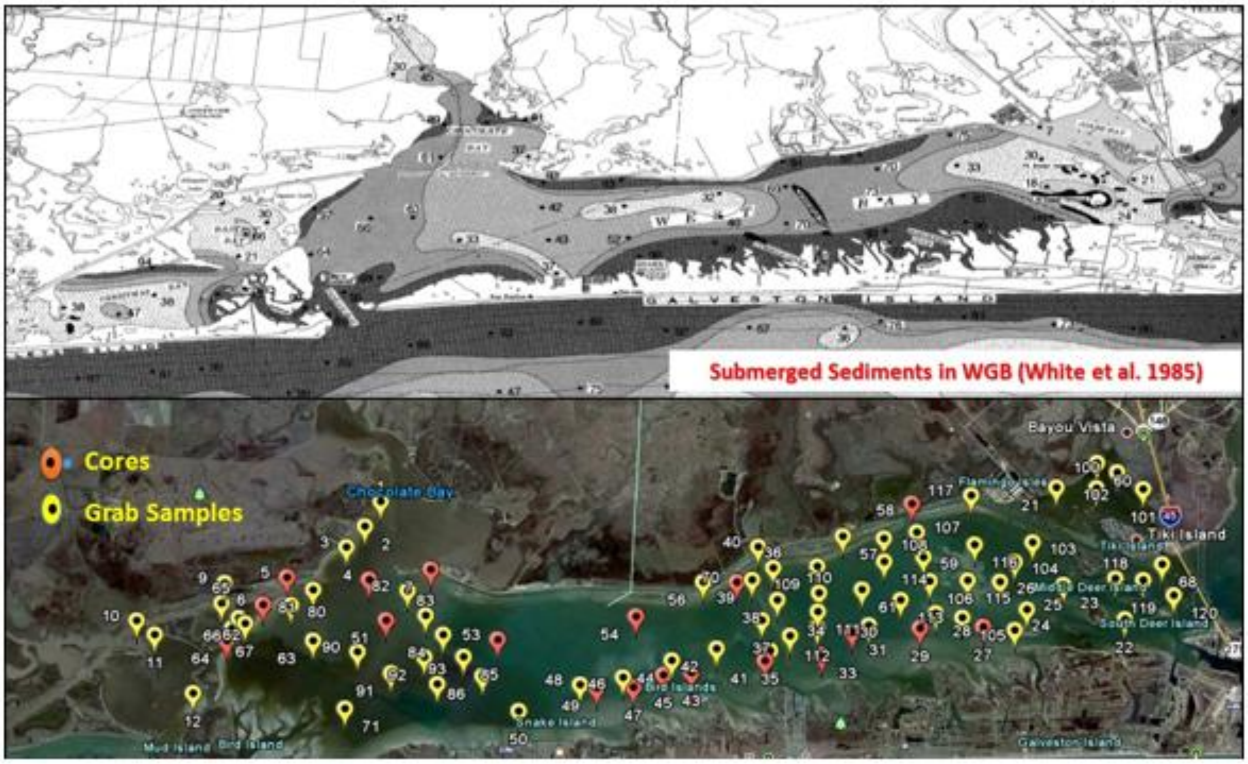


Figure 5-10, Sediment Availability Model developed by the comparison of different bay bottom geologic databases in West Galveston Bay with data from 1985 and 2011. (White et al., 1985 and Moya et al., 2012).

Table 5-4
Maximum Estimates of Sediment Volumes Available Per Geologic Area (Moya et al., 2012)

Area	Volumes in Cubic Meters	Volumes in Cubic Yards
1. San Luis Pass Flood Delta (Distal Area)	1,500,000	1,962,000
2. West of West Basin	4,800,000	6,278,000
5a. Galveston Island West Basin	660,000	863,247
5b. Galveston Island West Basin	960,000	1,255,632
5c. Galveston Island West Basin	840,000	1,098,678
6a. Galveston Island East Basin	720,000	941,724
6b. Galveston Island East Basin	1,800,000	2,354,000
6c. Galveston Island East Basin	792,000	1,036,000
7. Central Portion of WGB West Basin	5,500,000	7,000,000
Total	17,572,000	22,789,281

The identification of potential sediment source areas suggested that from the dynamic point of view, West Galveston Bay is composed of different active sedimentary cells. Some of these cells are transitional to the main sediment sink, which is the San Luis Pass and the West Basin of West Galveston Bay (Moya et al.,2012) (Figure 5-11). Sediments moving along the bay shorelines are transported west trying to reach the West Basin (deepest depression in the local bay). On the north side, anomalies such as the GIWW and Chocolate Bayou navigation channel modify the sedimentation because the channels act as local sediment sinks where sediments become trapped as dredge material. On the south side of West Galveston Bay, the study shows that sandy sediments migrate as a set of sand bars parallel to the island shorelines (Figure 5-14). The data collected by Moya et al., (2012) suggests that the sediment being transported next to the shorelines can be naturally re-routed by infrastructure and deposition can be induced for natural restoration. The best example of this natural accretion is the sediment running parallel to the center of Galveston Island, where local modifications to the sediment transport have induced the creation of submerged habitats on new sandy bars close to Delehite Cove (Moya et al.,2012) (Figure 5-14). A “Zone of Potential Marsh Establishment” was proposed to create a no dredging zone because sediment loss is not renewed in that area. It was suggested that dredging inside of these zones will create more damage than solutions in the restoration of the Galveston Island marshes.

Figure 5-11, Sediment Cells in West Galveston Bay identified as part of the sediment transport and geomorphological processes (Moya et al., 2012).

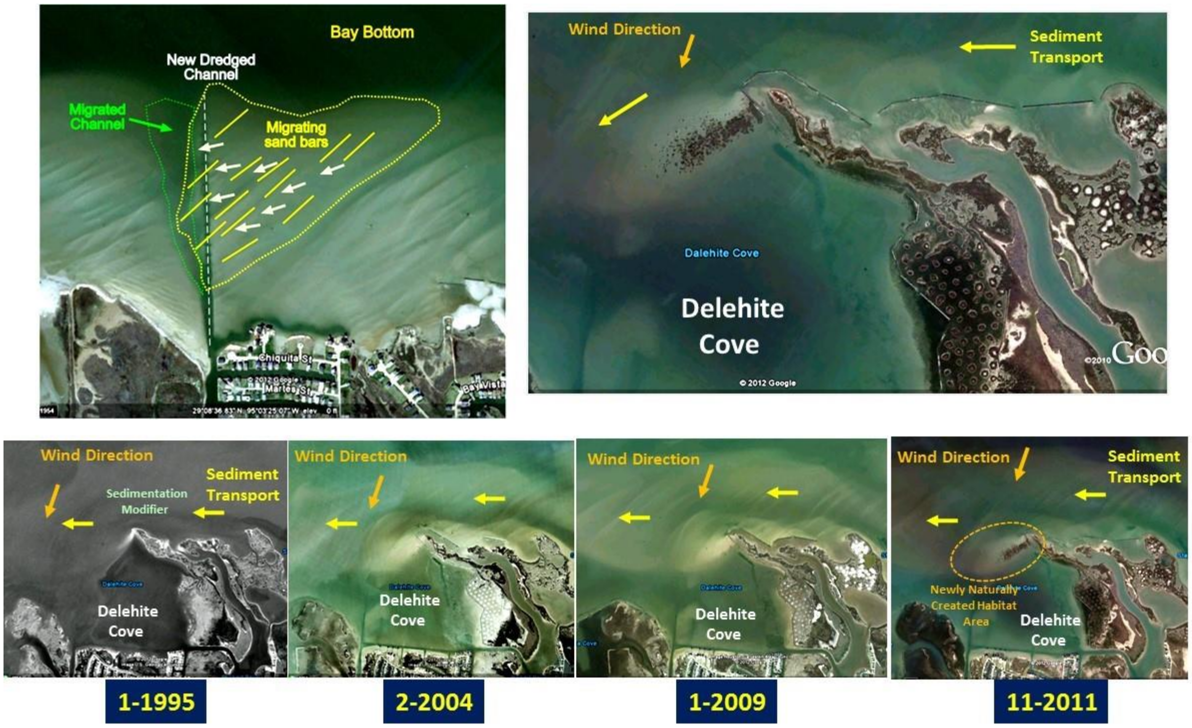


Figure 5-12, Sediment Transport Model showing how the sediment has moved along Galveston Island shorelines in the last 20 years. Modifications to the sediment processes can induce natural deposition and therefore, naturally creates submerged habitats (After Moya et al., 2012).

5.3.1 Former Incised Valley in West Galveston Bay

In recent years, detailed geophysical, geological, and specific stratigraphic investigations have been conducted in West Galveston Bay (Figure 5-12) searching for the presence of former incised fluvial channel and the thickness of the Holocene and Pleistocene fluvial and costal units before the formation of Galveston Island (Rodriguez et al., 2005; Laverty, 2014; and Dellapenna et al., 2014). These sediment investigations provided data of the paleo-geomorphological evolution of West Galveston Bay before the recent sea level rise. This is what can be considered “building with nature”.

Laverty (2014) and Dellapenna et al., (2014) collected a total of 30 core samples and more than 160 kilometers of CHIRP seismic data in West Galveston Bay and Chocolate Bay. The analysis of the data found the Beaumont Formation as a key feature to analyze sedimentation that occurred during the stages of fluvial incision and deposition and sea level inundation. Incised fluvial channels were observed on top and as part of the Pleistocene that formed the basal surface of paleo Chocolate River valley fills (during Pleistocene and early Holocene). Radiocarbon dating revealed that several flooding events related to Late-Pleistocene-Holocene sea-level rise caused the landward back-stepping and geographic reorganization of depositional environments within West Bay similar to the large-scale events occurred in Trinity Bay.

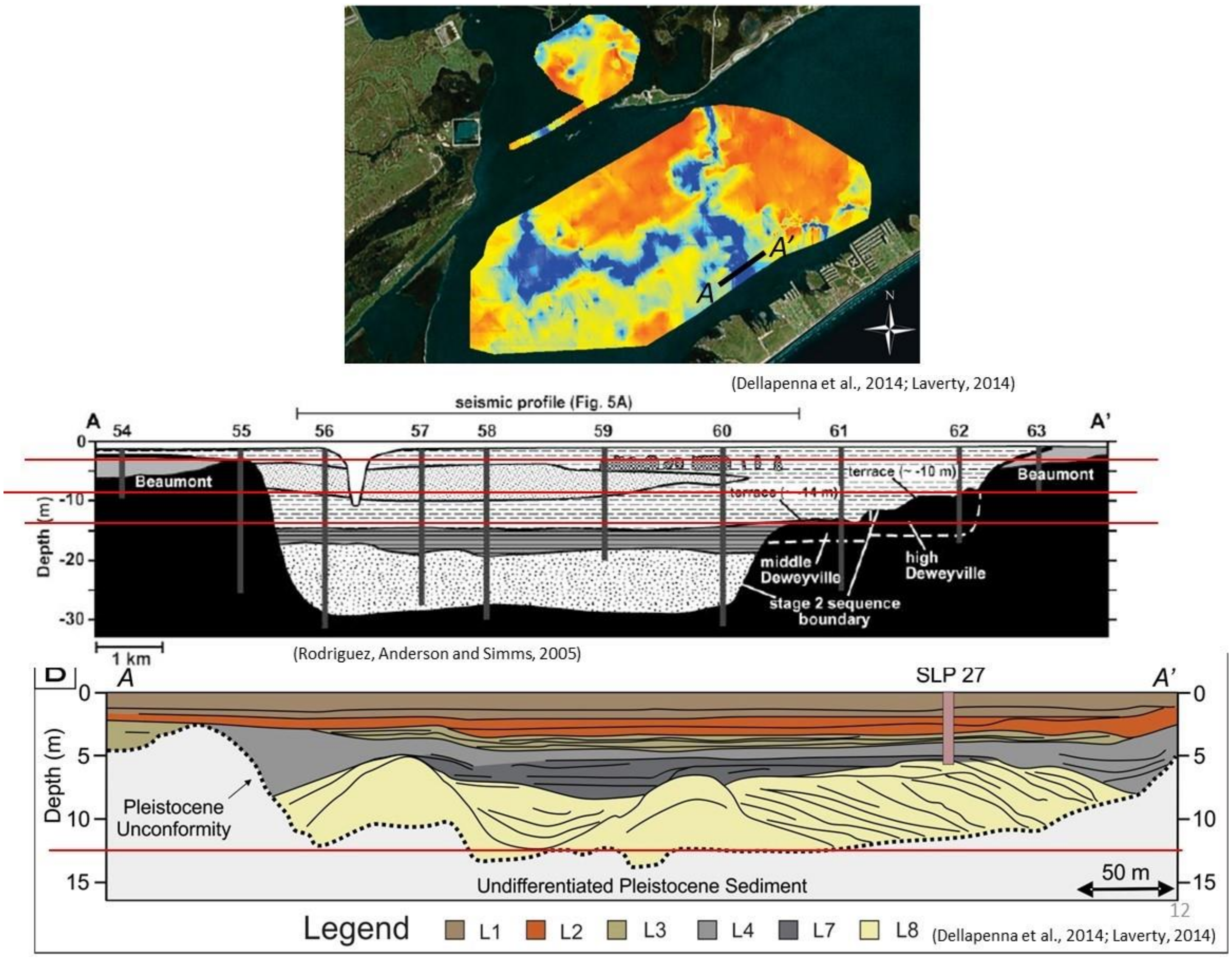
As presented by Laverty (2014) and Dellapenna et al., (2014), the first flooding event occurred about 7,600 years BP caused both fluvial-dominated sedimentation and the initiation of estuarine conditions. The next flooding event occurred at around 6,800 Cal. yr. BP and created ideal brackish conditions for oyster reef proliferation. Then a new change occurred and the migration of the Brazos River impacted the bay returning to fluvial dominated conditions, which increased turbidity from the Paleo-Brazos River that was flowing into the San Luis Pass area between around 6,100 and 4,400 Cal. yr. BP, which ceased oyster reef production. The final flooding event occurred at around 4,400 Cal. yr. BP, which possibly established the connection between Galveston Bay and West Bay. This is the time where the bay started to exist as we know it today and almost parallels the formation of East Galveston Island.

Based on the results of the geophysical and sedimentary investigations, Dellapenna et al., (2014) suggested that up to around 639,400,000 cubic meters (about 836,000,000 cubic yards) of fluvial and estuarine sediments were quantified as part of these valley fill flooding events (Figure 5-14). Assuming that the deposits investigated are at least 25 feet thick, and using the area from Jamaica Beach to San Luis Pass as the area of analysis and correlating the thickness to the rest of the former valleys, then the authors made the assumptions that up to around 639,400,000 cubic meters (830,000,000 cubic yards) should be a conservative estimate for the sediments available below the West Galveston Bay bottom.

The following figure (Figure 5-13) shows the results of the sedimentary investigations conducted on West Galveston Bay by Rodriguez et al., (2005), Laverty (2014) and Dellapenna et al., (2014) on the sedimentary units associated with paleo-river valleys filled during the last sea level rise event. Section A-A’ in Sub-Figure A shows a cross section of a former river valley and its extension into West Galveston Bay. Figures B and C show the interpretation of the geophysical and sedimentary profiles. It was suggested that up to 639,400,000 cubic meters (830,000,000 cubic yards) of fluvial sandy sediments are available on these filled valleys just in the blue areas shown in Figure 5-13 and Table 5-5.

Table 5-5
Sediments Post-Hurricane Ike

Geologic Unit	Potential Sediment Volume
Incised Valleys in West Galveston Bay	~639,400,000 cubic meters



(Dellapenna et al., 2014; Laverty, 2014)

(Rodriguez, Anderson and Simms, 2005)

(Dellapenna et al., 2014; Laverty, 2014)

Figure 5-13, Results of the sedimentary investigations conducted on West Galveston Bay by Rodriguez et al., (2005), Laverty (2014) and Dellapenna et al., (2014) on the sedimentary units associated with paleo-river valleys filled during the last sea level rise event (the last 7,600 years). Section A-A' in Sub-Figure A shows a cross section of a former river valley and its extension into West Galveston Bay. Figures B and C show the interpretation of the geophysical and sedimentary profiles. It was suggested that up to 639,400,000 cubic meters (830,000,000 cubic yards) of fluvial and bay sediments are available on these filled valleys just in the blue areas shown in Figure A.

5.4 MATAGORDA BAY

The Matagorda-Lavaca Bay system is one of the oldest bay systems in Texas. The valley fill processes started approximately 11,600 years ago (Maddox et al., 2008) (Figure 5-13). The valley fill deposition followed very similar processes as the Trinity and Sabine Rivers, with initial flooding of the ancestral Lavaca River incised valley. The former river valley was flooded by landward shifts in the river mouth, followed by episodes of fluvial aggradation. A big jump in aggradation occurred approximately between 11,600 and 9,600 years BP. By about 9,500 years BP, the deep, narrow part of the Lavaca incised valley had been flooded and was occupied by a bay-head delta. The river mouth shifted landward, and then seaward within between 9,500 and 8,200 years BP (Maddox et al., 2008). A large change occurred between 7,300 and 6,700 years BP, when the bay-head delta stepped landward at least 30 kilometers, establishing most of modern Matagorda Bay (Figure 5-13). During the last 6,700 years, the bay-head delta of the Lavaca River retreated slowly up the valley forming the configuration of the Lavaca and Matagorda Bays. The coastal barrier island of Matagorda Island was dated as created about 4,000 years ago (Anderson et al.,2016).

The morphology of the paleo-river valley was in some areas up to 40 meters deep. A geological/geophysical cross section just north of the Matagorda peninsula east of the Matagorda ship channel (Figure 5-13) called Section A-A’ by Maddox et al., (2008) shows how the valley fill processes left a sedimentary record connected to the inundation created by sea level rise. The geologic A-A’ cross section is presented in Figure 5-14 and shows a sequence of fluvial and estuarine deposition as the Matagorda River valley was flooded, changing from a fluvial dominated environment to a bay and bay head delta dominated environment (Figure 3-8), until the area became a bay environment by the formation of Matagorda Island and Matagorda Peninsula (Maddox et al., 2008).

Radiocarbon dates were used to constrain the ages of geological units during the different stages of the formation of Matagorda Bay (Maddox et al., 2008). The cross section in Figure 5-14 and the valley fill evolution of the Lavaca River valley (Figures 3-8 and 5-15) show different flooding surfaces: large sedimentary units representing the fluvial-dominated environment and later covered by the bay-head delta and bay deposits and interrupted sometimes by sandy spits. Two large sandy spits were deposited as part of the early formation of the barrier island. These sand spits were common during the evolution of the bay (Maddox et al., 2008) (Figure 5-15). These sand spits are potential sandy resources to be investigated in detail for sediment sources.

Considering the paleo depth of the Lavaca River system of at least 25 meters deep (although is suggested to be 40 meters deep) and a minimum of 6 kilometers wide with a minimum former river length of 20 kilometers (Figures 5-14 and 5-15), it is suggested that at least 3,000,000,000 cubic meters (3,923,851,857 cubic yards) of sediments may be available as valley fill deposits in the paleo-valley of the former Lavaca River in Matagorda Bay (Table 5-6). The data opens the door for future detailed sediment investigations, considering the potential over burden materials on top for the valley fill and the spits.

Figure 5-14 shows the Paleo geomorphologic configuration of the Lavaca-Matagorda bay complex about 17,000 years ago (Anderson et al.,2016). Contours are in meters. Section A-A' (parallel to the modern Matagorda peninsula) is presented in a geologic cross section generated by Maddox et al., (2008) on figures 5-15 and 5-16 showing the sedimentary records left by the effects of sea level rise.

Table 5-6
Lavaca Incised Valley in Matagorda Bay

Geologic Unit	Potential Sediment Volume
Lavaca Incised Valley in Matagorda Bay	~3,000,000,000 cubic meters

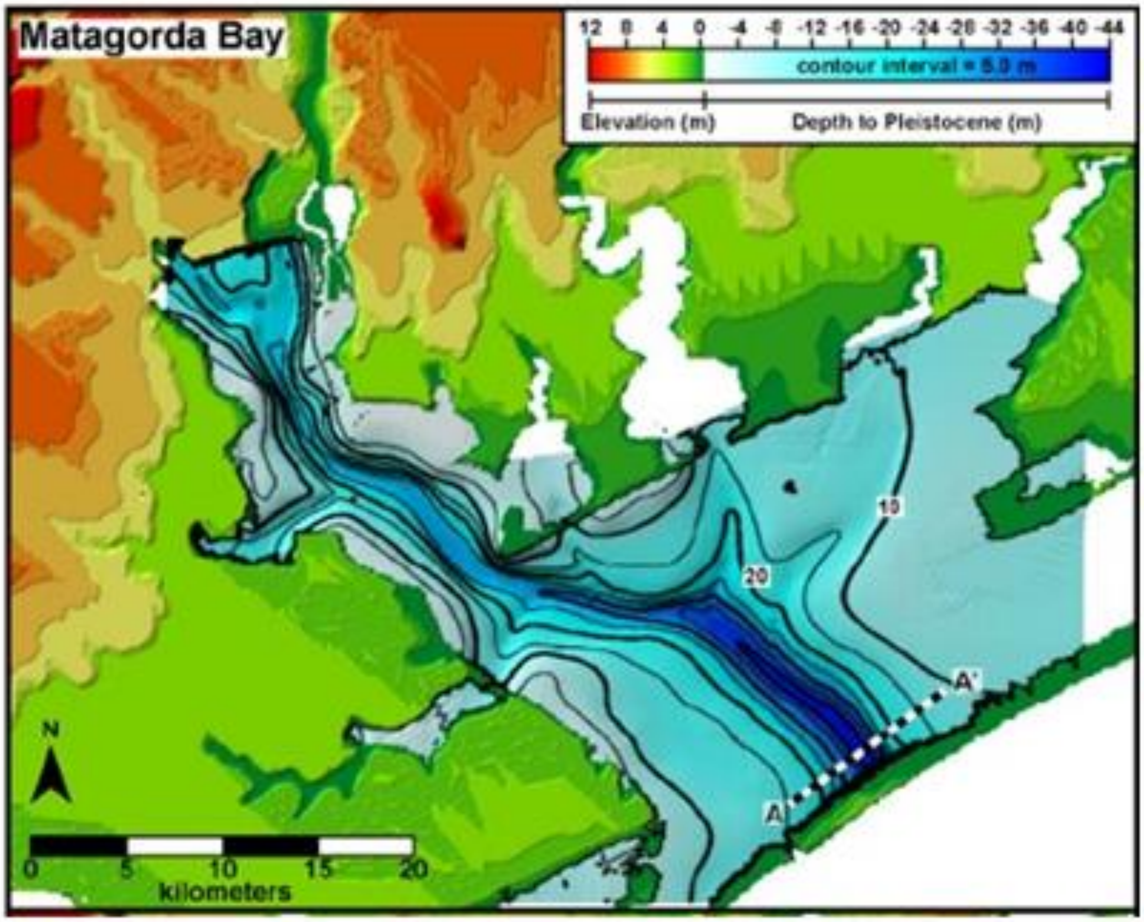


Figure 5-14, Paleo geomorphologic configuration of the Lavaca-Matagorda bay complex about 17,000 years ago (Anderson et al.,2016). Contours are in meters. Section A-A' (parallel to the modern Matagorda peninsula) is presented in a geologic cross section generated by Maddox et al., (2008) on Figure 4-15 showing the sedimentary records left by the effects of sea level rise.

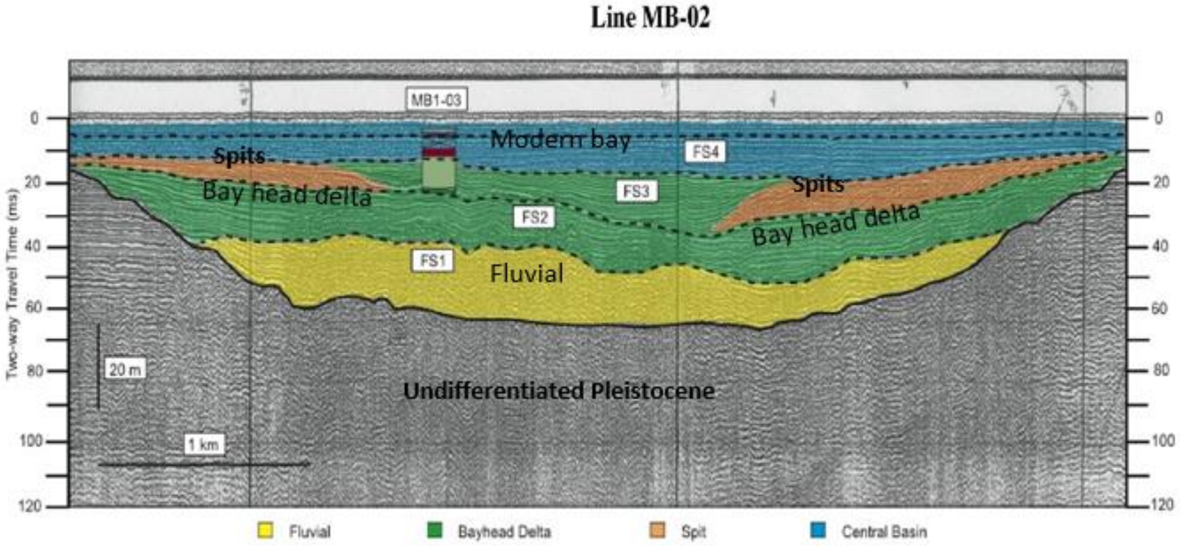


Figure 5-15, Seismic and interpreted geologic profile conducted by across the Lavaca incised valley in southern Matagorda Bay by Maddox et al., (2008) (Section A-A’ in Figure 5-14). Note the sequence of deposition as the Matagorda River valley was flooded changing from a fluvial dominated environment at the bottom to a bay and bay head delta dominated environment. Two large sandy spits were deposited as part of the early formation of the barrier island.

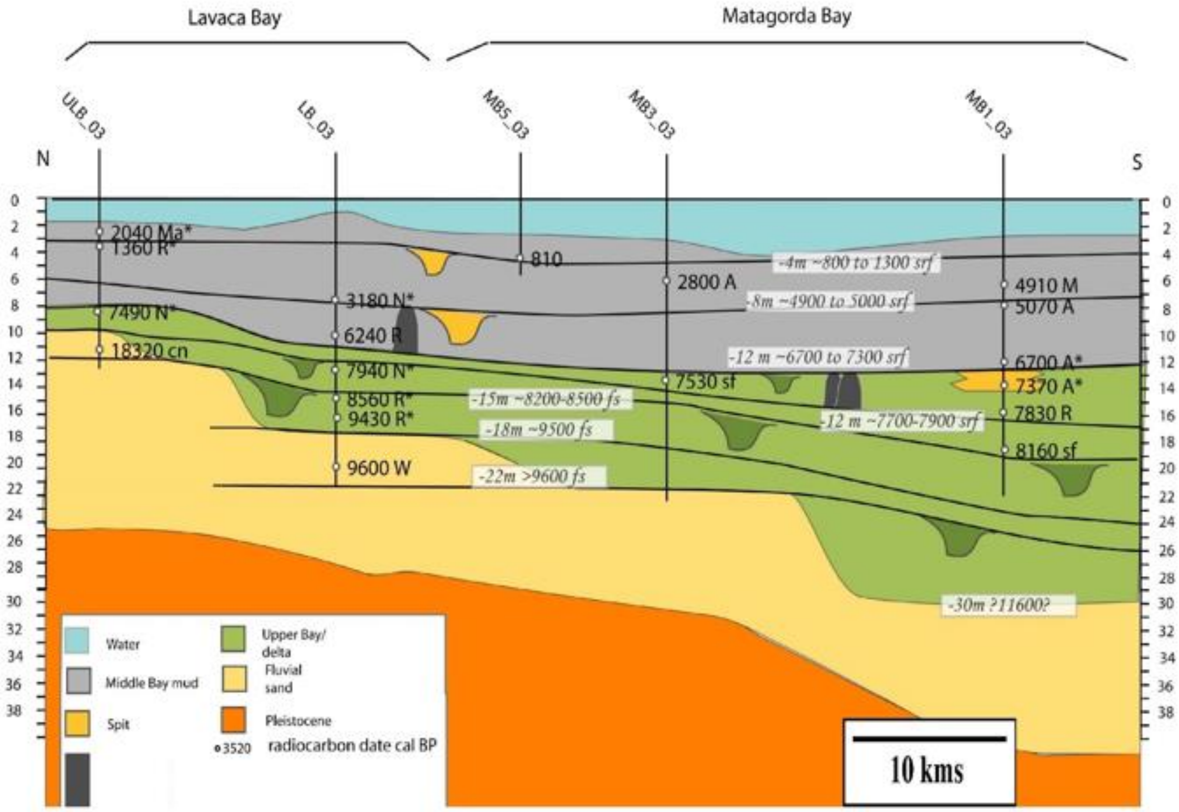


Figure 5-16, Sedimentary (chronostratigraphic) profile along the axis of the Lavaca incised valley showing flooding surfaces and radiocarbon dates used to constrain the ages of these surfaces. The longitudinal profile shows the axis of the upper Lavaca Bay river valley on the left and the Matagorda Bay river valley on the right. Note the different deposition including the Pleistocene clays, then fluvial deposits, then the bay flooding and bay-head delta deposits ending with the modern bay deposits (Maddox et al.,2008).

5.4.1 The Modern Matagorda Bay

Geologically speaking Matagorda Bay is today a deep bay with strong fetches. Strong waves and currents are dominant in the different sections of the bay where high rates of shoreline retreat are affecting large shoreline areas across the bay system. Shoreline retreat rates are up to -32 feet per year on the west shorelines of Matagorda Bay north of Port O'Connor and -20 feet per year north of Magnolia (McGowen and Brewton, 1975). The sediment removed from the shorelines across the bay does not show indicators of large accumulation on the bay bottoms (McGowen et al., 1975; White et al.,1989). The recent accumulation on the bay bottom appears to follow the trends of evolution and new energy adapted to the modern bay system as reflected in the geologic maps of the bay bottom.

Modern sandy sediments on the bay bottom are limited. Some sandy deposits are located on the west side of the bay following the shorelines of the former Pleistocene barrier island and Lavaca bay from Port O'Connor to Magnolia (White et al.,1989. Plate 1). Some deposits are observed close to the Half Moon peninsula. The rest of the bay bottom appears to be a mud-dominated environment with limited information on coarse sediments on the surface. Abundant amounts of sands are observed close to the barrier islands and the two major inlets (Matagorda Ship Channel and Pass Cavallo). This is an area where specific sediment investigation may be conducted to determine sediment availability.

In general, the modern Colorado River Delta appears to be the major source of sediment to the bay system. This should be considered as a potential area for a sediment management program. Discussion of the Colorado River Delta sediment supply is provided in Section 7.0. On the south side of the bay, next to the entrance of the Matagorda Ship Channel, a new sand bank is accumulating on the northeastern side of Sundown Island. This bank has grown consistently over the last 10 years due to the large size of the ship channel dimensions, which has allowed stronger inlet process and flood delta accumulation. This is another area for potential investigations. Based on the comparison of historic bathymetric maps showing bathymetries of -6 feet and the most recent data compiled from site visits by the authors of this report, the north side of Sundown Island changed from a bathymetry of -6 feet to -1 and -2 feet deep, which suggest the creation of a large sand bank that appears to have a minimum of 5,000,000 cubic meters (6,539,753 cubic yards) of sandy sediments (Figure 5-16 and Table 5-7).

The following figure (Figure 5-17) shows the location of the new sand bank created north of Sundown Island as result of the stronger tidal prism coming from the Gulf of Mexico through the Matagorda Ship Channel inlet.

Table 5-7

Sundown Island North Bank

Geologic Unit	Potential Sediment Volume
Sundown Island North Bank	~5,000,000 cubic meters

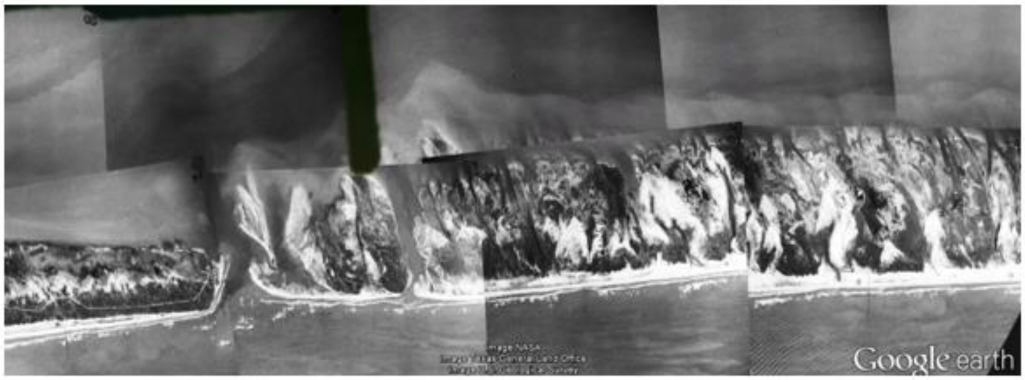
Figure 5-17, Location of the new sand bank created north of Sundown Island as result of the stronger tidal prism coming from the Gulf of Mexico through the Matagorda Ship Channel inlet.

5.4.2 Matagorda Bay Barrier Island Sediment Processes

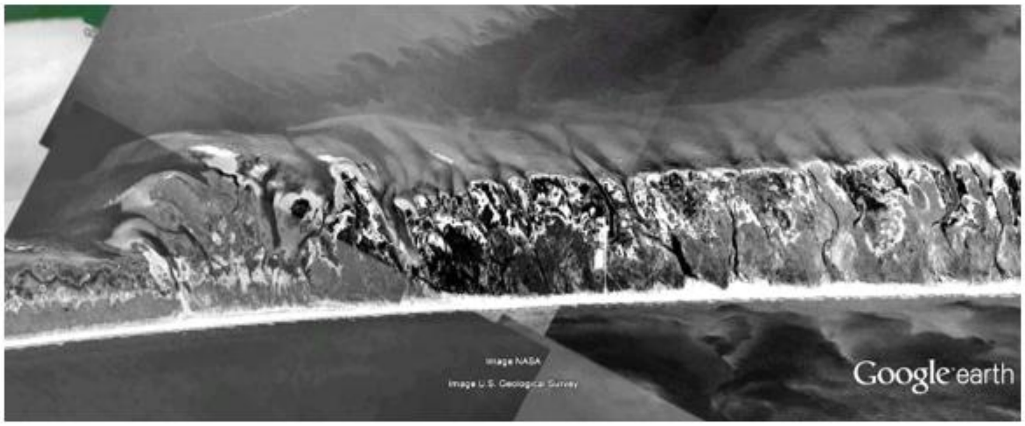
The bay shorelines of Matagorda Peninsula show patterns and processes similar to the ones on the bay side of Galveston Island (Figures 5-12 and 5-18). The bay sediment transport processes appear to move the sandy sediment on the island shorelines to the deepest part of the bay as sand bars that migrate parallel to the shorelines. As in Galveston Bay, sediments migrate parallel to the shoreline managed by the wind processes as shown in the comparison of aerial photos from 1943 to 2011 (Figure 5-18). On August 30, 1942, a hurricane moved inland on Matagorda Peninsula. The aerial photos available from 1943 (Google Earth 2016) were collected a year after the storm and show the washover channels and fans created by the storm surges.

The following figure (Figure 5-18) shows the evolution of the bay shorelines and the submerged sediments on Matagorda Peninsula after storms. Note the sand bars migrating into the bay and to the south looking for the regional base level (Source Google Earth, 2016).

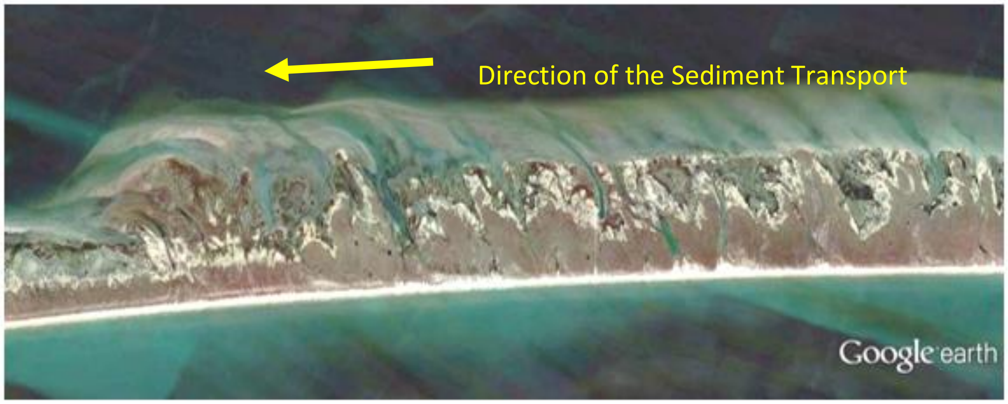
Figure 5-18 shows the morphology of the peninsula after the storm in 1943 with a predominant pattern of wash over fans and channels. Sediments from the beach side were brought to the bay side as part of the storm surge processes. By 02/1995, the wash over channels were already recovered and the wash over fans and sand bars in the bay started the process of migration on the shorelines and the slope of the island. Modifications of the submerged wash over channels and fans by the migration of the sand bars is clear in Figure 5-18 B and C. By 11/2011, the sand bars on the island slope are elongated and some have migrated into the bay system and are not visible in the aerial photos (Figure 5-18 C).



A. 12/1943



B. 2/1995



C. 11/2011

Figure 5-18, Evolution of the Bay Shorelines and the Submerged Sediments on Matagorda Peninsula after a large storm in 1942.

The sequence of aerial photos shows that sediment transport processes after storms on the bay side of barrier islands, mainly on the bay slope (bay shoreface) and the nearby bay bottoms, can be a source of sediment for restoration purposes. The after storms sediment transport processes need to be analyzed for the potential use of those sediments during barrier island breaching. Figure 5-18 also shows that sediments can be returned to the barrier island system if the processes are understood and sediments are kept close to the barrier island. Some of the sediments carried by storm surges to the bay side, mainly on the interaction of the bay shoreface and the bay bottom may be considered a potential sediment source on specific areas on the Texas bays or barrier islands. No recommendations for the use of these sediments can be presented until more detailed studies are conducted.

5.5 CORPUS CHRISTI BAY

In general, with some local modifications, Corpus Christi Bay followed the same processes of valley fill and back-stepping sedimentation as the larger Texas bays previously described (Simms et al., 2008). The paleo-topographic map of the Nueces River Valley (Figure 5-19) (Morton and Payne, 1984) shows a deep valley more than 40 meters deep (about 130 feet). For Corpus Christi Bay, the flooding events were registered at 9,600, 8,000, 4,800, and 2,600 years BP (Simms et al., 2008) (Figure 5-19). The 9,600 years BP flooding surface represents the initial drowning of the ancestral Nueces River Valley.

The back-filling sedimentation followed the sequence of back-stepping of bay head deltas, tidal deltas, oyster reefs, and other bay environments that covered the former fluvial environments (Simms et al., 2008), very similar to the evolution of other bays (Anderson et al., 2016). The presence of fine bay muds has been present for the last 4,000 years (Figure 5-20). As in the case of other Texas bays, only the areas close to present or former inlets and barrier islands show important amounts of recent deposition of coarse sediments as expressed in the geologic maps (Brown et al., 1976; Simms et al., 2008).

In general, the bay bottom as we know it today has not changed within the last centuries and probably within the last 4,000 years. There is limited amount of sand inputs to the bay bottom because the bay currently is and continues to be a mud-dominated environment (Simms et al., 2008). Considering the morphology of the Nueces paleo-river channel, just as in the previously described river valleys, an estimate of potential sediment volumes can be projected. Considering an average depth of 25 meters, with a width of 5 kilometers and a minimum length of 15 kilometers, it is suggested that at least 1,875,000,000 cubic meters (2,452,407,411 cubic yards) of sediments are available on the paleo river valley of the Nueces River (Table 5-8).

The following figure (Figure 5-20) shows the geological evolution of Corpus Christi Bay that followed the sequence of back-stepping of Bayhead deltas, tidal deltas, oyster reefs, and other bay environments that covered the former fluvial environments (Simms et al., 2008).

Table 5-8
Nueces River Incised Valley

Geologic Unit	Potential Sediment Volume
Nueces River Incised Valley	~1,875,000,000 cubic meters

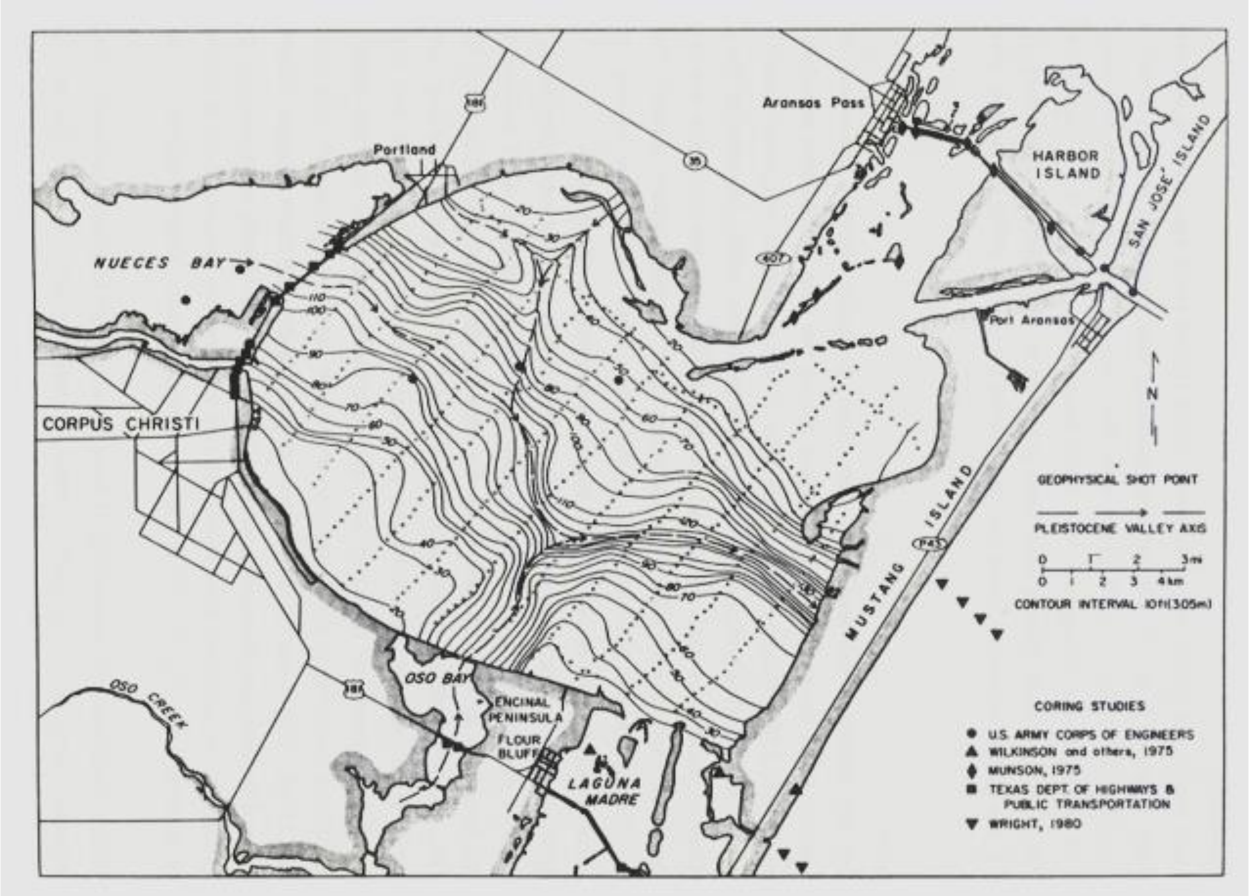


Figure 5-19, Paleo-Topographic Map of the Nueces River Valley (after Morton and Payne, 1984)

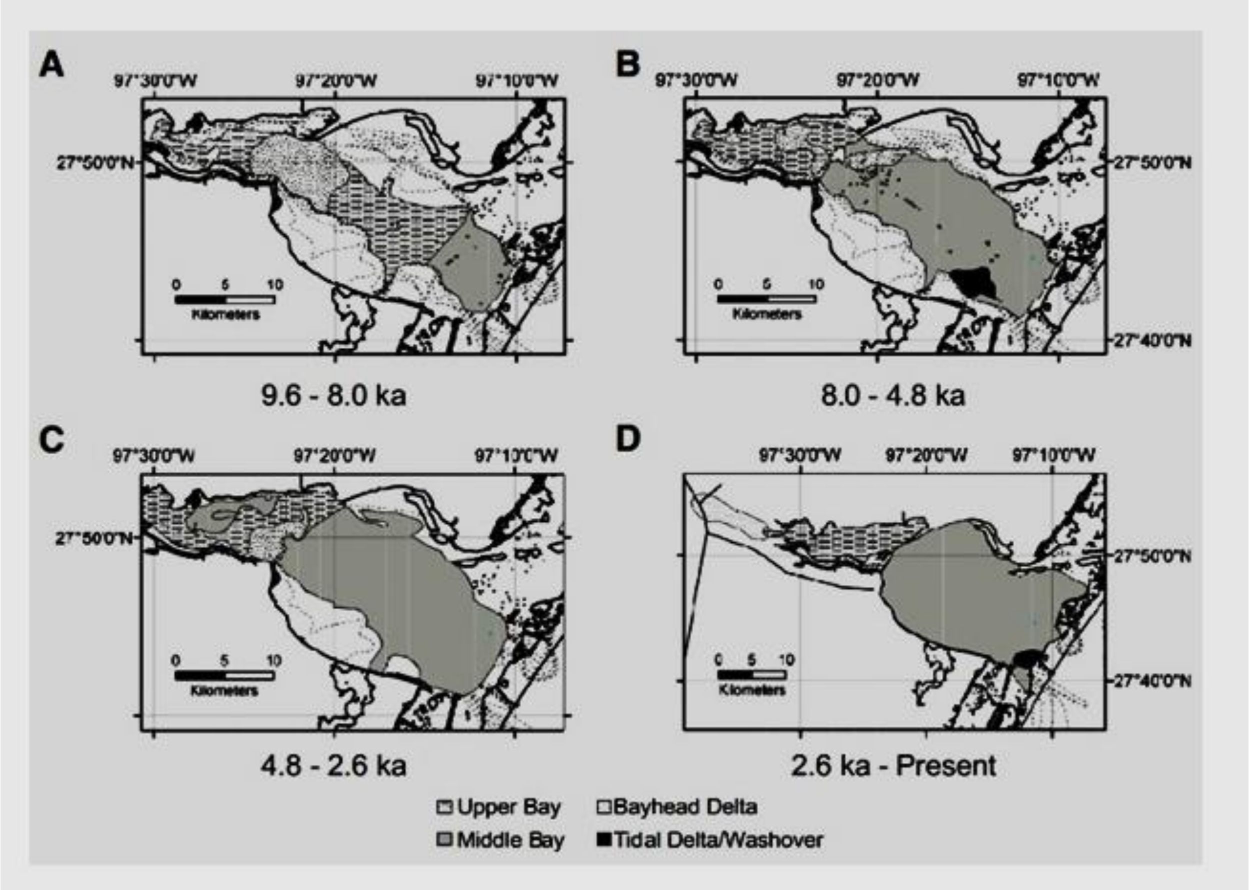


Figure 5-20, Geological evolution of Corpus Christi Bay that followed the sequence of back stepping of bay head deltas, tidal deltas, oyster reefs, and other bay environments that covered the former fluvial environments (Simms et al., 2008).

6.0 INVENTORIES OF COASTAL AND BAY SEDIMENT SOURCES

This chapter is a compilation of the sediment inventories presented in the earlier chapters. The sediment inventory tables presented in this chapter provide the background information necessary to plan for further actions that could entail undertaking sediment field investigations; designating sites as sediment borrow source locations; and/or incorporating areas in near-term restoration project plans for sediment harvesting. The reader should consider the data carefully since it is based on previous studies, and specific or localized areas may show differences when compared with the general investigations.

This chapter of the report presents summary tables of areas analyzed that “captured and retained” sediments under cycles of erosion and deposition connected to changes associated with sea level drops and rises.

Sediment availability and characteristics are grouped by sea level rise cycles (Anderson et al., 2016). For the sediment availability of paleo-river valleys and valley fills, the report followed the sedimentation models presented by at least Anderson 2007; Dellapenna et al. 2014; and Anderson et al. 2016 (Figures 3 4, 3-8, 3-10, 5-2, 5-13, 5-15, and 5-16) where the valley in-fills followed a sequence of the fluvial sediments and environments at the bottom of the valley (with predominance of sand deposits) to bay and bay head delta environments, to estuarine modern environments (with predominance of fine sediment deposits). The sedimentary sequence indicates that at the bottom of river valleys, more sandy environments are present, and at the top and end of the valley in-fill, more fines are present. Occasional sandy bodies can be observed in the early formation of the modern bays (Figure 5-15), but in general the valley fills appear to have more fines as they approached the present times.

Sandy sediment appears to be more abundant near deposits close to the mouths of the rivers, along major watersheds, and throughout old and modern barrier islands. The barrier islands and inlets are connected to the sands and coarse sediments produced by the ravinement processes and sediments that were pushed against the continent and ended as large sand bodies (Anderson et al. 2016). Since the new coastal sediment supply is minimum or non-existing, the disintegration of these sand bodies (some as barrier islands) are slowly occurring and is a source of sand moving into the bays or moving toward the Gulf of Mexico shoreface, at times with higher volumes of sands. These sands in the Gulf of Mexico shoreface get enriched with fines as they move away from the coast.

Perhaps, the best opportunity for the presence of large scale sand bodies, mainly sands, are the paleo-deltas and should be one of the largest sediment sources for coastal projects. However, it should be noted that fine deposits are as valuable as sandy deposits since marshes and other ecosystems reside on top of substrates that are composed of fine materials or mixed sediments. The presence of large amounts of fines should not be considered a problem since it is the core of the coastal substrates as they exist in many bays today.

Detailed geophysical and geotechnical investigations are necessary to ascertain the true characteristics (qualities and quantities) of localized sediment targets by sediment source area. Geologically speaking, only a few areas have been surveyed in detail for sediment source investigations (i.e. West Galveston Bay, offshore Galveston Island, offshore Trinity and Sabine River and Sabine and Heald Banks) to analyze the sediment availability with potential qualities and quantities (See tables below). Further geophysical and geotechnical investigations are required to provide for a better understanding of the extent and characteristics of possible sediment sources areas.

One final consideration is the consistency of the overburden material on top of the sedimentary units. Detailed CHIRP profiles and coring results on some of the sediment bodies analyzed show thick and hard overburden materials (Dellapenna personal communications). Detailed investigations will provide the consistency of these overburden layers, which can also be used as sediment sources for specific purposes.

Sediment availability is located at the incised paleo-valleys, due to geologic conditions. The general sediments applicability is indicated in the following tables for various coastal geomorphic features and are summarized in Appendix A as Summary of Potential In-Situ Offshore and In-Bay Sediment Borrow Areas.

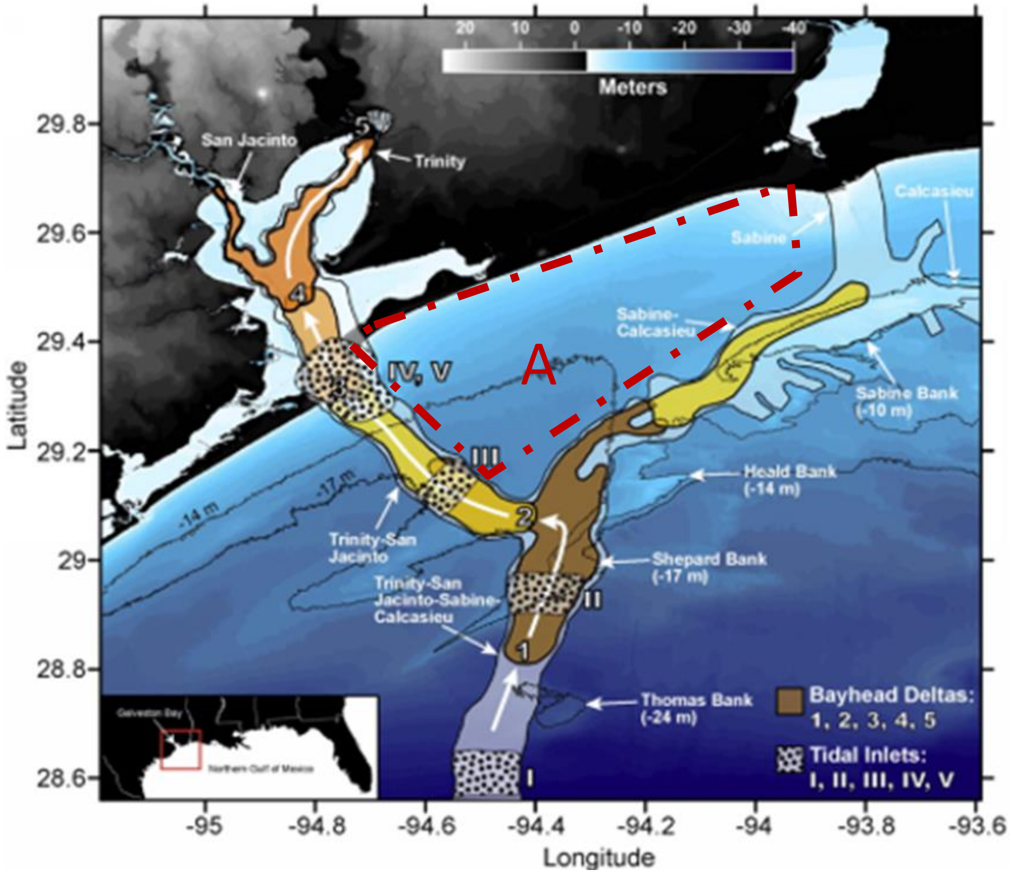


Figure 6-1, Location of the Trinity and Sabine Incised River valleys and sedimentary sequences. Also, location of the Sabine and Heald Banks (Anderson et al., 2016). A. Location of areas that may contain small paleo-streams connecting to the Paleo Sabine River (Dellapenna et al., 2009).

Table 6-1
Potential Sediment Availability Volumes and Data Gaps for the Offshore Trinity and Sabine Incised Valleys

Geologic Unit: Offshore Trinity and Sabine Incised Valleys
Location: From 10 to 50 km offshore
Areal Extent: In average >150 km long, 10 km wide
Water Depth: From 10 to 50 meters water depth
Layer Thickness: >25 meters, variable depending of the paleo environment
Sediment Characteristics: Episodic paleo river channel deposits (sand), bay head deltas (fines and sands), bays (fines), deltas (sand/mud)
Potential Volumes/Quantities: 40,000,000,000 cubic meters
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some bay and fluvial deposits. This will also require analysis of the consistency of the overburden.

Table 6-2
Potential Sediment Availability Volumes and Data Gaps for the Offshore Small Channels of the Trinity and Sabine Incised Valleys

Geologic Unit: Offshore Small Channels of the Trinity and Sabine Incised Valleys
Location: From 2 to 15 km from the beach
Areal Extent: In average >5 km long, 0.5 km wide
Water Depth: In average -5 meters (See Figure 6-1)
Layer Thickness: 5 meters depending of the paleo environment
Sediment Characteristics: Episodic paleo river channel deposits and bay head deltas
Potential Volumes/Quantities: <500,000 cubic meters depending upon the local conditions
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (gravels, sand, and fines) and compaction levels may be high for some fine fluvial deposits. This will also require analysis of the consistency of the overburden

6.1 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE COLORADO RIVER PALEO-DELTAS

Table 6-3
Potential Sediment Availability Volumes and Data Gaps for the Colorado River Paleo-Deltas

Geologic Unit: Colorado River Delta Stage 3

Location: From 10 km 60 km from the beach (*)

Areal Extent: See Figure 6-2

Water Depth: From -10 to -60 meters

Layer Thickness: Variable depending of the paleo environment

Sediment Characteristics: Episodic paleo river and delta deposits

Potential Volumes/Quantities: 21 km^3 (Anderson et al., 2016)

Compatibility for Restoration of: Marshes and barrier islands

Gaps: This is the closest paleo delta to the beach. Specific studies need to be conducted for specific targets in terms of composition (abundant sand was reported). Compaction levels may be high for some deltaic deposits. This will also require analysis of the consistency of the overburden. Some deposits may have high percent of fines. (* = High uncertainty-requires more data)

Table 6-4
Potential Sediment Availability Volumes and Data Gaps for the Colorado River Paleo-Deltas

Geologic Unit: Colorado River Delta Stage 2 to 1

Location: From 5 to 150 km from the beach on paleo incised channels (*)

Areal Extent: In average >70 km long. See Figure 6-2

Water Depth: From -10 to -120 meters

Layer Thickness: Estimated volume 21 km^3 (Anderson et al., 2016)

Sediment Characteristics: Episodic paleo river channel deposits

Potential Volumes/Quantities: 77 km^3

Compatibility for Restoration of: Marshes and barrier islands

Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (gravels, sand, and fines) and compaction levels may be high for some fine fluvial deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

Table 6-5

Potential Sediment Availability Volumes and Data Gaps for the Colorado River Paleo-Deltas

Geologic Unit: Colorado River Delta Stage 1
Location: From 3 to 50 km from the beach (*)
Areal Extent: See Figure 6-2
Water Depth: From -5 to -25 meters
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo delta and river channel deposits
Potential Volumes/Quantities: 10 km^3 (Anderson et al., 2016)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

6.2 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE BRAZOS RIVER PALEO-DELTAS

Table 6-6

Potential Sediment Availability Volumes and Data Gaps for the Brazos River Paleo-Delta.

Geologic Unit: Brazos River Delta Stage 5e to 5b
Location: From 3 to 50 km from the beach (*)
Areal Extent: Varies See Figure 6-2
Water Depth: From -50 to -120 meters
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo delta deposits
Potential Volumes/Quantities: ~ 33 km^3 (33,000,000,000 cubic meters) (Anderson et al., 2016)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic deposits. Distance may be a limitation. (* = High Uncertainty-requires more data)

Table 6-7

Potential Sediment Availability Volumes and Data Gaps for the Brazos River Paleo-Delta.

Geologic Unit: Brazos River Delta Stage 5a to 4
Location: See Figure 6-2
Areal Extent: See Figure 6-2
Water Depth: See Figure 6-2
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo delta deposits
Potential Volumes/Quantities: 27 km^3 (27,000,000 cubic meters) (Anderson et al., 2016)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (gravels, sand, and fines) and compaction levels may be high for some fine deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

Table 6-8

Potential Sediment Availability Volumes and Data Gaps for the Brazos River Paleo-Delta.

Geologic Unit: Brazos River Delta Stage 3
Location: See Figure 6-2
Areal Extent: Varies through an extensive area (See Figure 6-12)
Water Depth: 60 meters or more (*)
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo delta deposits
Potential Volumes/Quantities: 112 km^3 (112,000,000 cubic meters) (Anderson et al., 2016)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: This is a very extensive delta area. Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

Table 6-9

Potential Sediment Availability Volumes and Data Gaps for the Brazos River Paleo-Delta.

Geologic Unit: Brazos River Delta Stage 2 to 1
Location: From 10 to 50 km from the beach (*)
Areal Extent: See Figure 6-2
Water Depth: From -5 to -50 meters (*)
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo river channel, bay head deltas, and coastal deposits
Potential Volumes/Quantities: 28.6 km^3 (28,600,000 cubic meters) (Anderson et al., 2016)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic and bay deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

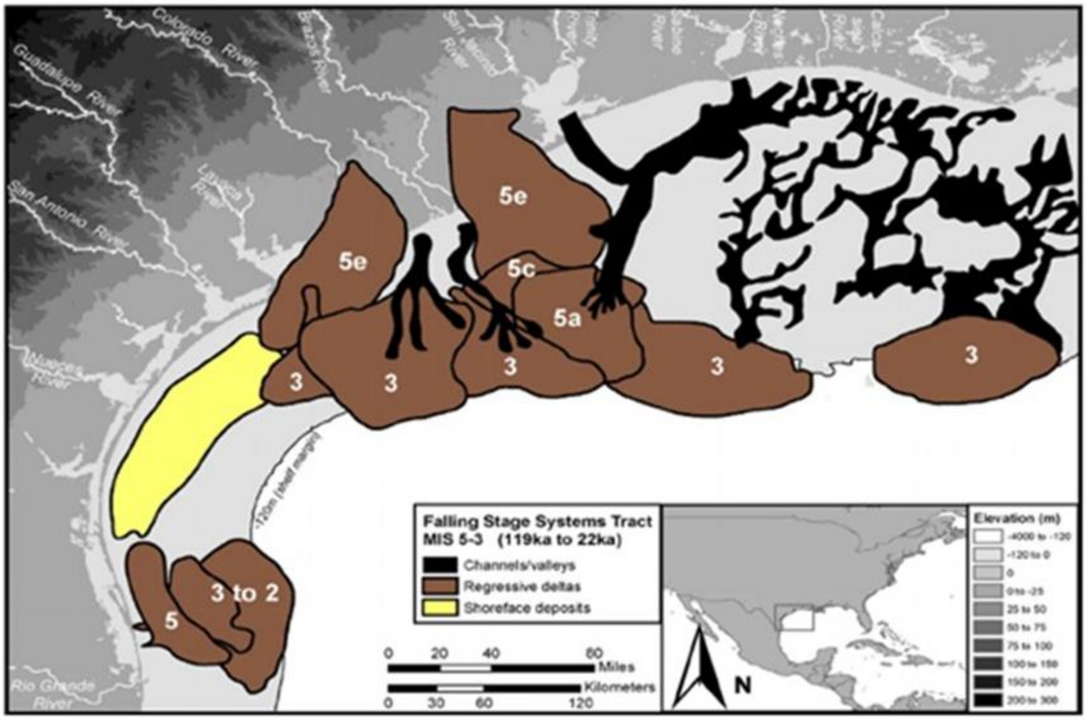


Figure 9-2, Location of the Former Deltas of the Brazos and Colorado Rivers According to the Depositional System Tracks (Anderson et al., 2016)

6.3 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE TEXAS MUD BLANKET

Table 6-10

Potential Sediment Availability Volumes and Data Gaps for the Brazos River Paleo-Delta

Geologic Unit: Texas Mud Blanket
Location: From 20 to 100 km from the beach (*)
Areal Extent: See Figure 6-3
Water Depth: From -30 to -100 meters (*)
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo river channel, bay head deltas and coastal deposits
Potential Volumes/Quantities: 1,000,000,000 cubic meters (Anderson et al., 2016)
Compatibility for Restoration of: Marshes
Gaps: The deposits consist of fines and muds. (* = High Uncertainty-requires more data)

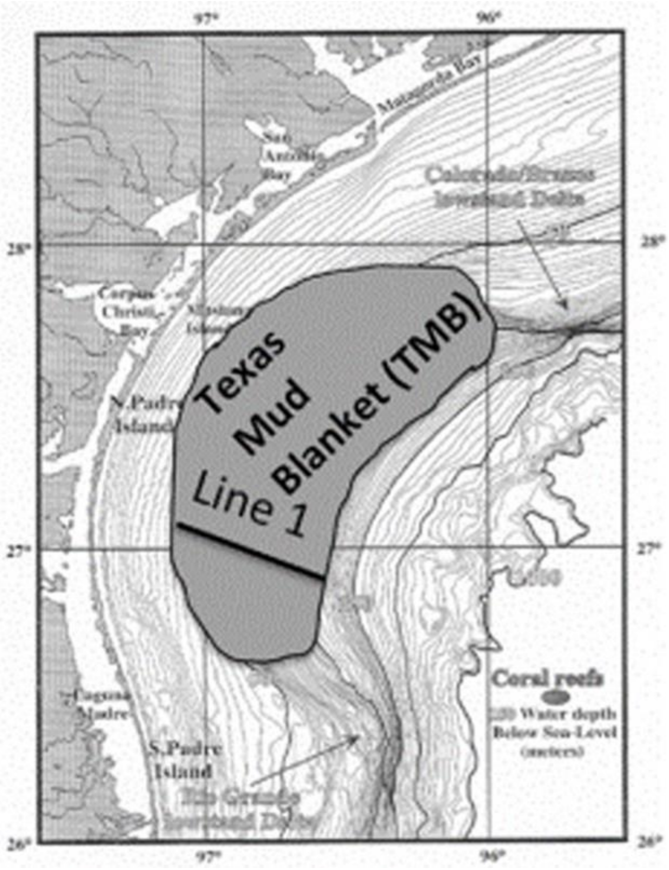


Figure 6-3, Location of the Texas Mud Blanket on the Shoreface of Central Texas (Anderson et al., 2016).

6.4 POTENTIAL SEDIMENT SOURCES CLOSE TO THE BARRIER ISLANDS

Table 6-11

Potential Sediment Availability Volumes and Data Gaps for the Sabine and Held Banks.

Geologic Unit: Sabine Bank Facies A1

Location: From 30 to 50 km from the beach (*)

Areal Extent: See Figure 6-1

Water Depth: >-10 meters (*)

Layer Thickness: ~2 meters (Variable depending of the paleo environment)

Sediment Characteristics: Former Barrier Island

Potential Volumes/Quantities: 413,000,000 cubic meters (Dellapenna, 2009)

Compatibility for Restoration of: Beaches and marshes

Gaps: The deposits consist of sandy deposits. (* = High Uncertainty-requires more data)

Table 6-12

Potential Sediment Availability Volumes and Data Gaps for the Sabine and Held Banks.

Geologic Unit: Sabine Bank Facies A1

Location: From 30 to 50 km from the beach (*)

Areal Extent: See Figure 6-1

Water Depth: >-10 meters (*)

Layer Thickness: Up to 3 meters

Sediment Characteristics: Former Barrier Island with marine deposits

Potential Volumes/Quantities: 338,000,000 cubic meters (Dellapenna, 2009)

Compatibility for Restoration of: Beaches and marshes

Gaps: The deposits consist of shells and sandy deposits. (* = High Uncertainty-requires more data)

Table 6-13

Potential Sediment Availability Volumes and Data Gaps for the Sabine and Held Banks.

Geologic Unit: Heald Bank Facies A1
Location: From 40 to 50 km from the beach (*)
Areal Extent: See Figure 6-1
Water Depth: >-14 meters (*)
Layer Thickness: ~2 meters (Variable depending of the paleo environment)
Sediment Characteristics: Former Barrier Island
Potential Volumes/Quantities: 643,000,000 cubic meters (Dellapenna, 2009)
Compatibility for Restoration of: Beaches and marshes
Gaps: The deposits consist of sandy deposits. (* = High Uncertainty-requires more data)

Table 6-14

Potential Sediment Availability Volumes and Data Gaps for the Sabine and Held Banks.

Geologic Unit: Heald Bank Facies A2
Location: From 40 to 50 km from the beach (*)
Areal Extent: See Figure 6-1
Water Depth: >-14 meters (*)
Layer Thickness: Up to 3 meters
Sediment Characteristics: Former Barrier Island with marine deposits
Potential Volumes/Quantities: 273,000,000 cubic meters (Dellapenna, 2009)
Compatibility for Restoration of: Beaches and marshes
Gaps: The deposits consist of shells and sandy deposits. (* = High Uncertainty-requires more data)

Table 6-15

Potential Sediment Volumes for Sabine and Heald Bank Facies

Geologic Unit	Potential Sediment Volume
Sabine and Heald Bank Facies A1	~777,000,000 cubic meters
Sabine and Heald Bank Facies A2	~ 661,000,000 cubic meters
Total	~1,390,000,000 cubic meters

6.5 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE SAND BARS ON THE SHOREFACE OF GALVESTON ISLAND

Table 6-16

Potential Sediment Availability Volumes and Data Gaps for the Sand Bars on the Shoreface of Galveston Island

Geologic Unit: Sand Bars on the Shoreface of Galveston Island
Location: From 2 to 12 km from the beach (*)
Areal Extent: See Figure 6-4
Water Depth: -2 to 15 meters (*)
Layer Thickness: Up to 1 meter
Sediment Characteristics: Sandy migrating bars
Potential Volumes/Quantities: 1,800,000 to 3,000,000 cubic meters (Dellapenna, 2009)
Compatibility for Restoration of: Beaches and marshes
Gaps: The deposits consist of sand migrating to deeper areas and it may content fine deposits. These deposits may be available after storms in other portions of the Texas coast. (* = High Uncertainty-requires more data)

Table 6-17

Potential Sediment Availability Volumes and Data Gaps for the Sorted Bedform Shoals of the Shoreface

Geologic Unit: Sorted Bedform Shoals of the Shoreface
Location: From 2 to 20 km from the beach (*)
Areal Extent: Variable (See Figure 6-4)
Water Depth: -2 to 15 meters (*)
Layer Thickness: Up to 1 meter
Sediment Characteristics: Sandy migrating bars
Potential Volumes/Quantities: 180,000 cubic meters (Dellapenna and Johnson, 2012)
Compatibility for Restoration of: Beaches and marshes
Gaps: The deposits consist of sand migrating to deeper areas and it may content fine deposits. These deposits may be available after storms in other portions of the Texas coast. They exist in the east side of the Gulf of Mexico and the coast of North Carolina. (* = High Uncertainty-requires more data)

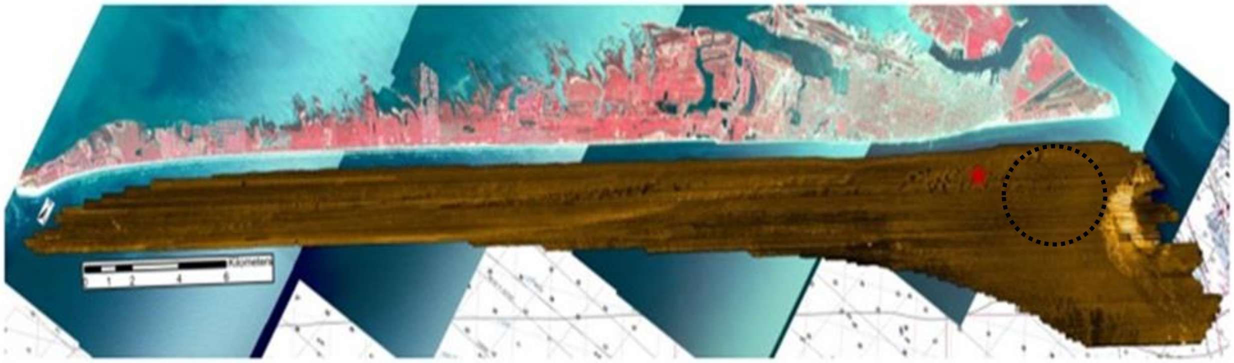


Figure 6-4, Potential Sediment Availability Volumes and Data Gaps for the Sand Bars on the Shoreface of Galveston Island. A. Migrating sand bars after storms (Dellapenna et al., 2009). B. Sorted bedform shoals identified by Dellapenna and Johnson (2012).

6.6 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE TRINITY RIVER INCISED VALLEY IN GALVESTON BAY

Table 6-18
Potential Sediment Availability Volumes and Data Gaps for the Trinity River Incised Valley in Galveston Bay

Geologic Unit: Trinity River Incised Valley Stage in Galveston Bay
Location: Galveston Bay (*)
Areal Extent: See Figure 6-5
Water Depth: From -5 to -30 meters (*)
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo river channel, bay head deltas and coastal deposits
Potential Volumes/Quantities: 3,00,000,000 cubic meters from paleo topographic maps
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic and bay deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

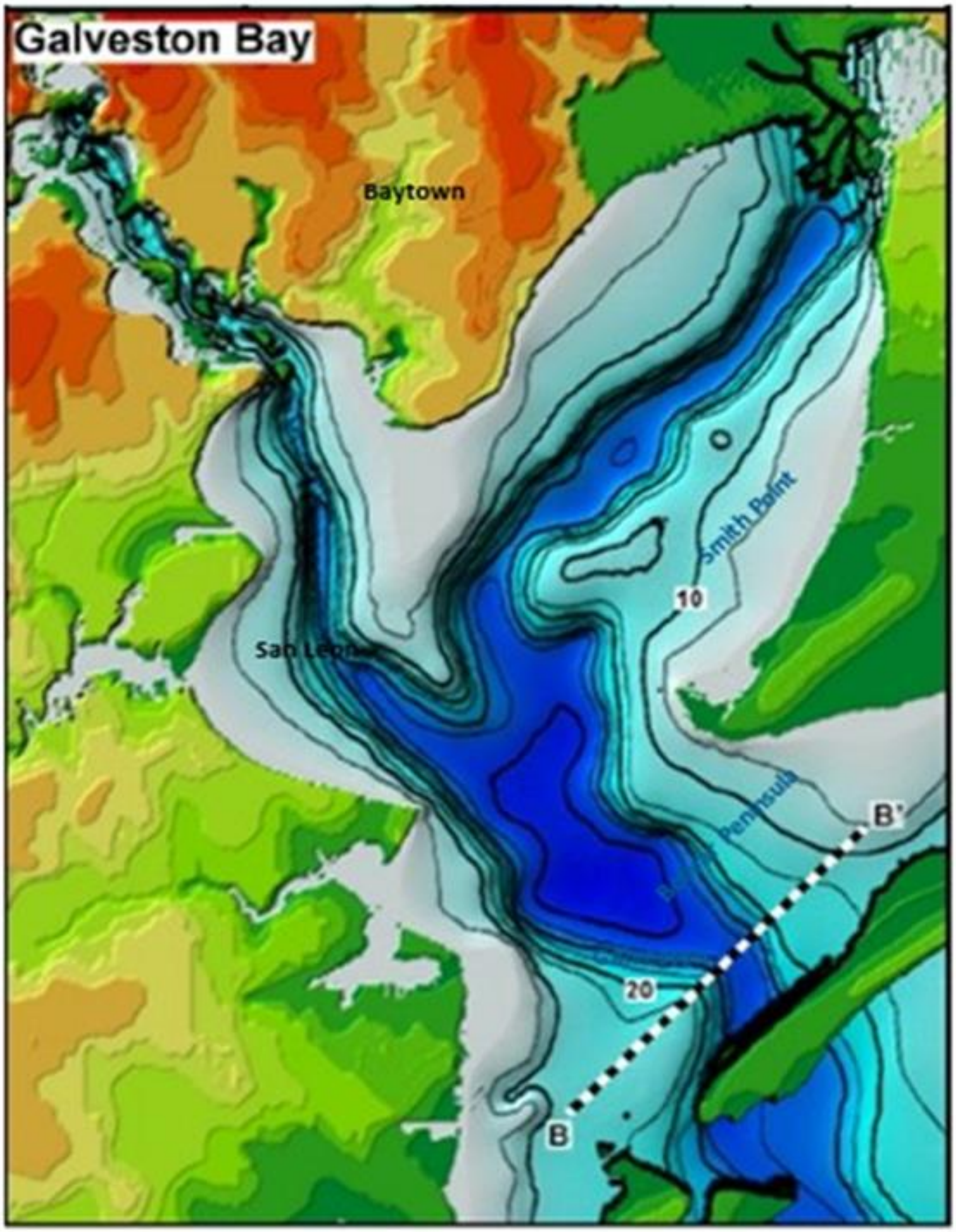


Figure 6-5, Paleo-topography of the Paleo Trinity and San Jacinto Rivers Incised Valleys below Galveston Bay. The former valley was filled as response to sea level rise (Anderson et al., 2016).

6.7 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE OLD GALVESTON BAY TIDAL DELTA

Table 6-19

Potential Sediment Availability Volumes and Data Gaps for the Old Galveston Bay Tidal Delta

Geologic Unit: East Bay Old Galveston Bay Tidal Delta
Location: Galveston Bay
Areal Extent: See Figure 6-6
Water Depth: From -3 to -10 meters (*)
Layer Thickness: Up to 10 meters (*)
Sediment Characteristics: Sandy flood delta deposits
Potential Volumes/Quantities: 400,000,000 cubic meters (Dellapenna pers. comm.)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: These deposits consist of sand coming from the former inlet. These deposits may content fines and shell layers. Specific surveys may be required for specific targets. (* = High Uncertainty-requires more data)

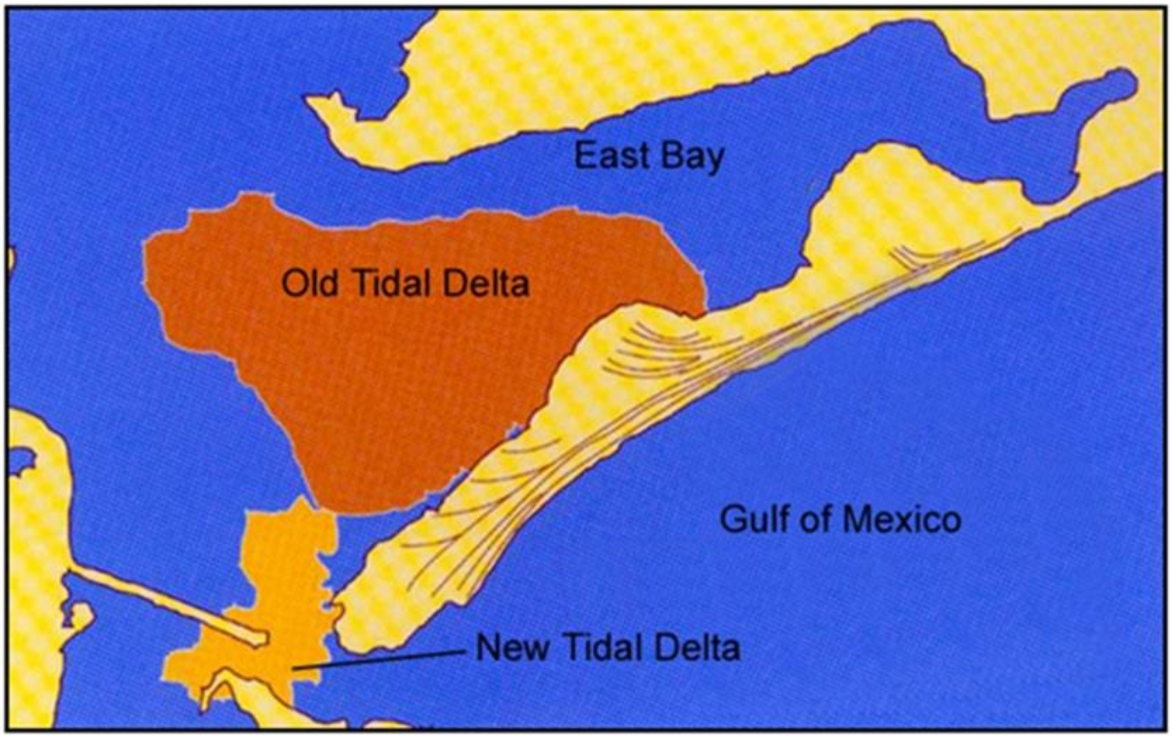


Figure 6-6, Location of the Old and New Galveston Bay Tidal Deltas on East Galveston Bay (Anderson 2007).

6.8 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR WEST GALVESTON BAY

Table 6-20
Potential Sediment Availability Volumes and Data Gaps for West Galveston Bay

Geologic Unit	Volumes in Cubic Meters	Volumes in Cubic Yards
1. San Luis Pass Flood Delta	1,500,000	1,962,000
4. West of West Basin	4,800,000	6,278,000
5a. Galveston Island West Basin	660,000	863,247
5b. Galveston Island West Basin	960,000	1,255,632
5c. Galveston Island West Basin	840,000	1,098,678
6a. Galveston Island East Basin	720,000	941,724
6b. Galveston Island East Basin	1,800,000	2,354,000
6c. Galveston Island East Basin	792,000	1,036,000
7. Central Portion of WGB West Basin	5,500,000	7,000,000
Total	17,572,000	22,789,281

Data Gaps: These areas were already tested. Some deposits may have some percent of fines or shells.

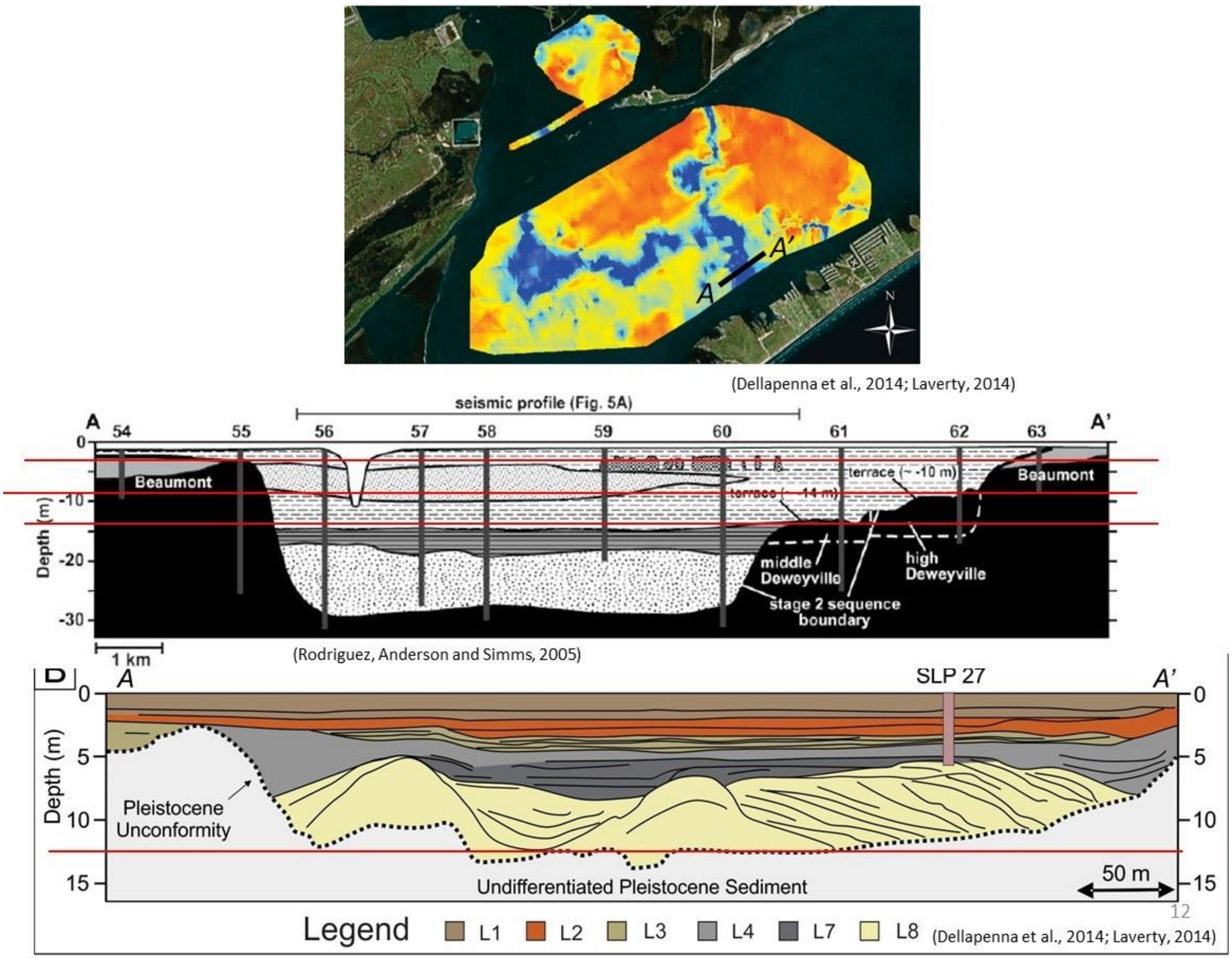
Figure 6-7, Areas with Tested Sediment Availability Volumes in West Galveston Bay (Moya et al., 2012)

6.9 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE INCISED PALEO VALLEY IN WEST GALVESTON BAY

Table 6-21

Potential Sediment Availability Volumes and Data Gaps for the Incised Paleo Valley in West Galveston Bay

Geologic Unit: Incised Paleo Valleys in West Galveston Bay
Location: West Galveston Bay (*) **Areal Extent:** See Figure 6-8 **Water Depth:** From -3 to -25 meters (*) **Layer Thickness:** Variable depending of the paleo environment **Sediment Characteristics:** Episodic paleo river channel, bay head deltas and coastal deposits **Potential Volumes/Quantities:** 639,000,000 cubic meters (Dellapenna pers. Comm.) **Compatibility for Restoration of:** Marshes and barrier islands **Gaps:** Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic and bay deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)



(Dellapenna et al., 2014; Laverty, 2014)

(Rodriguez, Anderson and Simms, 2005)

(Dellapenna et al., 2014; Laverty, 2014)

Figure 6-8, Location of the Incised Paleo Valley in West Galveston Bay (Dellapenna, 2014).

6.10 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE INCISED PALEO VALLEY IN MATAGORDA BAY

Table 6-22
Potential Sediment Availability Volumes and Data Gaps for the Incised Paleo Valley in Matagorda Bay

Geologic Unit: Incised Paleo Valleys in Matagorda Bay
Location: Matagorda Bay
Areal Extent: See Figure 6-9
Water Depth: From -3 to -25 meters (*)
Layer Thickness: Variable depending of the paleo environment
Sediment Characteristics: Episodic paleo river channel, bay head deltas and coastal deposits
Potential Volumes/Quantities: 30,00,000,000 cubic meters from paleo topographic maps
Compatibility for Restoration of: Marshes and barrier islands
Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic and bay deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

6.11 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE SUNDOWN ISLAND NORTH BANK

Table 6-23
Potential Sediment Availability Volumes and Data Gaps for Sundown Island North Bank

Geologic Unit: Sundown Island North Bank
Location: Matagorda Bay
Areal Extent: See Figure 6-9
Water Depth: From -0.3 to -3 meters (*)
Layer Thickness: Up to 5 meters (*)
Sediment Characteristics: Sandy flood delta deposits
Potential Volumes/Quantities: ~5,000,000,000 cubic meters from historic maps
Compatibility for Restoration of: Marshes and barrier islands
Gaps: These deposits consist of sand coming from the inlet. These deposits may content fines and shell layers. Specific surveys may be required for specific targets. (* = High Uncertainty-requires more data)

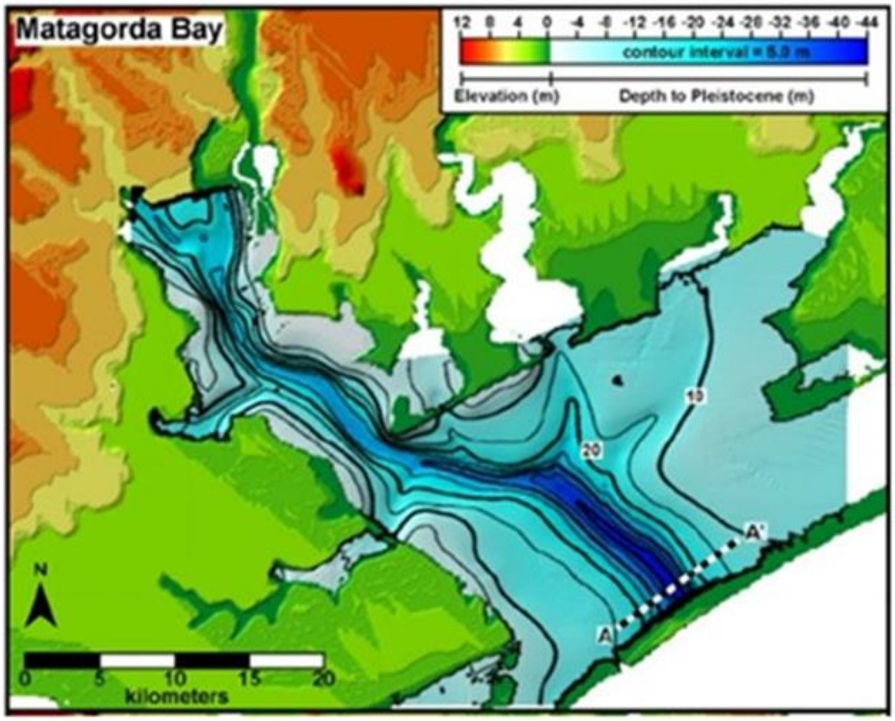


Figure 6-9, Paleo-topography of the Paleo Lavaca River Incised Valley Below Lavaca and Matagorda Bays. The former valley was filled as response to sea level rise (Anderson et al., 2016).

Figure 6-10, Location of the New Sand Bank on the North-Northwestern Side of Sundown Island.

6.12 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE INCISED PALEO VALLEY IN CORPUS CHRISTI BAY

Table 6-24

Potential Sediment Availability Volumes and Data Gaps for the Incised Paleo Valley in Corpus Christi Bay

Geologic Unit: Incised Paleo Valleys in Corpus Christi Bay

Location: Corpus Christi Matagorda Bay

Areal Extent: See Figure 6-11

Water Depth: From -3 to -25 meters (*)

Layer Thickness: Variable depending of the paleo environment

Sediment Characteristics: Episodic paleo river channel, bay head deltas and coastal deposits

Potential Volumes/Quantities: 1,875,00,000,000 cubic meters from paleo topographic maps

Compatibility for Restoration of: Marshes and barrier islands

Gaps: Specific studies need to be conducted for specific targets in terms of composition due to the presence of mixed sediments (sand and fines) and compaction levels may be high for some fine deltaic and bay deposits. This will also require analysis of the consistency of the overburden (* = High Uncertainty-requires more data)

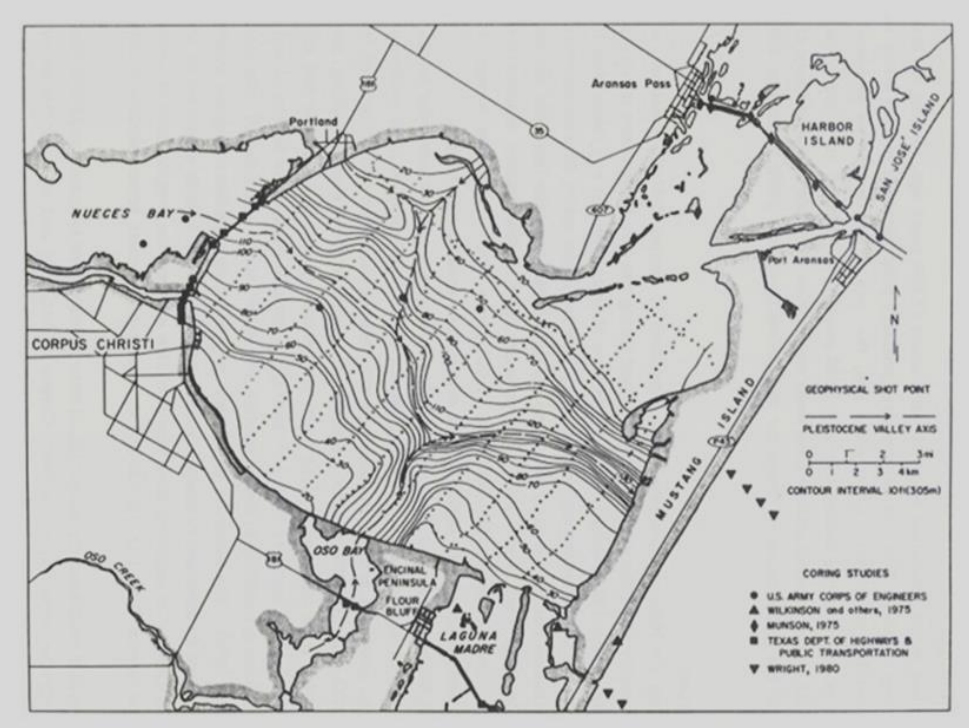


Figure 6-11, Paleo-topography of the Nueces River Incised Valley below Corpus Christi Bay. The former valley was filled as response to sea level rise (after Morton and Payne, 1984).

6.13 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE SAN LUIS PASS FLOOD DELTA

Table 6-25

Potential Sediment Availability Volumes and Data Gaps for the San Luis Pass Flood Delta

Geologic Unit: San Luis Pass Flood Delta

Location: West Galveston Bay

Areal Extent: ~3 km x 5 km

Water Depth: From -0.3 to -3 meters

Layer Thickness: Up to 5 meters

Sediment Characteristics: Sandy flood delta deposits

Potential Volumes/Quantities: ~1,500,000 cubic meters from historic maps on the distal area

Compatibility for Restoration of: Marshes and barrier islands

Gaps: These deposits consist of sand coming from the inlet. These deposits may content fines and shell layers. Specific surveys may be required for specific targets. (? = High Uncertainty-requires more data)

San Luis Pass Flood Delta (Total): ~9,000,000 cubic meters

Note: No image is provided for the San Luis Pass since the area may change in the future modifying the volumes estimated.

6.14 POTENTIAL SEDIMENT AVAILABILITY VOLUMES AND DATA GAPS FOR THE BOLIVAR ROADS AREA

Table 6-26

Potential Sediment Availability Volumes and Data Gaps for the Bolivar Roads South Side of the North Jetty

Geologic Unit: Bolivar Roads South Side of the North Jetty

Location: Bolivar Roads North Jetty

Areal Extent: See Figure 6-12

Water Depth: From -1 to -8 meters

Layer Thickness: Up to 8 meters

Sediment Characteristics: Sands trapped by the jetty

Potential Volumes/Quantities: ~3,000,000 cubic meters (Dellapenna et al., 2006)

Compatibility for Restoration of: Marshes and barrier islands

Gaps: These deposits consist of sands connected to the inlet. These deposits may content fines. Specific surveys may be required for specific targets. (* = High Uncertainty-requires more data)

Table 6-27

Potential Sediment Availability Volumes and Data Gaps for the Bolivar Roads North Side of the North Jetty

Geologic Unit: Bolivar Roads North Side of the North Jetty
Location: Bolivar Roads North Jetty
Areal Extent: See Figure 6-12
Water Depth: From -1 to -8 meters
Layer Thickness: Up to 8 meters
Sediment Characteristics: Sands trapped by the jetty
Potential Volumes/Quantities: ~2,250,000 cubic meters (Dellapenna et al., 2006)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: These deposits consist of Gulf longshore sand trapped by the jetty. These deposits may content fines. Specific surveys may be required for specific targets. (* = High Uncertainty-requires more data)

Table 6-28

Potential Sediment Availability Volumes and Data Gaps for Big Reef

Geologic Unit: Bolivar Roads South Side of the North Jetty
Location: Bolivar Roads South Jetty
Areal Extent: See Figure 6-12
Water Depth: From -1 to -8 meters
Layer Thickness: Up to 8 meters
Sediment Characteristics: Sands accumulated by the eddy created by the South Jetty
Potential Volumes/Quantities: ~6,880,993 cubic meters (Dellapenna et al., 2006)
Compatibility for Restoration of: Marshes and barrier islands
Gaps: These deposits consist of Gulf sands trapped by the eddy in the jetty. These deposits may content fines. Specific surveys may be required for specific targets. These deposits should be accumulating at the rated of ~188,845 cubic meters per year (Frey et al., 2016). (* = High Uncertainty-requires more data)

Table 6-29

Potential Sediment Availability Volumes and Data Gaps for the USACE Offshore Disposal Area No. 1

Geologic Unit: Bolivar Roads South Side of the North Jetty

Location: 3-10 miles offshore the Bolivar Roads South Jetty

Areal Extent: See Figure 6-12

Water Depth: From -1 to -10 meters

Layer Thickness: Unknown

Sediment Characteristics: Disposal sediment accumulated from dredging projects

Potential Volumes/Quantities: More than 6,000,993 cubic meters (Dellapenna pers. comm.)

Compatibility for Restoration of: Marshes and barrier islands

Gaps: These deposits consist of mixed sediments coming from dredging projects. Sands is available separated by the Gulf of Mexico energies. (* = High Uncertainty- requires more data)

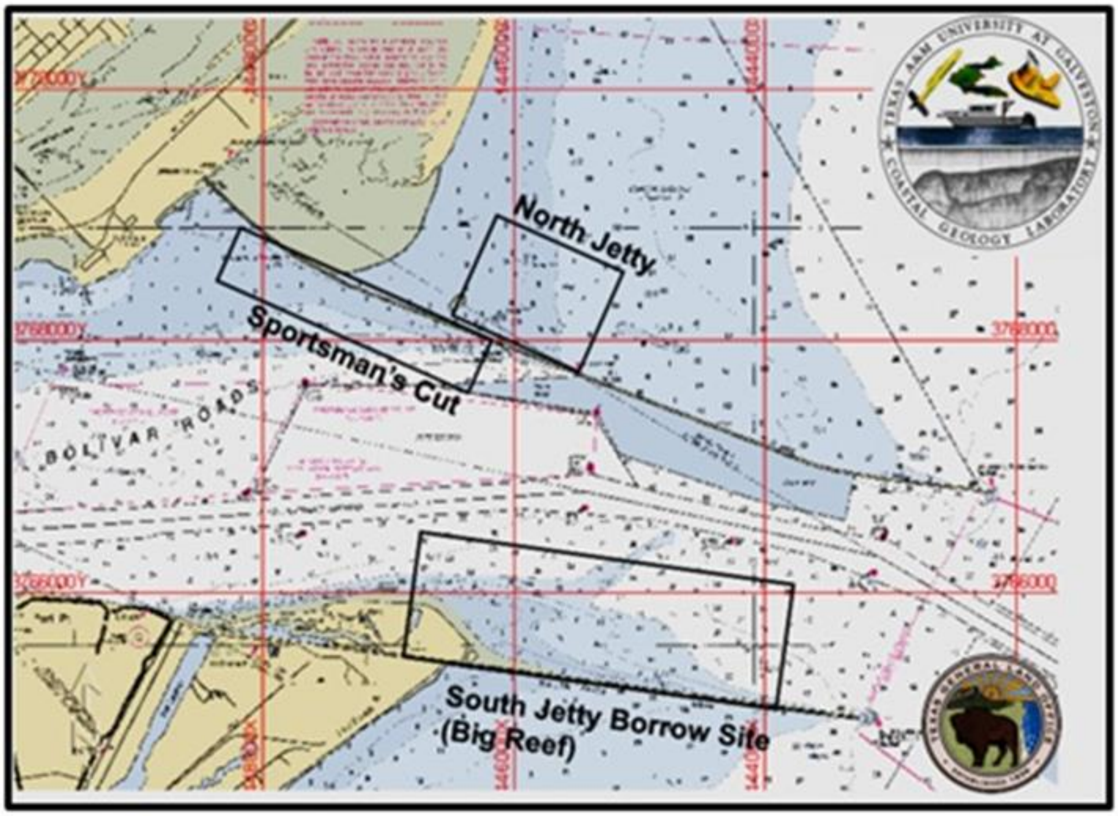


Figure 6-12, Location of the Areas Searched for Sediment Availability for the Bolivar Roads Area, Including the North and South jetties.

7.0 MODERN TEXAS INLETS AND SEDIMENTS

7.1 THE SEDIMENT DYNAMICS OF TEXAS UPPER COAST INLETS

The accumulation of sediment connected to the Texas Upper coast inlets can be considered a potential source of sediment under specific circumstances. The main challenge is that short- and long-term changes in energy, morphodynamics and sedimentation can make the inlet processes unpredictable. The use of sediments connected to the inlets will require approaches and analysis that consider habitats and infrastructure interacting with them considering that Gulf and bay changes can influence inlets.

7.2 SAN LUIS PASS

The San Luis Pass Inlet is one of the few remaining natural Texas inlets with no direct human modifications (at least not hard structures nearby). In the long-term Wallace et al., (2010) was able to quantify through the last centuries sediment rates at the flood delta. The method used the base of the flood delta, and compared the sedimentation rate using radiocarbon dates and then estimated the accumulation rate since its formation to the present. It was estimated that about 10,000 cubic meters (7,645 cubic yards) per year of sediment get deposited into the flood delta.

Using different methodologies Morang (2006) and CHE (2007) concluded that the fastest accumulation rate at the flood delta has occurred recently. In the short-term, the inlet flood delta appears to be accreting at a rate of about 76,455 cubic meters (about 100,000 cubic yards), which with this estimated rate, the flood delta would be the major source of sand coming to the west side of West Galveston Bay (Moya et al., 2012). The data suggest that the sand accumulating in the flood shoal delta started to grow at its fastest rates, at least, in the last 50-80 years as identified by Gibeaut et al., (2003b); Morang (2006) and CHE (2007).

The growth of the flood shoal delta has been toward the north and is getting larger over time (CHE 2007). The flood delta area covers a minimum area of approximately 13 square kilometers, including the mouth of the inlet and the shoals (Moya et al., 2012). Sediment cores available through several studies show that the flood delta area has grain size values close to 100 percent sand (CHE, 2007; Wallace et al.,2010; Moya et al., 2012). The San Luis Pass flood delta sediment volumes were estimated in a minimum of 1,500,056 cubic meters (1,962,000 cubic yards by 2012) on the distal area and a total of 9,021,747 cubic meters (11,800,000 million cubic yards) on the entire delta (Israel et al., 1987; Wallace et al., 2010).

The evolution of the flood delta as manifested in its geomorphologic changes, between 1995 and 2010, suggests that the distal area is the one that will tend to change faster due to new sediment accumulation. Moya et al., (2012) suggested that dredging of the west flood delta may cause impacts to the shorelines of Mud Island. Dredging the east side of the flood delta on the area that has accreted close to the bay shorelines of Galveston Island can be also problematic. The new shoals are becoming part of the island, creating a new zone of shallow flats on the southern tip of the island. It appears that the distal area on the north side would be the best area if sediment from the delta is consider for restoration.

On the Gulf side, the dimensions and morphology of the San Luis ebb delta have also changed with time (Morang, 2006; CHE, 2007). In general, the Gulf shorelines have significant rates of retreat (dry and submerge shorelines) and that include modifications to the submerged Gulf ebb deltas. Based on the dynamics of natural ebb deltas this report does not recommend to use sediment sources from the ebb deltas on natural inlets for coastal projects. Ebb deltas may have better sediment management options at smaller scales.

Table 7-1
San Luis Pass Flood Delta Data

Geologic Sedimentary Unit	Potential Sediment Volume
San Luis Pass Flood Delta (Distal Area)	~1,500,056 cubic meters on the distal area
San Luis Pass Flood Delta (Total)	~9,021,747 cubic meters total
San Luis Pass Flood Delta (Yearly Rate)	~76,455 cubic meters per year

7.3 THE BOLIVAR ROADS JETTIES

For the Bolivar Roads area, the inlet is controlled by jetties and maintenance dredging making the analysis of sedimentary processes a complex task. Due to the importance of these jetties for the Texas (and international) maritime industry, there is a diverse set of studies connected to sediment transport and sediment management of the Bolivar Roads jetties, also called the north jetty and the south jetty. Sediment transport studies on these jetties and on the north tip of Galveston island have analyzed the sediment transport processes through the definition of sediment cells or by the identification of geomorphic units (Morang, 2006; Moffat and Nichols, 2010, Moya, et al., 2012; and Frey et al., 2016). These studies had the purpose of quantifying the volumes of sediment that moves on the littoral and inlet system and the bay shorelines.

Other studies have focused on the Galveston Island effects of the jetties on the local sediment circulation and their impact on the beaches and the seawall on the island. Since beach nourishment has been important for the Galveston Island economy, the studies included sediment source investigations on the island shoreface and beach performance before and after beach replenishment events (Giardino et al., 1987; CP&E, 1993; USACE, 1993; Anderson et al., 1994; Brown and Kraus. 1994; Giardino, et al.,2000; Anderson and Wellner, 2002; Dellapenna et al., 2006; Dellapenna and Johnson, 2010; Williams et al.,2012).

More specifically, sediment transport models have documented the events and processes affecting the morphological configuration of the beach-coastal system (Morton, 1974; Hall, 1975; Morton, 1977; CP&E, 1993; Siringan and Anderson, 1994; Gibeaut et al., 2002; Gibeaut et al., 2003; Morang, 2006; Coast & Harbor Engineering, 2007; King, 2007; Wallace et al., 2010). These studies have differentiated the natural and man-made changes in the general geomorphology and how these changes have occurred in the short- and long-term.

Very important has been the analysis associated with storm impacts. During and after storms, studies have identified the sedimentation changes and the recovery of the coastal system next to the inlets, Galveston beaches and beach profiles in front of the Galveston sea wall (Goff et al., 2010; Dellapenna and Johnson, 2012; Hawkes and Horton, 2012). Finally, sediment and geotechnical testing funded by the Texas General Land Office has been conducted in several areas next to the jetties (Figure 7-1) trying to quantify the qualities and quantities available as part of the sediments trapped by interrupted sediment littoral processes.

With these datasets, a simple inventory of sediment availability can be proposed for planning purposes related to sediment management options connected to the inlet and the jetties. An early inventory of sediment sources for beach nourishment purposes was developed in 1993 (CP&E, 1993), identifying the most important sediment sources close to the jetties (Figure 7-1). Four areas were identified as important sediment sources connected to the jetties: North of the North Jetty, Big Reef, South of the South Jetty and the USACE offshore dredge material placement area (Figure 7-1). Recently, the south portion of the North Jetty was incorporated by the Texas General Land Office (Figure 7-2).

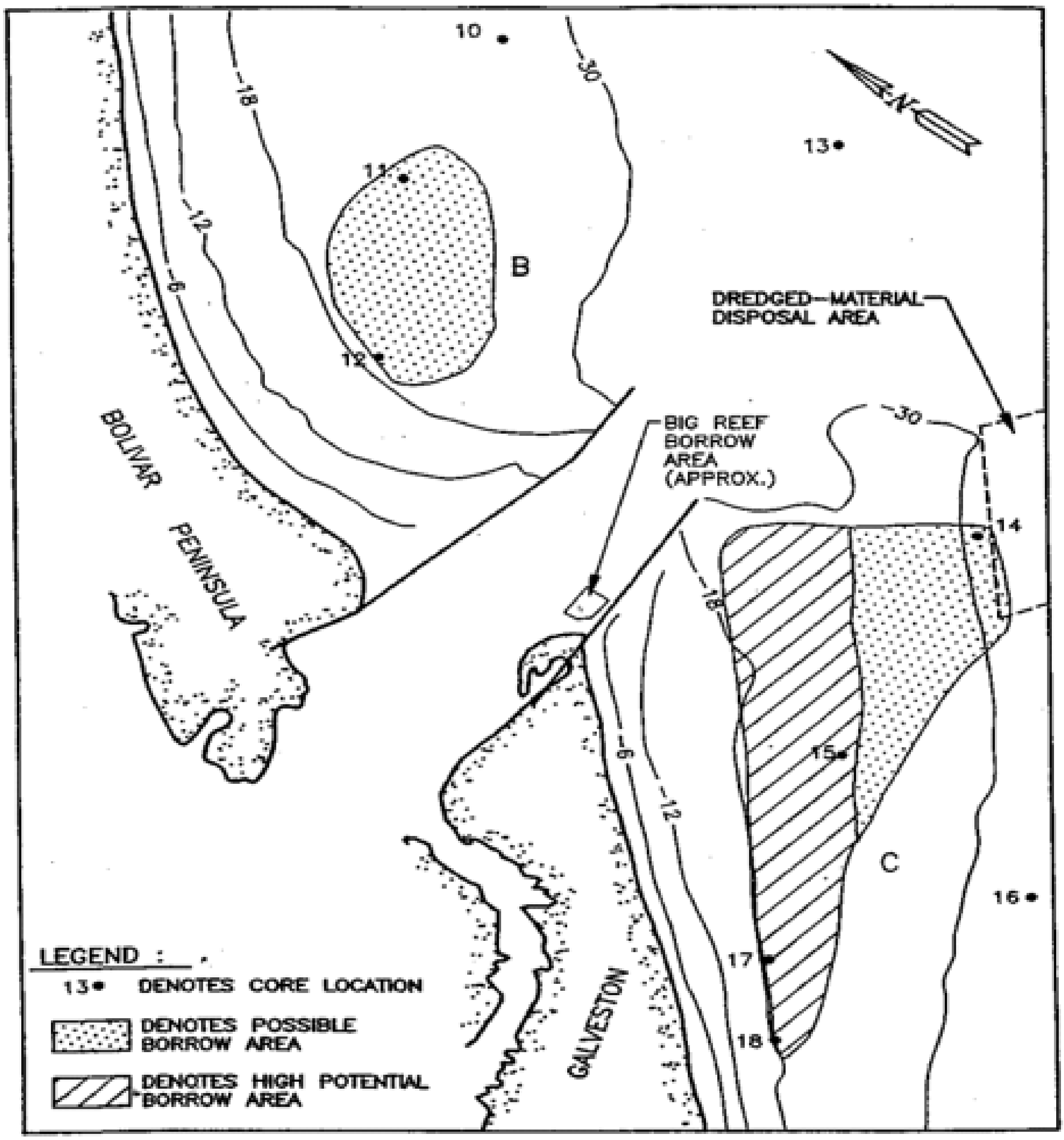


Figure 7-1, Potential Offshore Borrow Sites in Galveston Jetties Area (Source: CP&E, 1993)

7.3.1 The North Jetty

Sediment investigations have tested the qualities and quantities of sediment available on the north side of the jetty (Dellapenna et al., 2006; HDR, 2009) Figure 7-2. The tested areas included the south side (ship channel) and north side (Gulf on Bolivar) of the north jetty. For the ship channel side of the north jetty, also known as the "Anchored Area" or "Fisherman Cut", two investigations cored and analyzed the amount of beach quality sand available Figures 7-2 and 7-3. The first survey (HDR, 2009) collected close to 30 vibro cores showing feasible sandy sediments with a volume up to 2,446,575 cubic meters (3,200,000 cubic yards). If sediment is considered for coastal projects, the potential limitations proposed by the study is to prevent exceeding the authorized depth of the deep draft Anchorage Area to the east.

Using a similar approach, Dellapenna et al., (2006) identified ~3,900,000 million cubic meters (5,101,000 cubic yards) of sediment based on the dimensions of an area off 2000 m (long) x 750m (wide) x 2m (depth). The study found that the sand available at this area is a little coarser than the mean beach sand diameters on Bolivar beaches. Both studies (HDR, 2009 and Dellapenna et al., 2006) identified at least 3,000,000 cubic meters (3,900,000 cubic yards) of good quality sediments for coastal projects.

Table 7-2
South Side of the North Jetty Data

Geologic Sedimentary Unit	Potential Sediment Volume
South Side of the North Jetty	~3,000,000 cubic meters

7.3.2 The North Side of the North Jetty

Since the construction of the North Jetty in 1874, the Bolivar Peninsula started to accumulate littoral sediments moving south through longshore process on Bolivar Peninsula. At least 2.2 km (1.5 miles) of Gulf shoreline sandy accumulation occurred since the construction of the jetty considering the former shorelines of Port Bolivar on the Gulf side to the present shorelines. These accumulated areas show new large areas of marshes, dunes, and aquatic habitats.

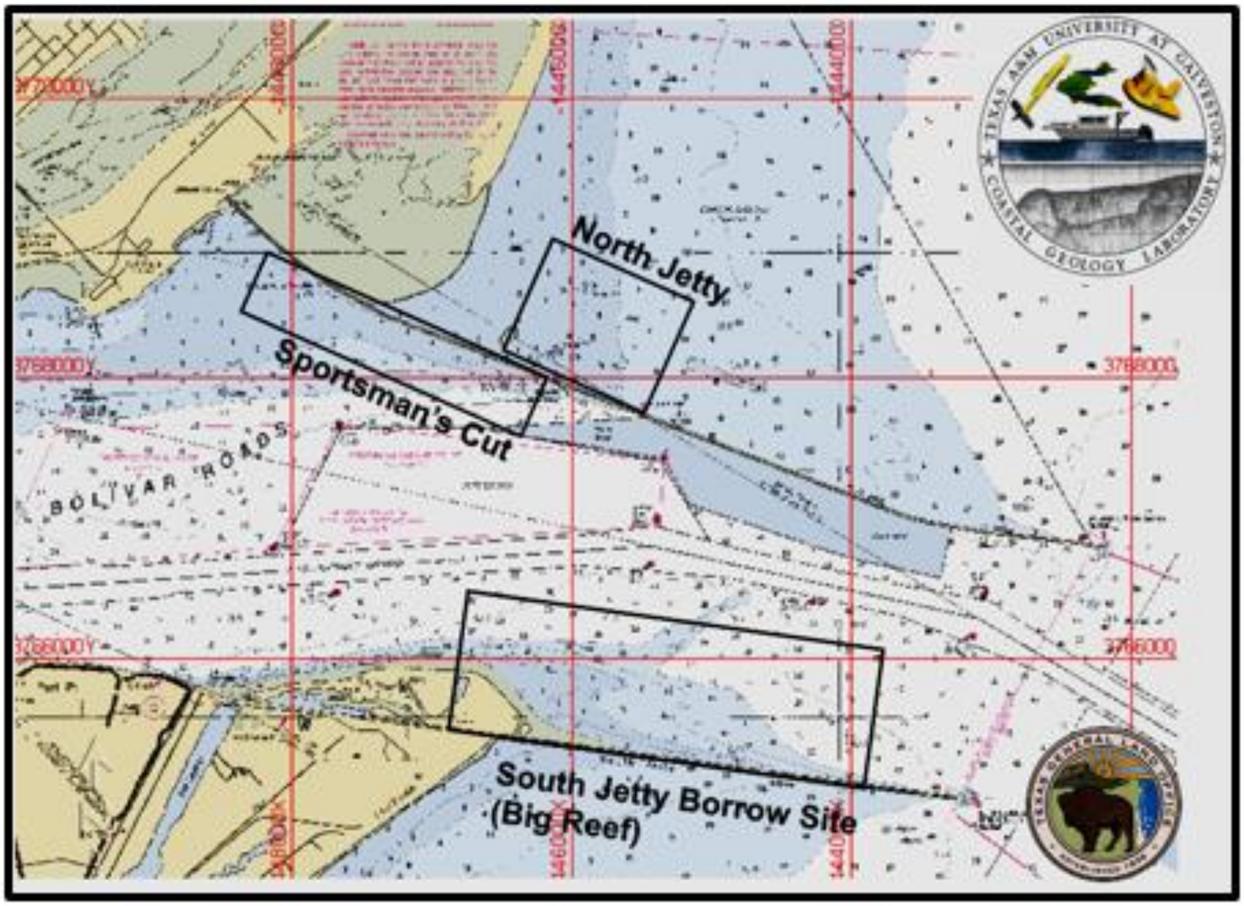


Figure 7-2, Location of Areas Tested for Sediment Investigations by the Texas General Land Office (Dellapenna et al., 2006)

Offshore sand investigations conducted by Dellapenna et al., (2006) collected 11 cores on the north side of the north jetty (Gulf side) and measured about 2,250,000 cubic meters (3,000,000 cubic yards) in an area of 1500m x 1500m x 0.5 x 2m. About 2,250,000 cubic meters (3,000,000 cubic yards) of sandy deposits should represent the minimum amount of sediment available offshore the Bolivar Peninsula on the north side of the jetty but more investigations should be conducted for potential deposits migrating to the Gulf.

Table 7-3
North Side of the North Jetty Data

Geologic Sedimentary Unit	Potential Sediment Volume
North Side of the North Jetty	~2,250,000 cubic meters (minimum)

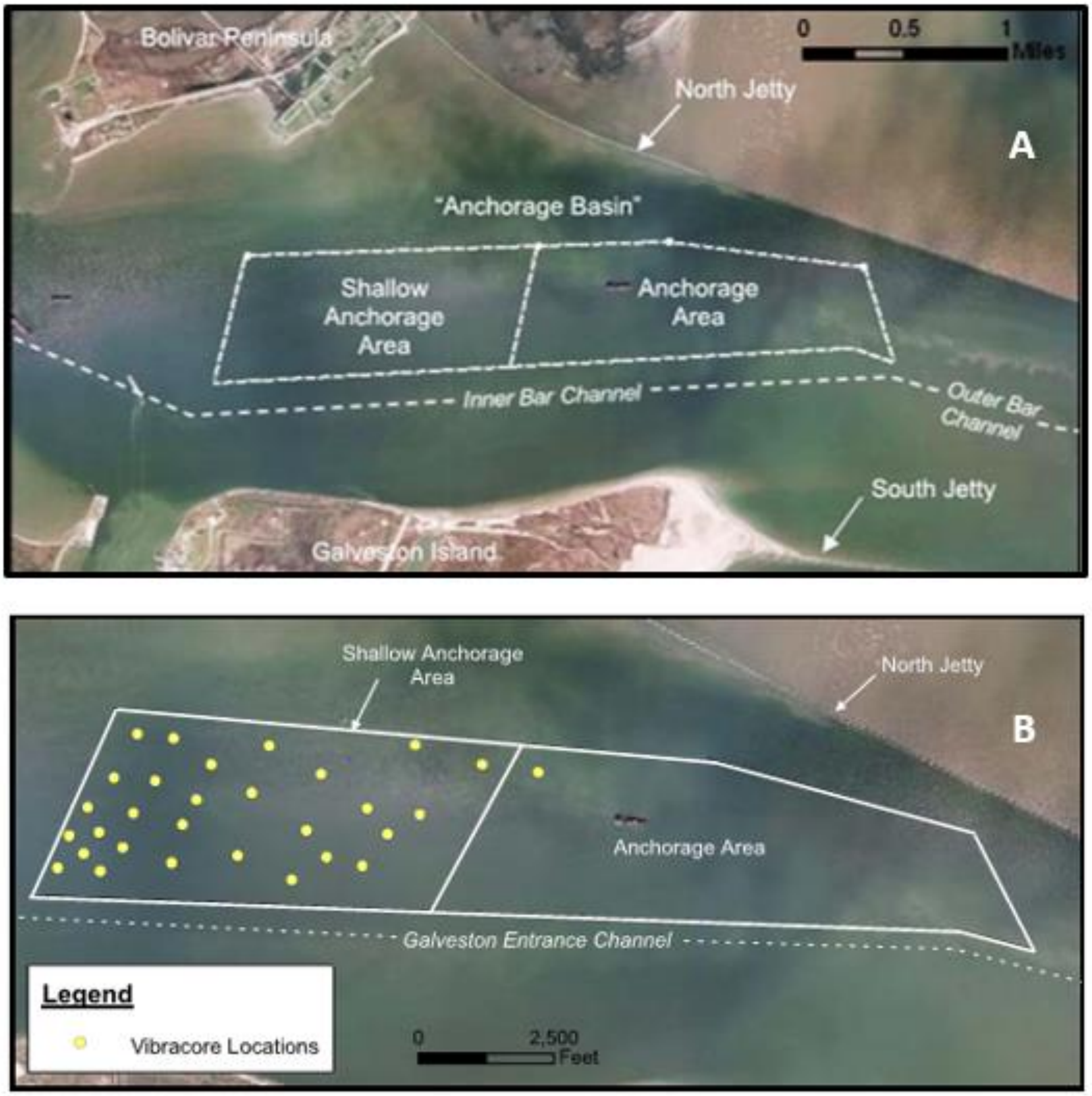


Figure 7-3, Location of Areas Tested for Sediment Analysis on the South of the North Jetty in Shallow Anchorage Area (HDR, 2009)

7.3.3 South Jetty

Just as the north jetty, the south jetty can be divided into the north side and the south side of the South Jetty.

7.3.3.1 North Side of the South Jetty: Big Reef

A dynamic sand bank located on the north side of the south jetty is called Big Reef (Figures 7-1, 7-2 and 7-4). The reef is considered an area of recycled sediment connected to the circulation and sediment cells on East Beach and the dynamics of the South Jetty (Frey et al., 2016). Big Reef accumulates sands that come from a circulation eddy created in front of the East Beach (Gulf side) where sediments get over washed at the tip of the island and then get carried to the ship channel by aeolian processes or storm surges to build a large sand spit. Once deposited, the sand bank tends to migrate to the Gulf as observed in Figure 7-4 (HDR, 2008).

Dellapenna et al., (2006) identified up to 6,880,993 cubic meters (9,000,000 cubic yards) of sediments available based on the potential boundary of the Pleistocene. Frey et al., (2016) suggested that sand movement coming from the Gulf through the south jetty into the inner and outer ship Houston ship channel temporarily storages sands on Big Reef at a rate of ~188,845 cubic meters (about 247,000 cubic yards) of sandy deposits per year. The changes in the reef morphology suggest that the rates change during storms.

The historical morphology also suggests that some sand returns to the ship channel and then gets trapped within the intertidal circulation processes of the inlet. The important aspect of Big Reef is that it can be considered an area that provides recycled sedimentation that can be a constant and dynamic source of sandy sediments. More information is needed to analyze how much sediment stays at East Beach and how much moves as longshore sediment to the west on Galveston Island.

Table 7-4
Big Reef Data

Geologic Sedimentary Unit	Potential Sediment Volume
Big Reef	~6,880,993 cubic meters (maximum)
Big Reef	~188,845 cubic meters (per year)

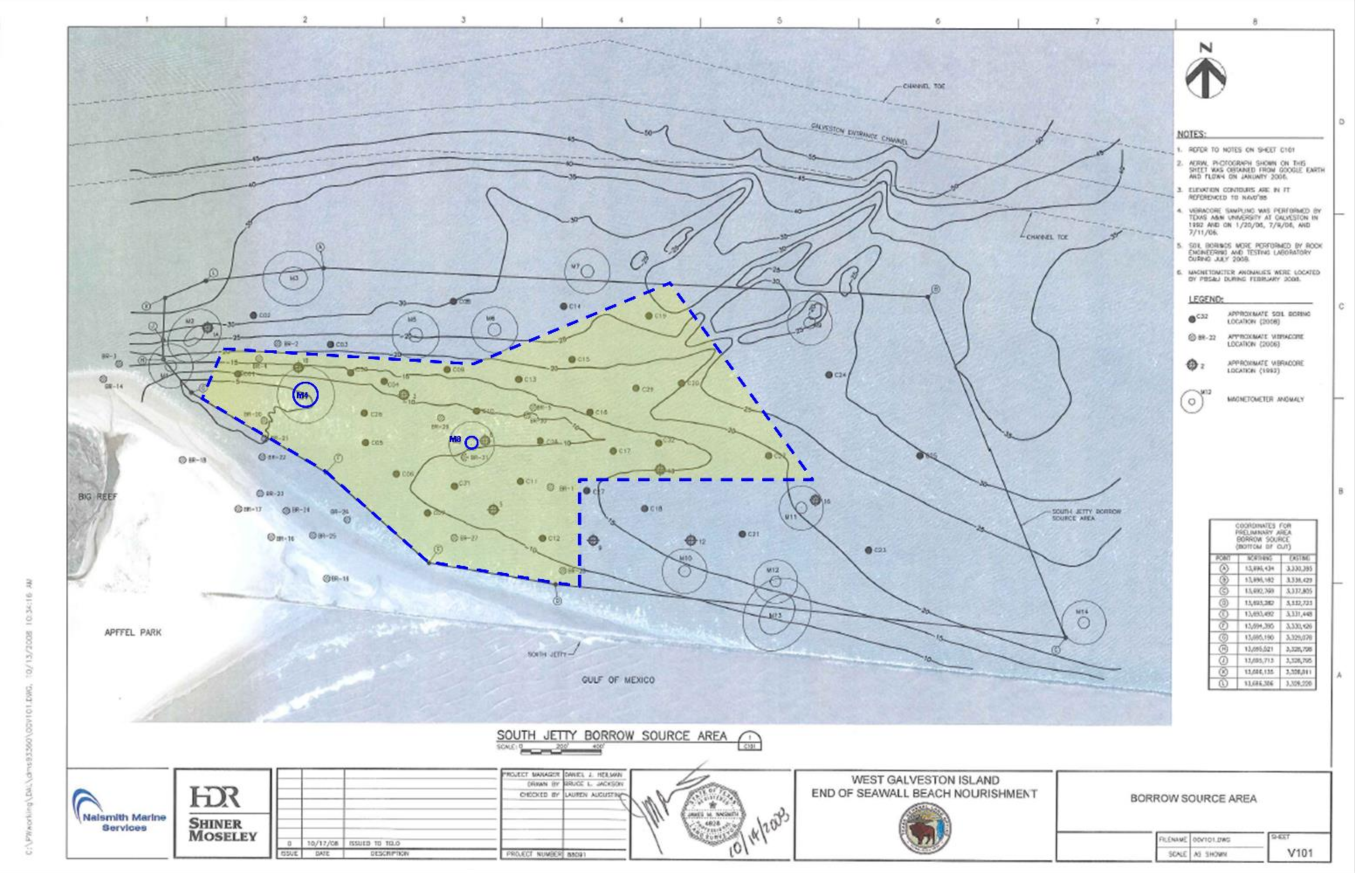


Figure 7-4, Location of the cored area on Big Reef for sand sources investigations (HDR, 2008).

7.3.3.2 South Side of the South Jetty: East Beach

East Beach is one of the few areas of accretion on the north side of Galveston Island (Payne et al., 2011). The sand accumulated at Big Reef goes thorough East Beach as part of the local conditions and energies modified by the South Jetty. Dellapenna and Johnson (2012) conducted seismic studies and sediment sampling offshore East Beach and south of the jetty identifying sandy deposits on the facies of the submerged profiles. The authors identified loose sandy bars but also areas where the sand created a hard seabed substrate that vibra-cores were not able to recover cores to quantify the sand present.

The sand that moves from East Beach to Big Reef through the jetty was estimated in an average volume of 188,845 cubic meters (247,000 cubic yards) per year (Frey et al., 2016). The sediment offshore East Beach close to the jetty moves to Big Reef, ends on the beach and moves south away from the jetty. The volumes on how much sand stays on the shoreface of East Beach or moves south to the shoreface in front of the seawall still unclear. The sandy bars observed by Dellapenna and Johnson (2012) in front of the seawall suggest that some volumes of sand should move toward the Gulf as they leave East Beach, but again, data is insufficient to identify sediment sources and volumes close to the jetty.

7.3.4 The USACE Offshore Disposal Area No. 1

Dellapenna and Johnson (2012) profiled the area called “USACE Offshore Disposal Area No. 1” about 4.4 miles offshore Galveston Island (Figures 7-5 and 7-6). The authors included some cross sections offshore East Beach as part of the surveys conducted on the entire shoreface of the island. After years of deposition of dredge materials, Area 1 dredge material disposal site has been physically sorted after storms and natural currents have removed muds leaving sandy deposits on the surface of a bathymetric low. A minimum of 600,000 cubic meters (792,000 cubic yards) of sandy deposits were measure on a very surficial analysis (Johnson, 2015), with the potential of having several times this estimated volume. More data is needed to assess the potential volumes and qualities of the sediment available.

Table 7-5
USACE Offshore Disposal Area No. 1 Sediment Data

Geologic Sedimentary Unit	Potential Sediment Volume
USACE Offshore Disposal Area No. 1	~6,000,000 cubic meters (minimum)

7.4 GALVESTON ISLAND

7.4.1 The Sorted Bedform Shoals of the Shoreface

The data collected by Dellapenna and Johnson (2012) and interpreted later by Johnson (2012) on the shoreface of Galveston Island shows migrating parallel sand bars that created after storms. But in the long term, sandy geomorphological features are also developed as part of the migration of sediments toward the Gulf that are called “sorted bedform shoals” also known as a shelf morpho-sedimentary continuum of bedforms (Rutecki et al., 2014). These geomorphological features can include rippled scour depressions, ridges and swales, shoals, and any other sandy sorted sedimentary bedforms. These deposits associated within the bedform shoals consist primarily of Holocene shelf sands, Holocene muds, and exposed Pleistocene deposits (Theiler et al., 2014).

The sorted bedform shoals appear to be common on the shelfs of North Carolina, Alabama and Florida and now start to be discovered as part of the Texas shoreface (Dellapenna and Johnson (2012) Figure A and B. These features combined can reach volumes of tens of millions of cubic yards of sediment (Rutecki et al., 2014) covering arge area (Figure 7-6 B). Limited analysis has been conducted on the Texas coast since require detailed studies on the morphological features at the macro-micro bedform morphology, but as whole, these bedforms can be a potential source of sand since may consist of loose Holocene sandy deposits. A basic analysis of one of these features 6 km offshore East Beach showed volumes of 184,257 cubic meters (241,000 cubic yards). More of these features should be available in Texas but their recent identification makes these sorted sandy features a potential target for future sediment sources investigations.

Table 7-6
Sorted Bedform Shoals of the Shoreface Sediment Data

Geologic Sedimentary Unit	Potential Sediment Volume
Sorted Bedform Shoals of the Shoreface	~184,257 cubic meters (on a single bedform)

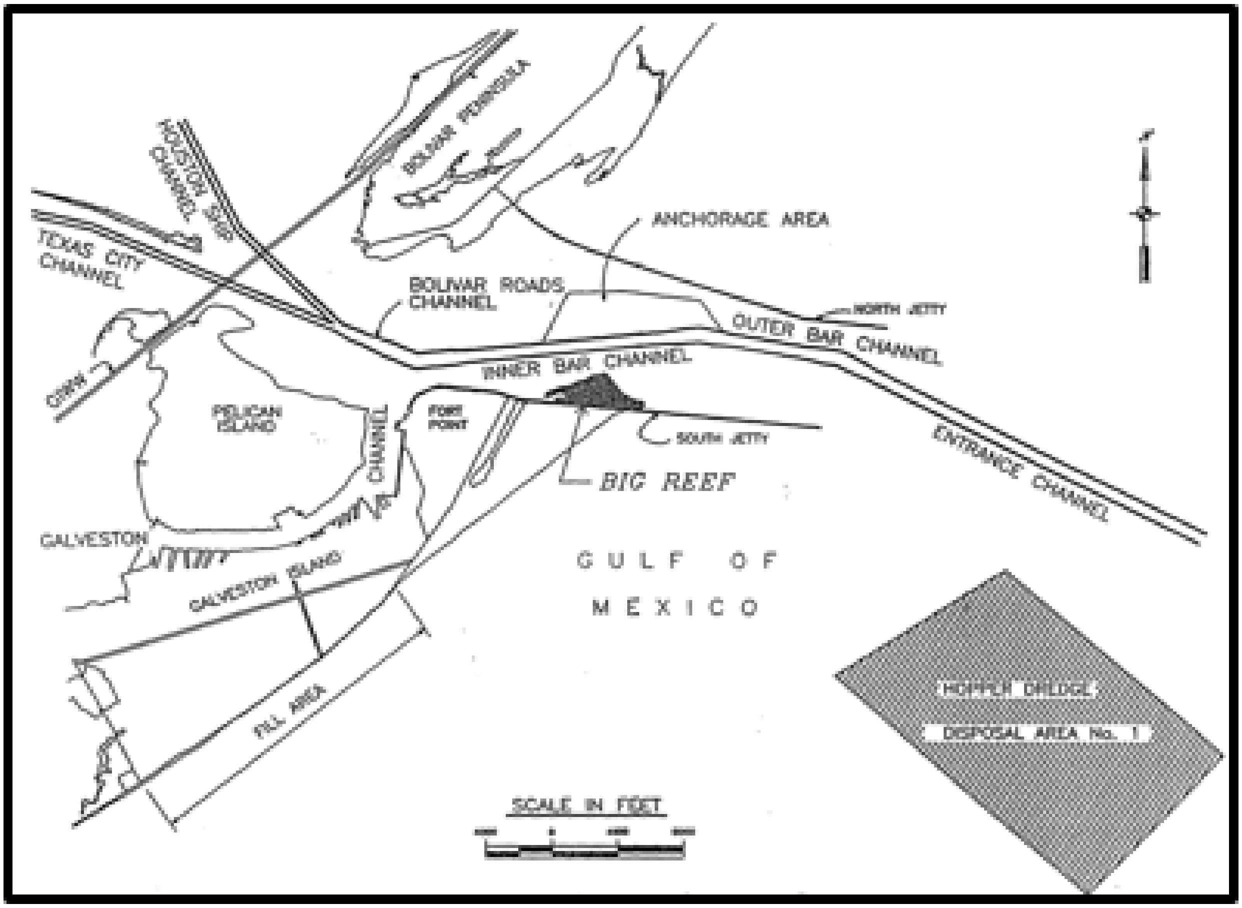


Figure 7-5, Location of the USACE Offshore Disposal Area No. 1 next to the tip of Galveston Island (USACE, 1993).

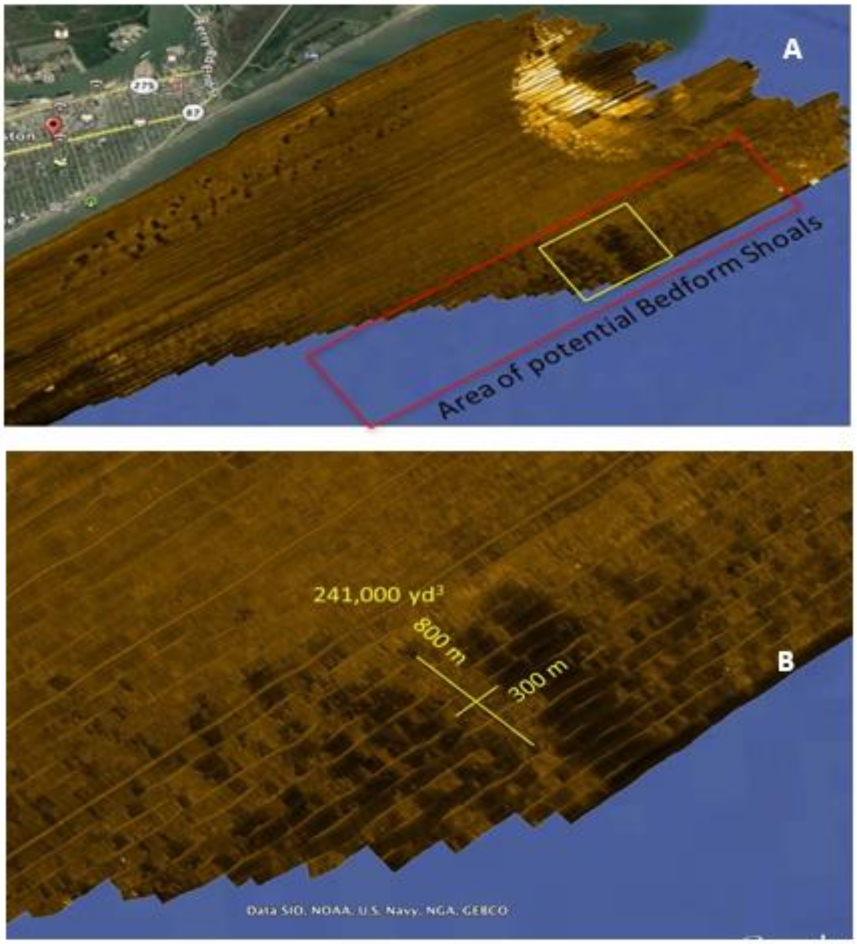


Figure 7-7, Area of potential Area of potential sorted bedform shoals as part of the migration of barrier island sediments toward the Gulf on the continental shelf. B. Potential volumes of sandy sediments on these individual bedforms as potential sand sources (Dellapenna and Johnson, 2012).

7.5 SABINE BANK

As sea level was approaching its present location, the ravinement surface was “deleting or levelling” some geologic and geomorphic features from the former coastal plain. Some of the transgressive deltas kept a good record on the shoreface as well as some sand banks considered former barrier islands, fluvial terraces, fluvial levees, etc., (Anderson et al., 2016). For the Texas upper coast, the remains of these geologic-geomorphologic features have been studied for the definition of the geologic history and potential sand sources (Rodriguez et al., 1999a, 1990b, 2001 and 2004; Morton and Gibeaut, 1995; Dellapenna et al., 2009, Dellapenna et al., 2010; Dellapenna et al., 2012; and Anderson et al., 2016).

Morton et al., (1995) suggested that the inner shelf is an important sink for eroded beach sand that is deposited principally as storm beds that slowly accumulate in water depths of 10 meters or more. The best analyzed area for the evolution and quantification of sand banks and their composition are the Sabine, Heald, Sheppard and Thomas banks (Figure 3-2) (http://gulf.rice.edu/ETexas/gulfeTexasS_T_SJ_tst.html) (Morton et al., 1995; Dellapenna et al., 2010; Anderson et al., 2016). Morton and Gibeaut (1995) suggested that Heald Bank contains roughly 585,000,000 cubic meters (765,000,000 cubic yards) of sandy and other deposits. For Sabine Bank, the authors suggested approximately 1,200,000,000 cubic meters (1,500,00,000 cubic yards) of sands, shells, and other type of sediments.

Dellapenna et al., (2009, 2010 and 2012) was able to measure the geometry, sediment volumes, and grain-size distribution of sands on two facies of the Sabine and Heald Banks and compared their composition with the East Texas Gulf Coast beach sands. The conclusion is that some of the sands available in the Sabine and Heald Banks have areas that can be considered potential compatible sand resources for beach replenishment on the Texas Gulf Coast beaches.

There are at least three main stratigraphic units (called Facies) at the Sabine and Heald Banks. Rodriguez et al., (1999) and (2004) observed two Facies: a shoreface sand Facies (Facies A), and covered with shelly sands is the called Facies B. Morton and Gibeaut (1995) measured the called Facies B consisting of fine-grained muddy quartz sand containing <15% mud. Morton and Gibeaut (1995) divided the upper Facies A into an upper unit of fine quartz sand, called by Dellapenna (2009) Facies A1. Then the lower unit of interlayered fine shelly sand and shell hash which has been recognized as Facies A2.

Facies A1 and A2 are on top of the stratigraphic column covering Facies B that tend to be siltier with organic components. Each Facies have different concentrations of beach quality sand on both the Sabine Bank and Heald Banks, being the cleaner layers Facies A1 and A2. Table 7-8 shows the volumes estimated by Dellapenna (2009) for the Banks and their Facies.

Sabine Bank was suggested to contain at least 413,000,000 cubic meters (540,000,000 cubic yards) of sediments on Facies A1. Facies A2 may contain up to 338,000,000 cubic meters (440,000,000 cubic yards). Facies B may contain 638,000,000 cubic meters (835,000,000 cubic yards) of sandy and other sediments.

Heald Bank was suggested to have at least 364,000,000 cubic meters (475,000,000 cubic yards) on Facies A1. For Facies A2, it was estimated a minimum of 273,000,000 cubic meters (360,000,000 cubic yards). Finally, for Facies B, up to 81,000,000 cubic meters (105,000,000 cubic yards) were suggested.

Facies A1 appear to be the best compatible and cleaner beach sandy deposits. Sabine and Heald Bank Facies A1 combined may reach up to 777,000,000 cubic meters (1,000,000,000 cubic yards) of sandy deposits (Dellapenna, 2009). For Facies A2, the Banks combined have the potential for up to 611,000,000 cubic meters (800,000,000 cubic yards). Facies B will be the most difficult unit to managed if needed for coastal projects due to the content of fine organic material.

Table 7-7
Volumes of Sandy Deposits in the Different Facies Observed in Sabine and Heald Banks (Dellapenna, 2009)

Geologic Sedimentary Unit	Potential Sediment Volume
Sorted Bedform Shoals of the Shoreface	~184,257 cubic meters (on a single Bedform)

Table 7-8
Volumes of Sandy Deposits in the different Facies Observed in Sabine and Heald Banks (Dellapenna, 2009)

Location	Volume Facies A1 million m^3	Volume Facies A2 million m^3	Volume Facies B million m^3
Sabine Bank	413	338	638
Heald Bank	364	273	81
Total	777	611	719

7.6 MOVING SEDIMENT ON THE SHOREFACE

The study conducted by Dellapenna and Johnson (2012) was also able to compare the changes in the total volume of the beach and shoreface from the surveys conducted in 2006 and 2011. The authors noticed that the shoreface profile also retreated during Ike. Sediments removed from the beach and upper shoreface areas ended also beyond the depth of closure deeper into the Gulf. Some of the sand bars observed by Dellapenna and Johnson (2012) should be part of the inner shelf sediments suggested by Morton et al., (1995), which consist of inner shelf deposits eroded from the sandy beaches that are deposited principally as storm beds that slowly accumulate in water depths of 10 meters or more.

Monitoring sediments migrating on the Shoreface should be a priority to recover these sediments and return them to the coastal system. These sediments are on top of the surface left by the ravinement processes, which makes these moving sediments “modern sedimentation” on the shoreface.

8.0 RIVERS AND WATERSHEDS SEDIMENT CONTRIBUTION TO BAYS AND ESTUARIES

8.1 SABINE RIVER WATERSHED

Anderson et al., (1992) stated that the offshore sands that form the southeast Texas barriers are largely derived from the drowned deltaic and fluvial deposits of the Trinity and Sabine Rivers. On an average annual basis, sediment delivery ratios of total basin erosion to sediment yield at the outlet are less than 10% for Texas Gulf Coastal plain (Phillips 2003; Phillips et al., 2004).

8.1.1 Hydrology

The Sabine River has a total drainage area of 25,267 square kilometers and about 26 percent (6,676 square kilometers) of its drainage area is downstream of the Toledo Bend Dam (Figure 8-1). Precipitation is year-round with low-flows and mid-summer droughts being a common occurrence. The mean annual precipitation ranges between 1100 to 1200 millimeters. The lower Sabine River flows are affected by the climate and hydrologic response of the drainage basin, releases from the Toledo Bend Reservoir, water withdrawals, and tidal and coastal backwater effects. The influences of dam releases are the most significant during wet, high-flow periods and most evident on an hour and daily time scale without substantial effect on the monthly, annual mean flows, or peak flows. The effects of the water diversions on flows have been less in recent decades. Coastal backwater effects decrease the importance of upstream at Sabine Lake (Phillips and Slattery, 2007).

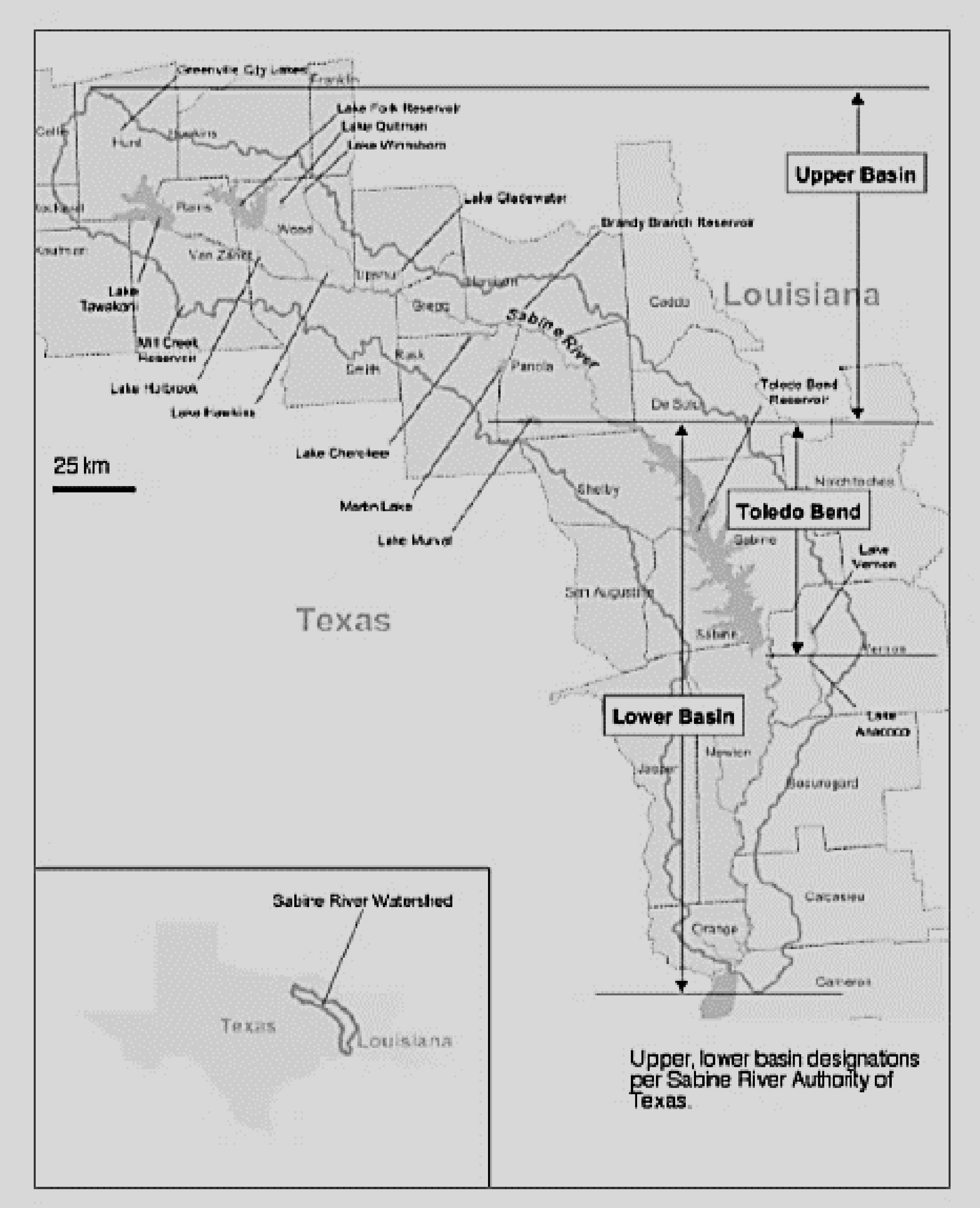


Figure 8-1, Sabine River Basin (Phillips and Slattery, 2007)

8.1.2 Sediment Loading

The U.S. Geological Survey (USGS) collected suspended sediment samples at the Deweyville Station between years 1974-1995. The results of this study are presented in Table 8-1 (Phillips and Slattery, 2007).

Table 8-1

Suspended Sediment Transport in the Sabine River at Deweyville (Phillips and Slattery, 2007)

Geologic Unit	Potential Sediment
Number of Measurements	136
Mean Sediment Concentration (mg/l)	39 mg/l
Mean Daily Sediment Transport (t/d)	589 t/d
Mean Annual Sediment Yield (t)	215,132 t
Mean Annual Specific Sediment Yield (t/km^{2}yr)	8.9 t/km^{2}yr

Phillips (2003) used reservoir survey data from the Upper Sabine Basin to estimate the delivery of eroded sediment to streams and found that if all the sediment delivered to channels was transported by the river, it would deliver more than 400 t km-2 yr-1 of sediment. The low sediment yields of 8.9 t/km^{2}yr at Deweyville is not unusual for southeast Texas coastal plain streams. Table 8-2 shows the sediments data based on suspended sediment. USGS sediment data for Deweyville does not show a temporal trend. No evidence of reduced sediment transport or alluvial sedimentation attributable to Toledo Bend Dam in the lower Sabine was found, except for a short scour zone immediately downstream from the dam (Phillips, 2003). The sediment data from Deweyville shows the suspended sediment is fine, with 81 percent being finer than 0.063 millimeters in diameter (standard deviation 16.9; range 27 to 100 percent). Phillips (2003) stated that considering the sandy bed of the Sabine River, the presence of active, downstream-migrating bedforms, such as sandy point bars, makes it likely that a significant amount of presumably sand sediment is transported as bed load (Phillips and Slattery, 2007).

Table 8-2

Measures and Estimates of Fluvial Sediment Yield in Southeast Texas (Phillips and Slattery, 2007)

Location	Yield (t/km^{2}yr)	Source
Sabine R. at Deweyville	8.9	Phillips and Slattery, 2007
Sabine R. at Tatum (Upper Sabine Basin)	89	Coonrod et al., 1998
B.A. Steinhagen Lake (Neches R.)	50	Austin et al., 2004
Neches River at Dibol	47	Coonrod et al., 1998
Angelina River Basin, Forested	3.3	Blackburn et al., 1986
Angelina River Basin, Logged	19 to 294	Blackburn et al., 1986
Angelina National Forest	2 to 70	Blackburn et al., 1990
Piney Cr. At Groveton	99	Coonrod et al., 1998
Trinity River at Tomayor	76	Phillips et al., 2004
San Jacinto River at Cleveland	188	Coonrod et al., 1998
Lower San Jacinto River Basin	143	Greiner, 1982
Houston Lake (San Jacinto River)	6	TWDB Reservoir Survey Data (yield calculated from date in this source)

The sedimentation rates in Sabine Lake were determined using 239,240 Pu profiles (4 to 5 millimeters/year in both upper and lower estuary) by Ravichandran et al., (1995). The sediment yields of the entire Sabine Lake (including the Neches and the Sabine River) is calculated as approximately 37 t/km2yr extrapolating the sedimentation yield over the 53,349 ha estuary surface area. Assuming a density of 0.7 t/m2, it results in a sediment yield of Phillips and Slattery (2006) stated that most of the sedimentation is likely to be from autochthonous organic matter, shoreline erosion, marine and coastal sources, reworking of bed sediments, and local fluvial inputs from coastal watersheds (Phillips and Slattery, 2007). This should be the same type of sediments available at the paleo valley fill deposits in the Texas incised channels of the Pleistocene.

8.2 TRINITY RIVER WATERSHED

The Texas Water Development Board collected suspended sediment samples at several sites along the Trinity River between years 1965-1989 (Phillips and Slattery 2006). The study conducted by Phillips and

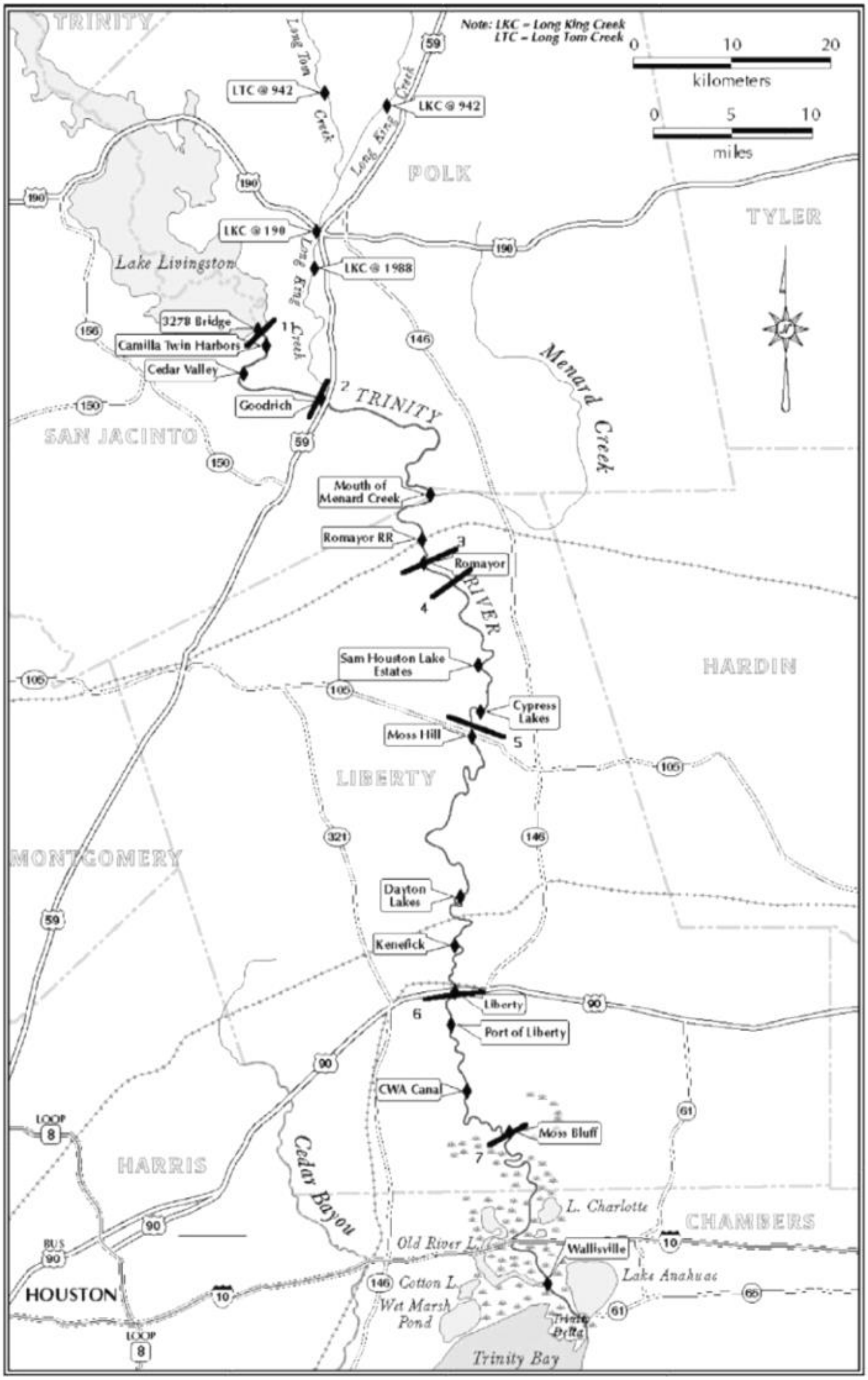


Figure 8-2, Study Area of Phillips et al., (2004) Slattery (2007) focuses on the downstream trends in a lower coastal plain river. The area considered in this study is presented in Figure 8-2. The downstream changes in flow and sediment transport capacity are affected by the systematic changes in channel and valley morphology, slope, the relative importance of fluvial versus coastal processes, inherited valley morphology, extensive water storage on floodplains, and low-water tributaries that might function as distributaries at high flow. The Trinity River drainage basin (46,100 km^2 area) drains on the Trinity Bay, which is part of the Galveston Bay System within the Gulf of Mexico. The Trinity/Galveston Bay has a mean volume estimated approximately 2.7 billion m^3 and drainage area of 85,470 km^2. Approximately 54 percent of the drainage area and of the freshwater inflow is accounted for the Trinity River (Philipps and Slattery, 2007).

8.2.1 Hydrology

The discharge regimes are presented in Table 8-3. Even though two major tributaries (Menard and Big Creeks) join the Trinity between Goodrich and Romayor, Goodrich has a higher discharge for six of the nine events. The table below shows that there is no consistent downstream increase in discharge within the fluvial-dominated Goodrich-Romayor reach (Philipps and Slattery, 2007).

Table 8-3

Reference Flows for Lower Trinity River Gaging Stations (Phillips and Slattery, 2007)

Reference Flow (m^3/s)	Goodrich	Romayor	Liberty
Mean Annual Discharge (MAQ)	231	246	509
50% Exceedance	82	77	433
10% Exceedance	677	640	1048
1% Exceedance	1550	1541	822
Q1	2130	1970	2484
Q2	2400	2330	2835
Q10	3002	2925	3600
2002 Flood	1872	2198	1602
1994 Flood	3540	3455	3823

8.2.2 Sediment Loading

Phillips and Slattery (2007) stated that systematic downstream pattern of increases or decreases in the discharge, stream power, or water surface slope of the lower Trinity River is not identified. The stream power and slope decrease in the lower reaches agree with the earlier findings of limited fluvial sediment delivery to the coastal zone. As shown in Table 8-4, their results indicate that the transition from fluvial to coastal dominance might be variable along the river, and this variability is controlled by the relative magnitude of river, tidal and backwater forcing, and valley topography controlled in part by antecedent landforms (Phillips and Slattery, 2007).

Table 8-4

Location of the Mouth of the Trinity River (Phillips and Slattery, 2006)

Criterion	Estimated Distance Upstream from Trinity Bay (km)	Estimated Mean Annual River Sediment Input (Tons x 1000)[1]
Channel Morphology	0	<70
Network Morphology	19.5	<70
Channel Bed Elevation	110	75 to 100
Tidal Influence	85 to 110	65 to 75
Salinity	7 to 85	<70
Turbidity	2 to 10	<70
Sedimentology	20 to 30	<70
Sediment Transport/Storage	130	3400

[1] Mean annual sediment load at Liberty = 69,673 t yr^{-1}; mean annual sediment load at Romayor= 3,378,461 t yr^{-1}

The study by Phillips et al., (2004) focuses on the lower Trinity River. The study area is presented in Figure 8-3 (shown below). The sediment delivery and yields in the lower Trinity River Basin are presented in Table 8-5 based on the sediment data from the Texas Water Development Board. Since the sediment measurements underestimate transport by ignoring bed load, the sediment transport estimates based on suspended measurements alone were increased by 10% (Phillips et al., 2004).

Table 8-5

Sediment Delivery and Yields in the Lower Trinity Basin

Station	Drainage Area (km^2)	Yield (t $year^{-1}$)	Specific Yield (t km^{-2} $year^{-1}$)
Long King Creek	365	170,637	467
Trinity at Crockett	36,029	5,112,515	142
Trinity at Romayer	44,512	3,378,461	76
Trinity at Liberty	45,242	69,673	1.6

The Trinity River experienced sediment delivery changes within the lower reaches of the river due to Lake Livingston and the Lake Livingston Dam. The reduction in sediments loads at Romayor (approximately 50 kilometers downstream) is observed by sediment monitoring. Lake Livingston surveys show sediment yields of 6 to 1002 t km2 year-1, with a mean of 275. This data includes cases where dredging, flushing, or increasing dam heights increased the measured storage capacities. The lake and Long King Creek data shows the sediment loadings within the lower Trinity basin as 400 t km-2 year-1. The Trinity basin loadings upstream of Lake Livingston are estimated as 400 t km-2 year-1. Most of the upstream sediment load is captured in Lake Livingston. A majority of the sediment transported at Romayor comes from the upstream dam or is derived from the channel erosion downstream of the dam (Phillips et al., 2004).

Figure 8-3, Sabine River Basin (Phillips and Slattery, 2007)

Between Romayor and Liberty, an increase in alluvial storage and a corresponding decrease in river sediment transport occurs. Table 7-6 shows the sediment yield and storage of the Trinity River as percentage of total input to the fluvial system. Table 7-7 shows the sediment yield and storage per unit area (Phillips et al., 2004)

Table 8-6
Sediment Yield and Storage as Percentage of Total Input to the Fluvial System (Phillips et al., 2004)

Reach	Total Input (t year^{-1})	Percent Yield	Percent Alluvial Storage
Headwater to Crockett	9,907,975	46.9	53.1
Crockett-Romayor	8,505,715	39.7	60.3
Romayor-Liberty	3,670,461	1.9	98.1
Liberty-Bay	412,873	<2	>98

Table 8-7
Sediment Yield and Storage Per Unit Drainage Area (t km^{-2}year^{1}) (Phillips et al., 2004)

Station	Yield	Alluvial Storage
Crockett	142	133
Romayor	76	147 to 223
Liberty	1.6	217 to 299
Trinity Bay	<1.6	>221 to <302

According to Phillips et al., (2004), the sediment fluxes and storage in the lower Trinity River reflects that the lowermost river reaches have a high rate of alluvial sediment storage and are a bottleneck for sediment delivery to the river mouth. This sediment storage buffers the Trinity delta from changes in sediment supply and transport upstream. Between Livingston Dam and Romayor, the Trinity Delta has a combination of sediment storage and aggradation on flood plains with degradation and scour of channels. Sediment supply from upstream and from the local drainage area is greater than the transport capacity. Sediment starvation effects due to dam are evident for approximately 52 kilometers downstream and the sediment budget shows the majority of the sediment is from the channel scour and bank erosion (Phillips et al., 2004).

8.3 BRAZOS RIVER WATERSHED

Dunn and Raines (2001) conducted a study focusing on the potential sources of change in sand transport to the Brazos River. The Brazos River basin (Figure 8-4) originates in eastern New Mexico and extends to 1,30 kilometers (640 miles) southeasterly across Texas to the Gulf of Mexico, south of Houston. An approximate area of 118,104 square kilometers (45,600 square miles) is drained by the Brazos River and its tributaries. The 24,786 square kilometers (9,570 square miles) of the upper part of the basin does not contribute to downstream flows. The Brazos River is an incised, meandering, sand-bed channel with unstable banks.

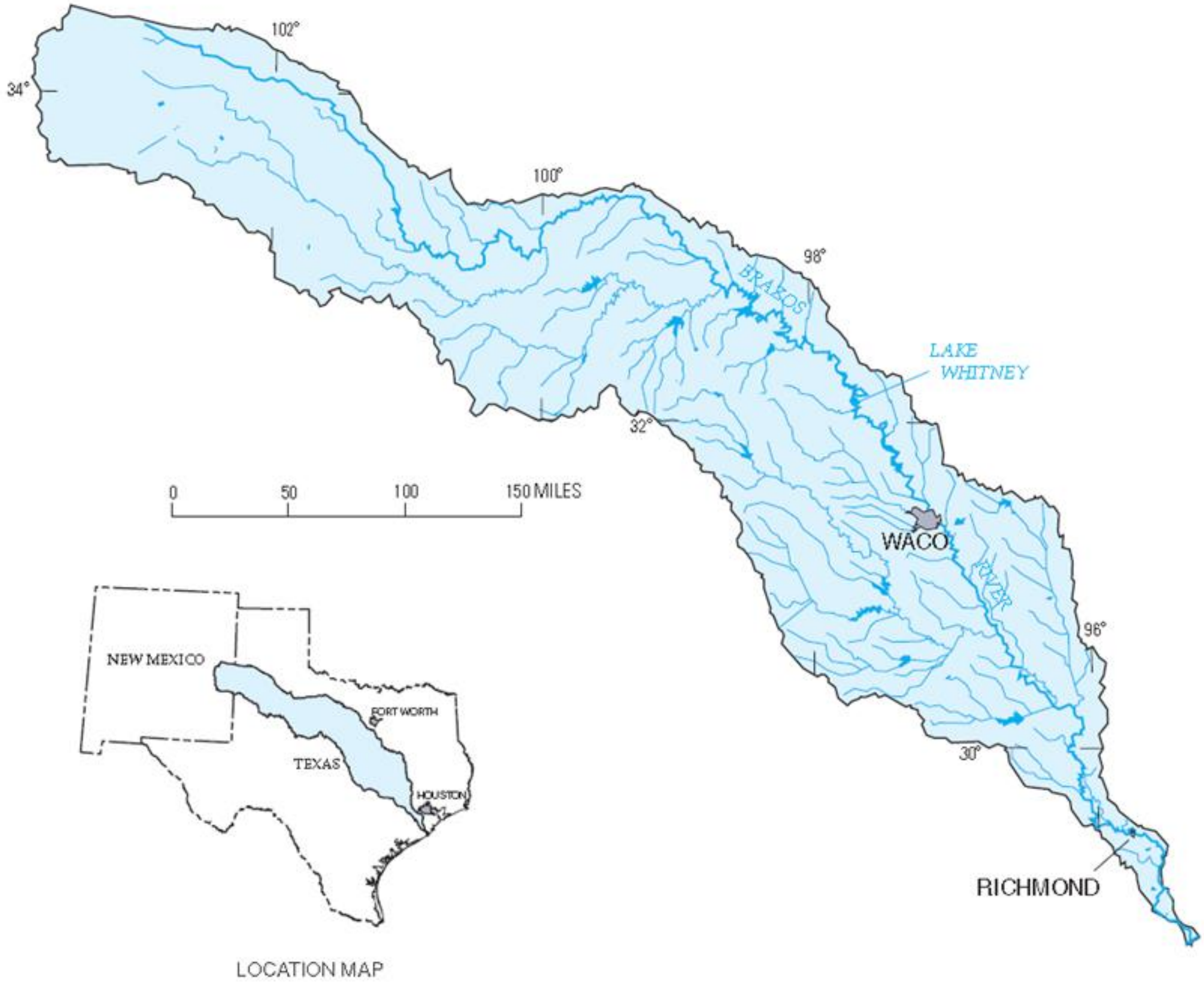


Figure 8-4, Brazos River Basin (Phillips and Slattery, 2007)

8.3.1 Hydrology

The median daily distribution charge of 85 m^3/s (3,000 ft^3/s) is measured at the stream-flow gaging station No. 08114000 Brazos River at Richmond, Texas with the channel width of 91.4 meters (300 feet). The mean annual discharge at the Richmond streamflow-gaging station for the period of 1941-1995 was 215 m^3/s (7,600 ft^3/s) (Dunn & Raines, 2001). The sediment data from the Brazos River was collected by the Texas Water Development Board and USGS. The suspended sediment concentration varies with depth; silts and clays are uniformly distributed with depth, but larger sand-size particles are present in greater concentration near the streambed (Dunn & Raines, 2001).

8.3.2 Sediment Loading

Andrews (1989) presented the mean monthly and annual suspended-sediment loads at the Brazos River Richmond gaging station for years 1966-1986. It is stated that the mean monthly suspended-sediment loads in the Brazos River at Richmond station ranged from 2,500 to 91,000 tons during years 1966-1986.

The relation between mean monthly sediment loads and the mean monthly discharges are presented in Figure 8-5 and Figure 8-6. The annual suspended-sediment load averaged about 10,900,000 tons for the period of record at Brazos River at Richmond (Andrews, 1989).

Andrews (1989) compared the studies performed by Texas Water Development Board and USGS at the Brazos River at Richmond (Table 8-8). The difference in the results is attributed to using different sampling methods. Comparison of results are presented in Andrews (1989). Brazos River continues to bring important amounts of sediment to the coastal system.

Table 8-8
Comparison of Annual Suspended-Sediment Loads (Andrews, 1989)

Year	Annual Suspended Sediment Loads (Tons)	
	Collected by TWDB	Collected by USGS
1966	18,484,000	19,899,594
1967	982,600	1,071,952
1968	29,618,000	30,799,205
1969	14,341,000	15,635,604
1970	8,705,000	9,202,515
1971	1,044,000	1,72,919
1972	3,919,000	3,943,243
1973	11,800,000	12,140,975
1974	11,400,000	10,813,593
1975	23,055,000	25,146,463
1976	8,585,000	9,154,709
1977	17,211,000	16,023,057
1978	993,900	1,146,300
1979	23,243,000	23,045,200
1980	Discontinued	5,374,995

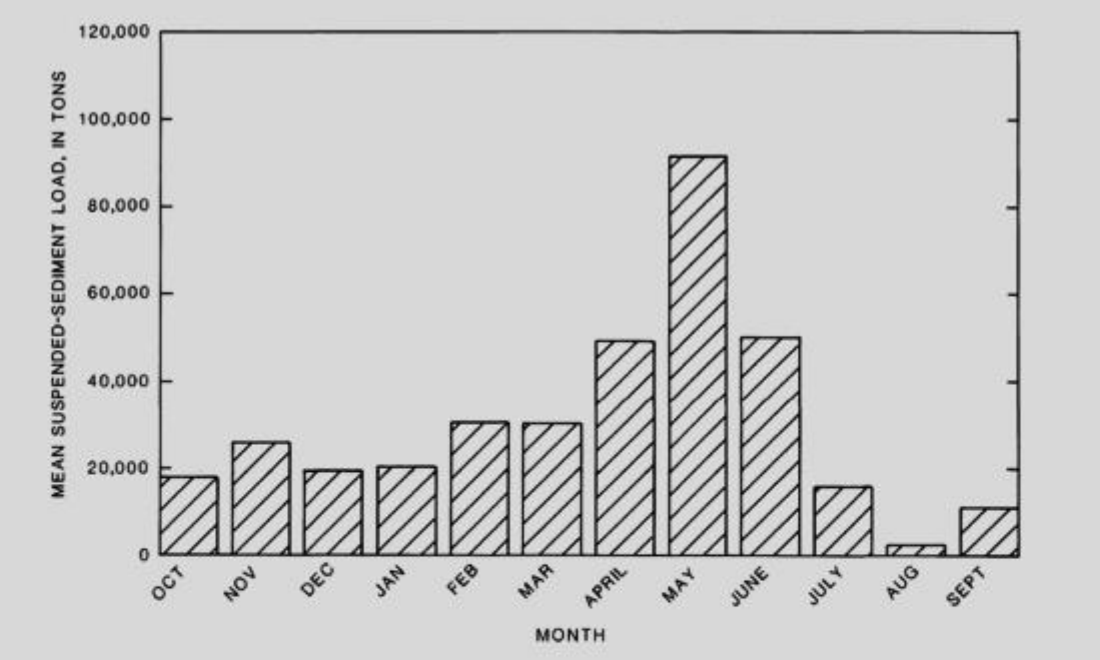


Figure 8-5, Mean Monthly Suspended-Sediment Load of Brazos River at Richmond, Texas, 1966-1986 Water Years (Andrews, 1989)

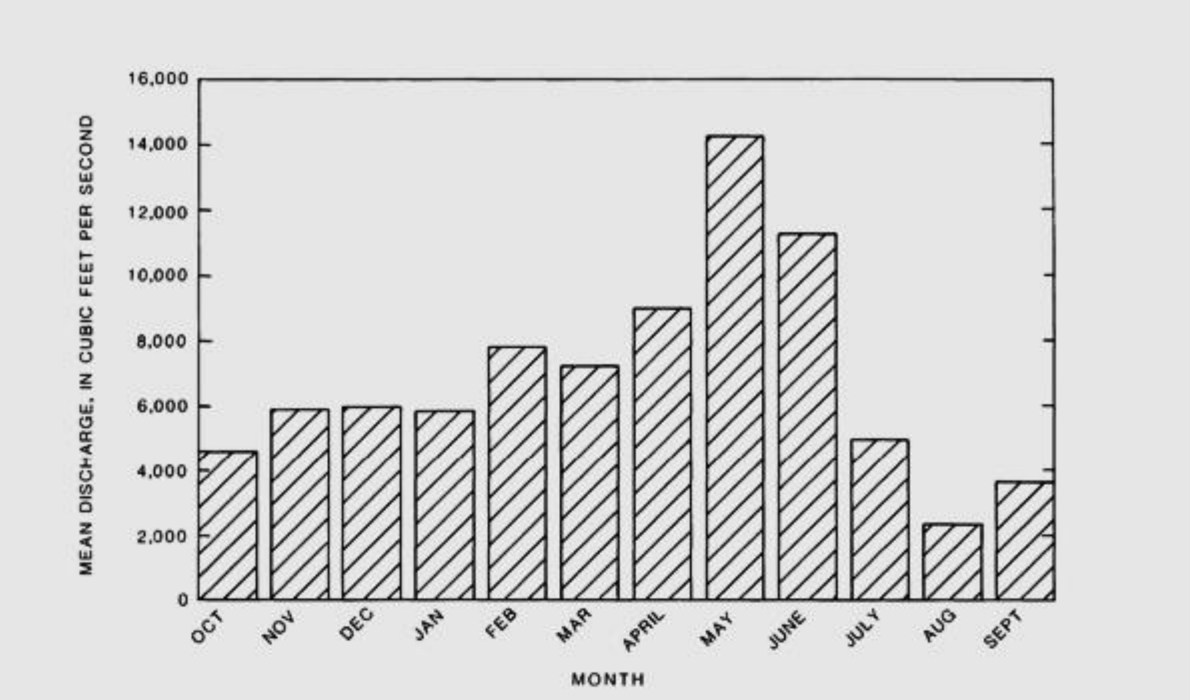


Figure 8-6, Mean Monthly Discharge of Brazos River at Richmond, Texas, 1966-1986 Water Years (Andrews, 1989)

The change in suspended sand concentrations from years 1969-1995 at the Richmond Gaging Station is presented in Figure 8-7. The suspended-sand concentrations decreased since 1982.The potential sources of change in sand transport can be summarized as: extensive reservoir construction in the Brazos River Basin and changes in land use and the sand and gravel mining. It is stated that the quantity of sediment extracted by instream sand and gravel mining operations represent 11-25 % of the total sand transported by the Brazos River. As the extraction occurs over a distance of 100 miles, the effects of mining lessons (Dunn & Raines, 2001).

The daily suspended sediment samples collected by the USGS at gaging stations along the main stem of the Brazos River and its tributaries are used to create sediment rating curves for six gaging stations in the upper basin (Black, 2006). The locations of those gaging stations are presented in Figure 8-8. The sediment rating curves for six gages within the upper basin are presented in Figure 8-9.

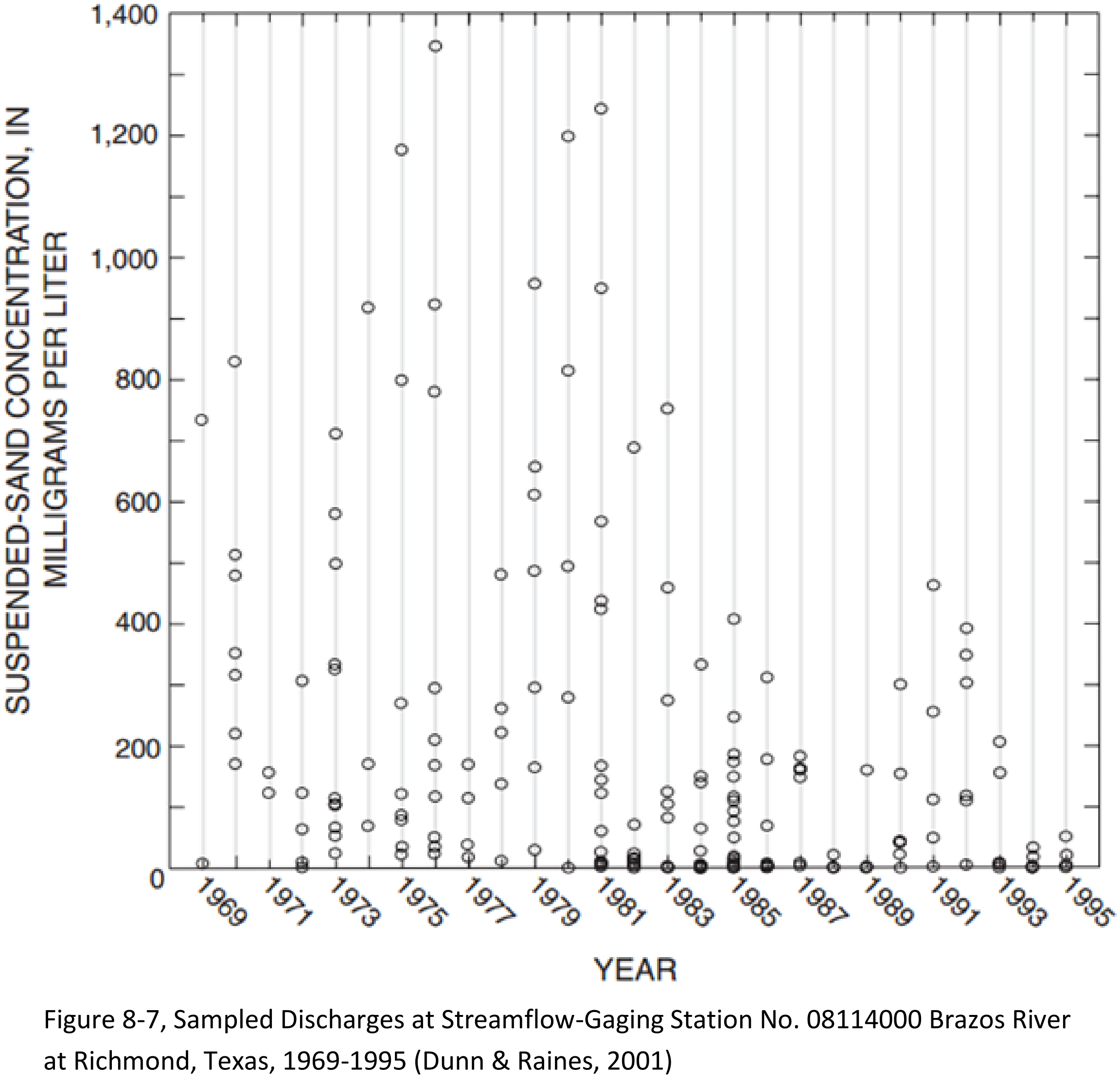


Figure 8-7, Sampled Discharges at Streamflow-Gaging Station No. 08114000 Brazos River at Richmond, Texas, 1969-1995 (Dunn & Raines, 2001)

Black (2006) calculated the sediment delivery per unit area by dividing the mean annual sediment yield by the upstream contributing area. The results obtained from the six gaging stations presented in Figure 8-8 are presented in Table 8-9.

Table 8-9
Specific Sediment Yield using Historical Data (Black, 2006)

Gage	Area	Sediment (t/yr) Historical Data	Sediment (t/km^2/yr) Historical Data
#1 Double Mountain Fort at Justiceburg	632 km2 (244 sq mi)	444,506	703
#2 Double Mountain Fork at Aspermont	4,827 km2 (1,864 sq mi)	504,439	104
#3 Salt Fork at Aspermont	6,464 km2 (2,496 sq mi)	44,430	7
#4 Brazos River at Seymour	15,467 km2 (5,972 sq mi)	26,421,444	1,708
#5 Millers Creek	269 km2 (104 sq mi)	12,868	47
#15 Brazos River at South Bend	33,947 km2 (13,107 sq mi)	695,264	20

① = Double Mountain Fork of the Brazos River at Justiceburg, TX

② = Double Mountain Fork of the Brazos River near Aspermont, TX

③ = Salt Fork of the Brazos River near Aspermont, TX

④ = Brazos River at Seymour, TX

⑤ = Millers Creek near Munday, TX

⑮ = Brazos River at South Bend, TX

Figure 8-8, Upper Brazos River Map showing the Positions of the 6 USGS Gaging Station (Black, 2006).

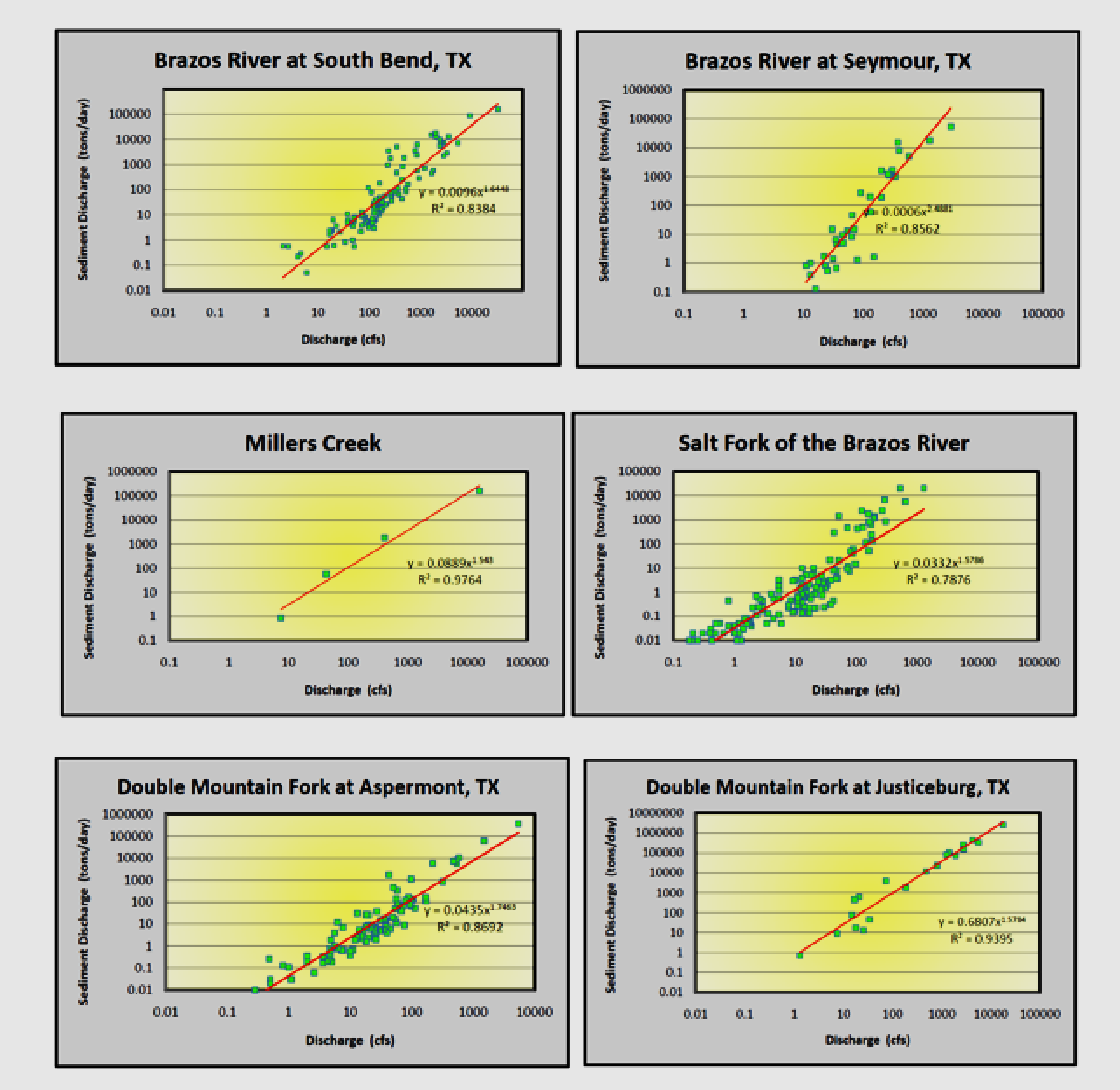


Figure 8-9, Sediment Rating Curves for the Brazos River at the Six Gaging Stations (Black, 2006)

8.4 COLORADO RIVER WATERSHED

Liang (1995) conducted a study on the sediment volume changes at the Colorado River Mouth, Texas (Figure 8-10). The Colorado River in Texas has a length of 1,550 kilometers with the drainage basin of 108.2 x 103 square kilometer.

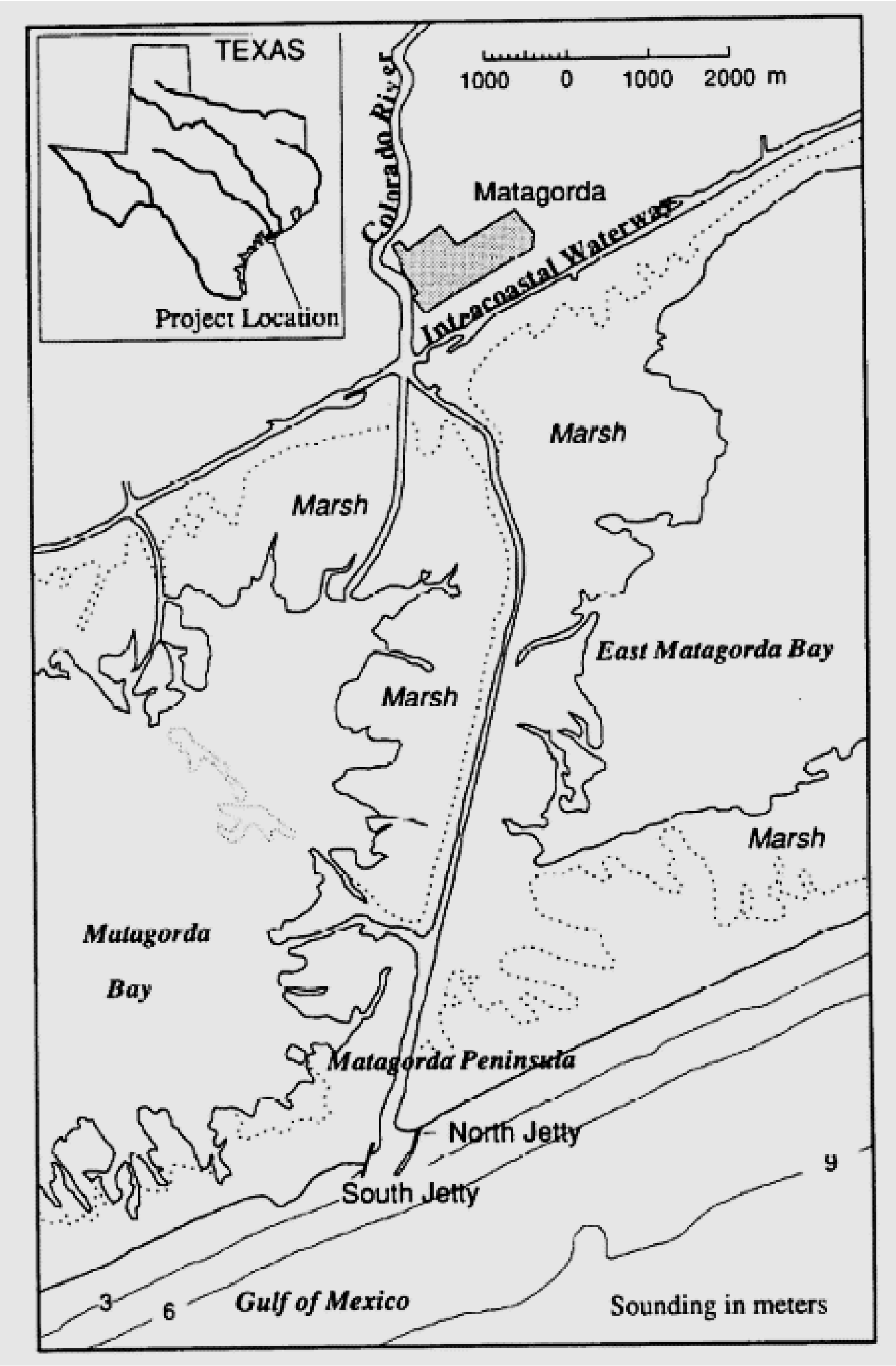


Figure 8-10, Locality Map of the Colorado River Mouth, Texas (Liang, 1995)

8.4.1 Hydrology

The annual water discharge is 2.2 x 109 m^3 (Aronow & Kacziriwski, 1985). The Colorado River contributes 7.1 x 106 m^3 of suspension load to Matagorda Bay and the Gulf of Mexico (MaGowen & Brewton, 1975).

8.4.2 Sediment Loading

Texas Water Development Board Report Number 306 presents the records of suspended-sediment loads from sampling stations on Colorado River as presented in Table 8-10.

Table 8-10
Specific Sediment Yield using Historical Data (Black, 2006)

Flow Stream Gaging Station	Net Drainage Area (sq. mi)	Record Period	Streamflow Acre-feet	Suspended Sediment Load of Streams (tons)	Dry Sediment Percentage by Weight
8146000 San Saba River at San Saba	7,871 km2 (3,039 square miles)	Max 1971	292,200	314,900	0.079
		Min 1979	91,865	15,480	0.012
		Average 16 years	158,378	99,939	0.046
8147000 Colorado River near San Saba	5,331 km2 (19,819 square miles)	Max 1935	2,564,000	728	0.413
		Min 1981	292,466	4	0.021
		Average 52 years	825,111	124	0.237
8148000 Lake Buchanan Near Burnet	53,126 km2 (20,512 square miles)	Max 1957	2,485,000	124,833	0.004
		Min 1979	96,421	1,070	0.001
		Average 35 years	541,806	17,186	0.002
8151500 Llano River at Llano	10,857 km2 (4,192 square miles)	Max 1952	285,200	5,551,820	1.430
		Min 1962	104,700	1,503	0.001
		Average 38 years	257,641	440,300	0.126
8158000 Colorado River at Austin	71,499 km2 (27,606 square miles)	Max 1968	2,511,000	1,016,000	0.030
		Min 1980	803,543	7,530	0.00
		Average 21 years	1,392,590	97,849	0.005

8.5 GALVESTON BAY

The Galveston Bay Programmatic Sediment Management Plan (Moffat & Nichols, 2010) was focused on the Galveston Bay on the Texas coast located along the northeastern Texas coastline. The Bay is divided into East Bay, West Bay, Upper Galveston Bay, Lower Galveston Bay, Trinity Bay and other small embayments. The study area is presented in Figure 8-11.

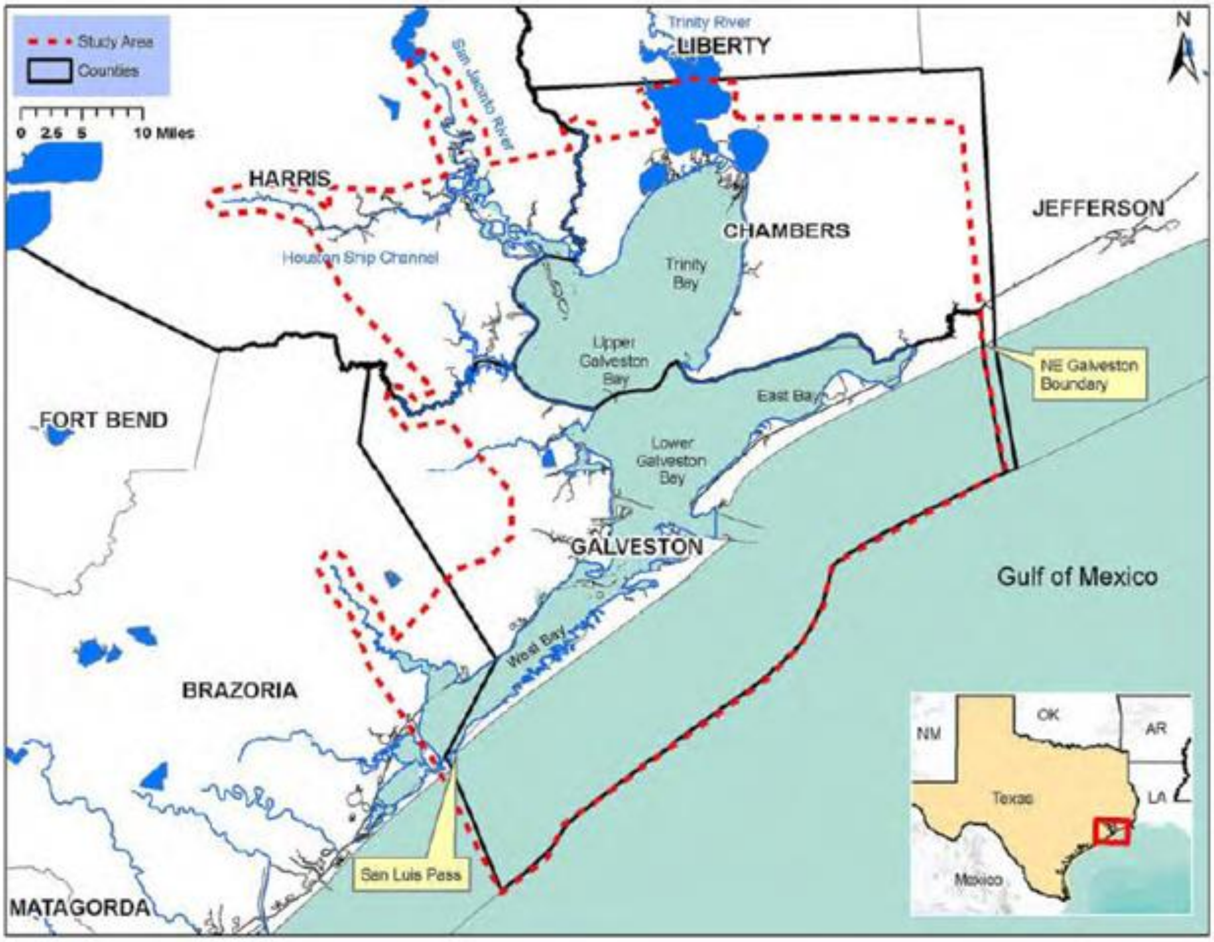


Figure 8-11, Galveston Bay, Study Area (Moffatt & Nichol, 2010)

The Moffatt & Nichol (2010) Plan stated that the largest sinks of sediment within Galveston Bay are the navigation channels. The concept was confirmed by Moya et al. (2012) for West Galveston Bay. The historical USACE dredging records for the navigation channels for consecutive events of channel dredging were studied. The sedimentation rates for the navigation channels within the Galveston Bay are presented in Table 8-11.

The Moffatt & Nichol (2010) Plan states that dredging records show approximately 11 million cubic meters (14.4 million cubic yards) is accumulated in Galveston Bay navigational channels annually. Using the accumulation rate of 3.5-3.8 mm/year estimated by Phillips (2005), an average of 5.4 to 5.9 million cubic meters (7,000,000 to 7,700,000 cubic yards) of sediment accumulation in the bay is calculated.

Table 8-11
Navigation Channel Sedimentation Rates (Moffatt & Nichol, 2010)

Channel Name	Shoaling Rate (tons/year)	Shoaling Rate (cubic yards/year)
Bayport Channel	750,000	980,000
Barbours Cut Channel	230,000	300,000
Galveston Harbor and Channel	1,370,000	1,790,000
Entrance Channel	40,000	50,000
Houston Ship Channel-Bay Reach	2,190,000	2,860,000
Houston Ship Channel Bayou Reach	2,430,000	3,180,000
GIWW-Eastern Reach	470,000	620,000
GIWW-Central Reach	290,000	380,000
GIWW-Western Reach	300,000	390,000
Chocolate Bayou	120,000	160,000
Texas City Channel	570,000	740,000
Galveston-Bolivar Ferry Terminal	310,000	400,000
Total	10,980,000	14,350,000

The shoreline erosion volumes were calculated assuming a shoreline relief of 0.3 meters (Phillips, 2005) and presented in Table 8-12. The fluvial sediment sources to Galveston Bay include local runoff around the bay margins from small watersheds discharging into the bay and larger tributaries. USGS's Elevation Derivatives for National Applications (EDNA) web-based GIS system data were used for the calculation of watershed areas. The accumulative sediment yield data, which includes sediment contributed from all upstream areas combined with sediment from the yield-point drainage area (Figure 8-12) are presented in Table 8-13.

Table 8-12
Calculated Shoreline Erosion Volumes within Galveston Bay (Moffatt and Nichol, 2010)

Cell Name	Length of Cell Shoreline (meters)	Yield (tons/year)
Trinity Bay and East Bay	173,000	38,000
Galveston Bay-La Porte	7,000	2,000
Galveston Bay-Texas City to Bayport	38,000	8,000
Galveston Bay-West Bay (Causeway)	13,000	3,000
West Bay	154,000	34,000
GIWW-West Reach	43,000	9,000
GIWW-East Reach	94,000	21,000
Galveston Bay-West Bay (Pelican Island)	13,000	3,000
Houston Ship Channel-Bayou Reach	97,000	21,000
Chocolate Bayou	62,000	14,000
Total	694,000	152,000

Table 8-13
Sediment Yield Point Values (Moffatt & Nichol, 2010)

Yield Point No.	Name	Accumulative Sediment Yield (tons/acre)
129	Buffalo Bayou-San Jacinto River	0.59
131	Galveston Bay	0.13
132	Cedar Bayou	0.54
133	Mustang Bayou (Chocolate Bayou)	0.39
134	Austin Bayou	0.10

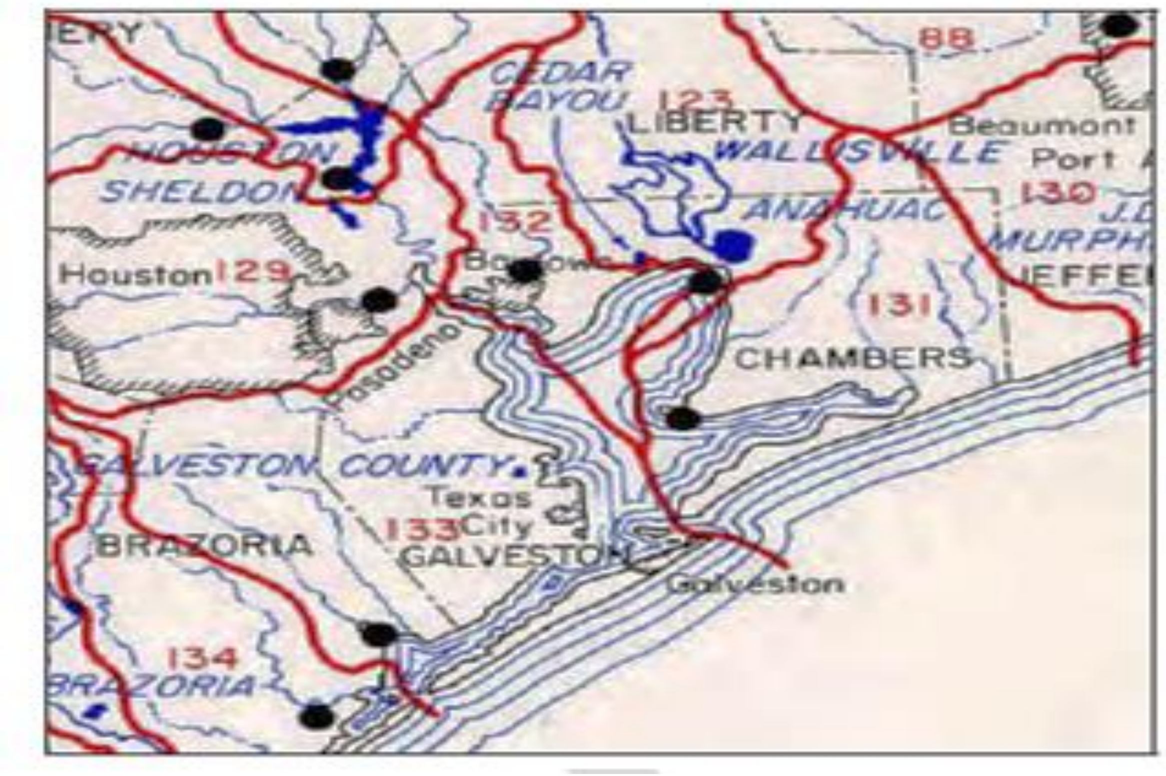


Figure 8-12, Sediment Yield Point Area (Greiner 1982)

The total yield and acreage of the major fluvial sources to Galveston Bay are presented in Table 8-14 using the data presented in Greiner (1982) and Phillips (2005).

Table 8-14
Sediment Yield Point Values (Moffatt & Nichol, 2010)

Name	Yield (tons/acre)	Area (acres)	Yield (tons/year)	Sink 1	Sink 2
Cedar Bayou	0.54	2,646,341	144,000	Trinity Bay and East Bay (100%)	NA
Chocolate Bayou	0.39	95,193	37,000	GIWW-West Reach (100%)	NA
Clear Creek	0.39	163,341	64,000	Galveston Bay-Bayport to Texas City (100%)	NA
Dickinson Bayou	0.39	63,577	25,000	Galveston Bay-	NA

				Bayport to Texas City (100%)	
Double Bayou	0.13	44,454	6,000	Trinity Bay and East Bay (100%)	NA
Oyster Bayou	0.13	197,393	25,000	Trinity Bay and East Bay (50%)	GIWW-East Reach (50%)
San Jacinto River	0.59	1,723,550	1,016,000	HSC-Bayou (100%)	NA
Lower San Jacinto	0.59	54,119	32,000	HSC-Bayou (100%)	NA
Buffalo Bayou East	0.59	19,156	11,000	HSC-Bayou (100%)	NA
Greens Bayou	0.59	134,159	79,000	Greens Bayou (100%)	NA
Buffalo Bayou	0.59	491,196	290,000	HSC-Bayou (100%)	NA
Trinity Bay	0.006	11,391,558	63,000	Trinity Bay and East Bay (100%)	NA
Total		14,642,037	1,800,000		

According to Moffatt and Nichols (2010), the total mass of sediment sources to the bay consisted of approximately 2 million tons/yr from fluvial sources and 0.2 million tons/ yr from shoreline erosion. The calculated sink volume was 11 million tons/yr. The unknown source of the volume of 8.8 million tons/yr can be explained by:

1. Underestimation of fluvial inputs,
2. Aeolian input,
3. Coastal and marine sources derived from barrier island overwash,
4. Fine-grain suspended sediment transported into Galveston Bay from Gulf of Mexico through Bolivar Roads,
5. Dredged material from navigation channels may have a significantly lower density then the assumed 1 tons/m3,
6. Shoreline erosion may be under-estimated based on a greater active profile height,

7. Channel wall and shoulder erosion due to ship and storm induced wave action,
8. Bed load transport particularly from San Jacinto River,
9. Dredged material may be escaping from some beneficial use sites and be transported back into navigation channels,
10. Navigation channels may be undergoing side-slope adjustment contributing to higher sedimentation rates,
11. Sediment being resuspended by waves and currents within the Bay system and transported into navigation channels (Moffatt & Nichol, 2010)

By using a weighted average method, the assumed suspended sediments for bay cells are presented in Table 8-15.

Table 8-15

Assumed Suspended Sediments for Bay Cells (Moffatt & Nichol, 2010)

Cell Name	Area (acres)	Percent of Total (%)	Cell Resuspension (tons/year)
Trinity Bay and East Bay	190,913	71.0	6,314,00
Galveston Bay -La Porte	4,005	1.5	132,000
Galveston Bay-Bayport to Texas City	37,344	13.9	1,235,000
Galveston Bay-West Bay (Causeway)	4,700	1.7	156,000
Galveston Bay-West Bay (Pelican Island)	3,045	1.1	100,000
West Bay	28,779	10.7	952,000
Total	268,786	100.0	8,890,000

9.0 USACE GALVESTON DISTRICT HISTORICAL DREDGE MATERIAL VOLUMES

9.1 USACE DREDGING DATABASE ANALYSIS

This chapter provides an illustration of available dredge material "hot spot" locations, where various quantities of dredge material are available, throughout Regions 1-4 along the Texas Coast. These identified dredging hot spot locations indicate an inventory of sediment sources potentially available for beneficial use to construct future coastal protection and restoration projects. The following information is provided for each of the eight systems identified:

- A comparison of the total quantity of cubic yards of sediment available per system;
- A comparison of the total quantity of cubic yards of sediment dredged annually per system;
- Regional maps displaying identified potential dredge volumes and USACE dredge placement areas within each system; and
- Regional charts displaying annual USACE Galveston District Dredge Volumes for each system.

The USACE Navigation Data Center Database (USACE, 2016) provided detailed information regarding past USACE dredging projects along the Texas Coast between the years of 1991 and 2015. For the USACE Galveston District, the database contained 418 dredge projects, from which the following information was extracted for each project:

- year the dredge event occurred;
- name and location of the project;
- latitude and longitude coordinates; and
- quantity of cubic yards dredged.

9.1.1 Regional Analysis Methodology

For this study, the Texas Coast was divided into eight systems and includes the GIWW and navigation channels maintained by the USACE Galveston District. The systems analyzed are:

- Region 1 Sabine Lake,
- Region 1 Trinity-Galveston Bay,
- Region 1 Brazos River,

- Region 2 Matagorda Bay,
- Region 3 Corpus Christi Bay; and
- Region 4 Lower Laguna Madre.

Other areas that were evaluated include Region 3 San Antonio-Aransas Bay and Region 4 Upper Laguna Madre (Figures 9-1 and 9-2).

An analysis of each region provided significant detail on the estimated quantity of dredged sediment available. In addition to this information, the USACE dredged sediment placement areas were incorporated into the analysis. This provided an illustration of available dredge material “hot spot” locations, where various quantities of dredge material are available.

These identified dredging hot spot locations indicate an inventory of sediment sources potentially available for beneficial use to construct future coastal protection and restoration projects.

The following methodologies were applied to the dredging availability analysis and may change due to the local conditions of the placement areas. These assumptions apply only to the dredge volume figures for each region (Figures 9-9, 9-11, 9-13, 9-15, 9-17, and 9-19):

Assumption 1: Out of the 418 dredge projects, 282 projects (67 percent) did not contain latitude and longitude coordinates, and therefore, are not represented in either the analysis or the figures shown below. Instead, these dredge projects are represented in two separate figures, one that illustrates the cumulative quantity of cubic yards dredged throughout each river system from years 1991-2015 (Figure 9-1) and one that shows the yearly average of cubic yards dredged for each river system previously mentioned (Figure 9-2).

Assumption 2: The USACE dredged sediment placement areas (represented by red outlined polygons) and navigation channels (represented by blue polylines) were imported into ArcGIS in addition to the dredging events. The USACE Galveston District dredged sediment data was symbolized according to the actual quantity of cubic yards dredged during a given year, with green representing the lowest quantity of cubic yards (less than 500,000 cubic yards) and maroon representing the highest quantity of cubic yards (greater than 4.5 million cubic yards). Assuming that the lower the quantity of sediment dredged the closer in proximity the sediment was deposited, a buffer was placed around each data point to identify which placement areas the sediment could have been deposited. In ArcGIS, buffers are useful for proximity analysis and create a zone around a map feature measured in units of distance. In this study, six increasing measures of distance (in miles) were used for the proximity analysis. Similarly, assuming the greater the quantity of sediment dredged the farther the sediment was deposited, a buffer was placed around each data point to identify which placement areas the sediment could have been deposited. The buffer distances applied to each of the quantity levels illustrates the distinction in relative magnitudes of dredged sediment quantities. This assumption was applied to each quantity of dredge material, based on cubic yards of sediment:

- 0-500,000 CY (1-mile buffer),
- 500,000-1,200,000 CY (3-mile buffer),
- 1,200,000 2,100,000 CY (4-mile buffer),
- 2,100,000-4,500,000 CY (5-mile buffer), and
- greater than 4,500,000 CY (6-mile buffer).

The analysis of the eight systems along the Texas Coast establishes a baseline for the quantity and general location of sediments dredged by the USACE Galveston District along the Texas coast, where the available dredge material may be utilized for future coastal protection and restoration projects.

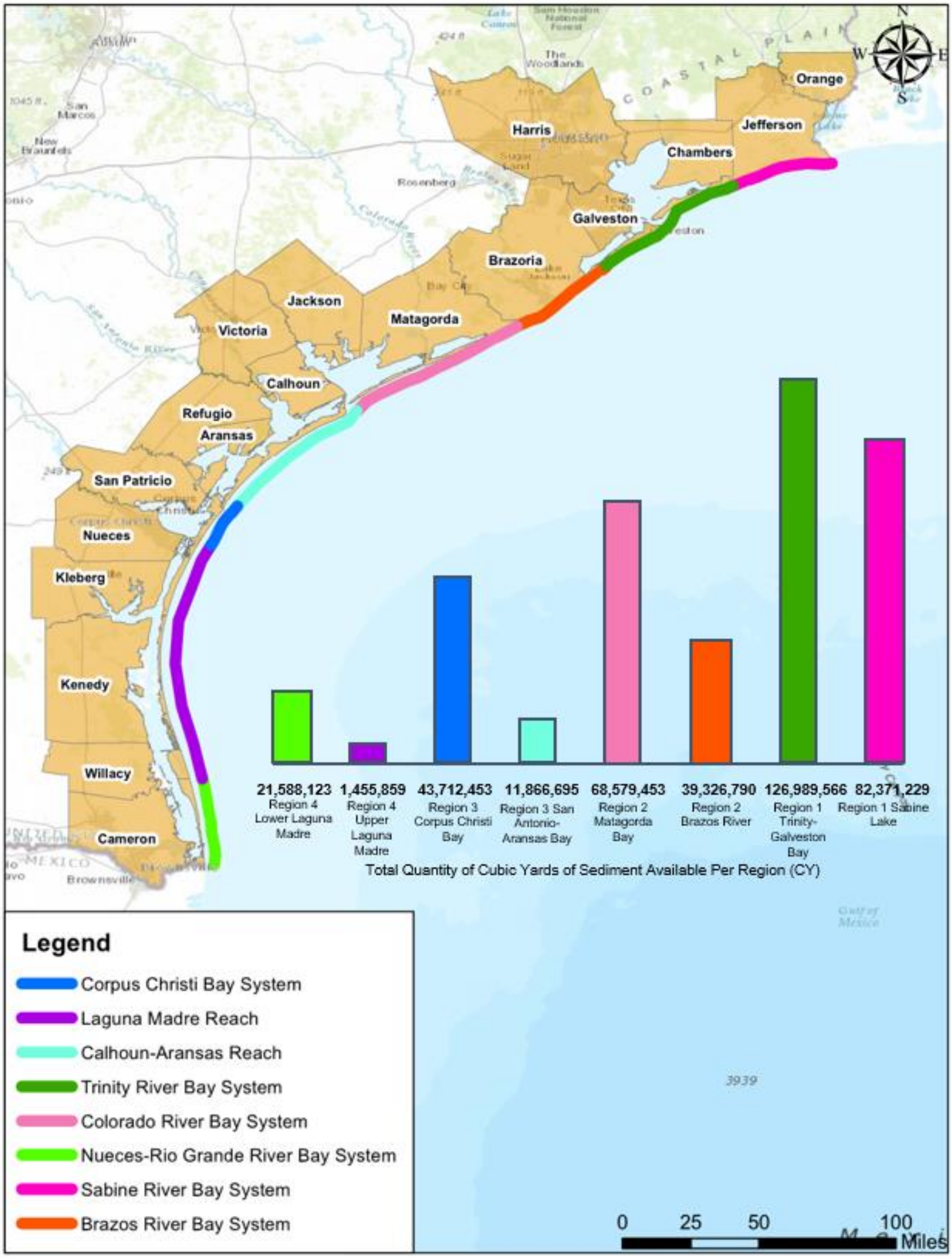


Figure 9-1, USACE Galveston District Cumulative Dredged Material by System (1991-2015).

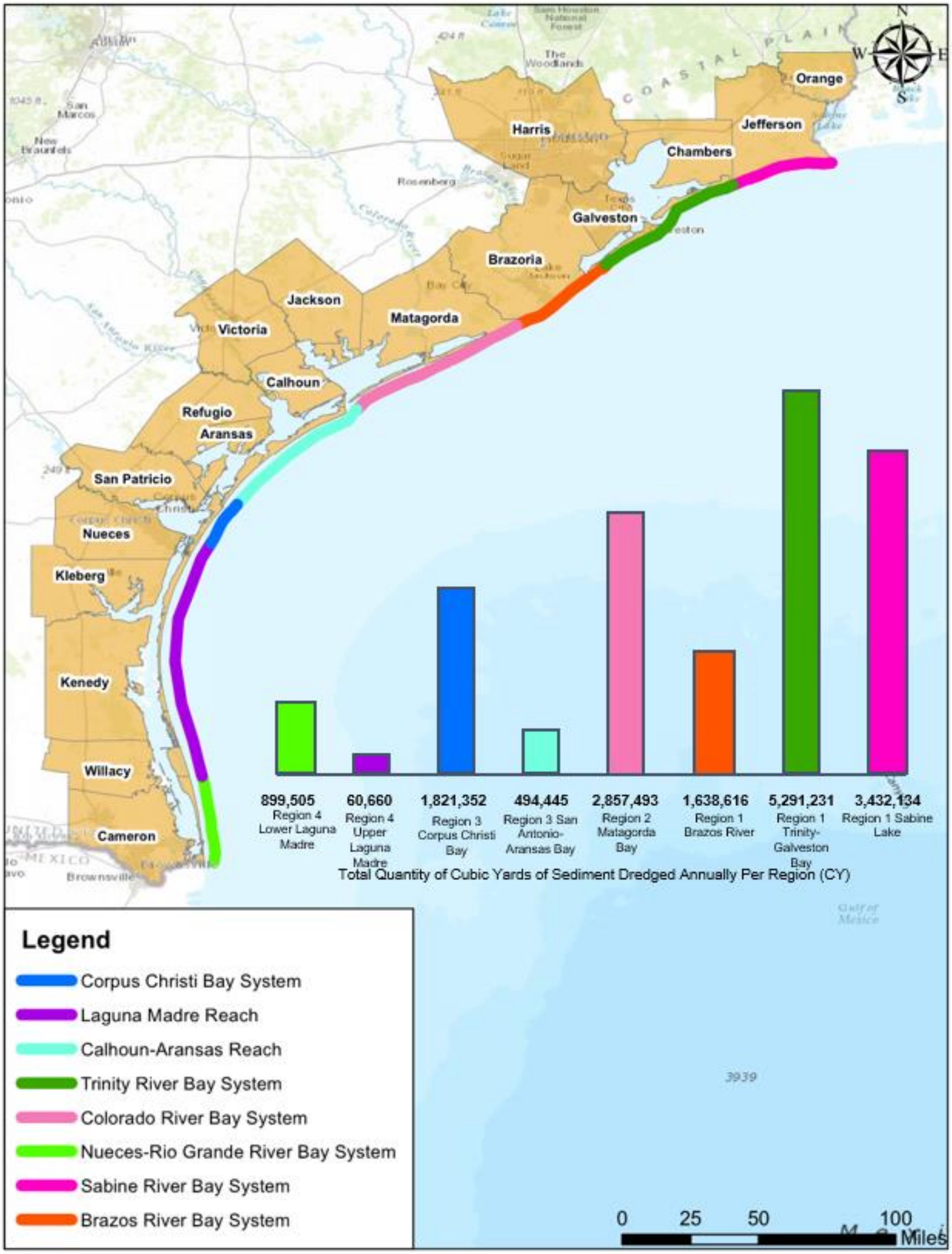


Figure 9-2, USACE Galveston District Yearly Average Dredged Material by River System (1991-2015).

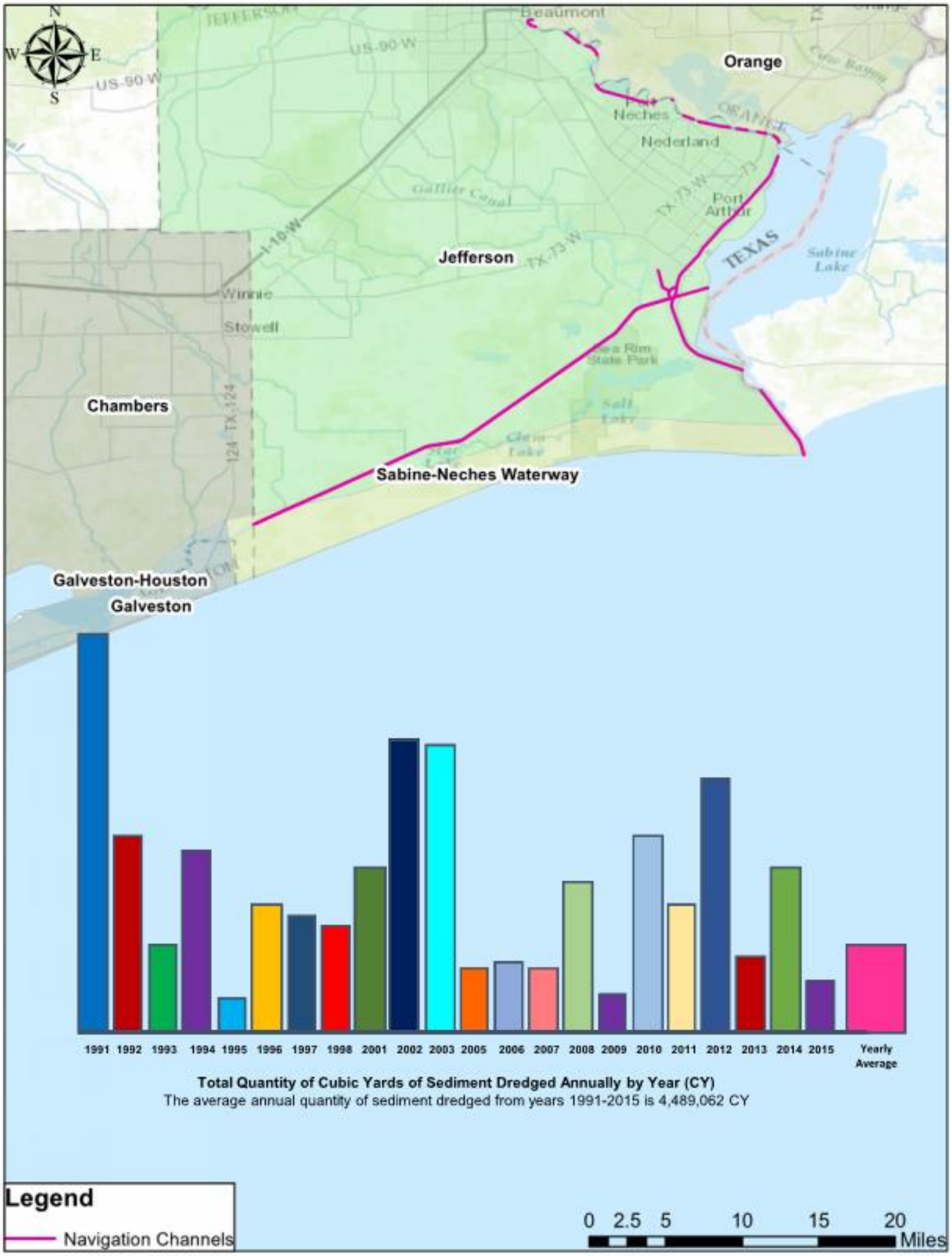


Figure 9-3, USACE Galveston District Total Quantity of Sediment Dredged Annually by Year (CY) for Region 1 Sabine Lake (1991-2015).

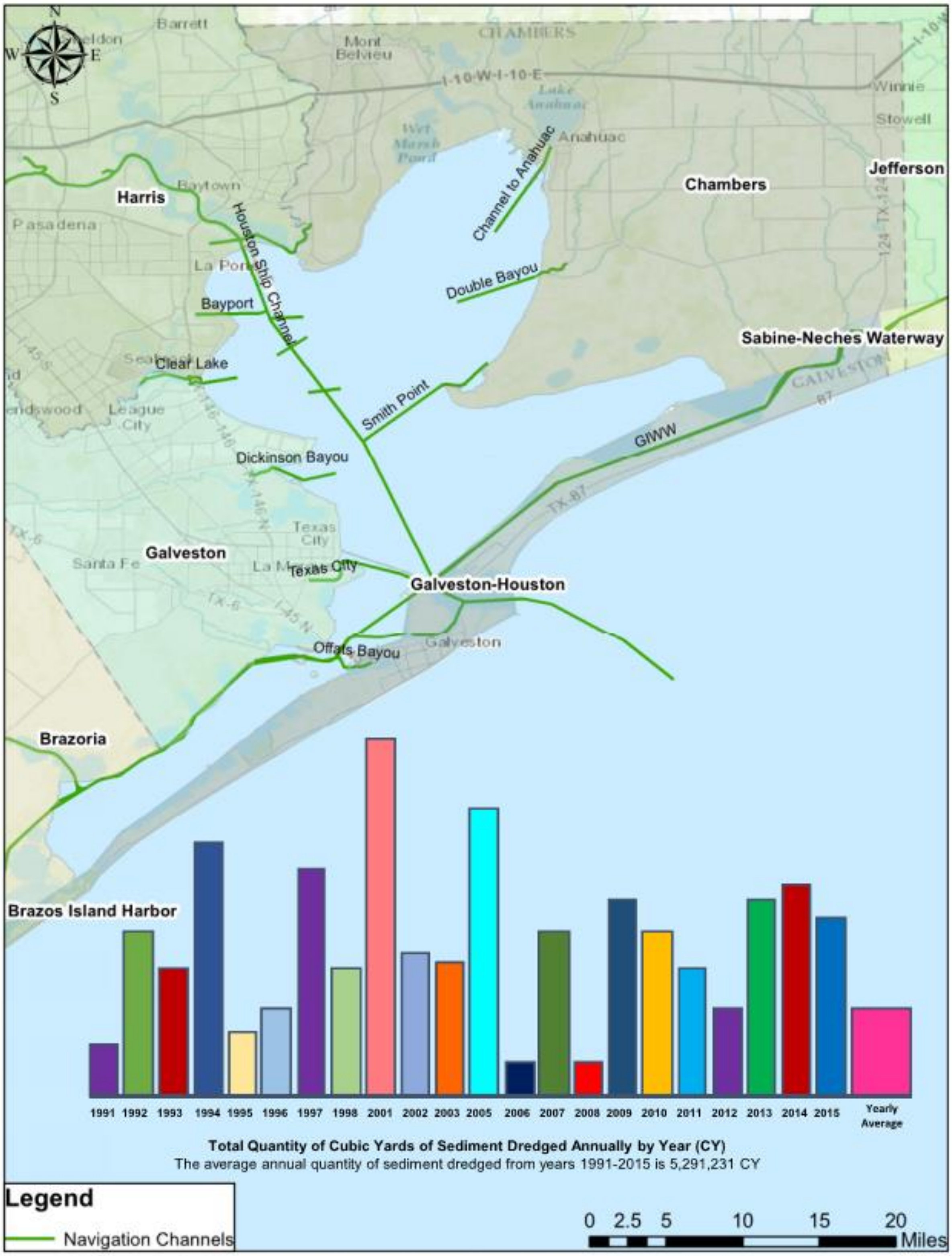
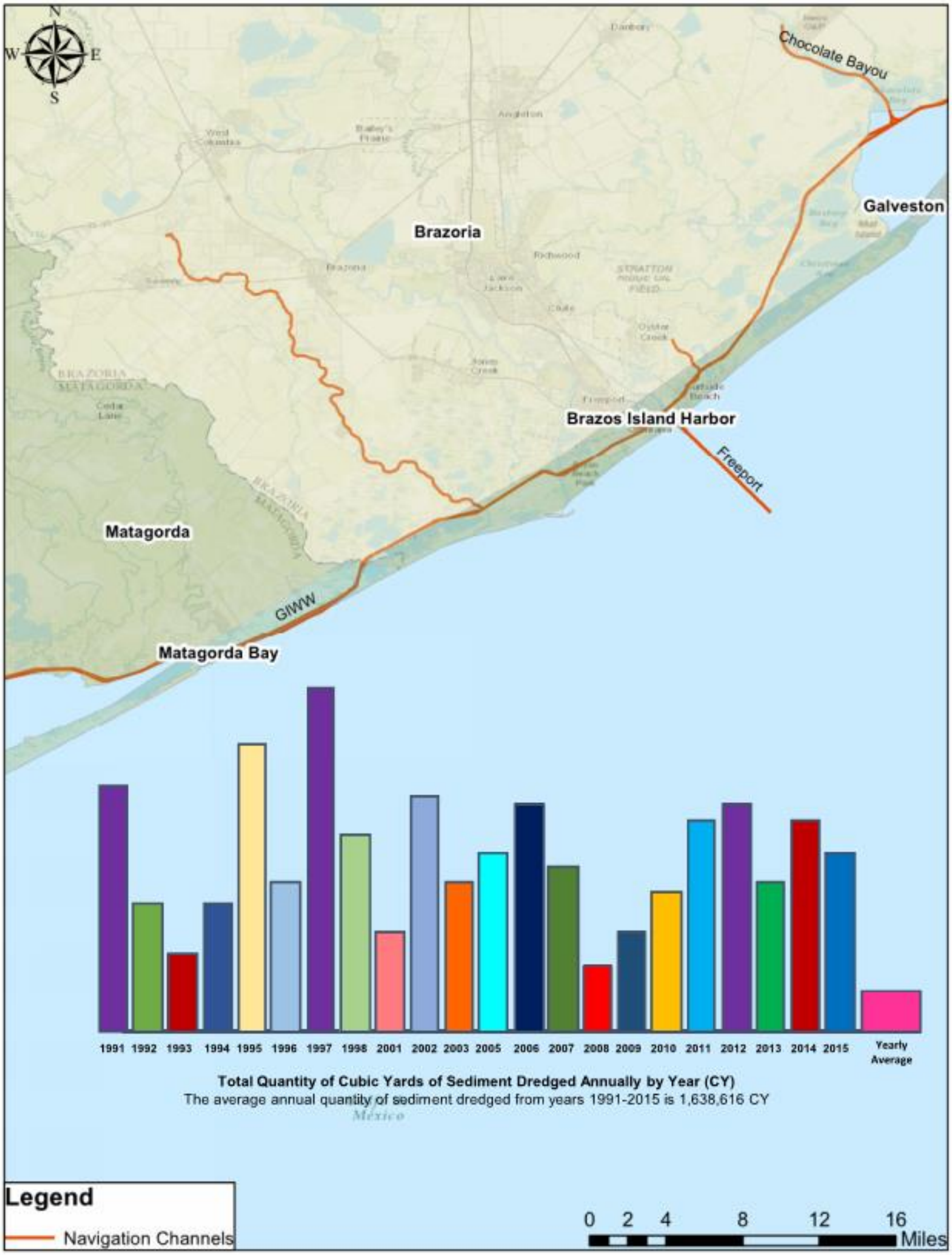


Figure 9-4, USACE Galveston District Total Quantity of Sediment Dredged Annually by Year (CY) for Region 1 Trinity-Galveston Bay (1991-2015).



Total Quantity of Cubic Yards of Sediment Dredged Annually by Year (CY)

The average annual quantity of sediment dredged from years 1991-2015 is 1,638,616 CY

Figure 9-5, USACE Galveston District Total Quantity of Sediment Dredged Annually by Year (CY) for Region 1 Brazos River (1991-2015).

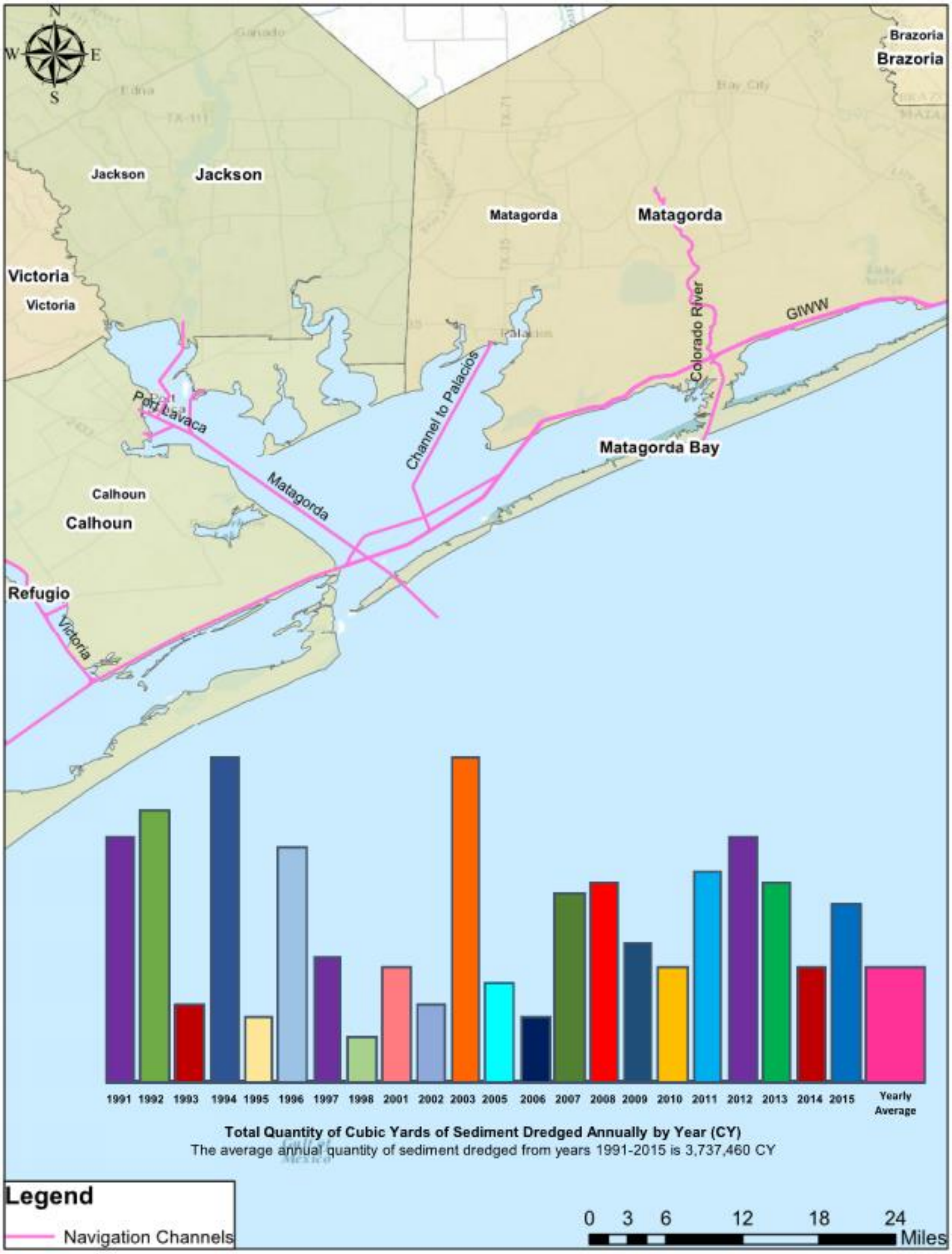


Figure 9-6, USACE Galveston District Total Quantity of Sediment Dredged Annually by Year (CY) for Region 2 Matagorda Bay (1991-2015).

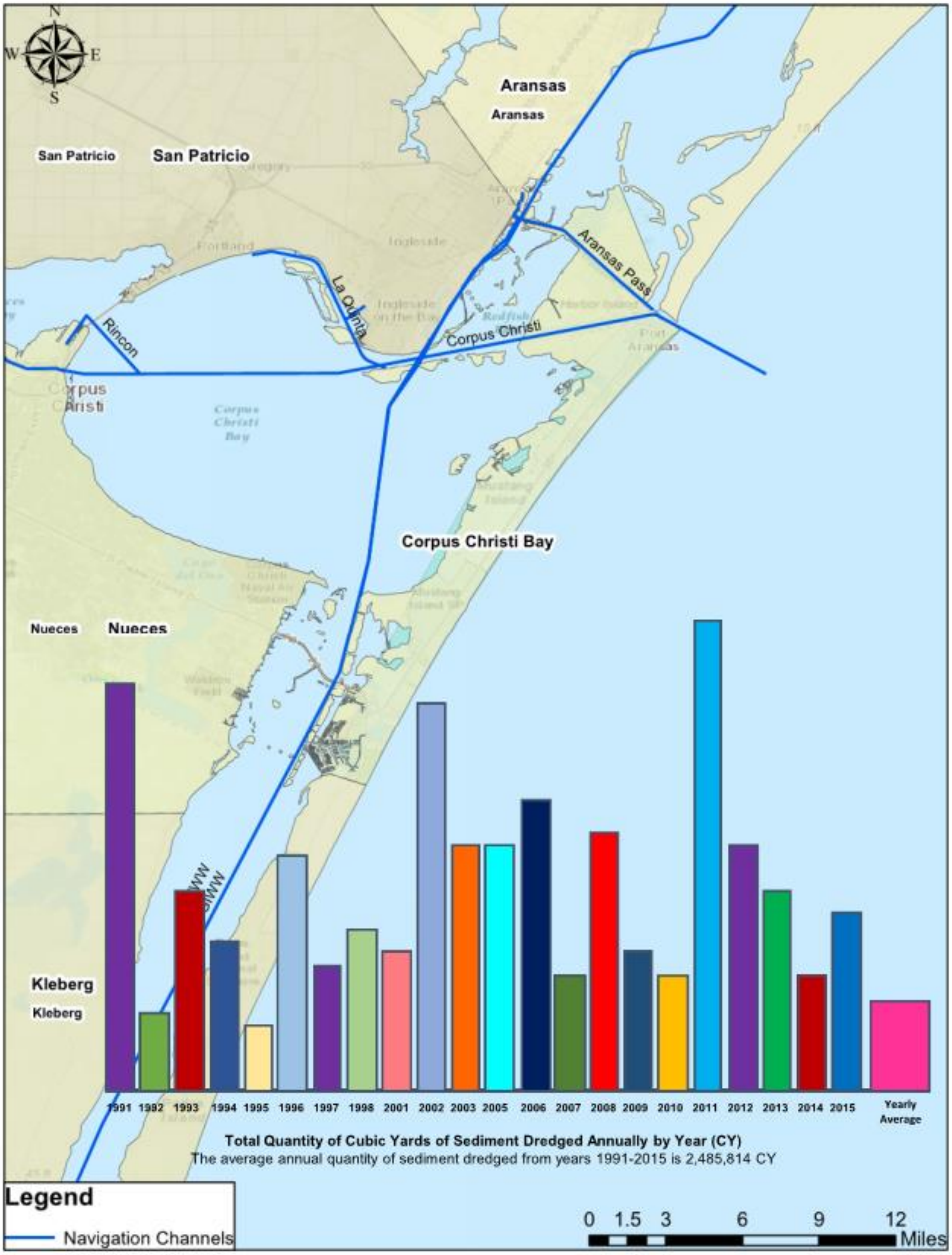


Figure 9-7, USACE Galveston District Total Quantity of Sediment Dredged Annually by Year (CY) for Region 3 Corpus Christi Bay including the GIWW (1991-2015).

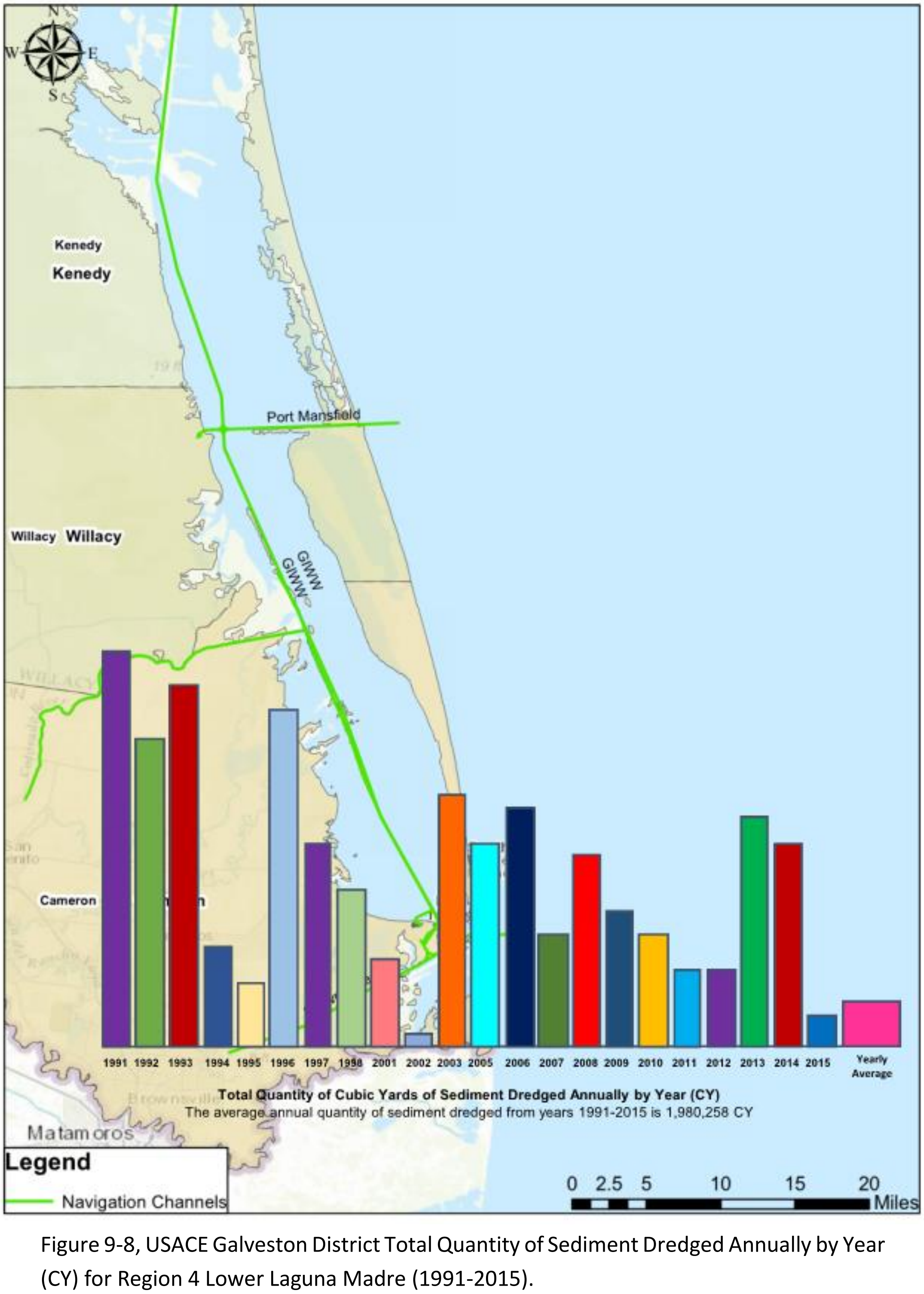


Figure 9-8, USACE Galveston District Total Quantity of Sediment Dredged Annually by Year (CY) for Region 4 Lower Laguna Madre (1991-2015).

9.2 SABINE LAKE

Within Sabine Lake, twenty-two dredging projects were collected from the USACE Navigation Center Database (USACE, 2016) and were imported into ArcGIS (Figure 9-9). The USACE dredged sediment placement areas (represented by red outlined polygons) and navigation channels (represented by blue polylines) were imported into ArcGIS in addition to these dredging projects. The USACE dredged sediment data was symbolized according to the actual quantity of cubic yards dredged during a given year, with green representing the lowest quantity of cubic yards (less than 500,000 cubic yards) and maroon representing the highest quantity of cubic yards (greater than 4.5 million cubic yards).

Based on the assumption, dredging projects that included Latitudes and Longitudes were incorporated into the Sabine Lake analysis for years 1991, 1992, 1994, 1996.

9.2.1 Offshore Data

In Figure 9-9 (shown below), twelve of the twenty-two dredge sediment points are offshore data points. According to the data collected, seven of the eight largest dredge projects (represented in red and maroon) occurred offshore along the Sabine Pass navigation channel; this sediment was most likely transported to the eight nearby offshore placement areas, contributing 5.3 million cubic yards (4 million cubic meters) of sediment in year 1991, 19.3 million cubic yards (14.8 million cubic meters) of sediment in year 1996, and 4.7 million cubic yards (3.6 million cubic meters) of sediment in year 1997, for an estimated total of 29.3 million cubic yards (22.4 million cubic meters) of sediment deposited in the offshore placement areas along the Sabine Pass navigation channel. This does not include the years in the database where latitudes and longitudes were not recorded (1993, 1995, and 1997-2015).

9.2.2 Lower Sabine Pass Data

Ten of the twenty-two dredging locations are in the Lower Sabine Pass (within distance of 15 miles landward of the shoreline), nine of these points follow the Sabine Pass navigation channel traveling to the Gulf of Mexico, and one point follows the GIWW navigation channel traveling to Sabine Lake. According to the data, this one project represents one of the eight largest dredging projects (represented in red) that occurred in the lower bay along the Sabine Pass navigation channel, contributing 1.8 million cubic meters (2.4 million cubic yards) of sediment in year 1992.

The other nine dredging projects occurred in the lower bay, along the GIWW and Sabine Pass navigation channel to the west of Sabine Lake (represented in green, yellow, and orange). According to the dredging database, 3.1 million cubic meters (4.1 million cubic yards) of sediment was dredged in year 1991, 1.5 million cubic meters (1.9 million cubic yards) in year 1992, 2.3 million cubic meters (3 million cubic yards) in year 1993, 840,000 cubic meters (1.1 million cubic yards) in year 1994, for an estimated total of 7.7 million cubic meters (10.1 million cubic yards) of sediment deposited in the lower bay placement areas along the GIWW and Sabine Pass navigation channel. This amount combined with the amounts described above gives an estimated total quantity of 9.6 million cubic meters (12.5 million cubic yards) of sediment deposited in the onshore placement areas along the navigation channels listed above. This does not include the years in the database where latitudes and longitudes were not recorded (1993, 1995, and 1997-2015).

Due to the large amount and vast extent of placement areas across a sixty-five-mile span within Sabine Lake, this sediment could have been placed in any one of eighty placement areas. However, the areas adjacent to the GIWW and Sabine Pass navigation channels have the highest probability of containing the sediment due to their close proximity to the dredging sites.

9.2.3 Upper Sabine Lake Data

Five of the twenty-two dredging locations occurred in the Upper Sabine Lake (represented in green, yellow, and orange). This sediment was likely deposited in the nearby twenty offshore placement areas, contributing 1.4 million cubic meters (1.8 million cubic yards) in year 1991, 1.4 million cubic meters (1.8 million cubic yards) in year 1994, 900,000 cubic meters (1.2 million cubic yards) in year 1995, and 1.4 million cubic meters (1.8 million cubic yards) in year 1996, for an estimated total of 5 million cubic meters (6.6 million cubic yards) of sediment deposited in the Upper Sabine Lake placement areas. This does not include the years in the database where latitudes and longitudes were not recorded (1993, 1995, and 1997-2015).

9.2.4 Conclusion

According to this data, a total estimate of 37 million cubic meters (48.4 million cubic yards) of sediment may be available in placement areas throughout Sabine Lake.

Table 9-1
Sabine Lake Data Overview (1991, 1992, 1994, 1996)

Offshore Projects	Offshore Dredged Material Quantity	Lower Sabine Pass Projects	Lower Sabine Pass Dredged Material Quantity	Upper Sabine Lake Projects	Upper Sabine Lake Dredged Material Quantity	Total Projects	Total Dredged Material Quantity
7	29,296,080 yd^3	10	12,491,053 yd^3	5	6,602,236 yd^3	22	48,387,133 yd^3
7	22,523,975 m^3	10	9,556,936 m^3	5	5,023,156 m^3	22	37,004,455 m^3

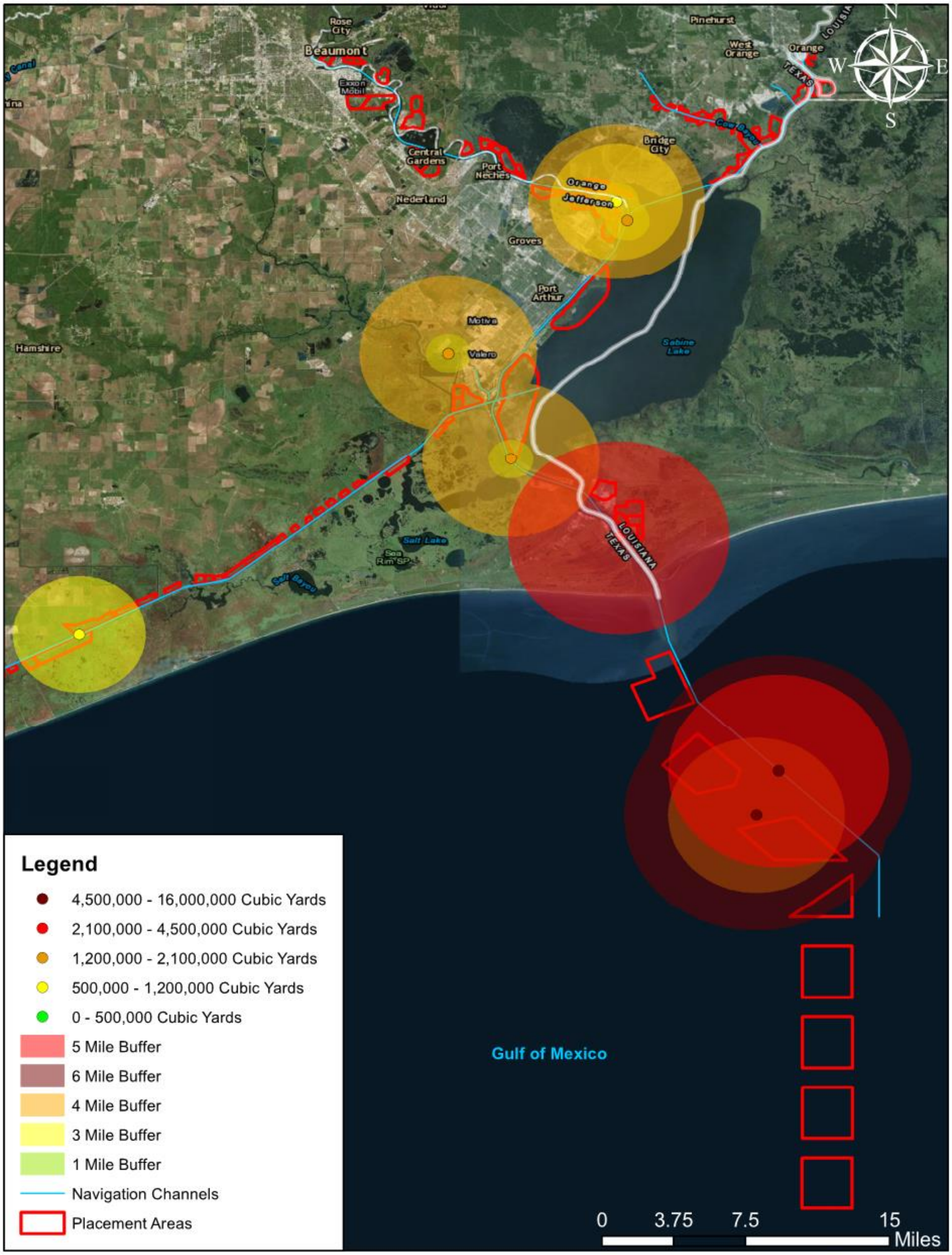


Figure 9-9, Sabine Lake Dredge Volumes (1991, 1992, 1994, and 1996).

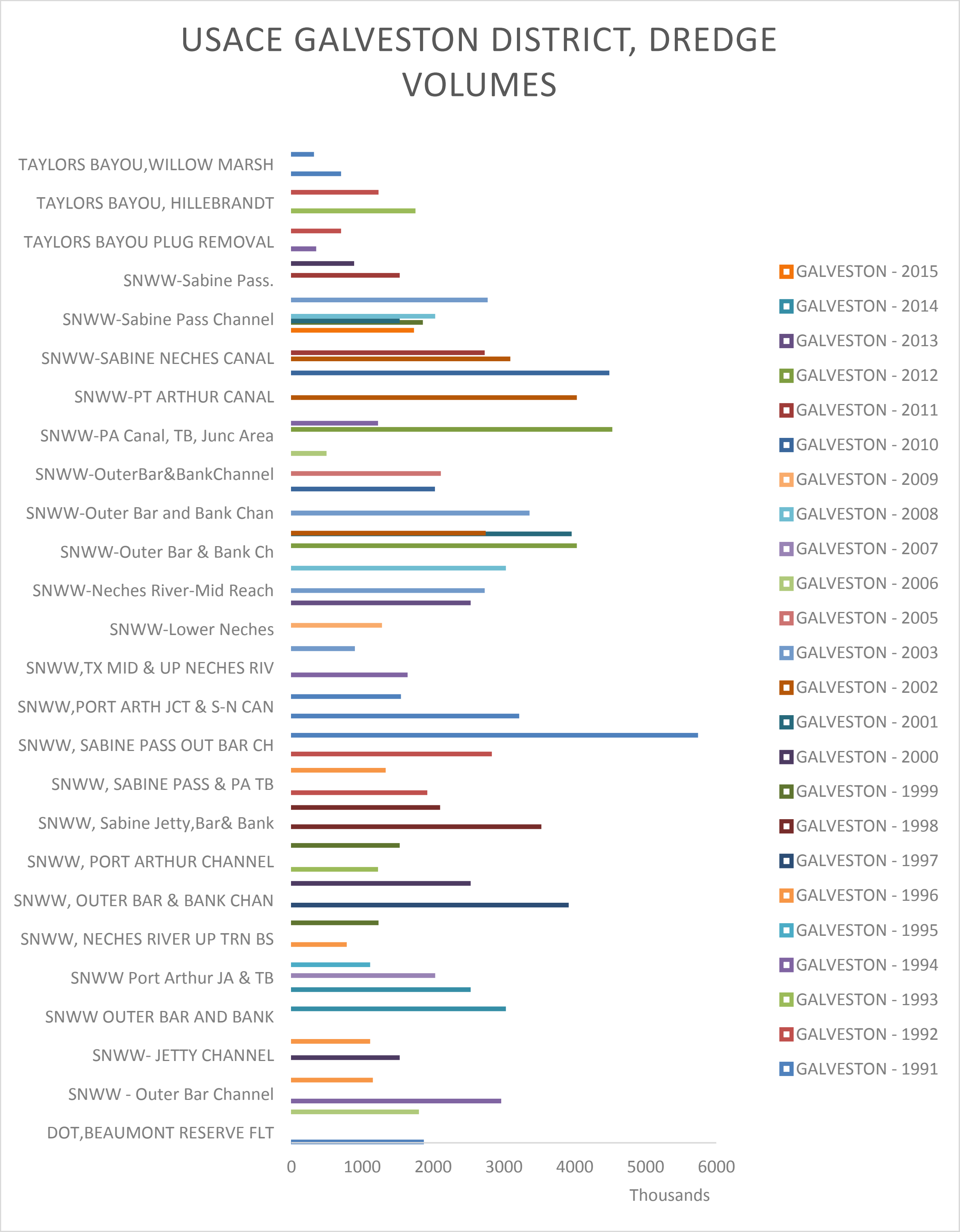


Figure 9-10, Sabine Lake System Dredge Volumes

9.3 TRINITY-GALVESTON BAY

Within Trinity-Galveston Bay, twenty-eight dredging projects were collected from the USACE Navigation Center Database (USACE, 2016) and imported into ArcGIS (Figure 9-11). The USACE dredged sediment placement areas (represented by red outlined polygons) and navigation channels (represented by blue polylines) were imported into ArcGIS in addition to these data points. The USACE dredged sediment data was symbolized according to the actual quantity of cubic yards dredged during a given year, with green representing the lowest quantity of cubic yards (less than 500,000 cubic yards) and maroon representing the highest quantity of cubic yards (greater than 4.5 million cubic yards).

Based on the assumption, dredging projects that included latitudes and longitudes were incorporated into the Trinity-Galveston Bay analysis for years 1991, 1994, 1996-1997, and 2000-2001.

9.3.1 Offshore Data

In Figure 9-11 (shown below), two of the twenty-eight dredge sediment points are offshore projects. According to the data collected, these points represent two of the nine largest dredging projects that occurred offshore along the Galveston Ship Channel and the Houston Ship Channel (represented in red). This sediment was likely transported to the three nearby offshore placement areas, contributing 2.2 million cubic meters (2.9 million cubic yards) of sediment in year 1993 and 2 million cubic meters (2.6 million cubic yards) of sediment in year 1997, for an estimated total of 2.4 million cubic meters (3.1 million cubic yards) of sediment deposited in the ocean disposal placement areas outside the Galveston Ship Channel and Houston Ship Channel. This does not include the years in the database where latitudes and longitudes were not recorded (years 1992-1993, 1995, 1998-1999, and 2002-2015).

9.3.2 Lower Galveston Bay Data

Thirteen of the twenty-eight dredging locations occurred in Lower Galveston Bay (within a distance of 15 miles landward of the shoreline). One of these projects follows the Chocolate Bayou navigation channel, seven follow the GIWW navigation channel traveling along the Galveston coast line, four follow the Galveston Ship Channel, and one project follows the lower Houston Ship Channel in Galveston Bay. According to the data, two of these projects represent two of the nine largest onshore dredging projects that occurred along the Galveston Ship Channel in Trinity-Galveston Bay (represented in maroon). This sediment was likely deposited in the thirty-two nearby onshore placement areas, contributing 3.9 million cubic meters (5.1 million cubic yards) of sediment in year 1994 and 4.2 million cubic meters (5.5 million cubic yards) of sediment in year 1997, for an estimated total of 8.1 million cubic meters (10.6 million cubic yards) of sediment deposited.

The other eleven dredging projects occurred in the Lower Galveston Bay along the navigation channels listed above (represented in green, yellow, and orange). According to the data collected, 1.9 million cubic meters (2.5 million cubic yards) of sediment was contributed in year 1991, 2.4 million cubic meters (3.2 million cubic yards) in year 1992, 1.6 million cubic meters (2.1 million cubic yards) in year 1993, 3.3 million cubic meters (4.3 million cubic yards) in year 1996, and 380,000 cubic meters (500,000 cubic yards) in year 1997, for a total of 9.6 million cubic meters (12.5 million cubic yards) of sediment deposited in the Lower Bay along the Galveston coast line. This amount combined with the amounts described above gives an estimated total quantity of 17.5 million cubic meters (23 million cubic yards) of sediment dredged throughout the Lower Galveston Bay. This does not include the years in the database where latitudes and longitudes were not recorded (years 1992-1993, 1995, 1998-1999, and 2002-2015).

Due to the large amount and vast extent of placement areas across a fifty-mile span in Trinity-Galveston Bay, this sediment could have been placed in any one of seventy placement areas. However, the areas adjacent to navigation channels list above have the highest probability of containing the sediment due to their close proximity to the dredging sites.

9.3.3 Upper Trinity Bay Data

Thirteen of the twenty-eight dredging projects occurred upland (out beyond a distance of 15 miles from the shoreline), one of these projects follows the Buffalo Bayou navigation channel, two follow along the Trinity River, and nine follow the upper Houston Ship Channel. According to the data, five of these projects represent five of the nine largest dredging projects that occurred in the Upper Trinity Bay (represented in red and maroon), contributing 2.3 million cubic meters (3 million cubic yards) of sediment in year 1992, 1.8 million cubic meters (2.3 million cubic yards) in year 1993, 2.9 million cubic meters (3.8 million cubic yards) in year 1994, 1.9 million cubic meters (2.5 million cubic yards) in year 1997, and 6.9 million cubic meters (9 million cubic yards) in year 2000, for an estimated total of 15.7 million cubic meters (20.6 million cubic yards) of sediment deposited.

The other eleven dredging projects occurred in the Upper Trinity Bay along the navigation channels listed above (represented in green, yellow, and orange). According to the data, 440,000 cubic meters (580,000 cubic yards) of sediment was dredged in year 1991, 560,000 cubic meters (730,000 cubic yards) in year 1992, 2.3 million cubic meters (3 million cubic yards) in 1994, 600,000 cubic meters (800,000 cubic yards) in 1996, 1 million cubic meters (1.4 million cubic yards) in year 1997, 200,000 cubic meters (270,000 cubic yards) in year 2000, and 12.2 million cubic meters (16 million cubic yards) in year 2001, for an estimated total of 17.6 million cubic meters (23 million cubic yards) of sediment deposited in the Upper Trinity Bay placement areas. This amount combined with the amounts described above gives an estimated total quantity of 33.1 million cubic meters (43.3 million cubic yards) of sediment dredged in the Upper Trinity Bay of Trinity-Galveston Bay. This does not include the years in the database where latitudes and longitudes were not recorded (years 1992-1993, 1995, 1998-1999, and 2002-2015).

Due to the large amount and vast extent of placement areas across a forty-five-mile span in Trinity-Galveston Bay, this sediment could have been placed in any one of fifty-five placement areas. However, the areas adjacent to navigation channels list above have the highest probability of containing the sediment due to their close proximity to the dredging sites.

9.3.4 Conclusion

According to this data, a total estimate of 53.2 million cubic meters (69.6 million cubic yards) of sediment may be available in placement areas throughout Trinity-Galveston Bay.

Table 9-2
Trinity-Galveston Bay Data Overview (1991, 1994, 1996-1997, and 2000-2001)

Offshore Projects	Offshore Dredged Material Quantity	Lower Galveston Bay Projects	Lower Galveston Bay Dredged Material Quantity	Upper Trinity Bay Projects	Upper Trinity Bay Dredged Material Quantity	Total Projects	Total Dredged Material Quantity
2	3,145,154 yd^3	13	23,126,570 yd^3	13	43,351,692 yd^3	22	69,623,416 yd^3
2	2,404,643 m^3	13	17,584,762 m^3	13	33,105,225 m^3	22	53,213,018 m^3

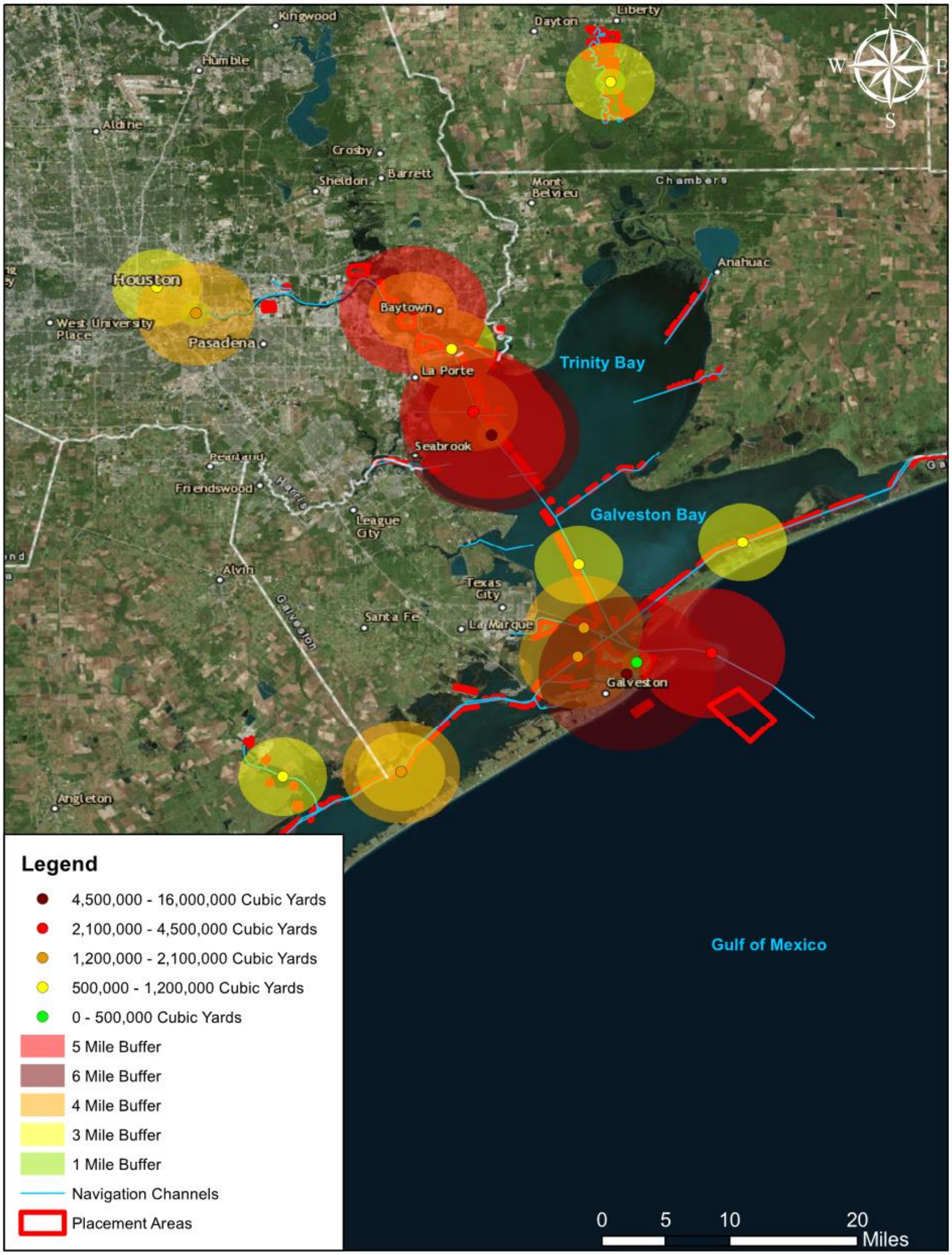


Figure 9-11, Trinity-Galveston Bay Dredge Volumes (1991, 1994, 1996-1997, and 2000-2001).

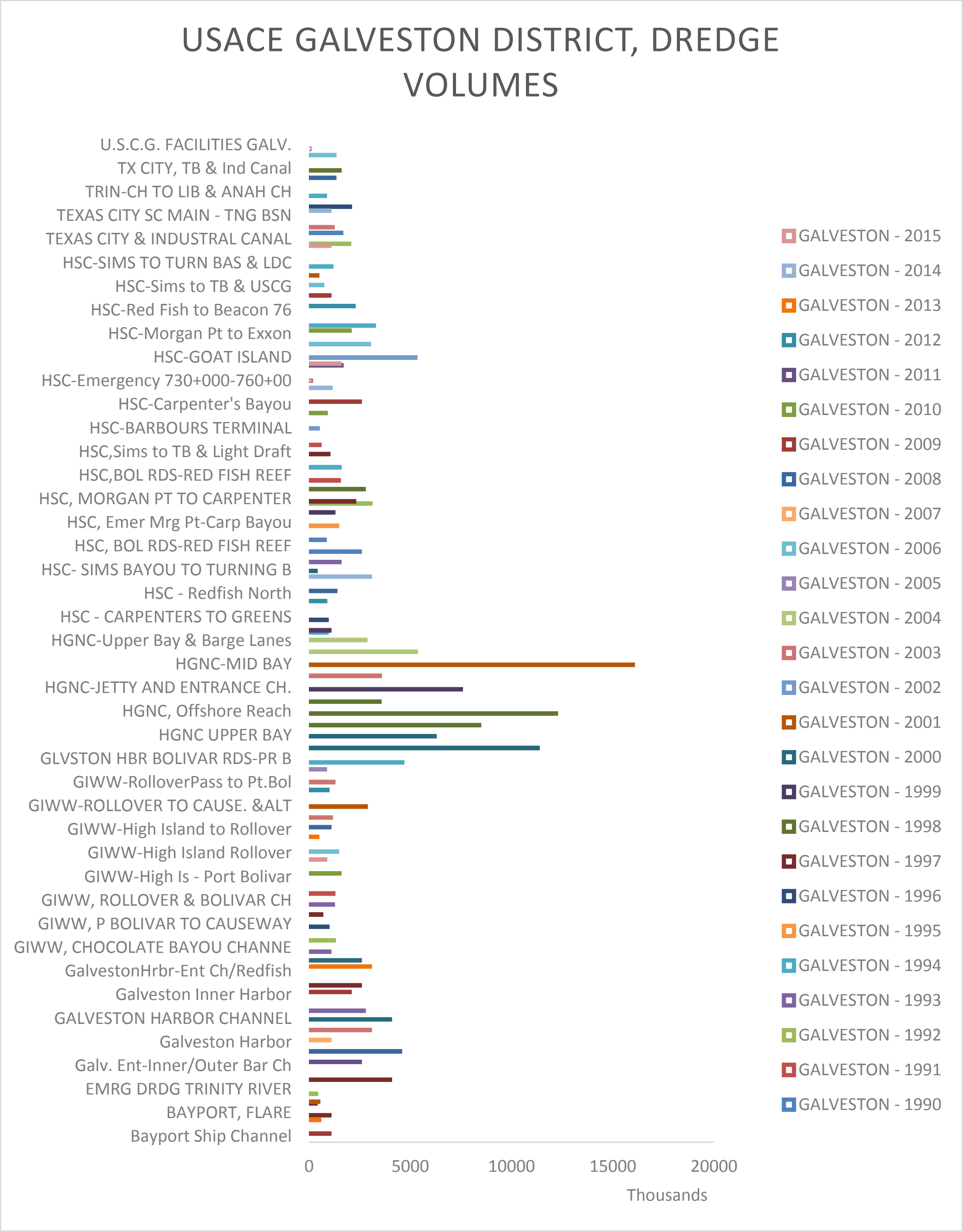


Figure 9-12, Trinity-Galveston Bay Dredge Volumes

9.4 BRAZOS RIVER SYSTEM

Within the Brazos River System, thirteen dredging projects were collected from the USACE Navigation Center Database (USACE, 2016) and imported into ArcGIS (Figure 8-13). The USACE dredged sediment placement areas (represented by red outlined polygons) and navigation channels (represented by blue polylines) were imported into ArcGIS in addition to these dredging projects. The USACE dredged sediment data was symbolized according to the actual quantity of cubic yards dredged during a given year, with green representing the lowest quantity of cubic yards (less than 500,000 cubic yards) and maroon representing the highest quantity of cubic yards (greater than 4.5 million cubic yards).

Based on the assumption, dredging projects that included Latitudes and Longitudes were incorporated into the Brazos River System analysis for years 1991, 1994, and 1996-1998.

9.4.1 Offshore Data

In Figure 8-13 (shown below), three of the thirteen dredging locations are considered offshore projects. According to the data, these points represent three of the six largest dredging projects that occurred offshore along the Freeport navigation channel (represented in red and maroon). This sediment was likely transported to the two nearby offshore placement areas, contributing 2.2 million cubic meters (2.9 million cubic yards) of sediment in year 1992, 2 million cubic meters (2.6 million cubic yards) of sediment in year 1994, and 1.9 million cubic meters (2.5 million cubic yards) of sediment for an estimated total of 6.1 million cubic meters (8 million cubic yards) of sediment deposited in the ocean disposal placement areas outside the Freeport navigation channel near the mouth of the Brazos River in Freeport, Texas. This does not include the years in the database where latitudes and longitudes were not recorded (1992-1993, 1995, and 1999-2015).

9.4.2 Lower Brazos River System Data

Ten of the thirteen dredging locations occurred in the Lower Brazos River System (within distance of 15 miles landward of the shoreline) and follow the GIWW navigation channel from Surfside Beach to Cedar Lake Creek. According to the data, three of these ten projects represent three of the six largest dredging projects that occurred in the Lower Brazos River System along the navigation channel listed above (represented in red and maroon). This sediment was likely deposited in the thirty nearby onshore placement areas, contributing 3.6 million cubic meters (4.7 million cubic yards) of sediment in year 1991, 1.8 million cubic meters (2.3 million cubic yards) in year 1997, and 1.8 million cubic meters (2.3 million cubic yards) of sediment in year 1998, for an estimated total of 7.1 million cubic yards (9.3 million cubic yards) of sediment deposited.

The other seven dredging locations occurred in the Lower Brazos River System along the navigation channel listed above (represented in green, yellow, and orange). According to the data, 230,000 cubic meters (300,000 cubic yards) of sediment was dredged in year 1991, 900,000 cubic meters (1.2 million cubic yards) in year 1992, 1.8 million cubic meters (2.4 million cubic yards) in year 1993, 700,000 cubic meters (920,000 cubic yards) in 1996, and 1.5 million cubic meters (1.9 million cubic yards) in 1997, for a total of 5.2 million cubic meters (6.8 million cubic yards) of sediment deposited in the Lower Brazos River System placement areas along the GIWW navigation channel from Surfside Beach to Cedar Lake Creek. This amount combined with the amounts described above gives an estimated total quantity of 12.4 million cubic meters (16.2 million cubic yards) of sediment deposited throughout the Lower Bay placement areas in the Brazos River System. This does not include the years in the database where latitudes and longitudes were not recorded (1992-1993, 1995, and 1999-2015).

Due to the large amount and vast extent of placement areas across a thirty-mile span in the Brazos River System, this sediment could have been deposited in any one of thirty placement areas. However, the areas adjacent to navigation channels list above have the highest probability of containing the sediment due to their close proximity to the dredging sites.

9.4.3 Conclusion

According to this data, a total estimate of 18.5 million cubic meters (24.2 million cubic yards) of sediment may be available in placement areas throughout the Brazos River System.

Table 9-3

Brazos River System Data Overview (1991, 1994, and 1996-1998)

Offshore Projects	Offshore Dredged Material Quantity	Lower Brazos River System Projects	Lower Brazos River System Dredged Material Quantity	Upper Brazos River System Projects	Upper Brazos River System Dredged Material Quantity	Total Projects	Total Dredged Material Quantity
3	8,008,304 yd^3	10	16,226,522 yd^3	0	0 yd^3	13	24,234,826 yd^3
3	6,116,439 m^3	10	12,385,789 m^3	0	0 m^3	13	18,502,228 m^3

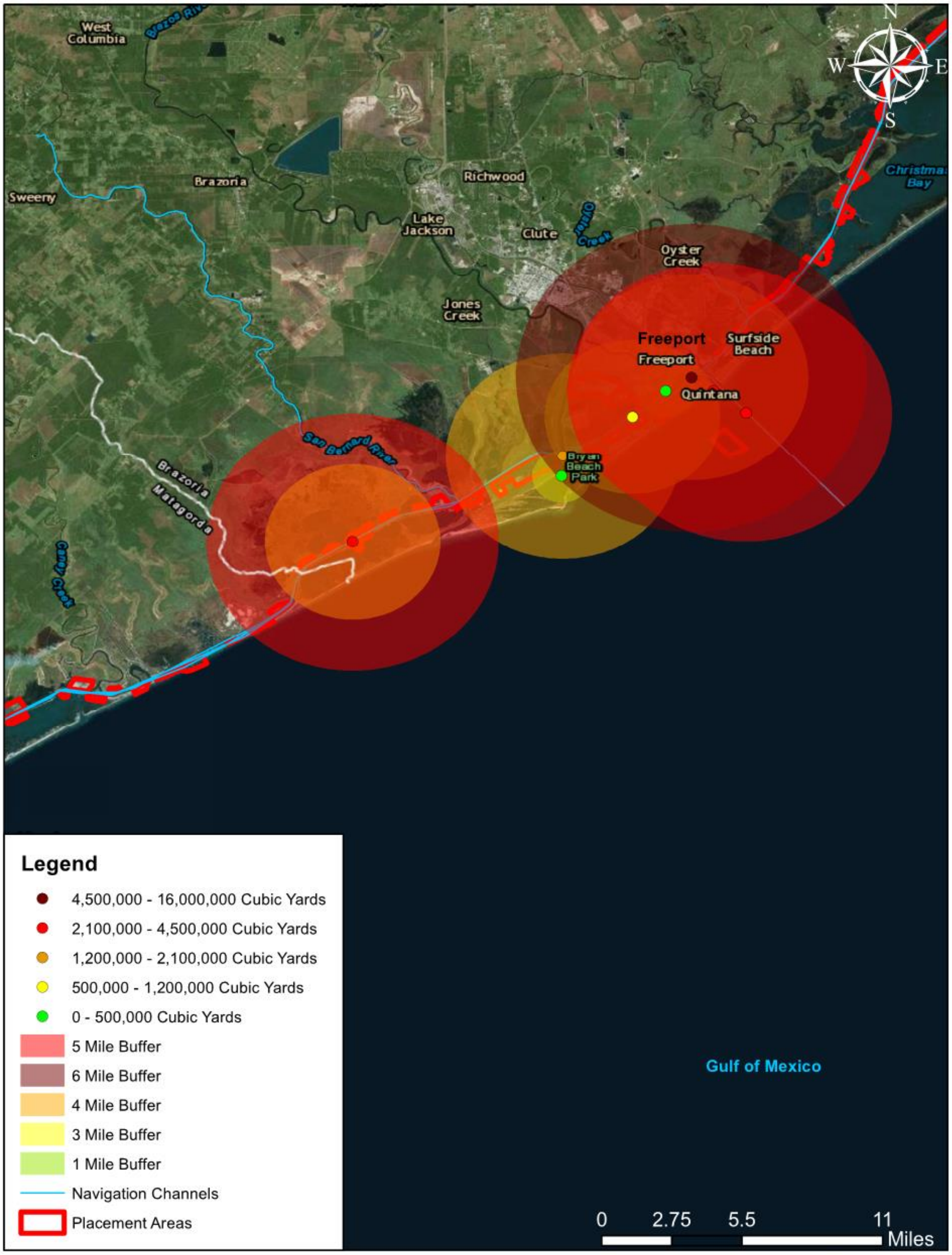


Figure 9-13, Brazos River System Dredge Volumes (1991, 1994, and 1996-1998).

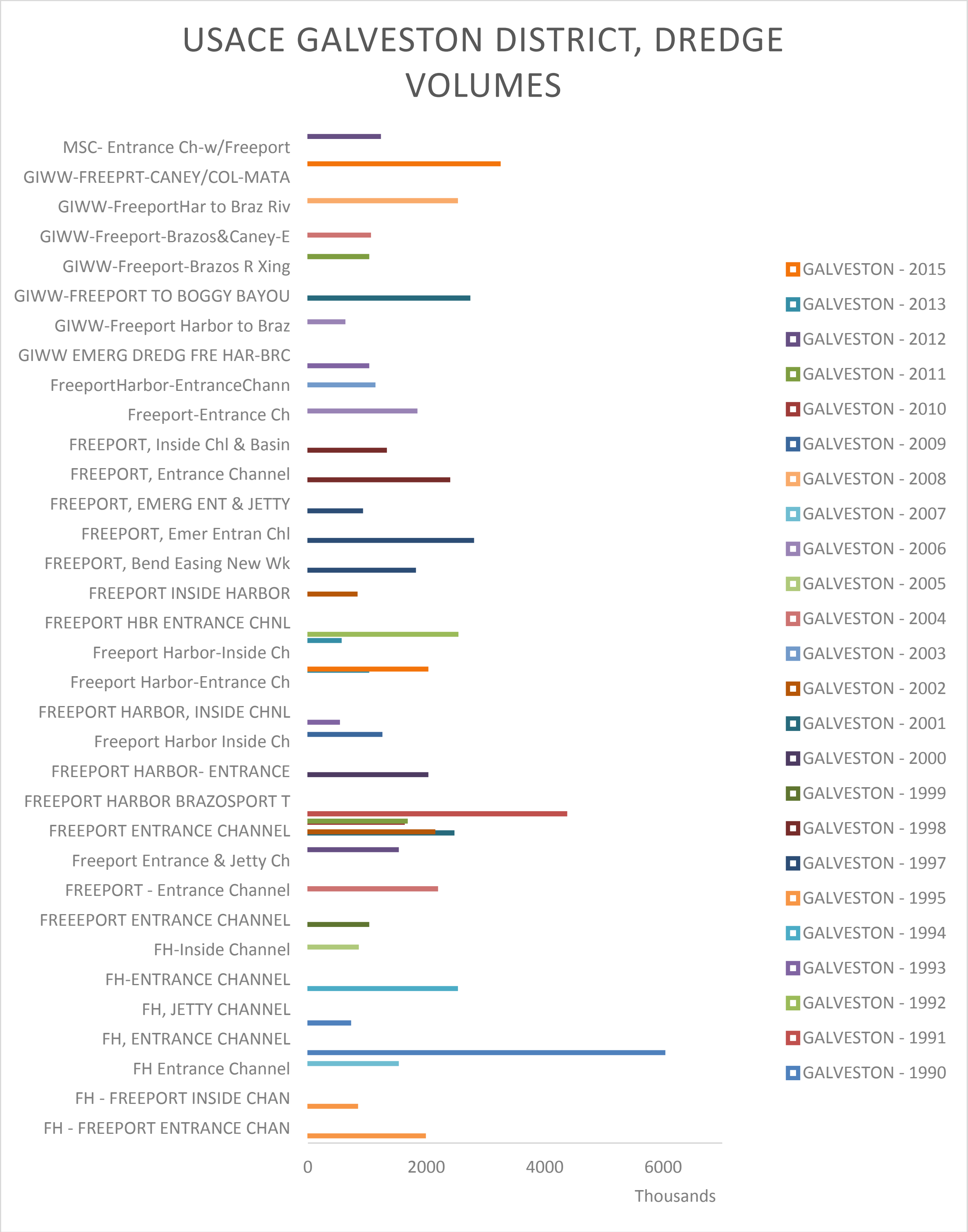


Figure 9-14, Brazos River System Dredge Volumes

9.5 MATAGORDA BAY

Within Matagorda Bay, twenty-three dredging projects were collected from the USACE Navigation Center Database (USACE, 2016) and imported into ArcGIS (Figure 9-15). The USACE dredged sediment placement areas (represented by red outlined polygons) and navigation channels (represented by blue polylines) were imported into ArcGIS in addition to these dredging projects. The USACE dredged sediment data was symbolized according to the actual quantity of cubic yards dredged during a given year, with green representing the lowest quantity of cubic yards (less than 500,000 cubic yards) and maroon representing the highest quantity of cubic yards (greater than 4.5 million cubic yards).

Based on the assumption, dredging projects that included Latitudes and Longitudes were incorporated into the Matagorda Bay analysis for years 1991-1998.

9.5.1 Offshore Data

In Figure 8-15 (shown below), one of the twenty-three dredging locations is an offshore project. According to the data, this dredge project occurred offshore in the Gulf of Mexico (represented in green); this sediment was likely transported to the two offshore placement areas near the lower portion of the Matagorda navigation channel, contributing 380,000 cubic meters (500,000 cubic yards) of sediment in year 1995. This does not include the years in the database where latitudes and longitudes were not recorded (1999-2015).

9.5.2 Lower Matagorda Bay Data

Seventeen of the twenty-three dredge dredging locations occurred in Lower Matagorda Bay (within distance of 15 miles landward of the shoreline). Eight of these projects follow the GIWW navigation channel along the Gulf of Mexico, five follow the Colorado River navigation channel, three projects follow the Matagorda navigation channel in Matagorda Bay, and one follows the navigation channel to Palacios. According to the data, three large dredging projects occurred in Lower Matagorda Bay (represented in red and maroon). This sediment was likely transported to any one of the fifty nearby onshore placement areas, contributing 3.9 million cubic meters (5.1 million cubic yards) of sediment in year 1991, 5 million cubic meters (6.6 million cubic yards) in year 1994, and 2.2 million cubic meters (2.9 million cubic yards) of sediment in year 1998, for an estimated total of 11.1 million cubic meters (14.6 million cubic yards) of sediment dredged.

The other nine dredging locations occurred in Lower Matagorda Bay along the navigation channels listed above (represented in green, yellow, and orange). According to the data, 4.7 million cubic meters (6.1 million cubic yards) of sediment was contributed in year 1992, 2 million cubic meters (2.7 million cubic yards) in year 1994, 900,000 cubic meters (1.2 million cubic yards) in year 1996, 2.2 million cubic meters (2.9 million cubic yards) in 1997, for a total of 9.9 million cubic meters (12.9 million cubic yards) of sediment. This amount combined with the amounts described above gives an estimated total quantity of 21.1 million cubic meters (27.6 million cubic yards) of sediment placed in the Lower Matagorda Bay placement areas. This does not include the years in the database where latitudes and longitudes were not recorded (1999-2015).

Due to the large amount and vast extent of placement areas across a sixty-mile span in Matagorda Bay, this sediment could have been placed in any one of fifty-five placement areas. However, the areas adjacent to navigation channels list above have the highest probability of containing the sediment due to their close proximity to the dredging sites.

9.5.3 Upper Matagorda Bay Data

Five of the twenty-three dredging locations occurred in Upper Matagorda Bay (out beyond a distance of 15 miles from the shoreline), one of these projects follows the navigation channel to Redbluff and four follow the Colorado River navigation channel. None of these projects represented large dredging project sites (represented in red or maroon). According to the data collected, 730,000 cubic meters (950,000 cubic yards) of sediment was deposited in year 1992, 570,000 cubic meters (750,000 cubic yards) in year 1993, 230,000 cubic meters (300,000 cubic yards) in 1994, and 150,000 cubic meters (200,000 cubic yards) in year 1997, for an estimated total of 1.7 million cubic meters (2.2 million cubic yards) of sediment dredged in the Upper Matagorda Bay placement areas. This does not include the years in the database where latitudes and longitudes were not recorded (1999-2015).

This sediment was most likely placed in any one of ten placement areas adjacent to the navigation channels listed above. The placement areas closet in proximity to the dredging sites have the highest probability of containing the sediment.

9.5.4 Conclusion

According to this data, a total estimate of 23.2 million cubic meters (30.3 million cubic yards) of sediment may be available in placement areas throughout Matagorda Bay .

Table 9-3

Matagorda Bay Data Overview (1991-1998)

Offshore Projects	Offshore Dredged Material Quantity	Lower Matagorda Bay Projects	Lower Matagorda Bay Dredged Material Quantity	Upper Matagorda Bay Projects	Upper Matagorda Bay Dredged Material Quantity	Total Projects	Total Dredged Material Quantity
3	8,008,304 yd^3	10	16,226,522 yd^3	0	0 yd^3	13	24,234,826 yd^3
3	6,116,439 m^3	10	12,385,789 m^3	0	0 m^3	13	18,502,228 m^3

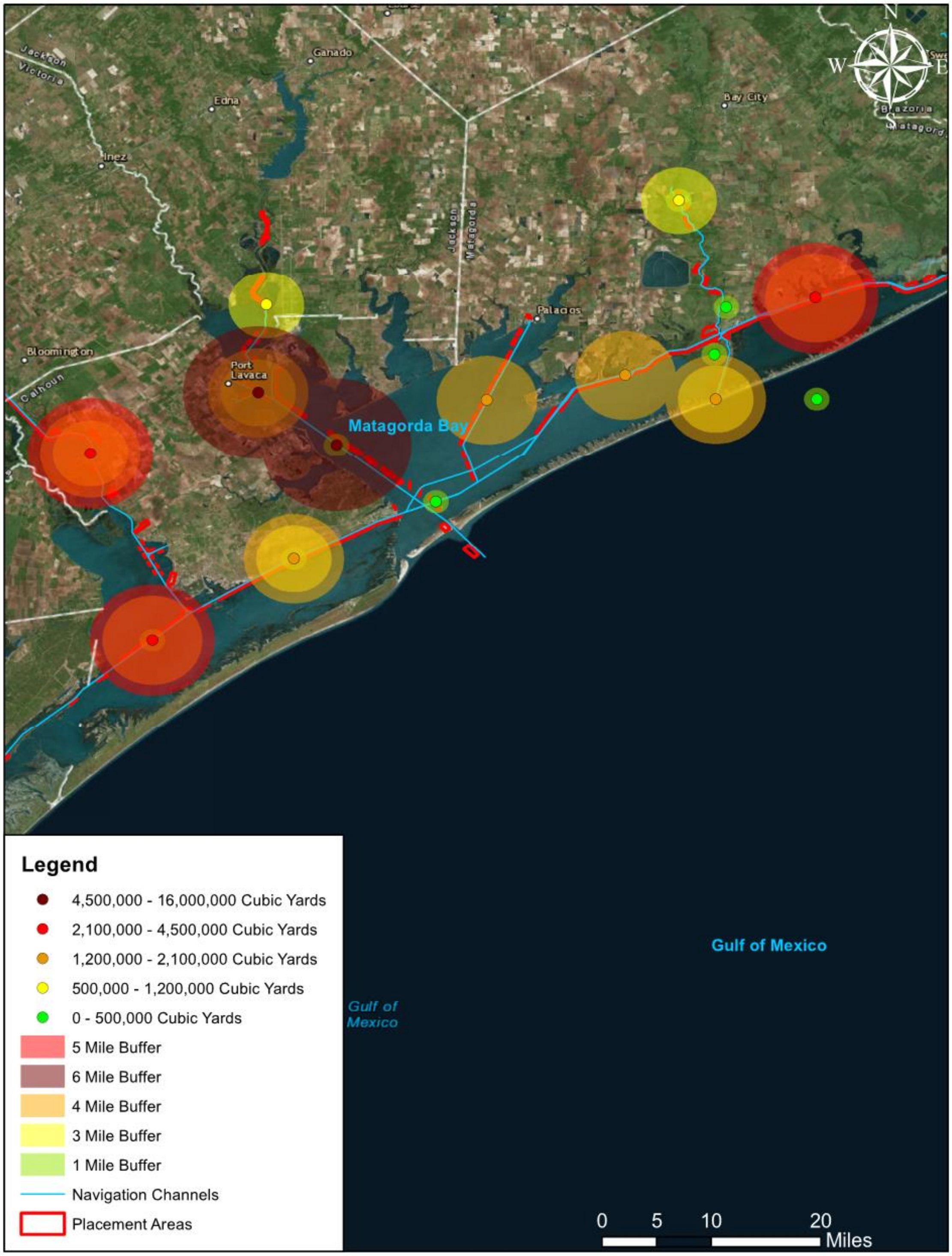


Figure 9-15, Matagorda Bay Dredge Volumes (1991-1998).

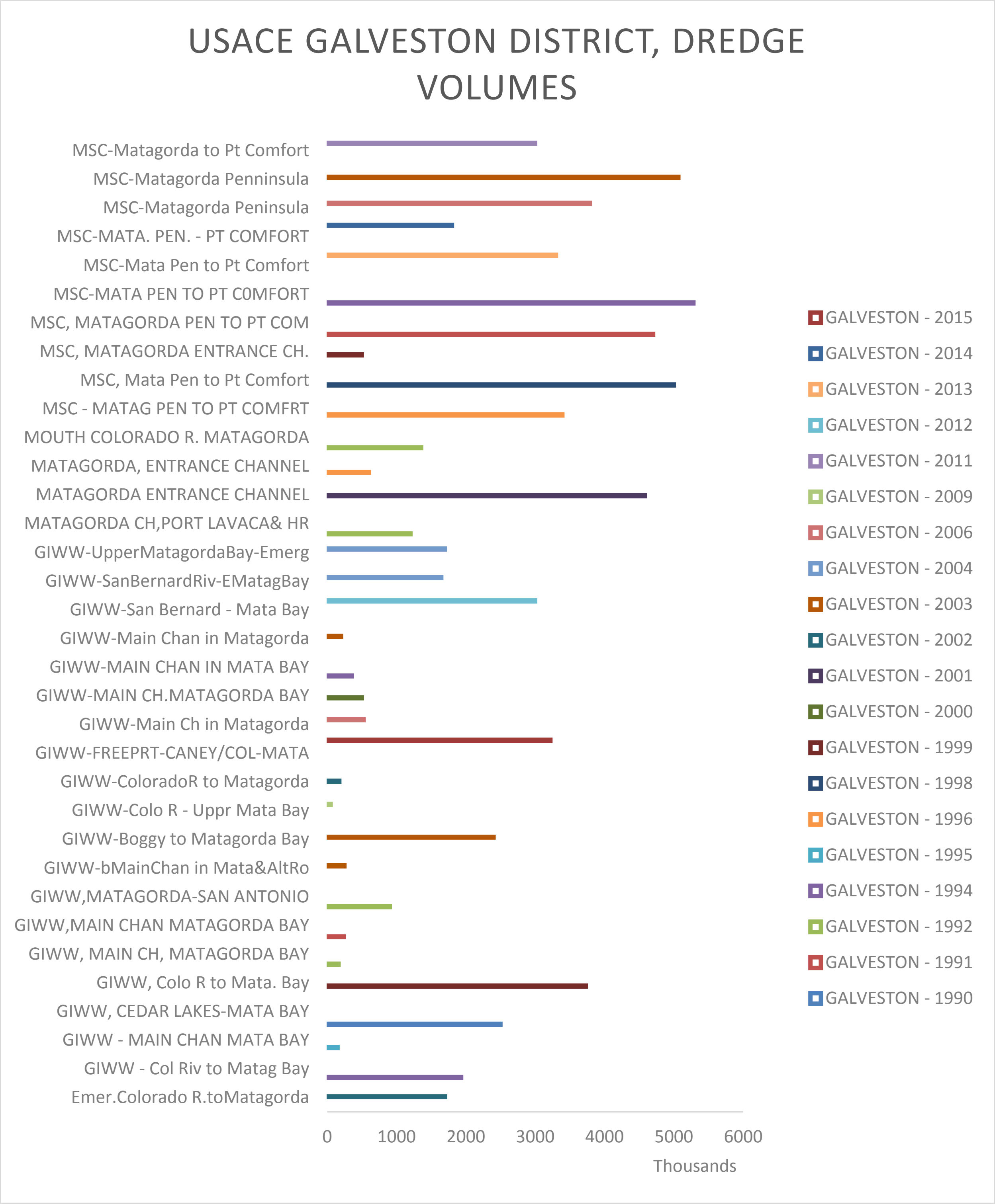


Figure 9-16, Matagorda Bay Dredge Volumes

9.6 CORPUS CHRISTI BAY

Within Corpus Christi Bay, eleven dredging projects were collected from the USACE Navigation Center Database (USACE, 2016) and were imported into ArcGIS (Figure 9-17). The USACE dredged sediment placement areas (represented by red outlined polygons) and navigation channels (represented by blue polylines) were imported into ArcGIS in addition to these dredging projects. The USACE dredged sediment data was symbolized according to the actual quantity of cubic yards dredged during a given year, with green representing the lowest quantity of cubic yards (less than 500,000 cubic yards) and maroon representing the highest quantity of cubic yards (greater than 4.5 million cubic yards).

Based on the assumption, dredging projects that included Latitudes and Longitudes were incorporated into the Corpus Christi Bay analysis for years 1991-1994, 1996, and 1998.

9.6.1 Lower Corpus Christi Bay Data

Eight of the eleven dredging locations are in Lower Corpus Christi Bay (within distance of 15 miles landward of the shoreline), two of these projects follow the GIWW navigation channel, one follows the Aransas Pass navigation channel, six follow the Corpus Christi navigation channel, and two follow the La Quinta navigation channel. According to the data, two of these projects represent the largest dredging projects (represented in red) that occurred in Lower Corpus Christi Bay along the La Quinta navigation channel, contributing 2 million cubic meters (2.7 million cubic yards) of sediment in year 1991 and 2 million cubic meters (2.7 million cubic yards) in year 1996.

The other six dredging projects occurred in Lower Corpus Christi Bay, along the GIWW navigation channel and the Aransas Pass navigation channel (represented in green, yellow, and orange). According to the dredging database, 3.1 million cubic meters (1.7 million cubic yards) of sediment was dredged in year 1992, 150,000 cubic meters (200,000 cubic yards) in year 1993, and 460,000 cubic meters (600,000 cubic yards) in year 199, for an estimated total of 1.9 million cubic meters (2.5 million cubic yards) of sediment deposited in Lower Corpus Christi Bay placement areas along the GIWW and Sabine Pass navigation channel. This amount combined with the amounts described above gives an estimated total quantity of 7.3 million cubic meters (9.5 million cubic yards) of sediment deposited in the Lower Corpus Christi Bay placement areas along the navigation channels listed above. This does not include the years in the database where latitudes and longitudes were not recorded (1995, 1997, 1999-2015).

Due to the large amount and vast extent of placement areas across a sixty-five-mile span in Corpus Christi Bay, this sediment could have been placed in any one of forty placement areas. However, the areas adjacent to the GIWW and Aransas Pass navigation channels have the highest probability of containing the sediment due to their close proximity to the dredging sites.

9.6.2 Upper Corpus Christi Bay Data

Three of the eleven dredging locations occurred in Upper Corpus Christi Bay (represented in green, yellow, and orange). This sediment was likely deposited in the nearby ten offshore placement areas, contributing 1.3 million cubic meters (1.8 million cubic yards) in year 1991, 1.2 million cubic meters (1.7 million cubic yards) in year 1994, and 1.4 million cubic meters (1.9 million cubic yards) in year 1998, for an estimated total of 4.1 million cubic meters (5.4 million cubic yards) of sediment deposited in the Upper Bay placement areas. This does not include the years in the database where latitudes and longitudes were not recorded (1995, 1997, 1999-2015

9.6.3 Conclusion

According to this data, a total estimate of 13 million cubic meters (17.3 million cubic yards) of sediment may be available in placement areas throughout Corpus Christi Bay.

Table 9-4
Corpus Christi Bay Data Overview (1991-1994, 1996, and 1998)

Offshore Projects	Offshore Dredged Material Quantity	Lower Corpus Christi Bay Projects	Lower Corpus Christi Bay Dredged Material Quantity	Upper Corpus Christi Bay Projects	Upper Corpus Christi Bay Dredged Material Quantity	Total Projects	Total Dredged Material Quantity
0	0 yd^3	8	9,591,053 yd^3	3	5,432,405 yd^3	11	15,387,133 yd^3
0	0 m^3	8	7,356,936 m^3	3	4,128,595 m^3	11	11,004,455 m^3

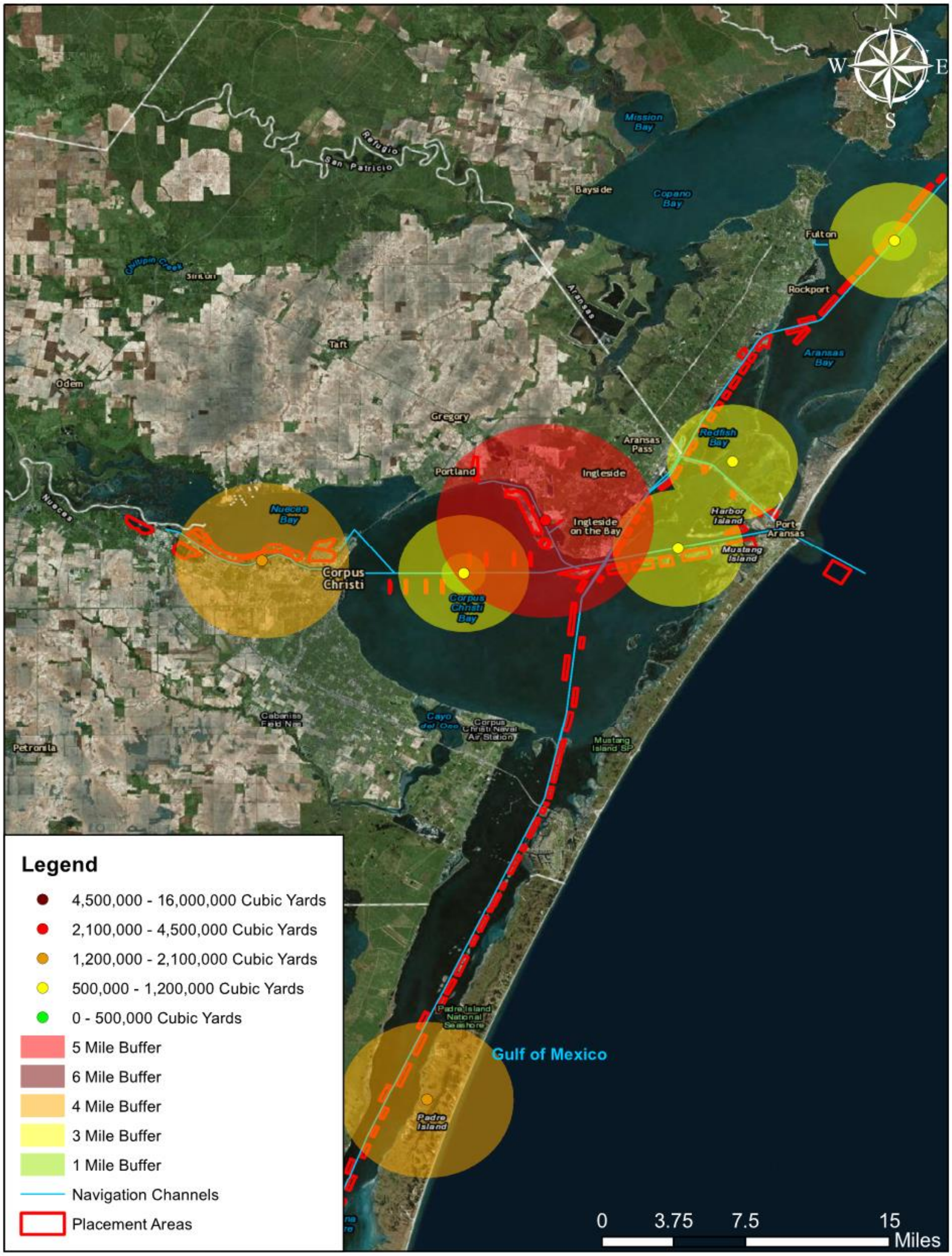


Figure 9-17, Corpus Christi Bay Dredge Volumes (1991-1994, 1996, and 1998).

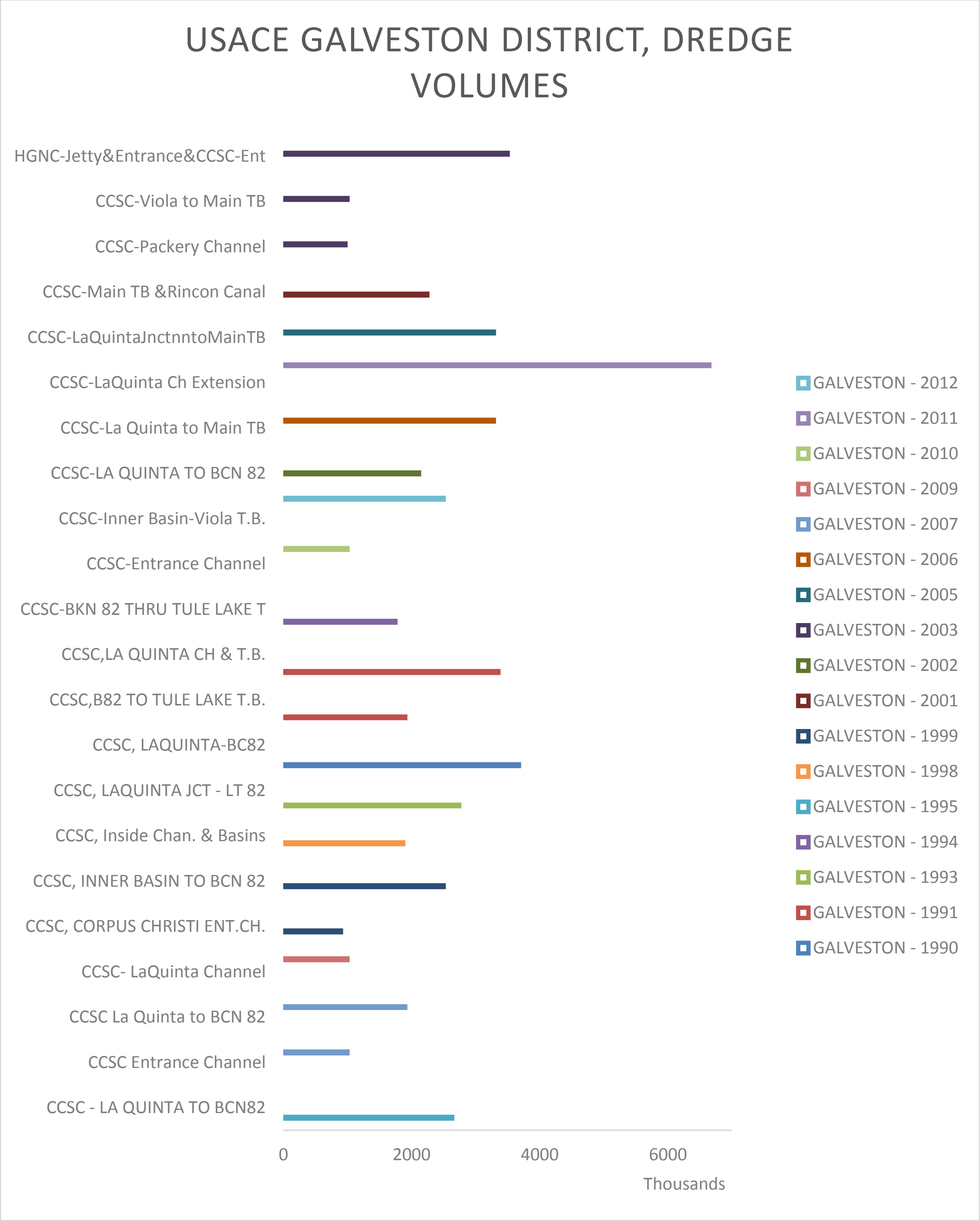


Figure 9-18, Corpus Christi Bay Dredge Volumes.

9.7 LOWER LAGUNA MADRE

Within the Lower Laguna Madre, sixteen dredging projects were collected from the USACE Navigation Center Database (USACE, 2016) and imported into ArcGIS (Figure 9-19). The USACE dredged sediment placement areas (represented by red outlined polygons) and navigation channels (represented by blue polylines) were imported into ArcGIS in addition to these dredging projects. The USACE dredged sediment data was symbolized according to the actual quantity of cubic yards dredged during a given year, with green representing the lowest quantity of cubic yards (less than 500,000 cubic yards) and maroon representing the highest quantity of cubic yards (greater than 4.5 million cubic yards).

Based on the assumption, dredging projects that included Latitudes and Longitudes were incorporated into the Lower Laguna Madre analysis for years 1991-1994, 1996-1997, and 1999.

9.7.1 Offshore Data

In Figure 9-19 (shown below), four of the sixteen dredging locations are offshore projects. According to the data, these dredging projects occurred offshore in the Gulf of Mexico at the entrance of Port Isabel (represented in yellow). This sediment was likely transported to the two offshore placement areas off the Brownsville navigation channel, contributing 440,000 cubic meters (575,000 cubic yards) of sediment in year 1991, 440,000 cubic meters (575,000 cubic yards) in year 1992, 680,000 cubic meters (890,000 cubic yards) in year 1997, and 530,000 cubic meters (690,000 cubic yards) of sediment in year 1999. These quantities combined gives an estimated total of 2 million cubic meters (2.7 million cubic yards) of sediment deposited offshore in the Lower Laguna Madre . This does not include the years in the database where latitudes and longitudes were not recorded (years 1995, 1998, and 2000-2015).

9.7.2 Lower Laguna Madre Data

Twelve of the sixteen dredging locations occurred in the Lower Lower Laguna Madre (within distance of 15 miles landward of the shoreline). Four of these projects follow the GIWW navigation channel along the Gulf of Mexico, four follow the Brownsville navigation channel, three projects follow the Port Mansfield navigation channel, and one follows the Port Isabel Small Boat Harbor. According to the data, four large dredge projects occurred in the Lower Bay in Laguna Madre (represented in red and maroon). This sediment was likely deposited to any one of the fifty nearby placement areas, contributing 2 million cubic meters (2.6 million cubic yards) of sediment in year 1991, 2 million cubic meters (2.6 million cubic yards) in 1992, 2.1 million cubic meters (2.8 million cubic yards) in 1993, and 3.9 million cubic meters (5.1 million cubic yards) of sediment in year 1994, for an estimated total of 12 million cubic meters (13.1 million cubic yards) of sediment deposited.

The other eight dredging locations occurred in the Lower Laguna Madre along the navigation channels listed above (represented in green, yellow, and orange). According to the data collected, 890,000 cubic meters (1.2 million cubic yards) of sediment was contributed in year 1992, 915,000 cubic meters (1.1 million cubic yards) in year 1993, 800,000 cubic meters (1 million cubic yards) in year 1994, 570,000 cubic meters (750,000 cubic yards) in year 1996, 1.3 million cubic meters (1.7 million cubic yards) in 1997, for a total of 4.4 million cubic meters (5.9 million cubic yards) of sediment. This amount combined with the amounts described above gives an estimated total quantity of 14.5 million cubic meters (18.9 million cubic yards) of sediment deposited in the Lower Laguna Madre placement areas. This does not include the years in the database where latitudes and longitudes were not recorded (years 1995, 1998, and 2000-2015).

Due to the large amount and vast extent of placement areas across a seventy-mile span in the Lower Laguna Madre, this sediment could have been placed in any one of fifty placement areas. However, the areas adjacent to navigation channels list above have the highest probability of containing the sediment due to their close proximity to the dredging sites.

9.7.3 Conclusion

According to this data, a total estimate of 16.6 million cubic meters (21.7 million cubic yards) of sediment may be available in placement areas throughout the Lower Laguna Madre .

Table 9-5
Lower Laguna Madre Data Overview (1991-1994, 1996-1997, and 1999)

Offshore Projects	Offshore Dredged Material Quantity	Lower Laguna Madre Projects	Lower Laguna Madre Dredged Material Quantity	Upper Bay Projects	Upper Bay Dredged Material Quantity	Total Projects	Total Dredged Material Quantity
3	8,008,304 yd^3	10	16,226,522 yd^3	0	0 yd^3	13	24,234,826 yd^3
3	6,116,439 m^3	10	12,385,789 m^3	0	0 m^3	13	18,502,228 m^3

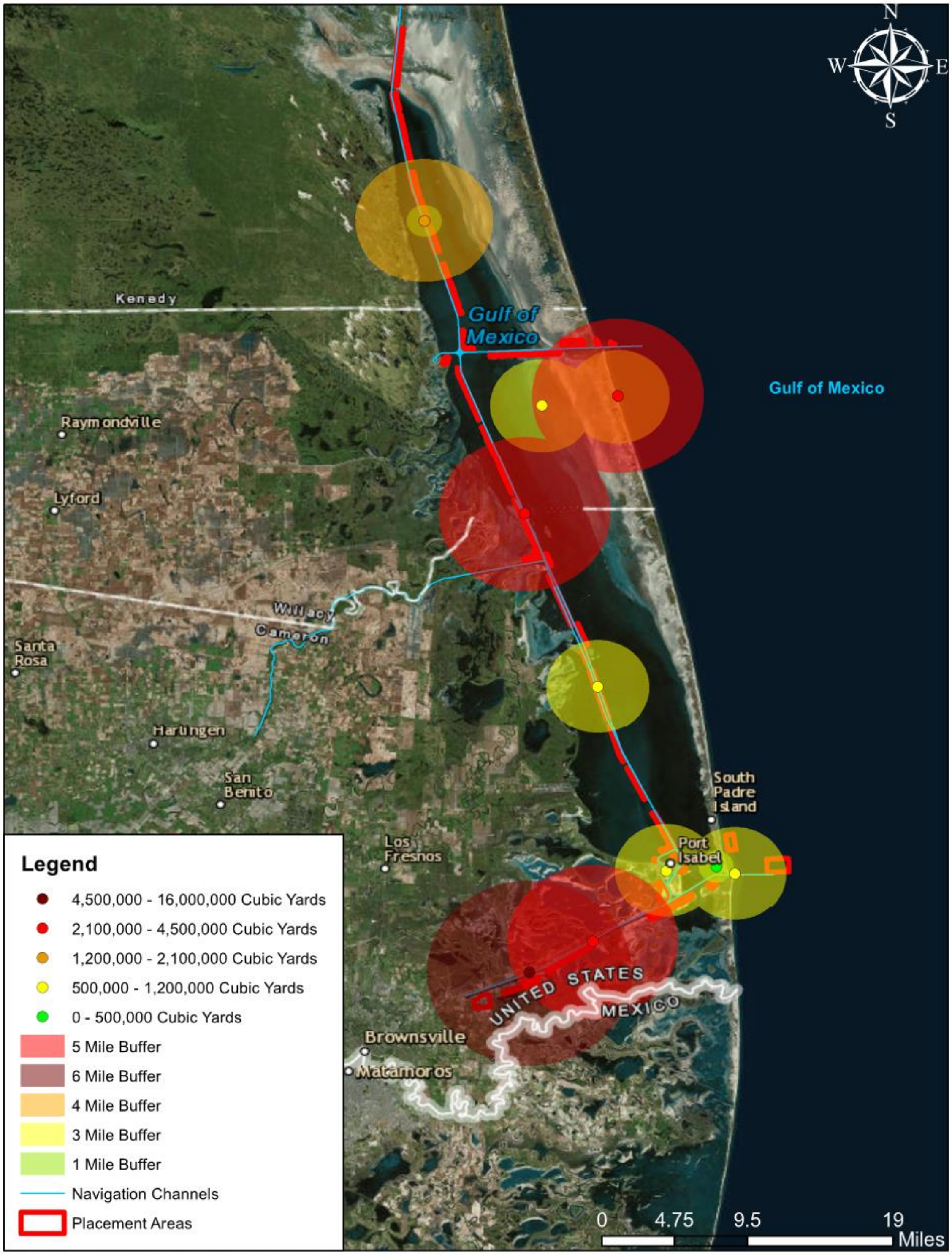


Figure 9-19, Lower Laguna Madre Dredge Volumes (1991-1994, 1996-1997, and 1999).

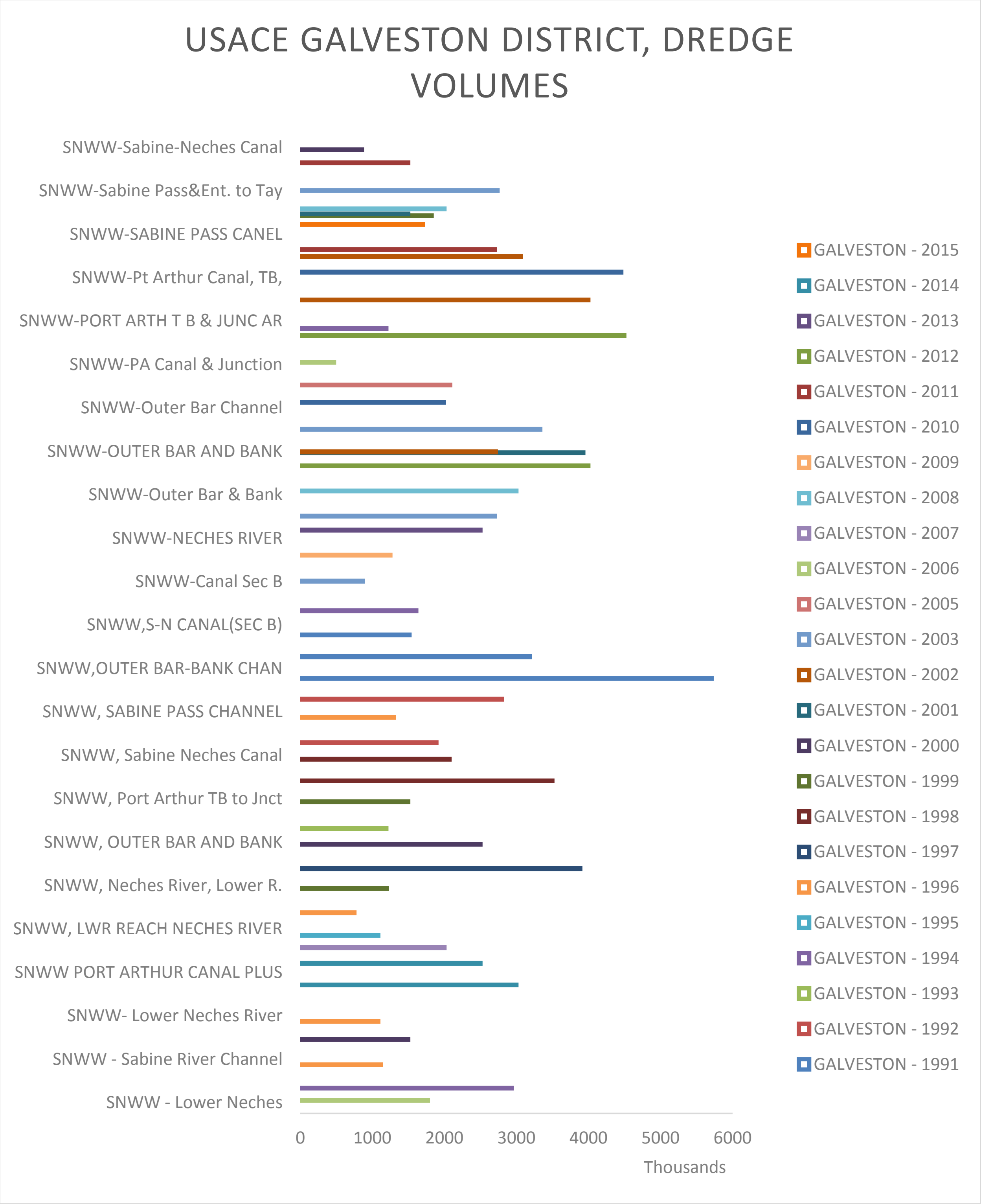


Figure 9-20, Lower Laguna Madre USACE Galveston District Dredge Volumes

10.0 SEDIMENT LOSSES THROUGH SHORELINE CHANGES AND SEDIMENT IMPOUNDMENTS

10.1 SEDIMENT LOSSES THROUGH SHORELINE CHANGES

The Texas coast contains 16-17 permanent inlets and inlet creation is an ongoing for environmental, commercial, and recreational reasons (Krause 2007). Inlets may be natural or man-made. The inlet locations for Texas are indicated in Figure 10-1. Krause further describes the volume of sand dredged from entrance channels may be between 100,000-300,000 cu m/yr, but may reach rates up to 500,000 cu m/yr. To maintain inlet stability, jetties or other control structures may be constructed and the inlets may be continuously dredged (or maintenance dredging may be used to provide a consistent geometry). When structures are installed, sand accumulation will occur on the updrift side and erosion will occur on the downdrift side. When updrift impoundment is present at a structure, sand by-passing will be implemented, where sediment is dredged from the updrift side of the inlet and mechanically moved to the downdrift side, effectively mimicking the natural process of sediment transport.

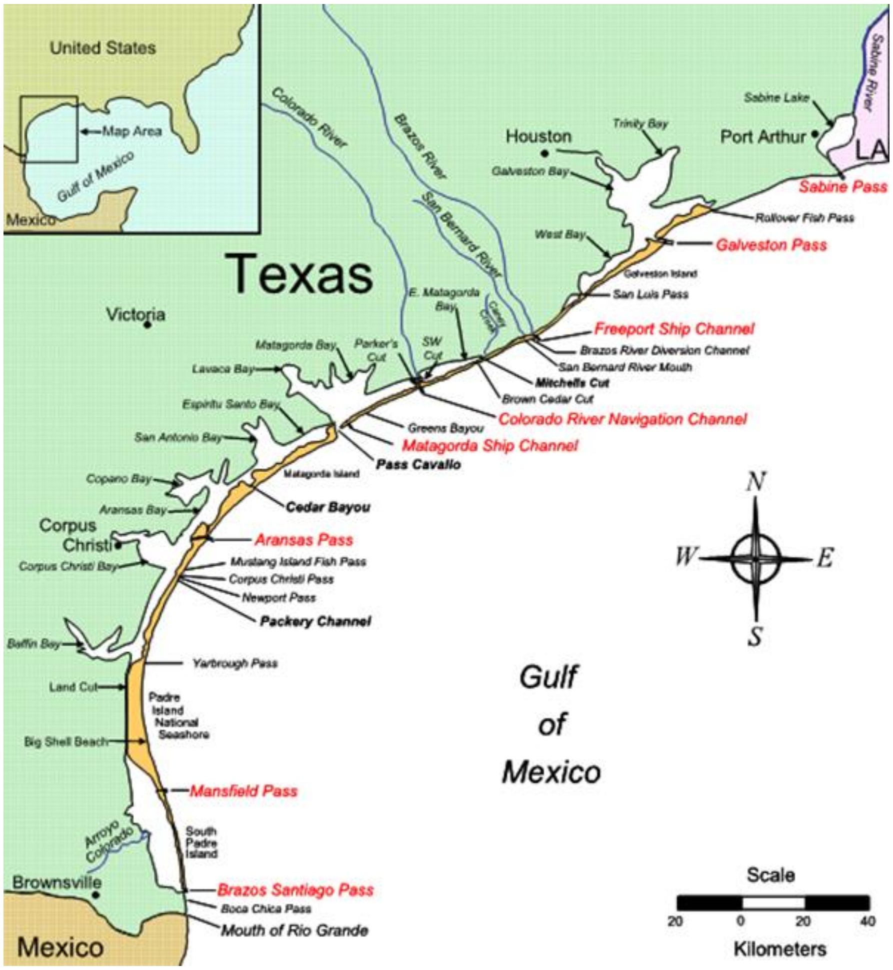


Figure 10-1, Location Map for Texas Coast with Presently Open and Other Inlets (Source: Coast Inlet of Texas, Krause 2007).

10.2 GULF SEDIMENT SHORELINE CHANGES

Based on the Bureau of Economic Geology (BEG) report from 2012, the average retreat rate for the entire coast is higher for the 1950’s to 2012 period than it is for the 1930’s to 2012 period (1.47 m/yr (4.8 ft/yr) and 1.26 m/yr (4.1 ft/yr), respectively. The BEG determined the average rate of retreat from 2000 to 2012 was lower at 1.18 m/yr (3.9 ft/yr), indicating the most recent retreat rates are lower than the longer-term rates. The BEG estimated loss rates of 86 ha/yr (213 ac/yr) between the 1950’s and 2012, but fall to 69 ha/yr (171 ac/yr), which was slightly below the longest-term rate of 72 ha/yr (178 ac/yr) from 2000 to 2012 (BEG 2012). A comparison of annual net rates is shown in Figure 10-2.

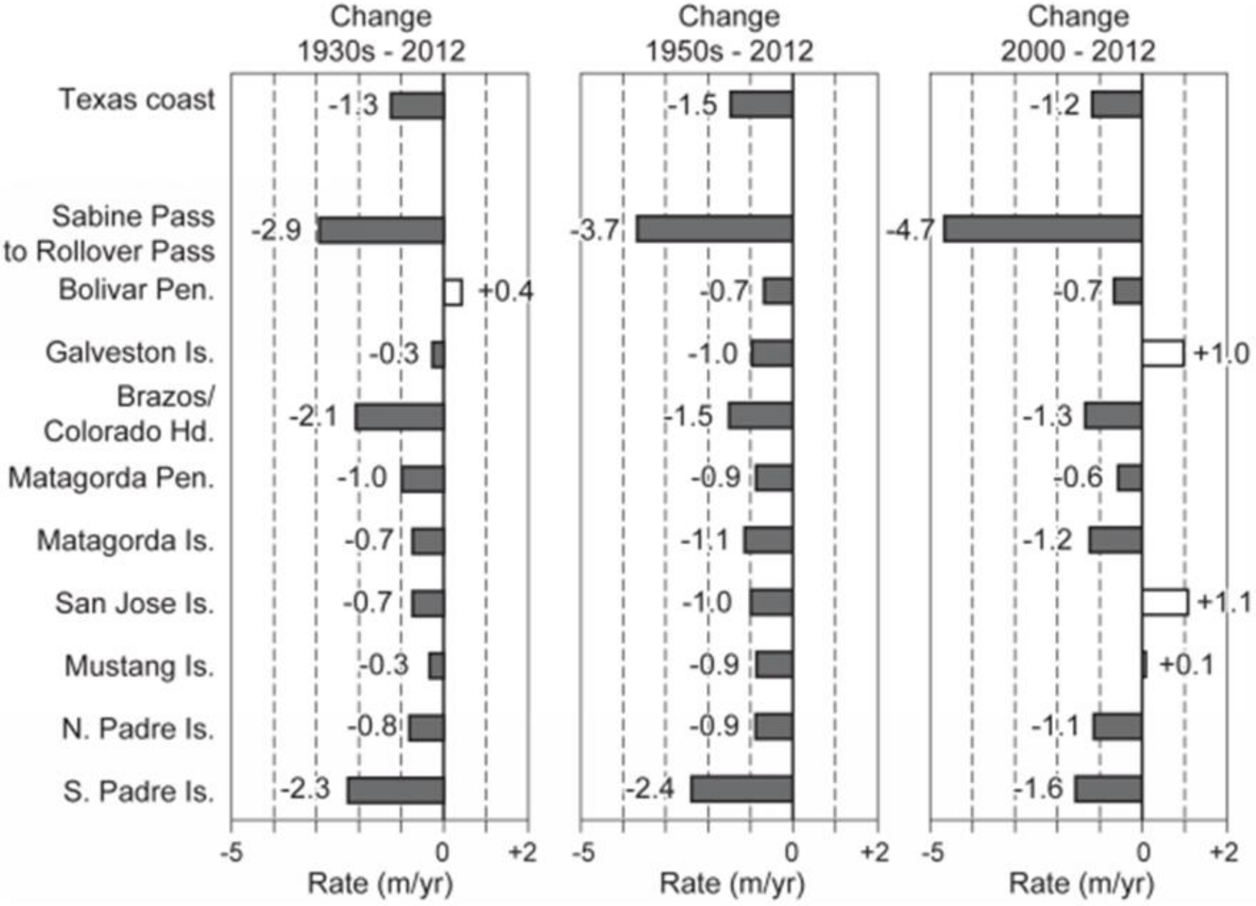


Figure 10-2, Comparison of net rates of shoreline movement for the Texas Gulf shoreline between Sabine Pass and the Rio Grande calculated from shoreline positions between the 1930’s and 2012, the 1950’s and 2012, and 2000 and 2012. Also shown are net rates for major geomorphic units along the coast. (BEG 2012)

10.2.1 Sabine and Trinity River Systems

The upper Texas coast exhibits very high erosion rates (-4.5 m/yr or almost -15 ft/yr) west of Sabine Pass along the Chenier Plain. This area has an accretion/erosion cycle over geologic time. Typically, this area has a sand-lends, or shallow sand venier, covering the Beaumont Clay formation, but recent erosion has virtually stripped all the sand from this section of the coast line. There also are several areas of accretion, specifically north and south of Bolivar Roads, generally about 4.5 m (15 ft) per year. A comparison of shoreline erosion rates is shown in Figure 10-3.

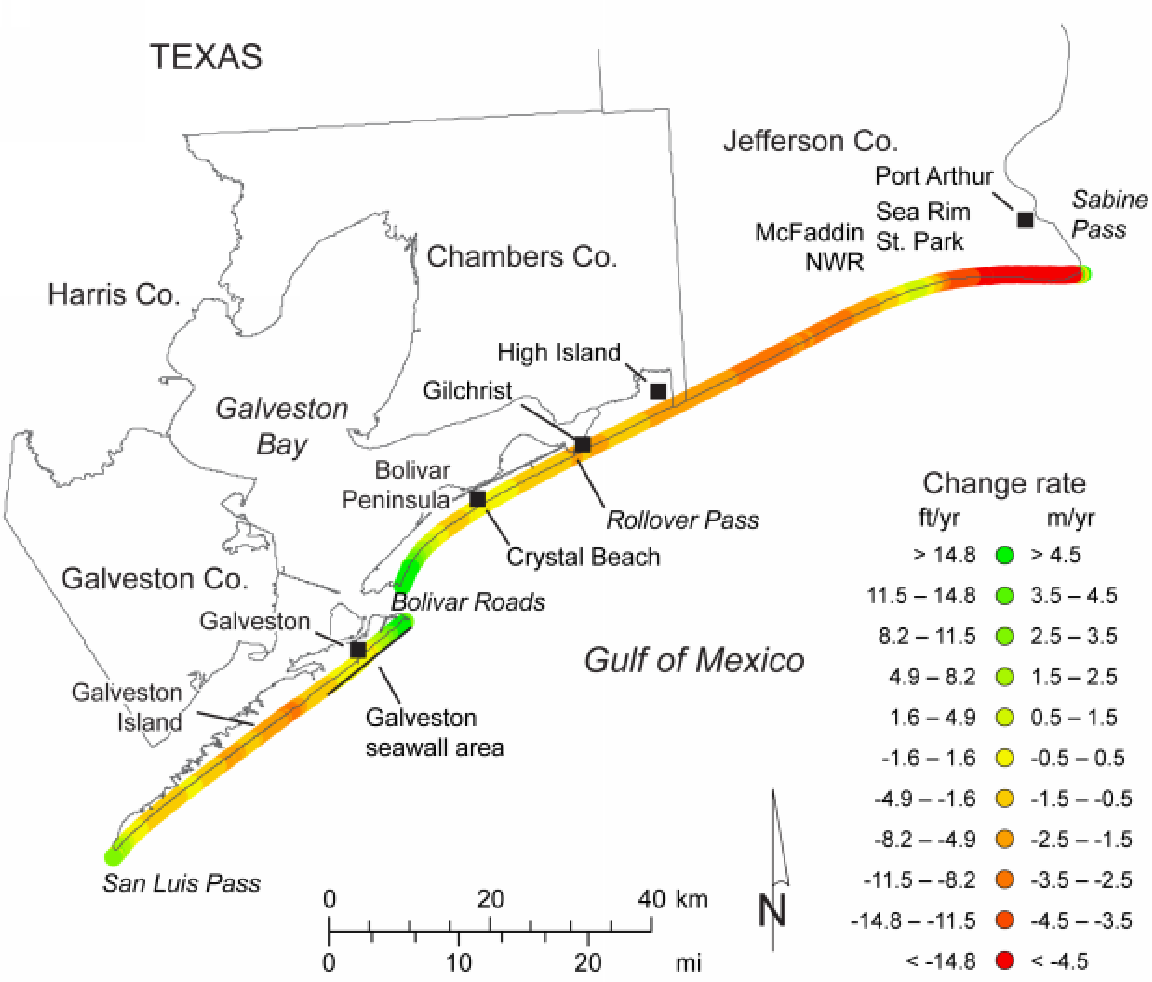


Figure 10-3, Sabine and Trinity Bay Systems Shoreline Change. (BEG 2012)

10.2.2 Colorado and Brazos Bay Systems

The upper, mid-Texas shoreline has consistently high erosion rates, generally near -4.5 m/yr (-15 ft/yr). The continuous erosion of the shoreline at Sargent Beach required structures be built to provide protection for the ICWW and Surfside and Quintana beaches are areas of consistent beach nourishment projects to replenish the lost beach sediments, likely due to the proximity to the Brazosport Jetties. Areas of accretion are south of the Brazos River, likely due to sediment loading from the San Bernard River; the south end of the Matagorda inlet, which is a result of local sediment impoundment north of the Matagorda inlet jetties; and at the north side of Pass Cavallo, again due to sediment impoundment resulting from southward sediment transport. These areas of higher sediment accumulation are 4.5 m/yr (-15 ft/yr). A comparison of shoreline erosion rates is shown in Figure 10-4.

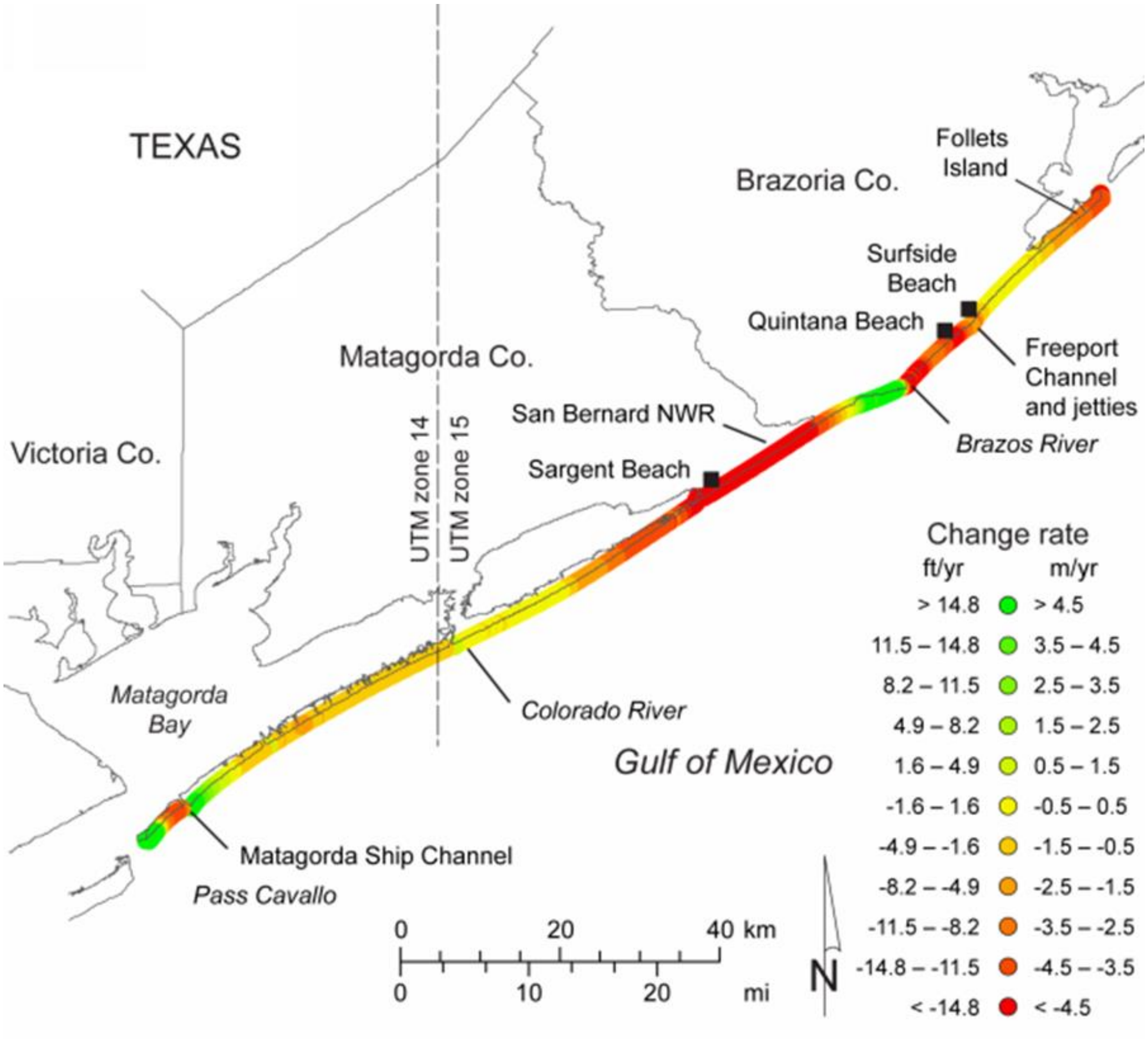


Figure 10-4, Colorado and Brazos Bay Systems Shoreline Change (BEG 2012) (BEG 2012)

10.2.3 Corpus Christi Bay System

Net rates at individual sites ranged from retreat of 16.8 m/yr (55.2 ft/yr) to accretion rates of 16.1 m/yr (52.9 ft/yr). The highest rates of net retreat (more than 3 m/yr [10 ft/yr]) were measured along Matagorda Island near Pass Cavallo. The retreat rates along the coastline were roughly less than about -1 m/yr (3 ft/yr) (BEG 2012). A comparison of shoreline erosion rates is shown in Figure 10-5.

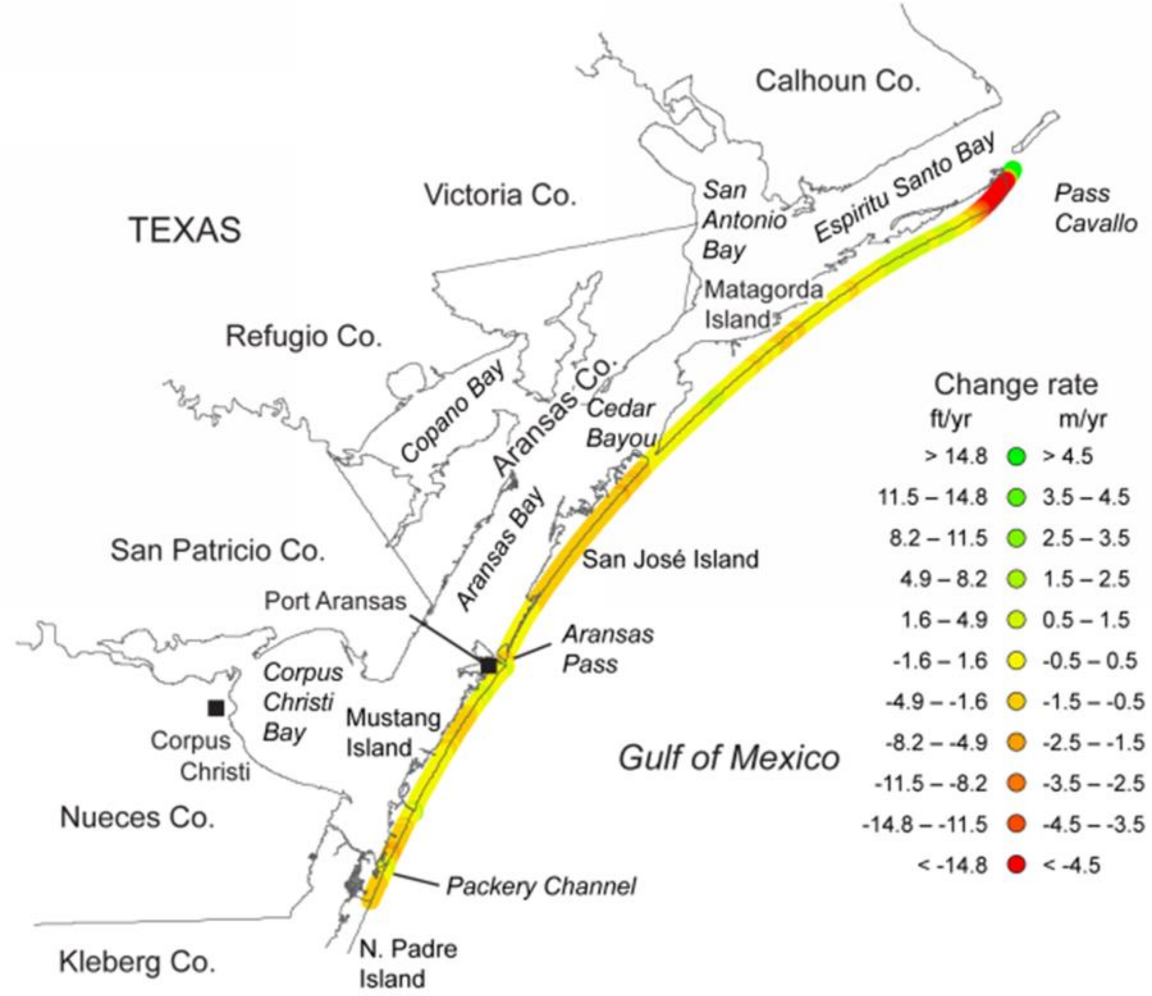


Figure 10-5, Corpus Christi Bay System Shoreline Change (BEG 2012)

10.2.4 Nueces Bay System

In the analysis from BEG, the net shoreline change rates average retreat at 0.82 m/yr (2.7 ft/yr) on northern Padre Island at Mansfield Channel to Packery Channel, and 2.27 m/yr (7.4 ft/yr) on southern Padre Island and Brazos Island, which is Mansfield Channel to the Rio Grande. In general, the shoreline along northern Padre Island has become more recessional over time. The net long-term retreat rate of 0.8 m/yr (2.7 ft/yr) between the 1930's and 2012 increased to 0.9 m/yr (2.9 ft/yr) between the 1950's and 2012, where the highest net retreat rate for northern Padre Island was measured between 2000 and 2012. Net retreat rates are higher on southern Padre Island and Brazos Island, but show a different trend over time, where rates from the 1930's to 2012 and the 1950's to 2012 are similar (2.3 and 2.4 m/yr [7.4 and 7.9 ft/yr]), but the most recent net retreat rates measured by the BEG, from 2000 to 2012, is lower than that for longer periods. (BEG 2012). A comparison of shoreline erosion rates is shown in Figure 10-6.

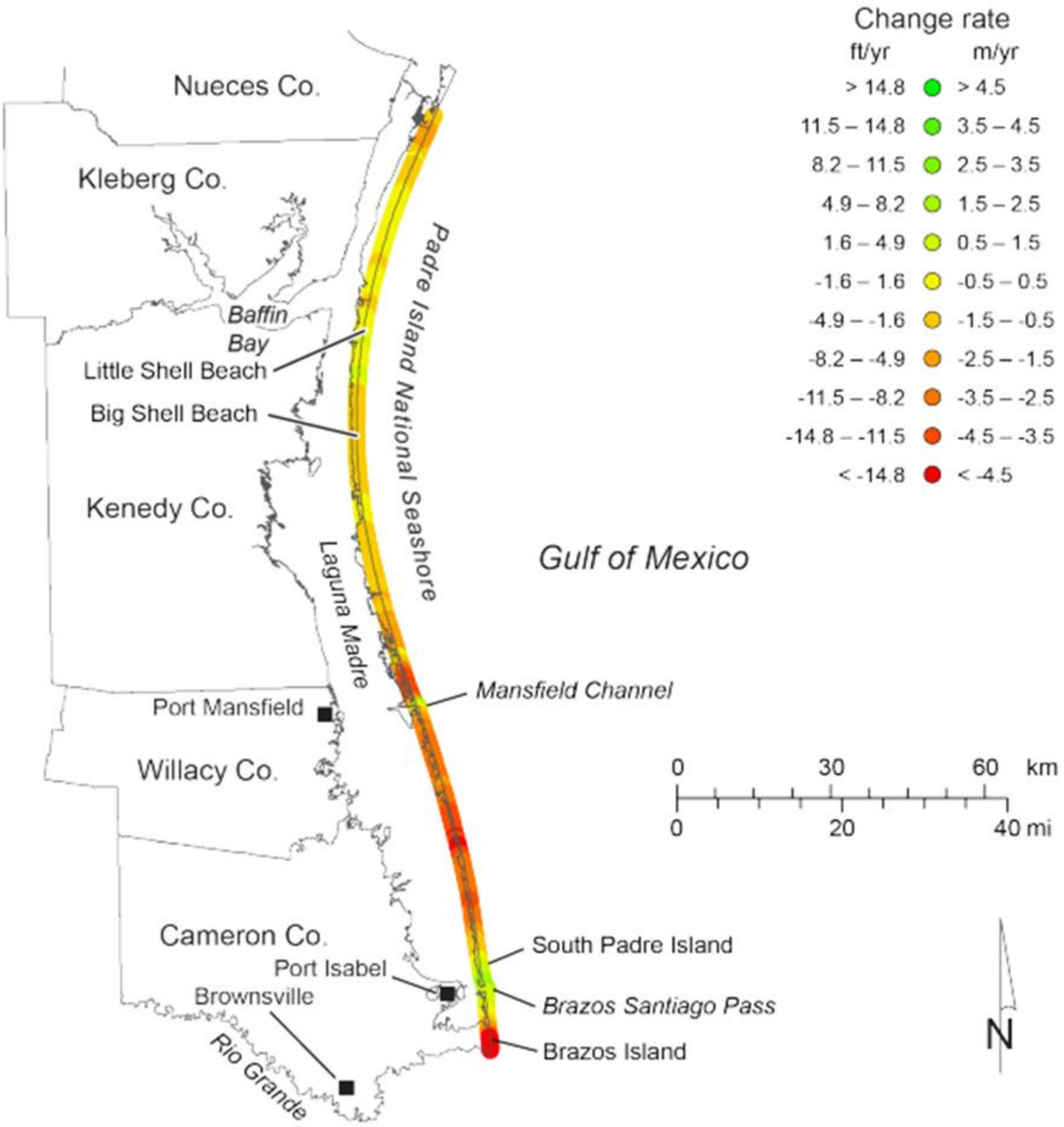


Figure 10-6, Nueces Bay System Shoreline Change (BEG 2012)

10.3 GULF COAST SEDIMENT IMPOUNDMENTS

Historically, three major rivers, Brazos, Colorado, and Rio Grande, discharge directly into the Gulf of Mexico (Figure 10-7). These rivers, in conjunction with the smaller San Bernard River, are the only sources of additional sand being supplied to the Texas Gulf beaches from outside the coastal system. Until recently these rivers played a significant role in shoreline maintenance (McGowen, 1977). However, dams constructed across the Brazos, Colorado, and Rio Grande rivers from the late 1800's to the mid-1900's have interfered with the downstream transport of sediments and have impounded both water and bedload material. As such, much of the bedload material that would have reached the Gulf of Mexico and would have nourished the beaches is now retained in reservoirs behind these dam structures. Other Texas rivers and streams discharge directly into bays and estuaries (Figure 10-7) where bedload material is trapped; however, these bedload sediments do not migrate to the Gulf coast to become part of the longshore drift system.

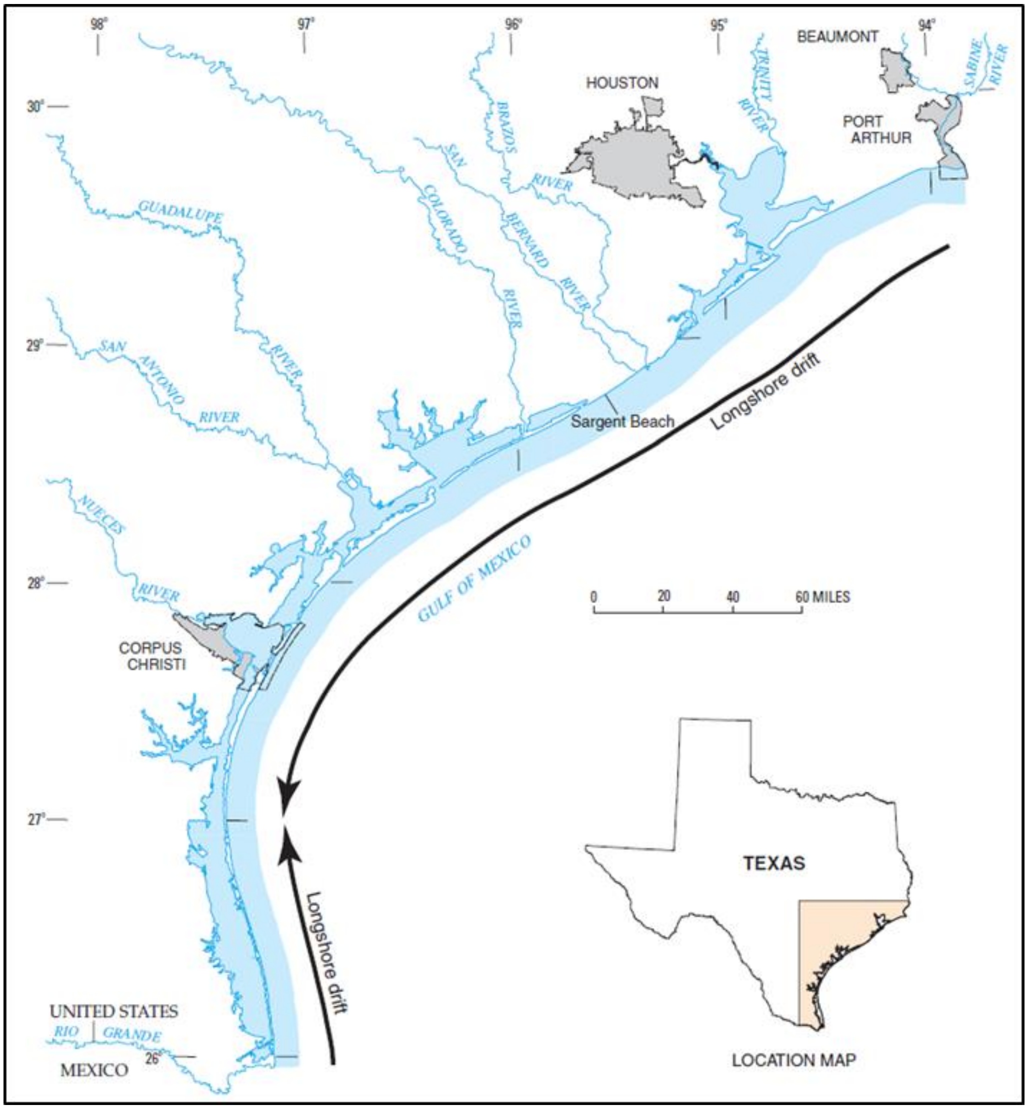


Figure 10-7, Map of Coastal Texas (USGS, 2001)

10.3.1 Gulf Coast Sediment Movement

The sand that constitutes much of the Texas shoreline along the Gulf of Mexico is in continual motion. Tides, storm surges, wave action, wind, river processes, and longshore (littoral) drift act upon the sand and transport it along the shoreline to form and erode beaches, barrier islands, and peninsulas. Longshore drift transports sand from the river deltas to other locations along the coast. The longshore drift generally moves material in a southwesterly direction along the coast from Port Arthur to south of Corpus Christi. An opposing current moves material in a northerly direction from the Mexico coastline toward Corpus Christi. A zone of convergence, also called a zone of stagnation, occurs at a latitude of about 27 degrees north (Figure 10-7). The exact location varies with prevailing tidal and weather patterns (USGS, 2001).

10.3.2 Disruptions to Sediment Movement

Dams constructed across major streams in Texas (Figure 10-8) that discharge directly into the Gulf of Mexico impound sand that would normally be transported to the Gulf of Mexico to nourish the beaches. Natural features may also prevent fluvially transported sand from reaching the beaches. Bays and estuaries are natural barriers to sand transport; sand is trapped near the point where a stream debouches into the bay or estuary. There is no known mechanism that will transport sand from the river mouth across a wide bay bottom and deliver sand to the open Gulf beaches (McGowen, 1977).

Along the Gulf shoreline, beaches lying within the longshore drift zone of convergence will continue to receive sand derived from erosion of other shoreline segments and will, therefore, remain in an equilibrium state for some time. However, equilibrium can be disrupted by erecting structures that extend from the shoreline into water depths greater than 15 feet (McGowen, 1977). Groins, jetties, or breakwaters are structures that interfere with the longshore drift along the coast, and will typically induce either erosion (shoreline downdrift from the structure) or accretion (shoreline updrift from the structure) of shorelines adjacent to these artificial structures (Figure 10-9).

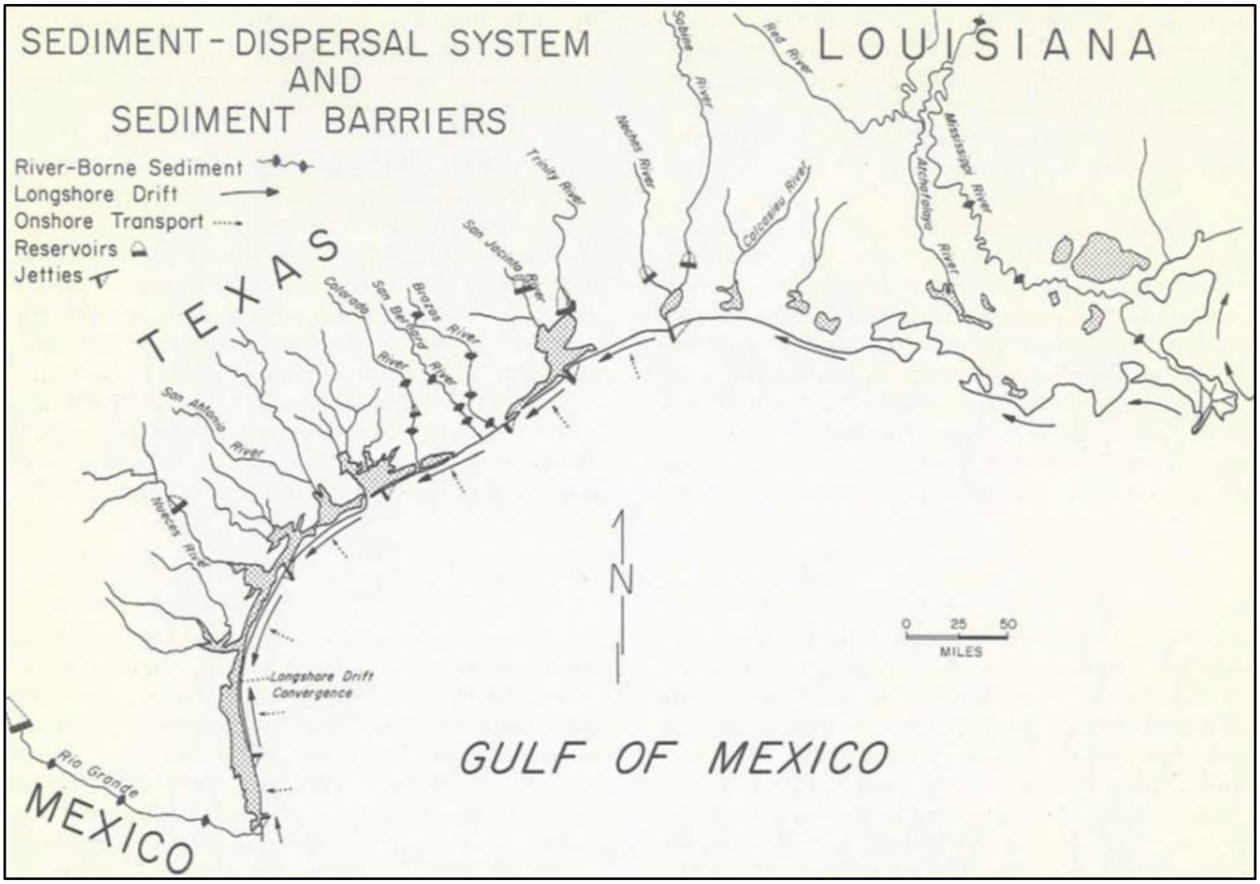


Figure 10-8, Texas Shoreline and River Structures (Modified from McGowen, 1977)

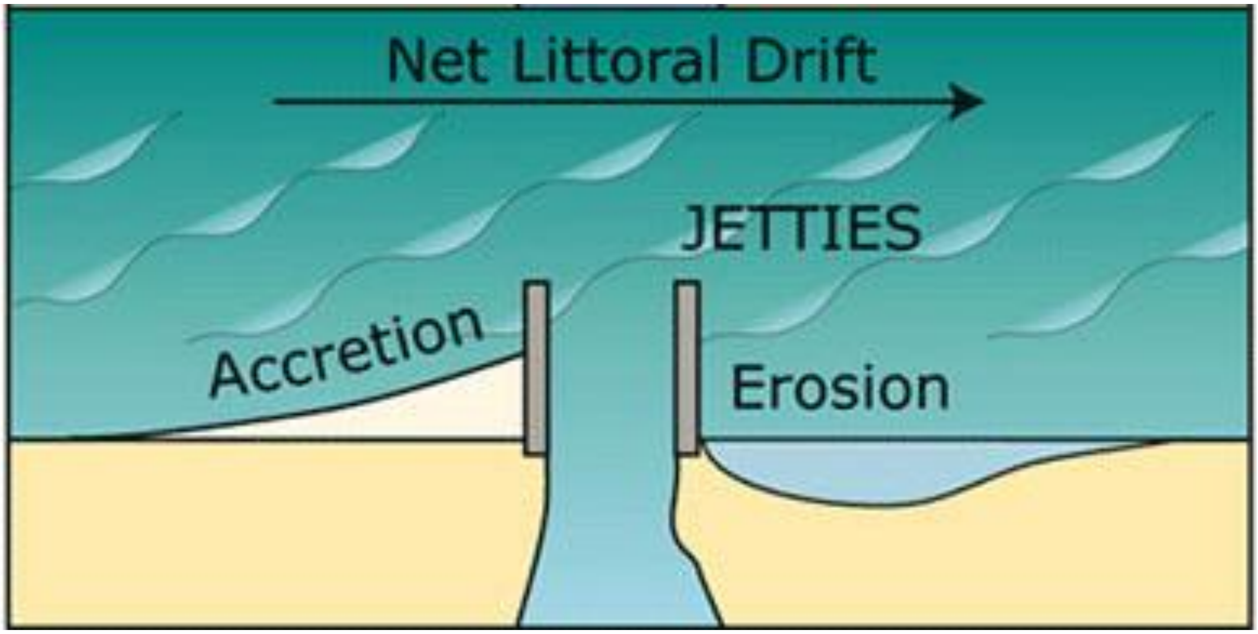


Figure 10-9, Accretion and erosion effects of jetties on adjacent shorelines with net littoral drift (USGS, 2007).

10.3.3 Texas Gulf Coast Sediment Budgets

GOMA, 2009 presented sediment budget values for two primary reaches covering the Texas Gulf Coast, which include a reach (Reach G7) from West Louisiana to East Texas (High Island) and a reach (Reach G8) from East Texas (High Island to Veracruz State, Mexico.

Reach G7 consists of a geographic area along southwest Louisiana and northeast Texas. The longshore sediment movement is generally to the west, but there are reversals near Sabine and Calcasieu Passes caused by wave refraction around their offshore shoals (Georgiou, FitzGerald, and Stone 2005). The Texas portion of the sediment budget for Reach G7 (from Sabine Pass to High Island) was developed by the Engineer Research and Development Center (Morang, 2006) and the values (m^3/yr) are displayed in Figure 10-10.

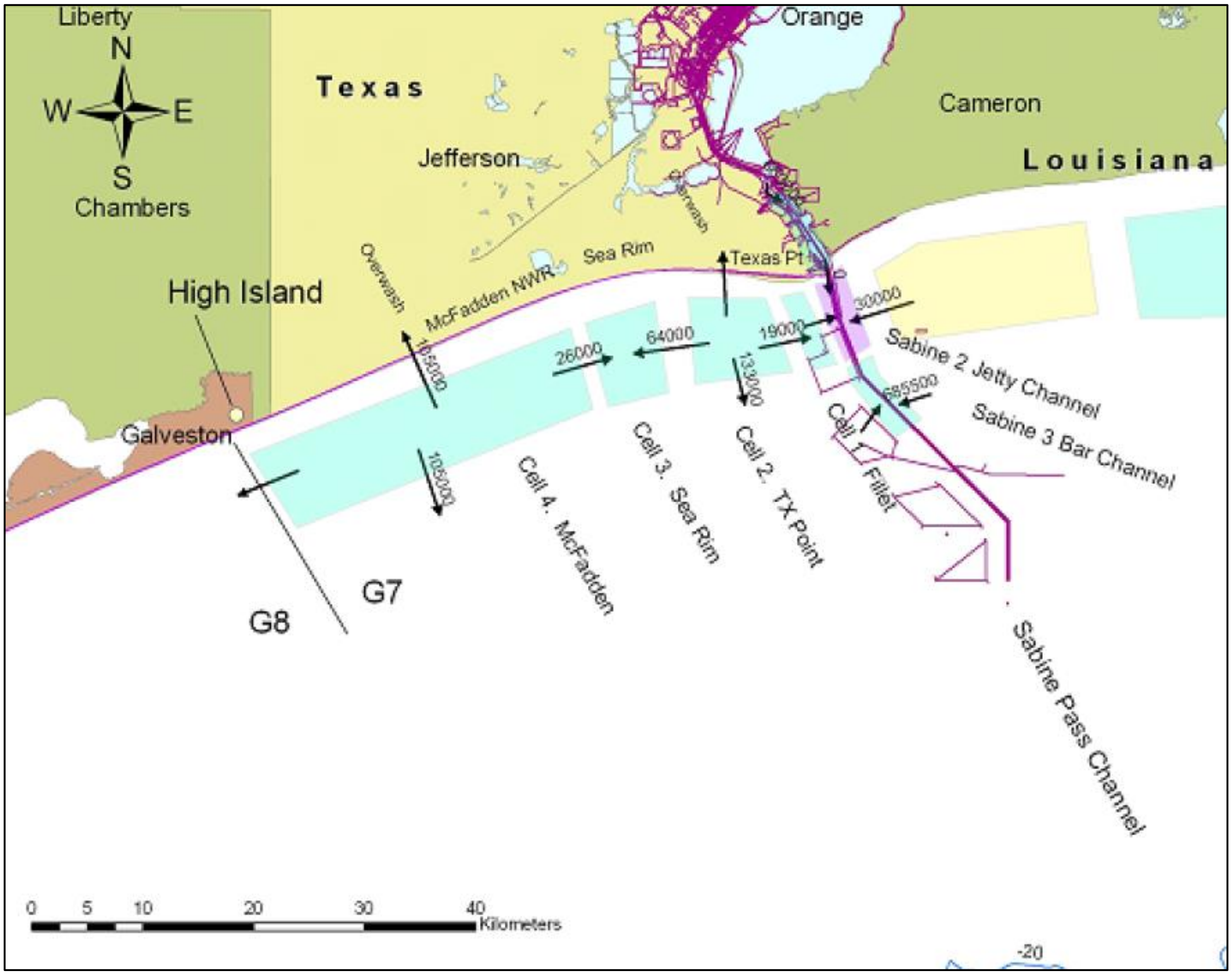


Figure 10-10, East Texas from Sabine Pass to High Island Sediment Budget (m^3/yr) (GOMA, 2009).

Reach G8 covers much of the western margin of the Gulf of Mexico, extending from High Island, TX southward to Veracruz-Llave State, Mexico. Along the eastern portion of Reach G8, the longshore transport is generally to the southwest, although a reversal occurs at Galveston Island near the south jetty of Bolivar Roads. Further south, longshore transport is bi-directional with a net component to the south or north depending on the specific location. Sediment budget values (m^3/yr) for the eastern portion of Reach G8 (Bolivar Peninsula to San Luis Pass) are shown in Figure 10-11. Sediment budgets are largely unavailable for the central and south Texas coast. The Texas coast is underdeveloped compared to many other states and, as a result, little information is available on sediment pathways, beach volume changes, and sediment budgets (GOMA, 2009).

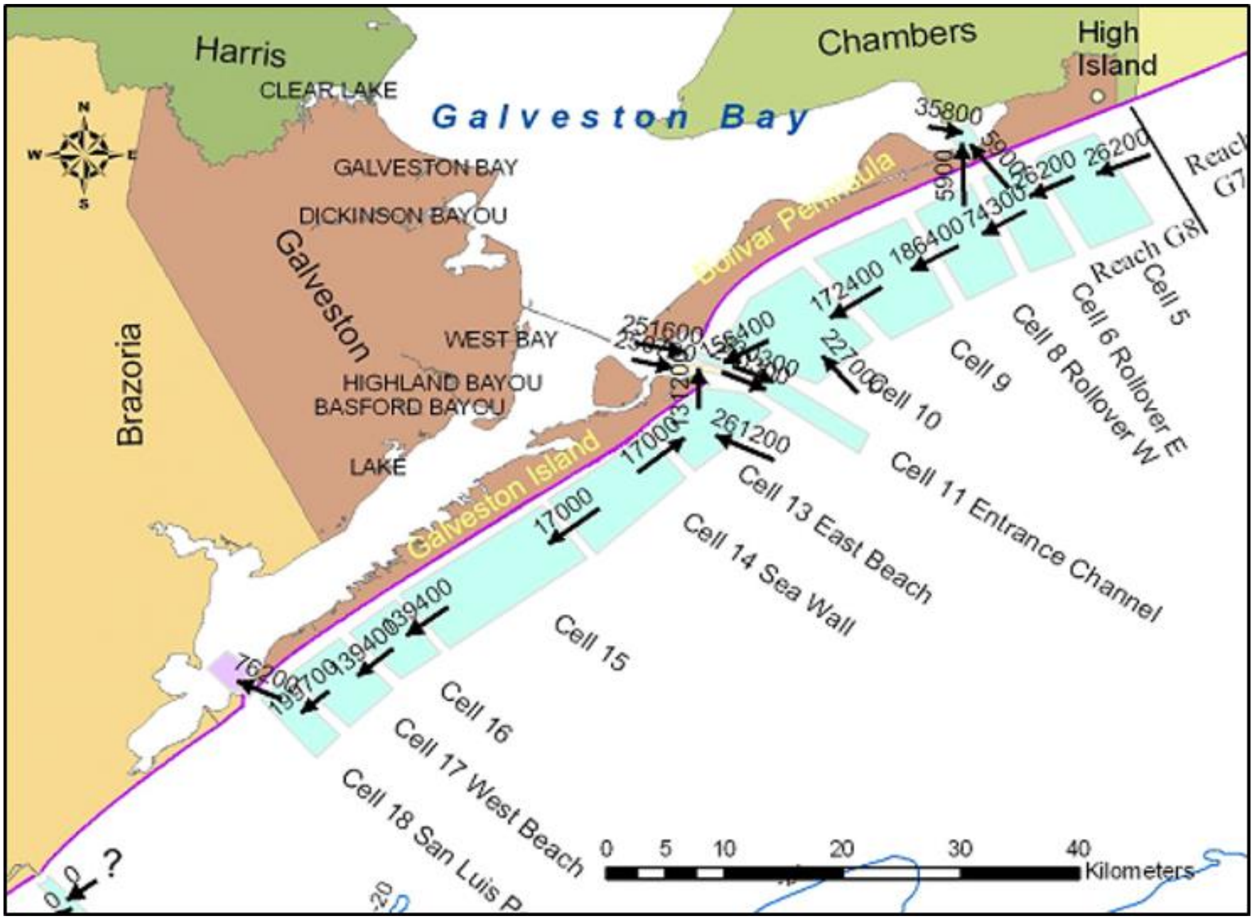


Figure 10-11, Bolivar Peninsula to San Luis Pass Sediment Budget (m^3/yr) (GOMA, 2009).

10.3.4 Texas Gulf Coast Sediment Impoundment Areas and Rates

According to McGowen, 1977, most of the 367 miles of Texas Gulf shoreline is in an erosional state (60 percent of total shoreline), a secondary portion is in equilibrium (33 percent of total shoreline), and a mere 7 percent of the shoreline is accretionary. Most of the equilibrium shorelines lie between Pass Cavallo and Port Mansfield jetties. Shorelines experiencing noticeable accretion along the Texas Gulf Coast are located for the most part adjacent to navigation structures, updrift of the longshore drift. Table 10-1 list areas along the Texas Gulf Coast with structures that are impounding sediments, resulting in net positive shoreline change. These areas are also displayed in Figures 10-12 through 10-16.

Table 10-1
Texas Gulf Coast Sediment Impoundment Areas

Figure No.	Area	Location	Shoreline Change Rate 1930s to 2012 (BEG, 2016) (m/yr)
10-12	Galveston Ship Channel Entrance	North & South Jetties	1.5 to 4.5
10-13	Matagorda Ship Channel Entrance	North Jetty	1.5 to 4.5
10-14	Corpus Christi Ship Channel Entrance	South Jetty	0.5 to 1.5
10-15	Port Mansfield Entrance Channel	South Jetty	0.5 to 3.5
10-16	Brazos Island Harbor Entrance Channel	South Jetty	0.5 to 3.5

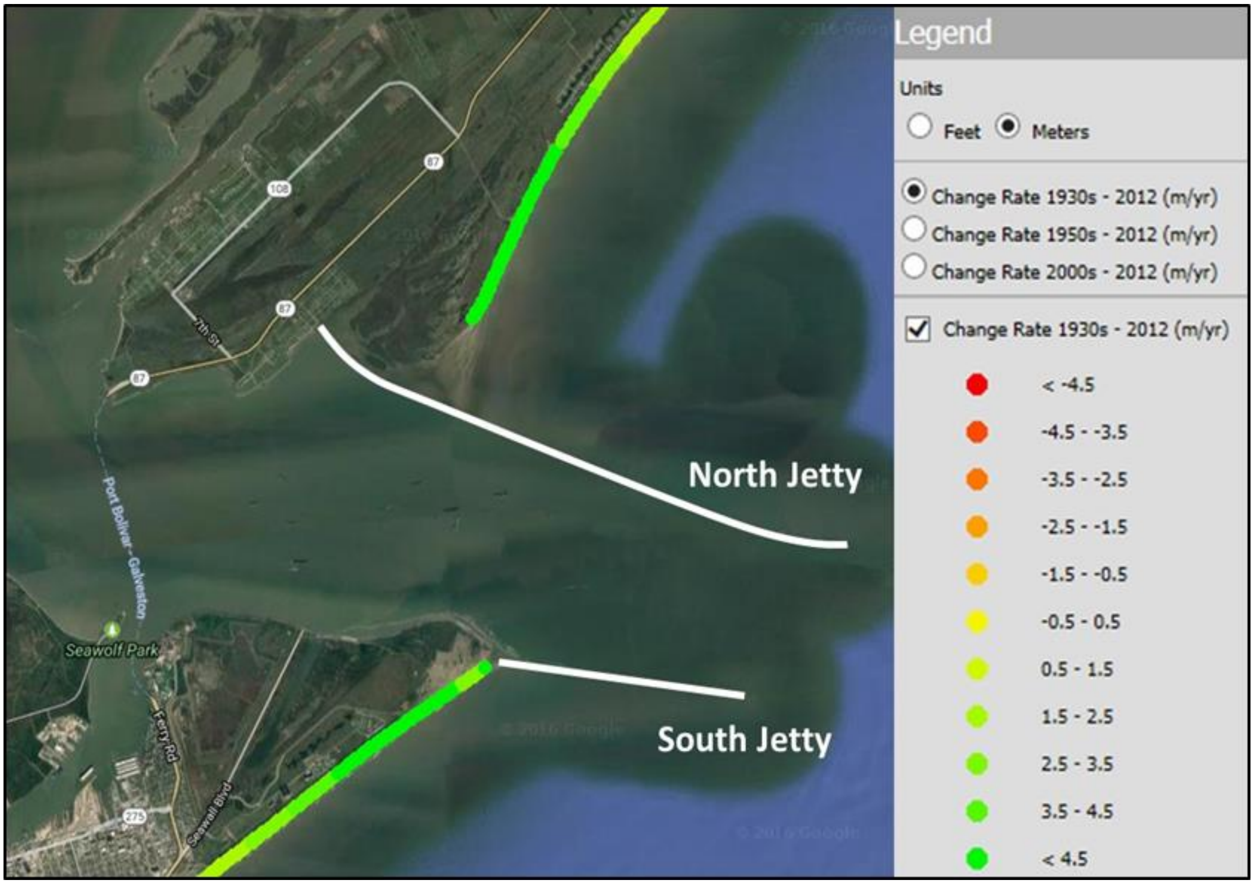


Figure 10-12, Galveston Ship Channel Entrance – Shoreline change Rate (BEG, 2016)

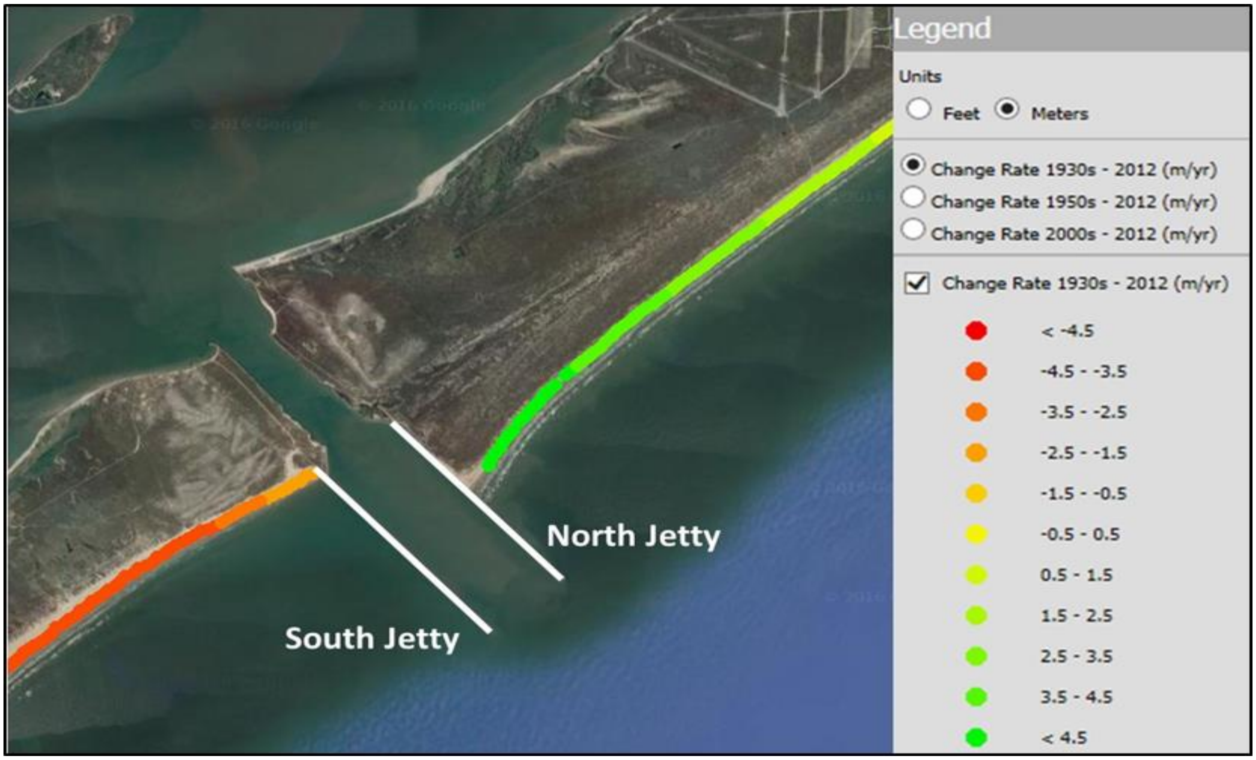


Figure 10-13, Matagorda Ship Channel Entrance – Shoreline change Rate (BEG, 2016)

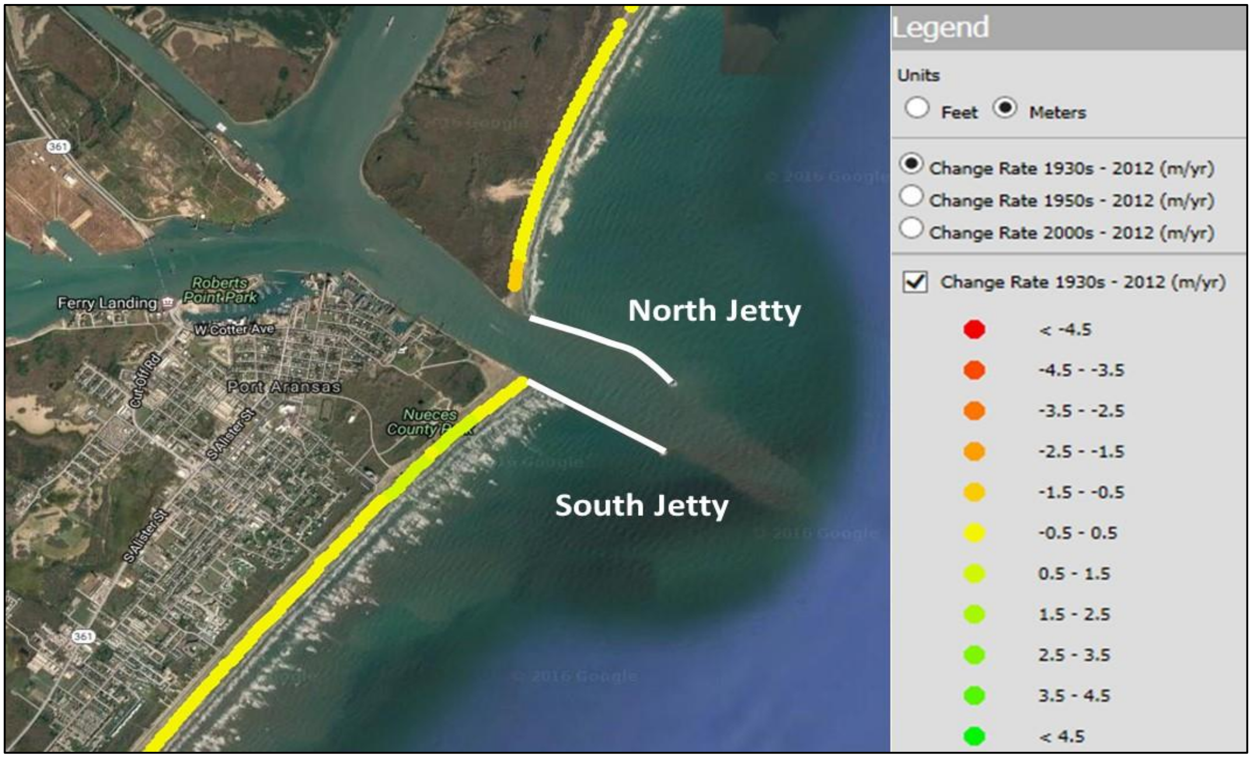


Figure 10-14, Corpus Christi Ship Channel Entrance – Shoreline change Rate (BEG, 2016)

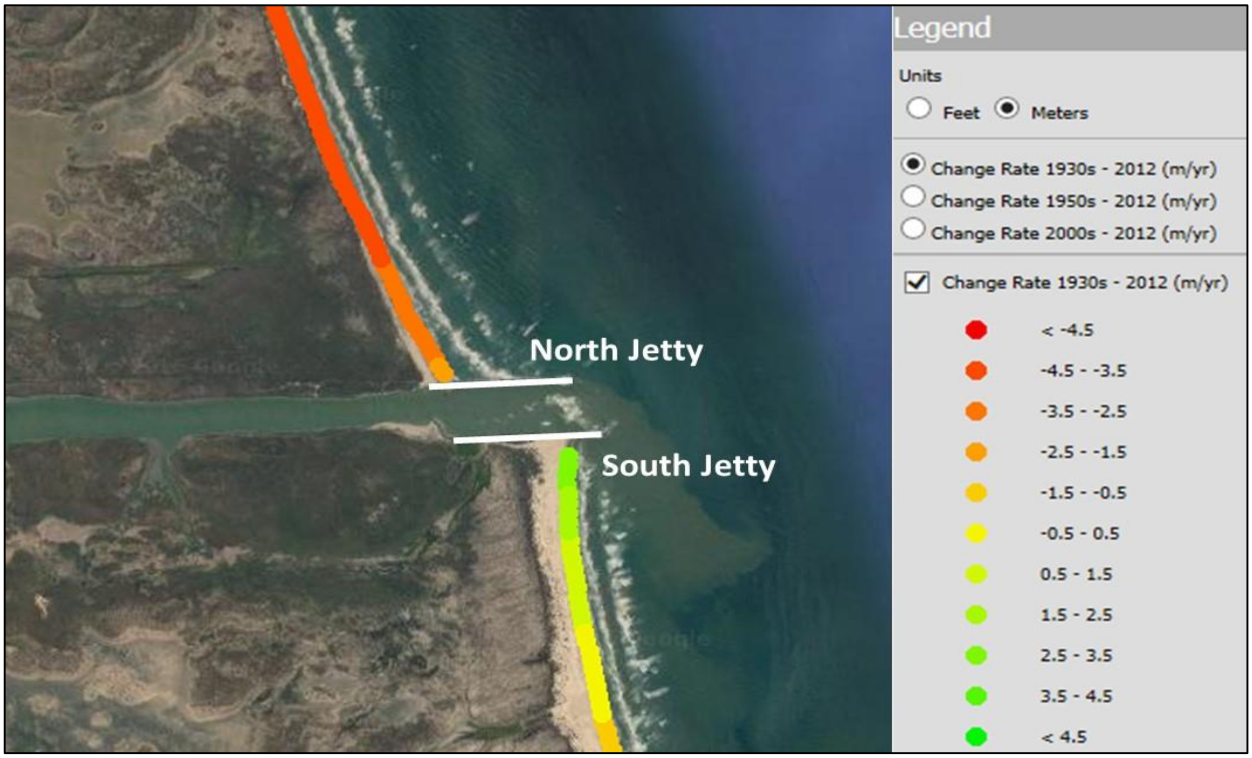


Figure 10-15, Port Mansfield Entrance Channel – Shoreline change Rate (BEG, 2016)

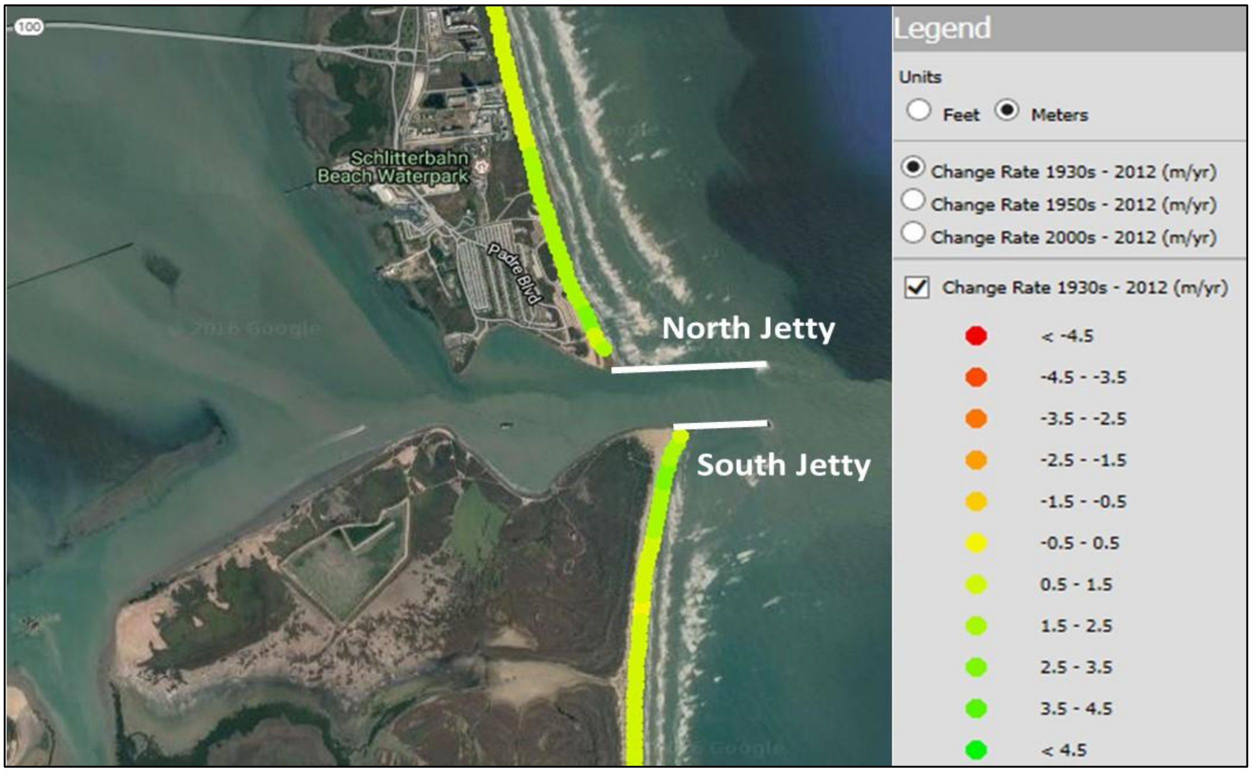


Figure 10-16, Brazos Island Harbor Entrance Channel – Shoreline change Rate (BEG, 2016)

An additional significant sediment impoundment artificial feature residing within the Texas coastal zone is the Lake Corpus Christi dam structure located in the Nueces River Basin (Figure 10-17). Localized sediment deposition within Lake Corpus Christi is affecting the water supply storage capacity of the municipal reservoir. Total accumulated sediment volume within Lake Corpus since construction of the dam is estimated to be 43,000 ac-ft, with an additional 73,000 ac-ft of sediments projected to be deposited by 2050 (USACE, 2010).

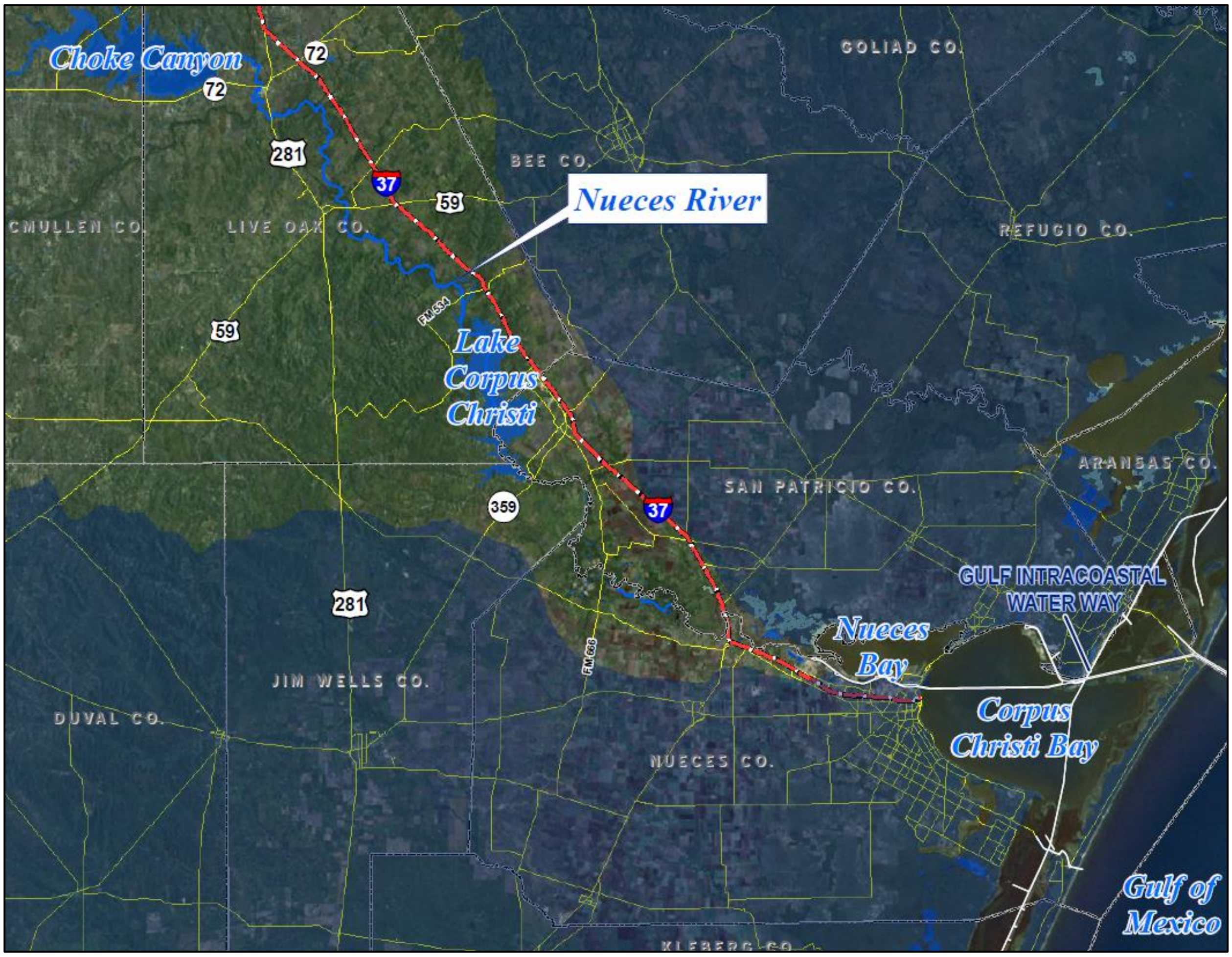


Figure 10-17, Lower Nueces River Basin and Lake Corpus Christi (USACE, 2010).

10.3.5 Sediment Management

Areas where sediments are being impounded along the Texas Gulf coast or within river basins afford an opportunity to manage these impounded sediments by either bypassing material to reintroduce these sediments back into the natural system or by harvesting the impounded material for direct beneficial use on restoration projects. Figures 10-12 through 10-16 display possible areas to manage impounded sediments along the Texas Gulf coast. Figure 10-23 displays sediment deposition locations greater than 2-ft within Lake Corpus Christi that may be harvested for beneficial reuses.

Figure 10-18, Galveston Ship Channel Entrance – Sediment Management Areas (Source Photo: Google Earth, 2016).

Figure 10-19, Matagorda Ship Channel Entrance – Sediment Management Area (Source Photo: Google Earth, 2016).

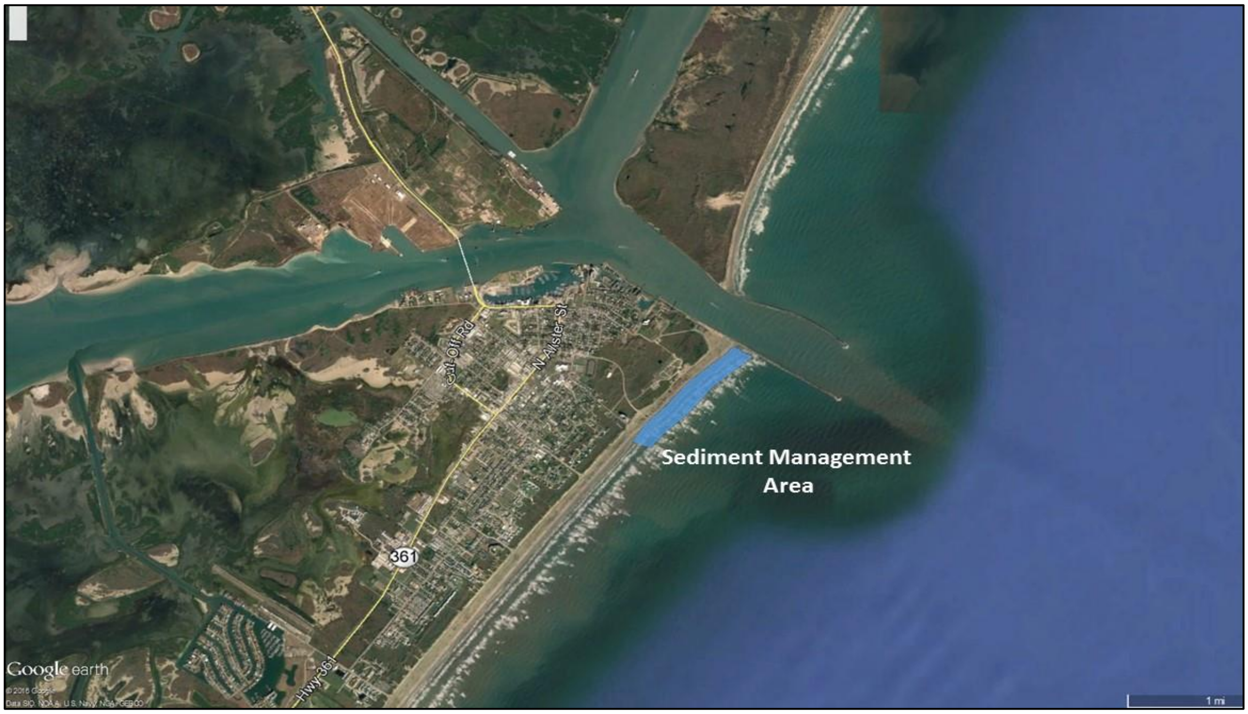


Figure 10-20, Corpus Christi Ship Channel Entrance – Sediment Management Area (Source Photo: Google Earth, 2016).

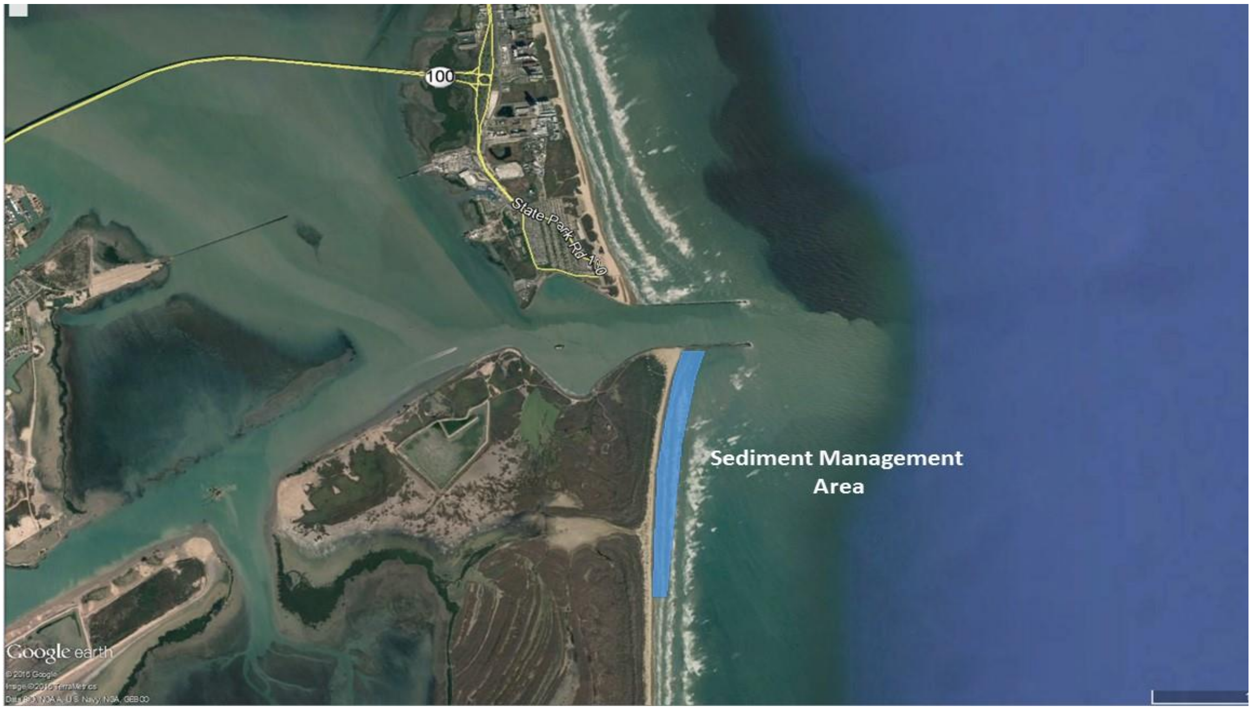


Figure 10-21, Port Mansfield Ship Channel Entrance – Sediment Management Area (Source Photo: Google Earth, 2016).

Figure 10-22, Brazos Island Harbor Entrance Channel – Sediment Management Area (Source Photo: Google Earth, 2016).

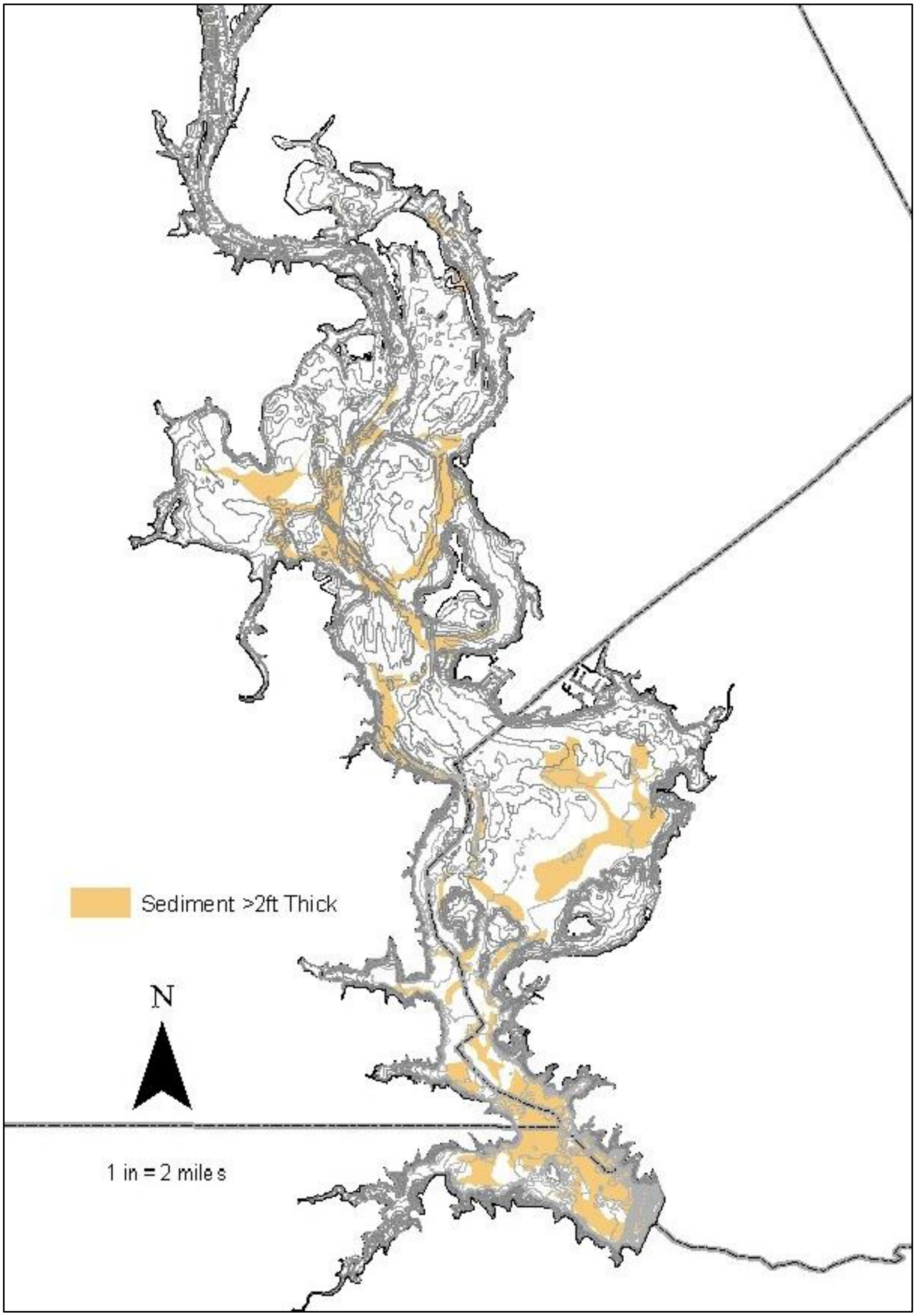


Figure 10-23, Lake Corpus Christi – Sediment Harvest Areas (USACE, 2011).

11.0 COASTAL REGION POTENTIAL SEDIMENT CONTAMINANTS AND POLLUTANTS

This section was included as a reference on the potential sources of contamination that may be considered when searching for sediment sources on bay environments. With decades of heavy commercial, industrial, and cargo shipping development along the Texas coast, a legacy of organic and heavy metal pollutants has been deposited within coastal bays and estuaries as well as offshore in the Gulf of Mexico. In addition, offshore discharges of petroleum products from catastrophic failures of drilling rigs, such as the Deepwater Horizon oil spill that occurred in April 2010, have the potential to further impact coastal sediment.

Several studies and databases have been developed to document the quality and the concentrations of contaminants and legacy pollutants in sediment at various scales across the coast. The results of these studies, including the Galveston Bay Indicators Project (Lester and Gonzalez, 2005) among others, are useful to identify localized areas within coastal bays where sediments have been impacted by legacy pollutants or organic contaminants, and, as such, excludes those localized areas as a viable source of dredged sediment for proposed coastal projects.

11.1 SEDIMENT CONTAMINANTS AND POLLUTANTS – BAYS

According to the Texas Commission on Environmental Quality (TCEQ) Texas Water Quality Assessment Report (TCEQ, 2010), over 3,700 square miles of Texas's bays and estuaries are impacted by land development upstream within the watershed of the riverine systems forming the coastal bays and direct impacts from land development along the bays and estuaries. The probable sources of contaminants and pollutants range from agricultural practices and industrial activates to non-point source discharges and urban-related storm water runoff (Table 11-1).

The presence of these pollutants and contaminants in the waters within the watershed and reaching the bays and estuaries indirectly results in the deposition of pollutants and contaminants in sediment in the bays. Recent investigations of contaminant impacts on sediments have documented that some selected dredged material areas show high levels of heavy metals, polycyclic aromatic hydrocarbons (PAHs, toxic organic compounds derived from fossil fuels and their combustion), polychlorinated biphenyls (PCBs, toxic volatile organic compounds released by plastics and electrical equipment), and dioxins (highly toxic manufacturing by-products) have contaminated selected sites in the Texas bays systems.

Table 11-1
Size of Assessed Waters with Probable Sources of Impairments (TCEQ, 2010).

Probable Source	Bays and Estuaries (Square Miles)	Coastal Shoreline (Miles)	Ocean and Near Coastal (Square Miles)
Agriculture	27.6		
Atmospheric Deposition		388.2	68.3
Industrial	542.2		
Municipal Discharges/Sewage	43.7		
Natural/Wildlife	13.7		
Other	611.9		
Unknown	1,110.5	388.2	68.3
Unspecified Nonpoint Source	1,006.9		
Urban-Related Runoff/Storm Water	361.2		

11.2 SEDIMENT CONTAMINANTS AND POLLUTANTS – TRINITY BAY

Trinity Bay is a shallow, depositional environmental that is approximately eight feet deep in the center at the confluence of the Trinity River. The source of sediments as well as contaminants and pollutants in Trinity Bay is largely influenced by the Trinity River system, the dam at Lake Livingston, and localized geomorphic features (Phillips, Slattery, and Musselman, 2004). The dam on the Trinity River at Lake Livingston further decoupled the connection of upper reaches of the Trinity River system from the lower river system and its reach to the Trinity Bay. However, the lower Trinity River system exhibits reduced sediment transport from geomorphic features along the lower river system that provide alluvial storage and further reduce the sediment carried and deposited into Trinity Bay. A study by Warnken and Santschi in 2009 reported that less than 20 percent of the sediment load containing trace metal pollutants from the Trinity River watershed reaches Galveston Bay. In addition, only a minor portion of the shoreline of Trinity Bay is developed for industrial purposes.

While generally widespread distribution of trace metals and low-level organic contaminants have been detected in Trinity Bay during previous sediment sampling events, no directly correlated hot spots for contaminants of pollutants have been identified. Figure 11-1 shows the limited number of regulated facilities and associated cleanup efforts near or along Trinity Bay (USEPA, 2016).

11.3 SEDIMENT CONTAMINANTS AND POLLUTANTS – GALVESTON BAY

Galveston Bay is a depositional environmental that is on average seven to nine feet deep in the center at the confluence of the Trinity and San Jacinto Rivers. The source of sediments as well as contaminants and pollutants in Galveston Bay are largely influenced by the river systems, industrial; and urban development around the bay, and the Gulf of Mexico (Melosi, 2007). The Galveston Bay shoreline has been predominantly developed with large industrial complexes for many decades. Figure 11-2 depicts the volume of regulated facilities and associated cleanup projects that are located along the Galveston Bay shoreline as reported by the U.S. EPA (2016).

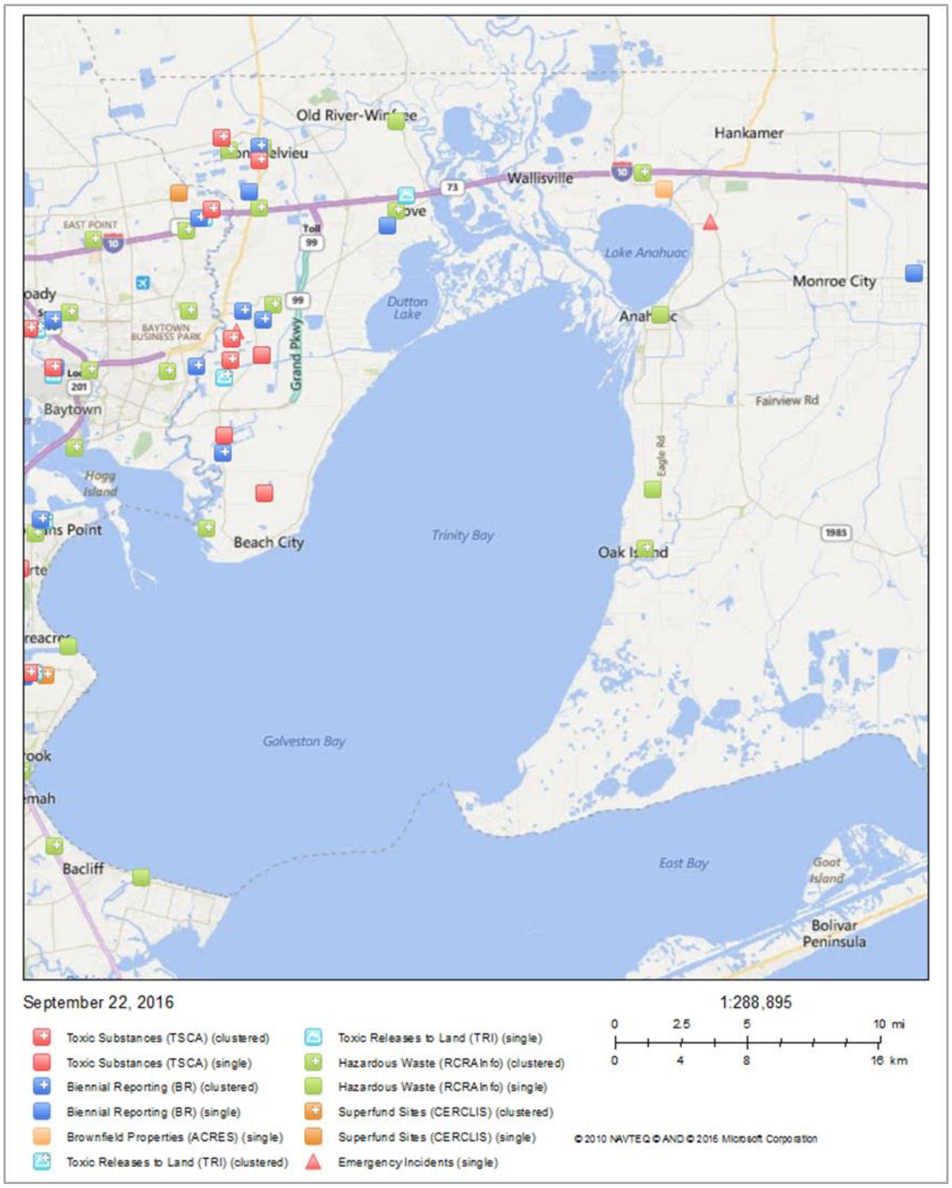


Figure 11-1, Regulated Facilities and Cleanup Efforts located near Trinity Bay (USEPA, 2016) that may have affected bay sediments.

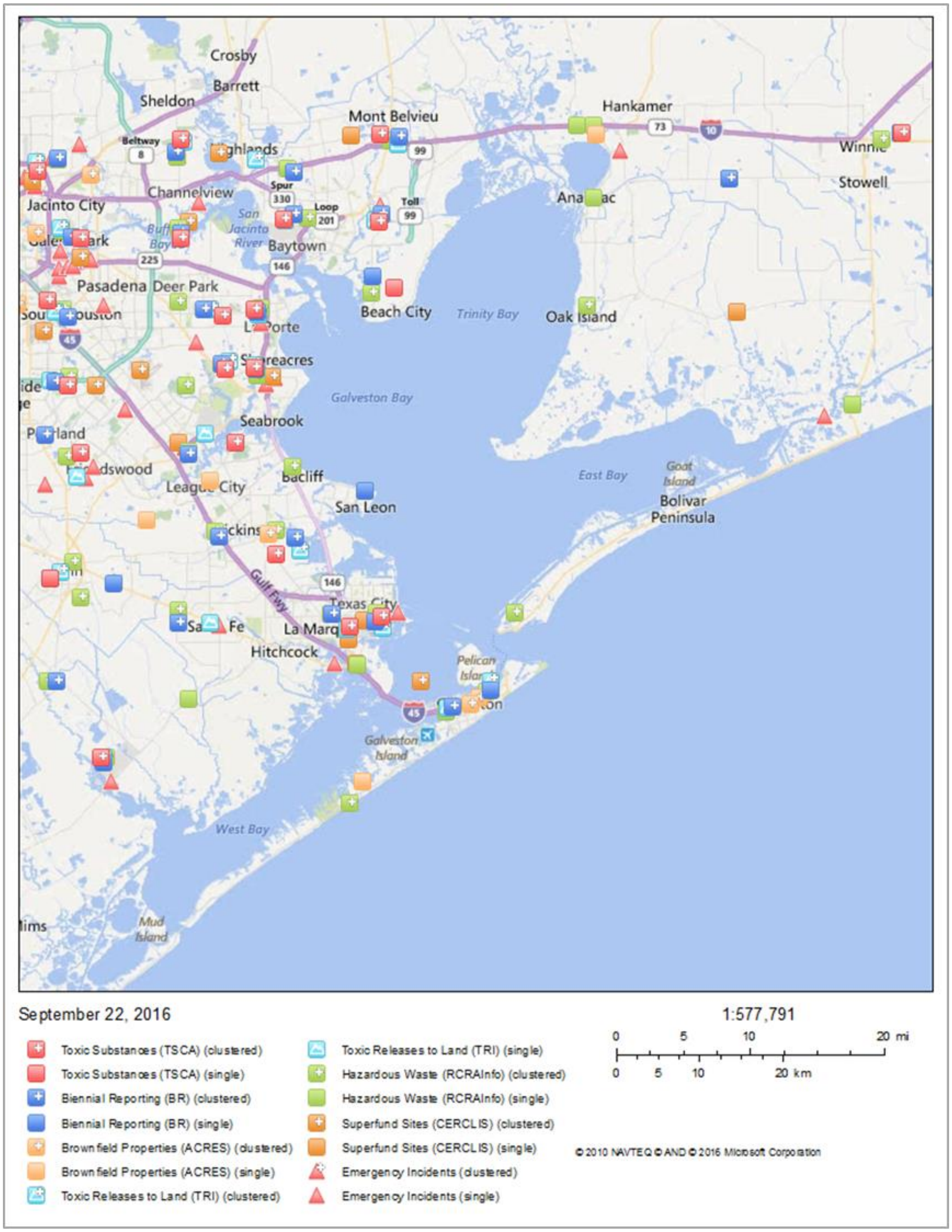
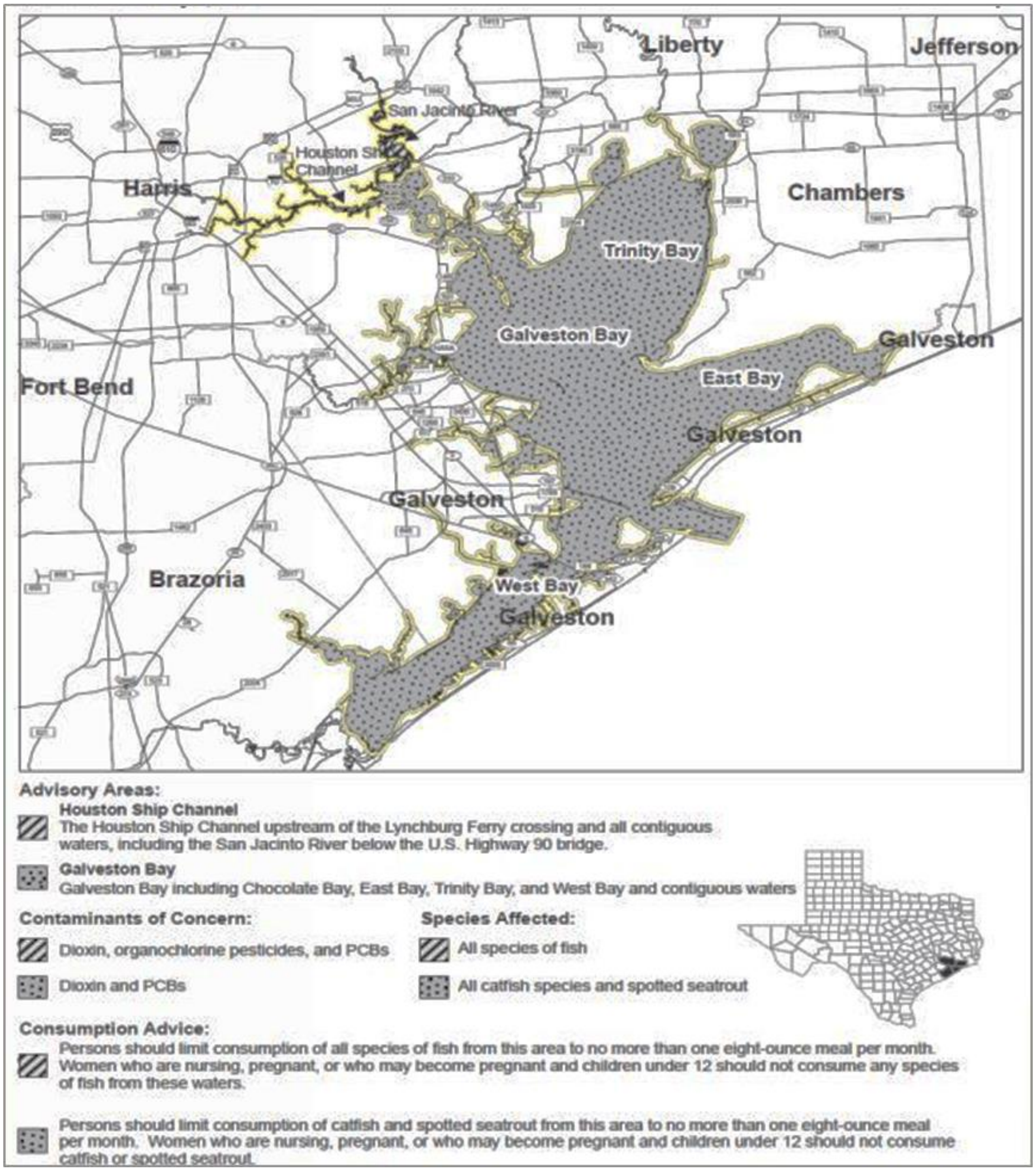


Figure 11-2, Regulated Facilities and Cleanup Efforts located near Galveston Bay (USEPA, 2016) that may have affected the bay sediments.



Advisory Areas:

▨ **Houston Ship Channel**
The Houston Ship Channel upstream of the Lynchburg Ferry crossing and all contiguous waters, including the San Jacinto River below the U.S. Highway 90 bridge.

⁘ **Galveston Bay**
Galveston Bay including Chocolate Bay, East Bay, Trinity Bay, and West Bay and contiguous waters

Contaminants of Concern:	**Species Affected:**
▨ Dioxin, organochlorine pesticides, and PCBs	▨ All species of fish
⁘ Dioxin and PCBs	⁘ All catfish species and spotted seatrout

Consumption Advice:

▨ Persons should limit consumption of all species of fish from this area to no more than one eight-ounce meal per month. Women who are nursing, pregnant, or who may become pregnant and children under 12 should not consume any species of fish from these waters.

⁘ Persons should limit consumption of catfish and spotted seatrout from this area to no more than one eight-ounce meal per month. Women who are nursing, pregnant, or who may become pregnant and children under 12 should not consume catfish or spotted seatrout.

Figure 11-3, PCB and Dioxin Distribution in Galveston Bay Area (Rifai, 2014)

While most Galveston Bay sediment data does not appear to exhibit problem areas or hot spots for toxic pollutants or organic contaminants in sediment, known oil spills and hazardous substance releases into the environment have directly impacted Galveston Bay sediment in localized areas. The Malone Service Company Superfund Site in Galveston County evaluated localized areas of marsh sediment impacted with pesticides, metals, PCBs, and PAHs adjacent to the facility along Swan Lake (TCEQ, 2015). Similarly, the Tex-Tin Superfund Site was established in 1998 for a tin smelter that operated in Texas City from 1941 to 1991. Several contaminants (primarily trace metals from the smelting process) were detected in sediments in the Wah Chang ditch, which exited the smelter facility into adjacent wetlands and the Swan Lake estuary of West Galveston Bay (TNRCC, 2001).

Directly adjacent to Lower Galveston Bay, the Houston Ship Channel has historically demonstrated elevated concentrations of heavy metals, such as mercury, PCBs, and dioxins. The Houston Ship Channel has several contributing sources of trace metal pollutants and organic contaminants, including the Patrick Bayou Superfund Site in Deer Park, which has been listed as a Superfund site since 2002 (Allen, 2015). Patrick Bayou sediment has exhibited elevated concentrations of pesticides, PAHs, metals, and PCBs from an accumulation of storm water and wastewater discharges from permitted industrial facilities and urban areas in its watershed.

11.4 SEDIMENT CONTAMINANTS & POLLUTANTS – MATAGORDA BAY

Matagorda Bay is a shallow, depositional environmental that is approximately 10 feet deep at the confluence of the Colorado River. Lavaca Bay adjoins the Matagorda Bay to the northwest at the confluence of the Lavaca River and is approximately eight feet deep. The source of sediments as well as contaminants in each of the bays is from natural and man-made tidal inlets, erosion of adjacent beaches, and the watershed of the Colorado and Lavaca Rivers. In addition, some industrial activities are located or have been present historically along and adjacent to Matagorda Bay that served as a source of contaminants for bay sediment. Figure 11-4 depicts the limited number of regulated facilities and associated cleanup efforts near or along Trinity Bay (USEPA, 2016).

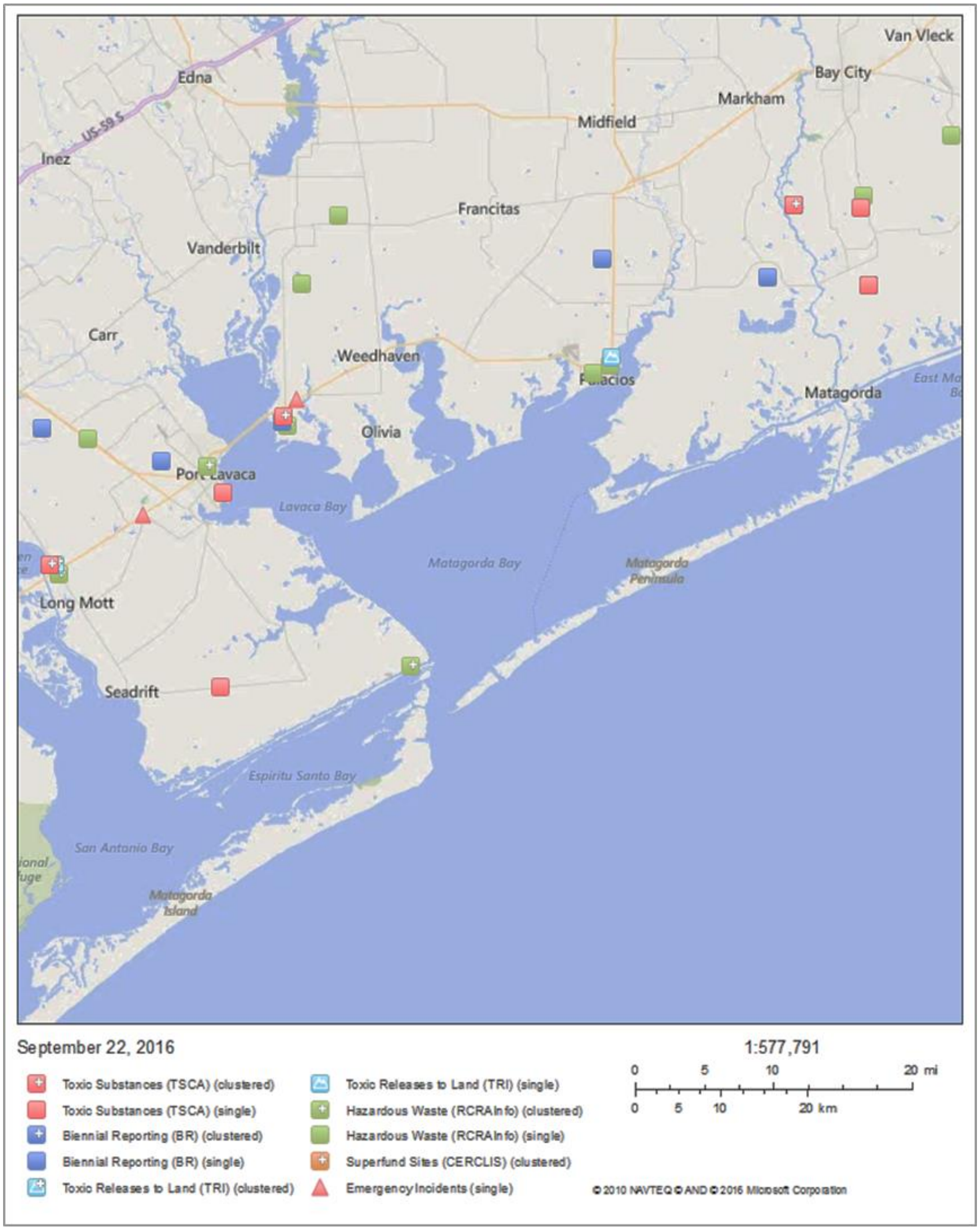


Figure 11-4, Regulated Facilitates and Cleanup Efforts near Matagorda Bay (USEPA, 2016) that may have affected bay sediments.

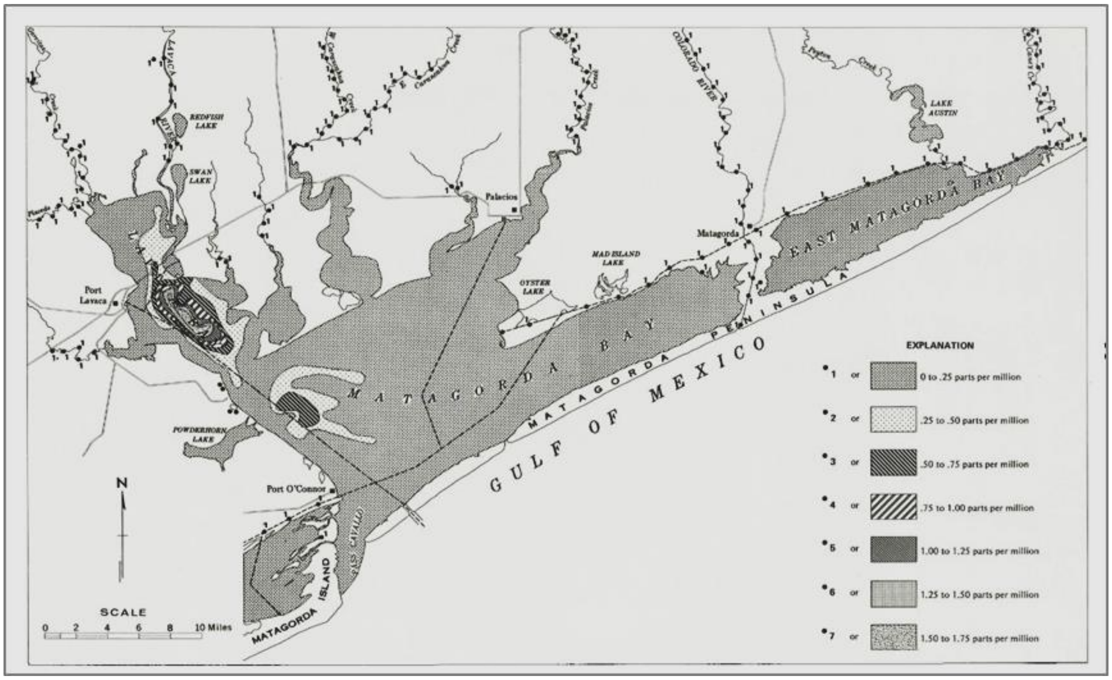


Figure 11-5, Mercury Distribution in Matagorda and Lavaca Bays (McGowen et al., 1979).

In general, trace metals and low-level organic contaminants occur throughout this bay system with the exception of mercury. Elevated mercury concentrations have been identified within Lavaca Bay and near its confluence with Matagorda Bay in Matagorda Bay. Figure 11-5 shows the distribution of mercury in sediment samples collected by MaGowen, Byrne and Wilkinson (1979). Mercury contamination within Lavaca Bay has been directly associated with an USEPA Superfund site for the Alcoa Point Comfort Operations Plant in Calhoun County (USEPA, 2011). The Alcoa Plant, while in operation in the 1960s and 1970s, used mercury in the production of chlorine gas and sodium hydroxide. Mercury-laden wastewater was allegedly released to Lavaca Bay during plant operations.

11.5 CONTAMINANTS & POLLUTANTS – CORPUS CHRISTI BAY

Corpus Christi Bay is a shallow, depositional environmental with an average depth of 12 feet (White et al., 1983). Several bays and estuarine habitats at the confluence of the Nueces River comprise the Corpus Christi Bay complex (Texas Water Commission, 1992). The source of sediments as well as contaminants and pollutants in Corpus Christi Bay include the Nueces River, industrial and urban runoff, and the Gulf of Mexico. The Corpus Christi Bay shoreline has been predominantly developed with large industrial complexes for many decades. Figure 11-6 depicts the volume of regulated facilities and associated cleanup projects that are located along the Corpus Christi Bay shoreline as reported by the U.S. EPA (2016).

Corpus Christi Bay sediments show elevated concentrations of several heavy metals including arsenic, barium, copper, mercury, nickel, and selenium (Barrera et al., 1995). While widespread distribution of trace metals has been detected in Corpus Christi Bay during previous sediment studies, no hot spots for contaminants or pollutants have been identified. Figure 11-7 shows the limited number of regulated facilities and associated cleanup efforts near or along Trinity Bay (USEPA, 2016).

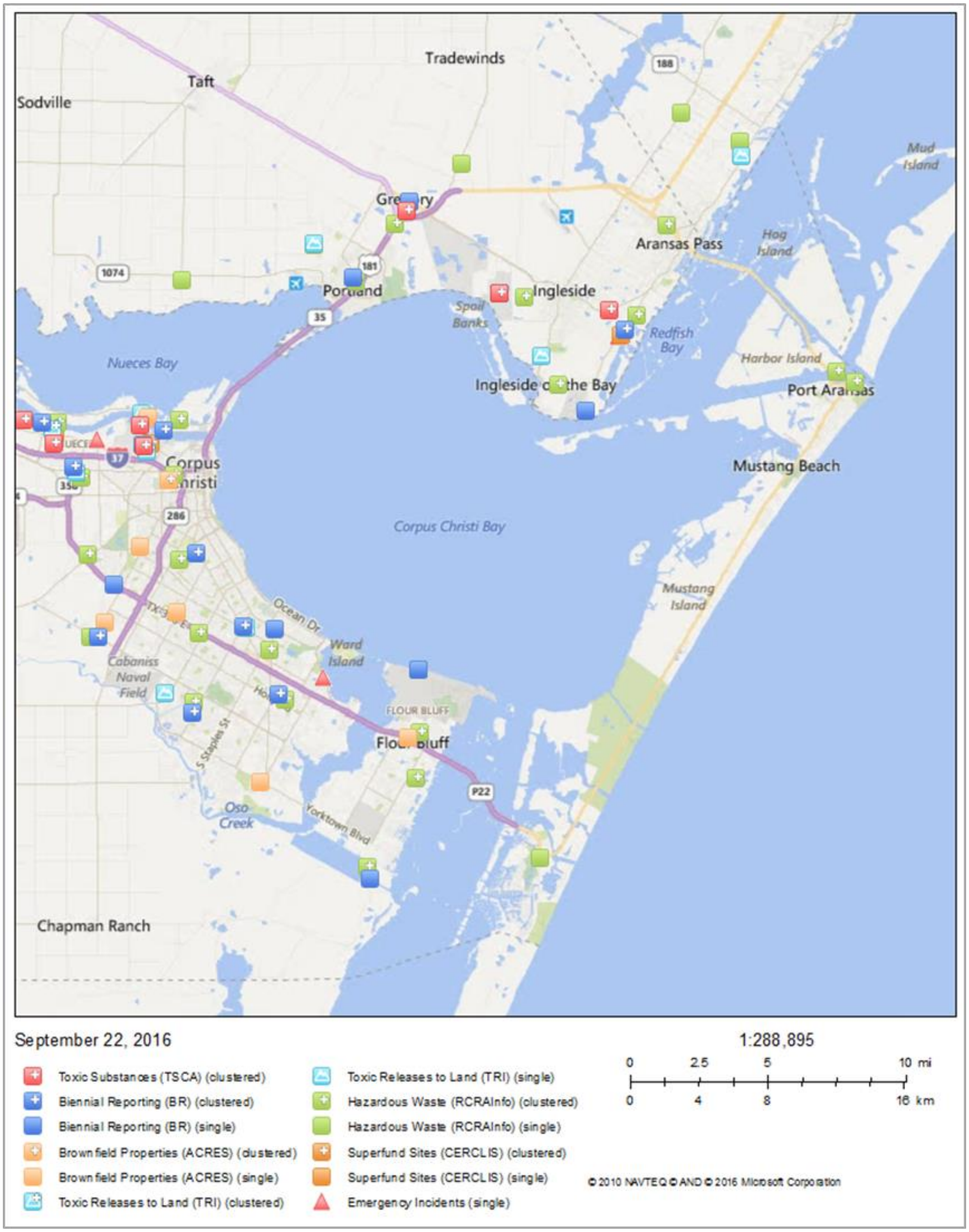


Figure 11-6, Regulated Facilities and Cleanup Efforts near Corpus Christi Bay (USEPA, 2016) that may have affected bay sediments.

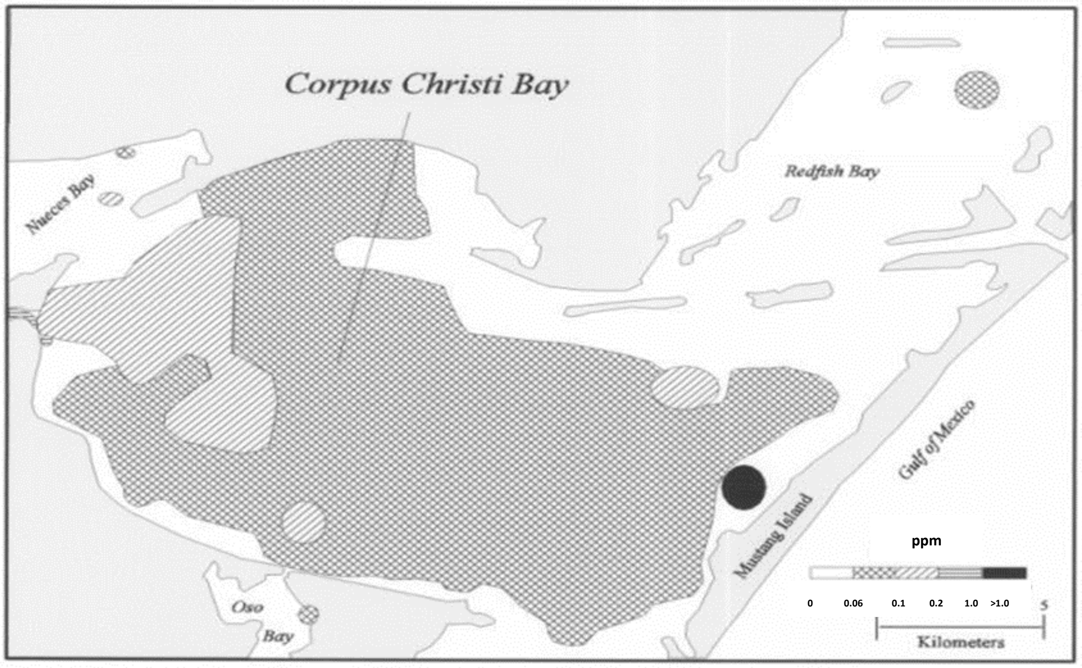


Figure 11-7, Mercury Distribution in Corpus Christi Bay (in ppm) (after Barrera et al., 1995). The mercury concentrations throughout Corpus Christi Bay range from 0 ppm (represented by the white coloration on the map) to greater than 1.0 (represented by the dark gray coloration on the map). The map also illustrations mercury concentrations ranging from 0.06-0.1 ppm (represented by the hatch marks), 0.1-0.2 ppm (represented by the right-slanting lines), and 0.2-1.0 ppm (represented by the parallel lines) throughout the bay.

12.0 RECOMMENDATIONS

The Texas Coastal Sediment Sources General Evaluation Study was developed for the Texas General Land Office as a desktop analysis to determine the potential availability of sediments within the Texas coastal system as possible sediment sources that may be applied to coastal protection and restoration projects. The purpose of this study is to provide an overview of locations of potential sediment sources within bay and offshore environments, and dredging activities that generate dredged sediments that may be used beneficial for coastal protection and restoration projects. The analyses performed under this study includes a general evaluation of potential volumes of sediments that may be available from in-situ sediment source locations and from reoccurring dredging events from offshore locations and targeted coastal bay-systems.

It must be noted that the study's analysis relied on existing and available data to estimate the extent, physical characteristics, and quantity of sediments potentially available for coastal protection and restoration projects. At times, the existing data was either limited or not readily available. Therefore, to better refine the sediment sources estimates it will be necessary to perform follow-on studies to include field investigations that should involve the collection of geophysical and geotechnical data. In the interim, this report can be used as a guide to coastal resources planning teams to generally identify potential sediment harvesting or beneficial use of dredged material availability and opportunities along the Texas coast.

To account for the limitations of the existing data sets used to develop estimations of sediments sources under this study, it is recommended the following actions be considered for implementation that will contribute to the development a system-wide sediment management approach for the protection and restoration of the Texas coast. These recommended actions include implementing or facilitating a mix of investigative programs, sediment stakeholder collaboration groups, and financial partnerships.

1. **In-Situ Sediment Borrow Sources Investigations Program.** This program involves undertaking geophysical and geotechnical investigations of potential offshore and onshore systems in-situ sediments sources as identified in this report. Large-scale protection and restoration of barrier island features on both the Gulf-facing shoreline and the back barrier marsh areas will require significant volumes for sediments to construct. Both offshore and onshore system in-situ sediments are potentially viable sources to provide the volume of sediments necessary to adequately restore and sustain barrier island beach, dune, and back marsh features.
2. **Innovative Technologies for Sediment Delivery Program.** Potential offshore sediments sources for barrier island restoration projects are predominantly located more than 10 miles from the shoreline. Therefore, it is a recommended that an Innovative Technologies program be implemented to facilitate the identification and evaluation of long-distance conveyance methodologies and systems to deliver sediments from offshore borrow sources to barrier island restoration locations. This program should be structured to also evaluate other innovative

technologies to cost-effectively deliver sediments required for a mix of restoration project types and sizes. Transferability and scalability should be additional consideration when evaluating new or innovative sediment delivery technologies.

3. **Dredged Material Placement Area Sediment Borrow Source Investigations Program.** There are over 500 dredged material placement areas (PAs) located throughout the Texas coastal region, as shown in Appendix B, that have and continue to receive sediments dredged from both deep- and shallow-draft navigation channels, to include navigation channels for coastal ports and the GIWW. Many of these PAs are located within the vicinity of areas requiring coastal protection and restoration, and most likely contain sediments suitable to construct restoration projects. Additionally, several PAs, particularly along the GIWW, are reaching their capacity to receive future dredged sediments. To facilitate opportunities to harvest sediments from the PAs to be used for constructing coastal protection and restoration projects, and to allow for regenerating disposal capacity within the PAs, it is recommended that a Dredged Material Placement Area Sediment Borrow Source Investigations Program be implemented. This program would facilitate the harvesting of sediments from the PAs by investigating and evaluating sediment features within PAs, to include sediment physical characteristics, sediment chemistry, sediment stratification, and, volume of available sediments. PAs within the vicinity of planned or proposed restoration projects could be prioritized for investigation and evaluation, with intent of designating suitable PAs as approved borrow areas to harvest sediments for coastal protection and restoration projects.

4. **Sediment Science and Technology Task Force.** It is recommended that a multi-agency and stakeholder task force be instituted to foster a comprehensive and collaborative approach to further the science of coastal sediment sourcing; and, technologies and methodologies for harvesting and delivery of sediments for coastal protection and restoration projects. This task force would serve as a platform to institute collaboration among various agencies, academia, and other stakeholder groups interested in the science, technologies, and programs for regionally managing sediments to achieve resiliency and sustainability of important natural resources along the Texas coast.

5. **Regional Beneficial Use of Dredge Material Task Force.** Similar to the recommended Sediment Science and Technology (SS&T) Task Force, the Regional Beneficial Use of Dredged Material (BUDM) Task Force would be a collaborative and multi-agency group. However, the charter of the BUDM Task Force would be to focus on the application of dredged sediments for restoration projects rather than investigating and evaluating potential sediment sources. The BUDM Task Force would facilitate a coordinate approach to identify opportunities and plan for the reuse of dredged sediments for coastal ecosystem restoration projects; coordinate the leveraging of other restoration programs and funding streams for BUDM actions; and, to develop a collaborative process to streamline permit decisions for BUDM projects.

6. **“Engineering with Nature” Program.** A detailed understanding of the geomorphological conditions along the Texas coast would allow for identifying opportunities to integrate natural processes with engineering solutions to modify environmental forces to redirect sediment transport for restoring shoreline and habitats. Some coastal environments only require the redistribution or redirection of geomorphological processes to naturally accumulate sediments. Understanding the coastal sedimentary and geomorphological processes can facilitate small and medium projects where sedimentation can be induced at a very low cost. It is recommended that an “Engineering with Nature” program be established to promote developing restoration solutions that integrate natural and system processes to achieve resilient and sustainable project outputs.

7. **Funding Strategies for Regional Sediment Management and BUDM Programmatic Efforts.** It is recommended that a strategy be develop to identify and leverage program funds and grants tied to ecosystem restoration projects. Funded coastal protection and restoration programs include, but are not limited to:

    a. Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012 (RESTORE Act) Program;

    b. Natural Resource Damage Assessment (NRDA) Program;

    c. Gulf Environmental Benefit Fund (GEBF) through the National Fish and Wildlife Foundation (NFWF);

    d. Gulf of Mexico Energy Security Act of 2006 (GOMESA);

    e. Coastal Zone Management Program; and

    f. Coastal Erosion Planning and Response Act (CEPRA).

8. **Post-Storm Sediment Management Program.** After major storms, sediments may become available on the upper portion of the shoreface on bay bottoms. A short window of opportunity exists to return these sediments to the natural habitats before they are lost to the coastal system (i.e. East Galveston Bay after Hurricane Ike or Galveston shoreface after Hurricane Ike). If planning, funding. and environmental coordination is developed with regulatory groups, a portion of these sediments can be recovered for specific projects by returning the sediment to the natural system. A systematic inventory of areas affected after storms should be developed to identify specific areas of interest where sediments may be harvested for restoration projects following storm events.

9. **Expansion of TXSed Program.** An expansion of the TXSed Program is recommended to include 3D mapping of the sediment sources identified will add valuable information regarding regulatory

concerns recommended by the natural resources group. Developing an inventory of environmental requirements for each borrow site will facilitate the develop of a programmatic approach to coastal protection and restoration.

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Appendix A

Summary of Potential In-Situ Offshore and In-Bay Sediment Borrow Areas

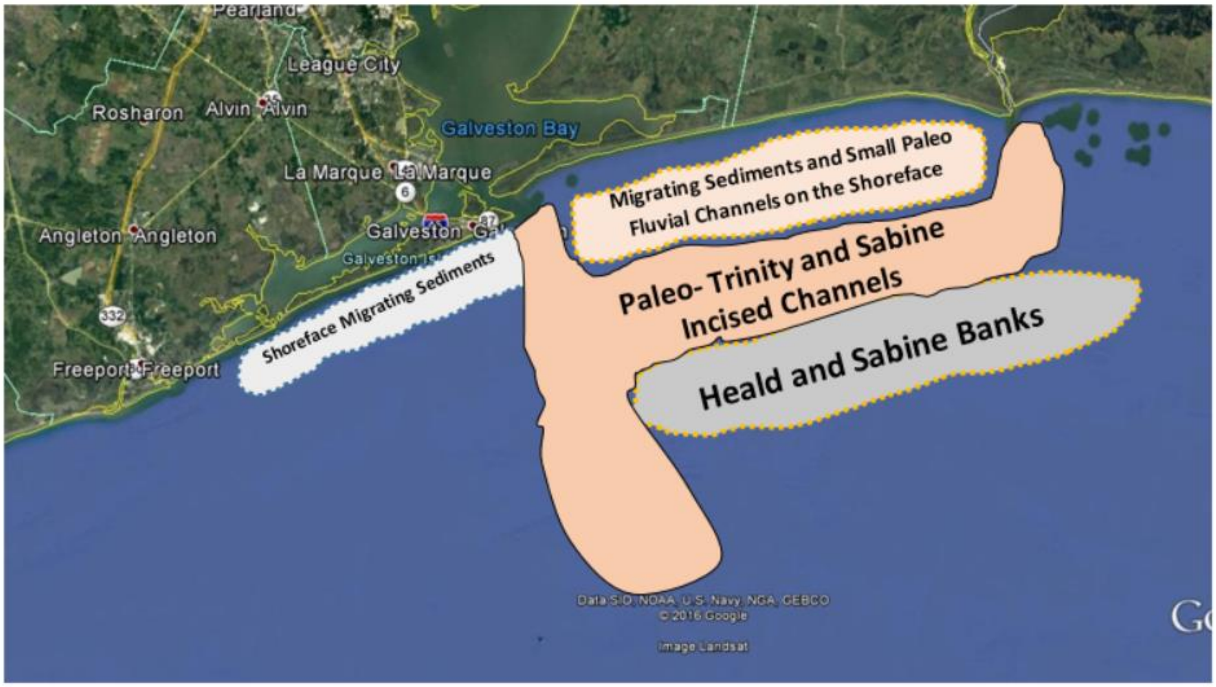

Figure 13-1, Potential Sediment Areas in the Upper Texas Coast

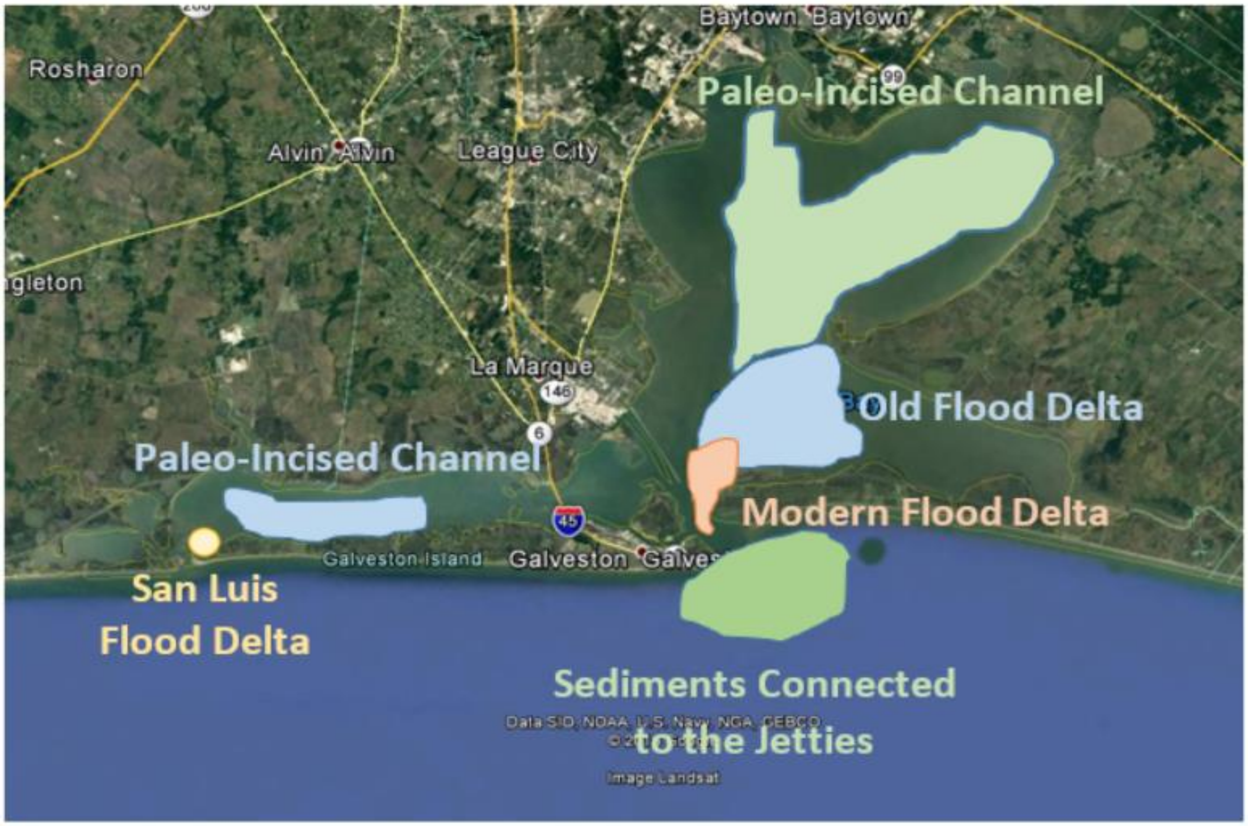

Figure 13-2, Potential Sediment Areas in the Galveston Bay Area

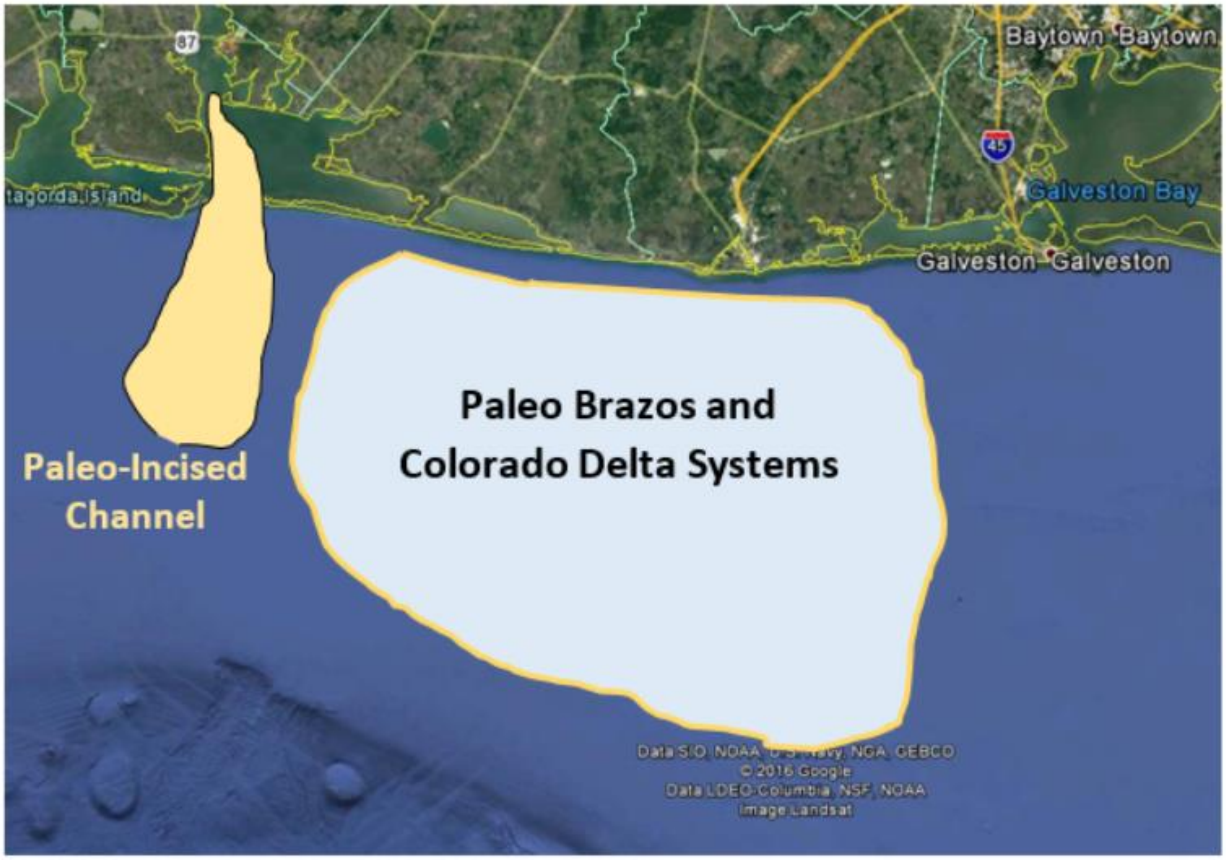

Figure 13-3, Potential Sediment Areas in the Colorado and Matagorda Counties and Coastal Areas

Figure 13-4, Potential Sediment Areas in the Matagorda Bay Area

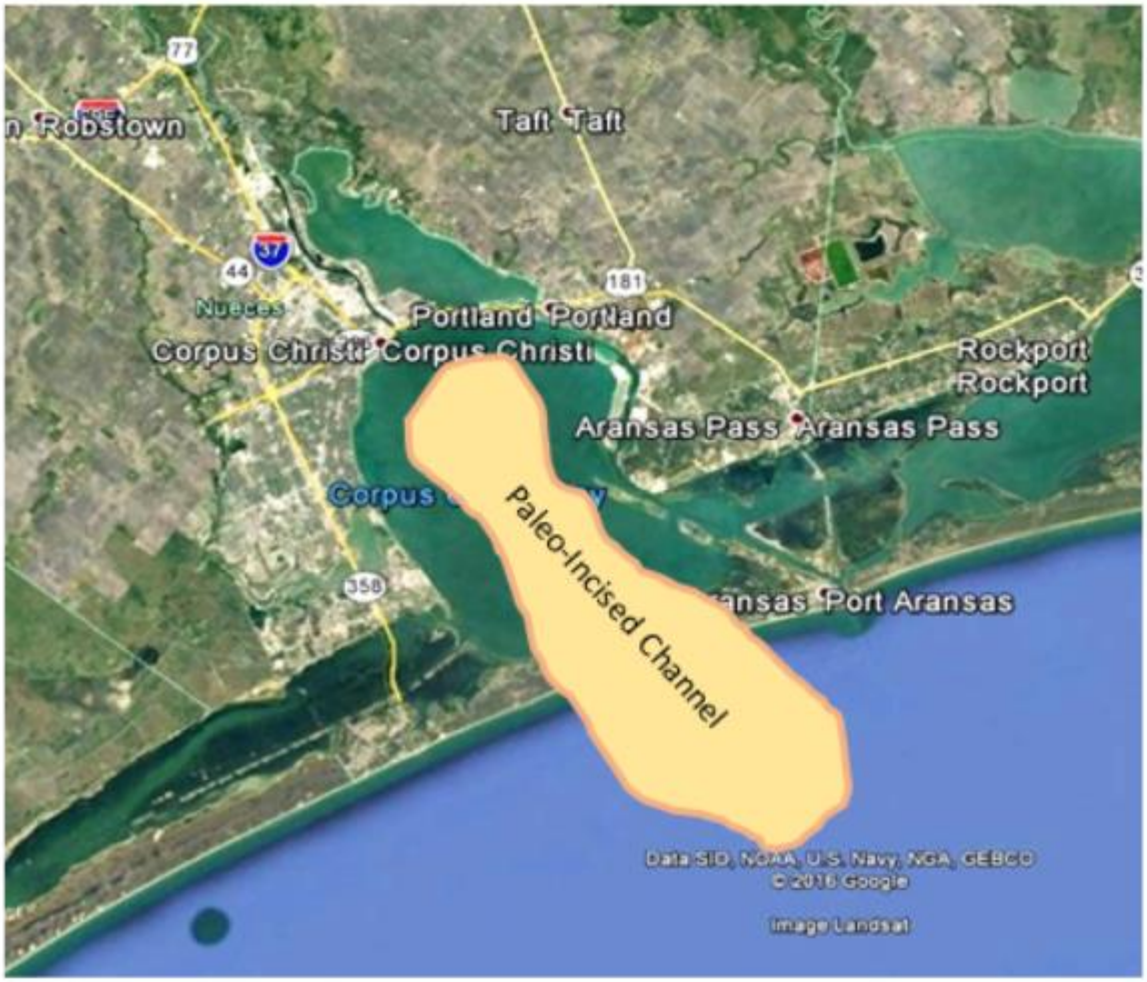

Figure 13-5, Potential Sediment Areas in the Corpus Christi Bay Area

Appendix B

Dredge Material Placement Area Locations

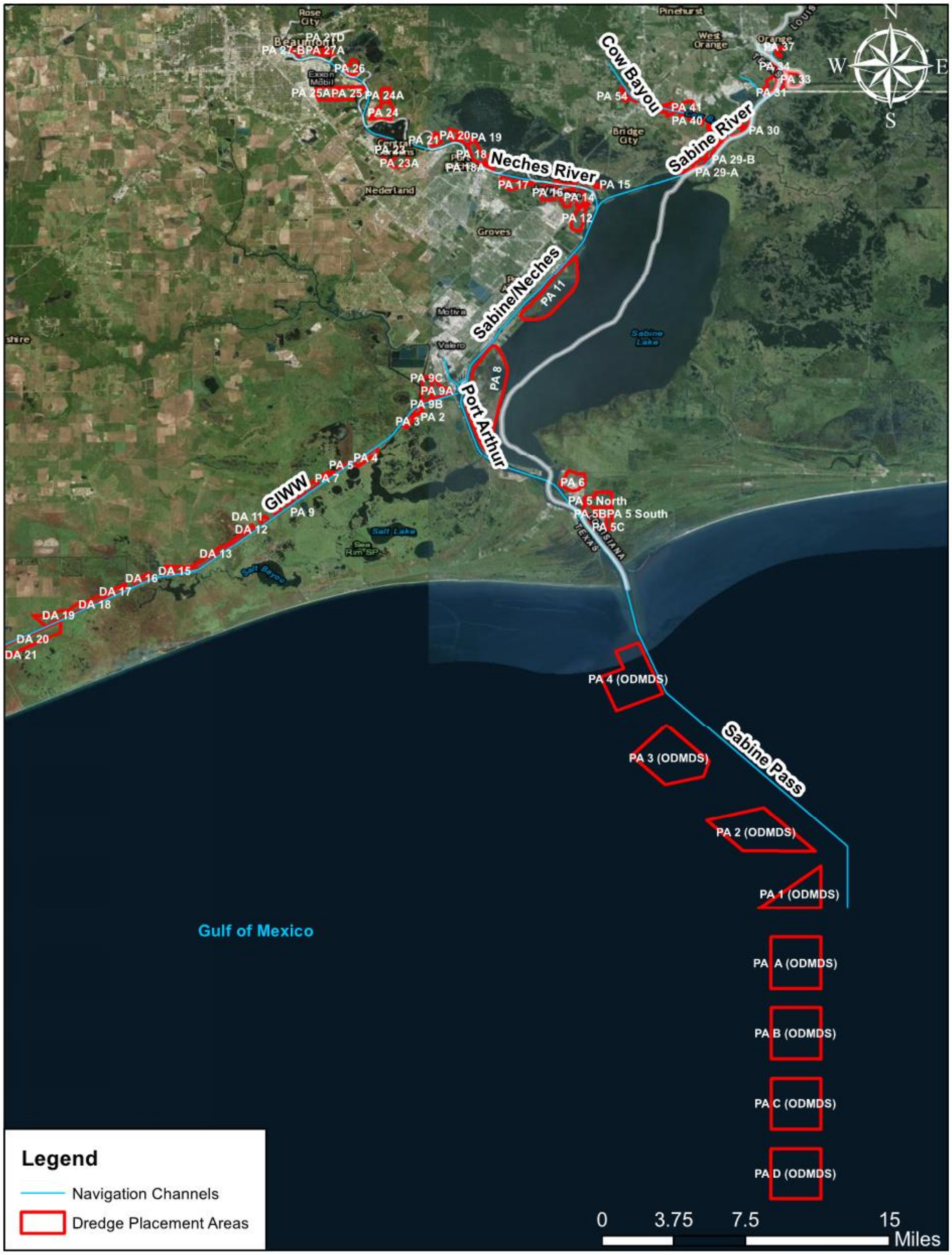

Figure 13-6, Dredge Placement Areas in the Sabine Navigation Channel

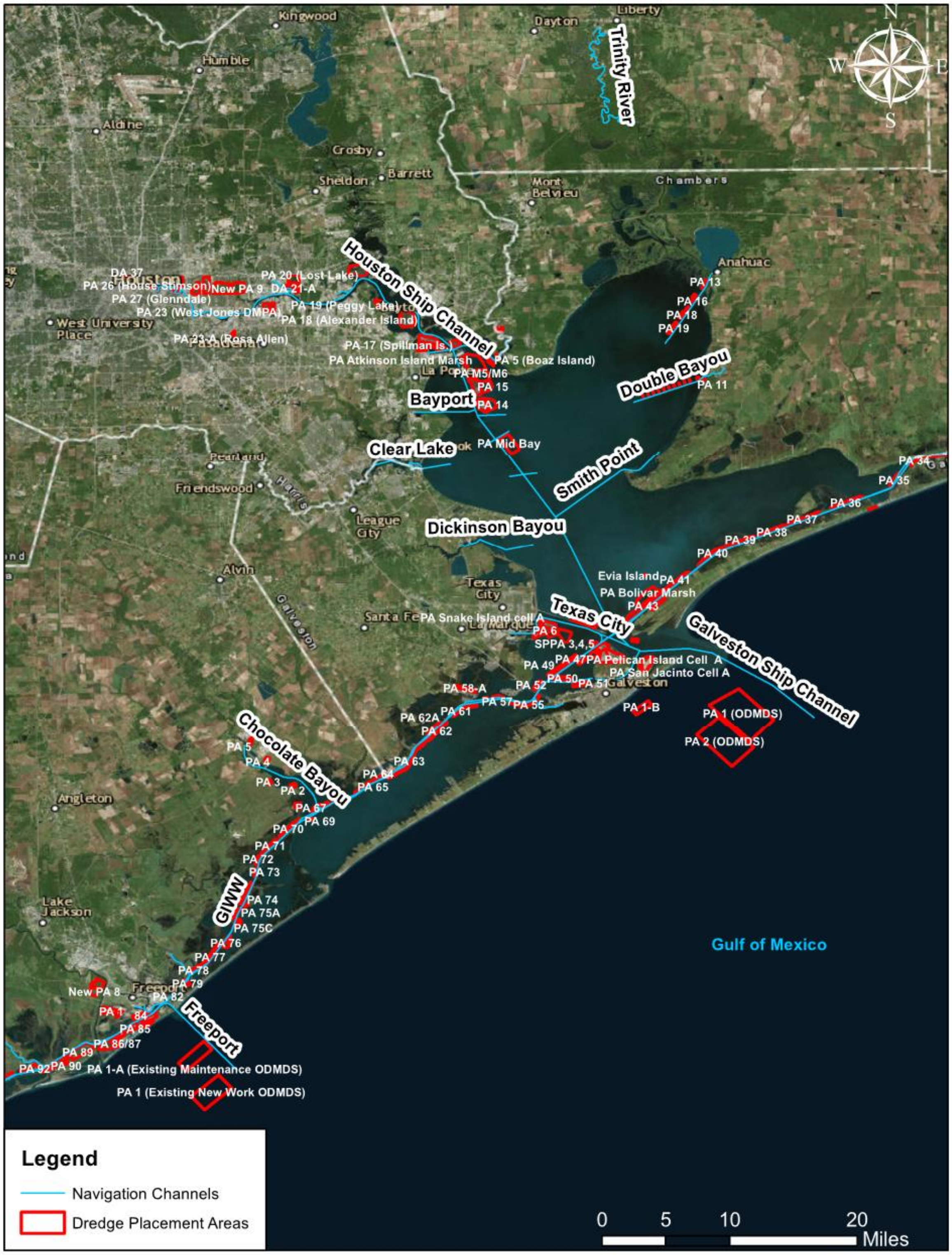

Figure 13-7, Dredge Placement Areas in the Trinity-Galveston Bay Area

Figure 13-8, Dredge Placement Areas in the Brazos-Freeport Area

Figure 13-9, Dredge Placement Areas in the Matagorda Bay Area

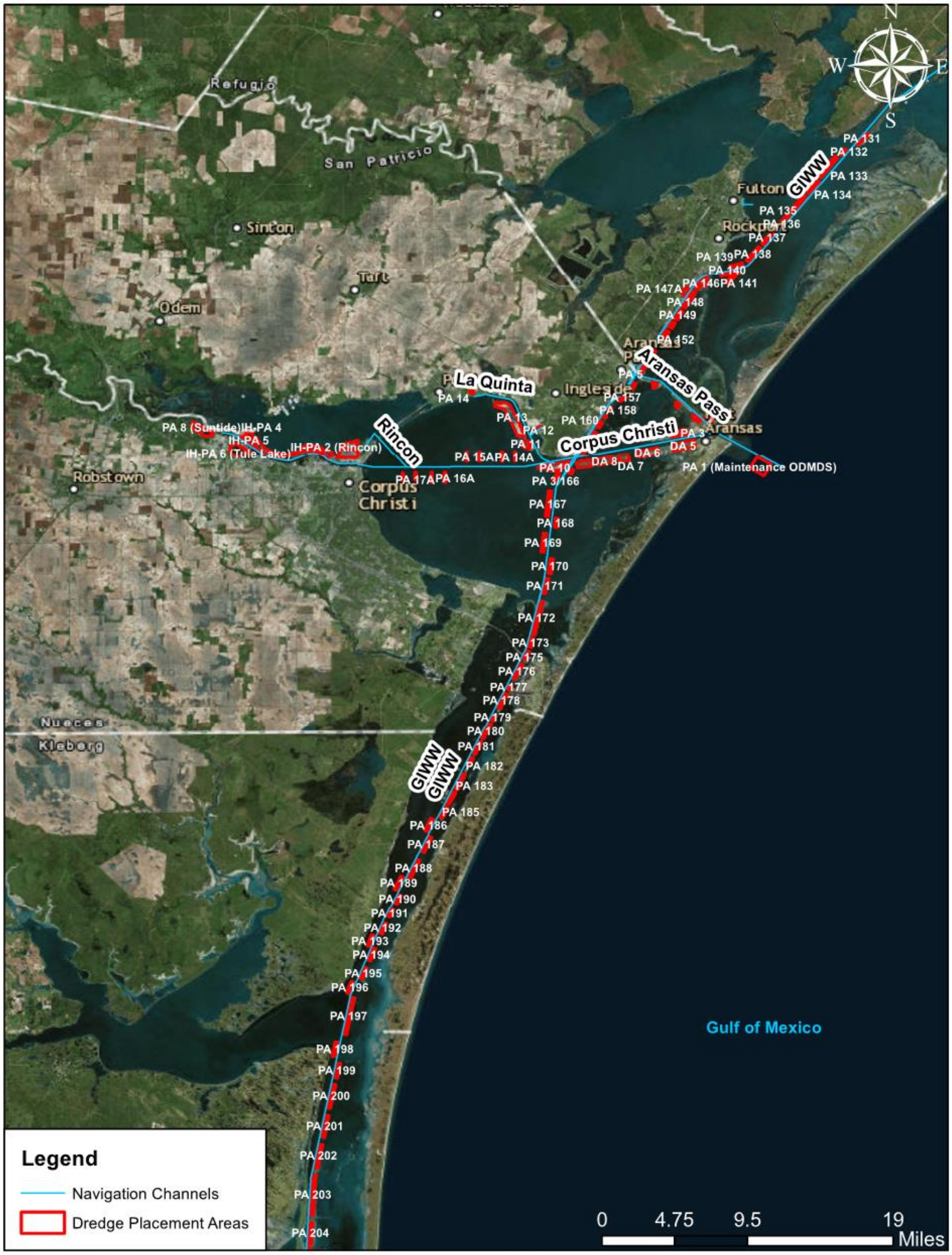

Figure 13-10, Dredge Placement Areas in the Corpus Christi Bay Area

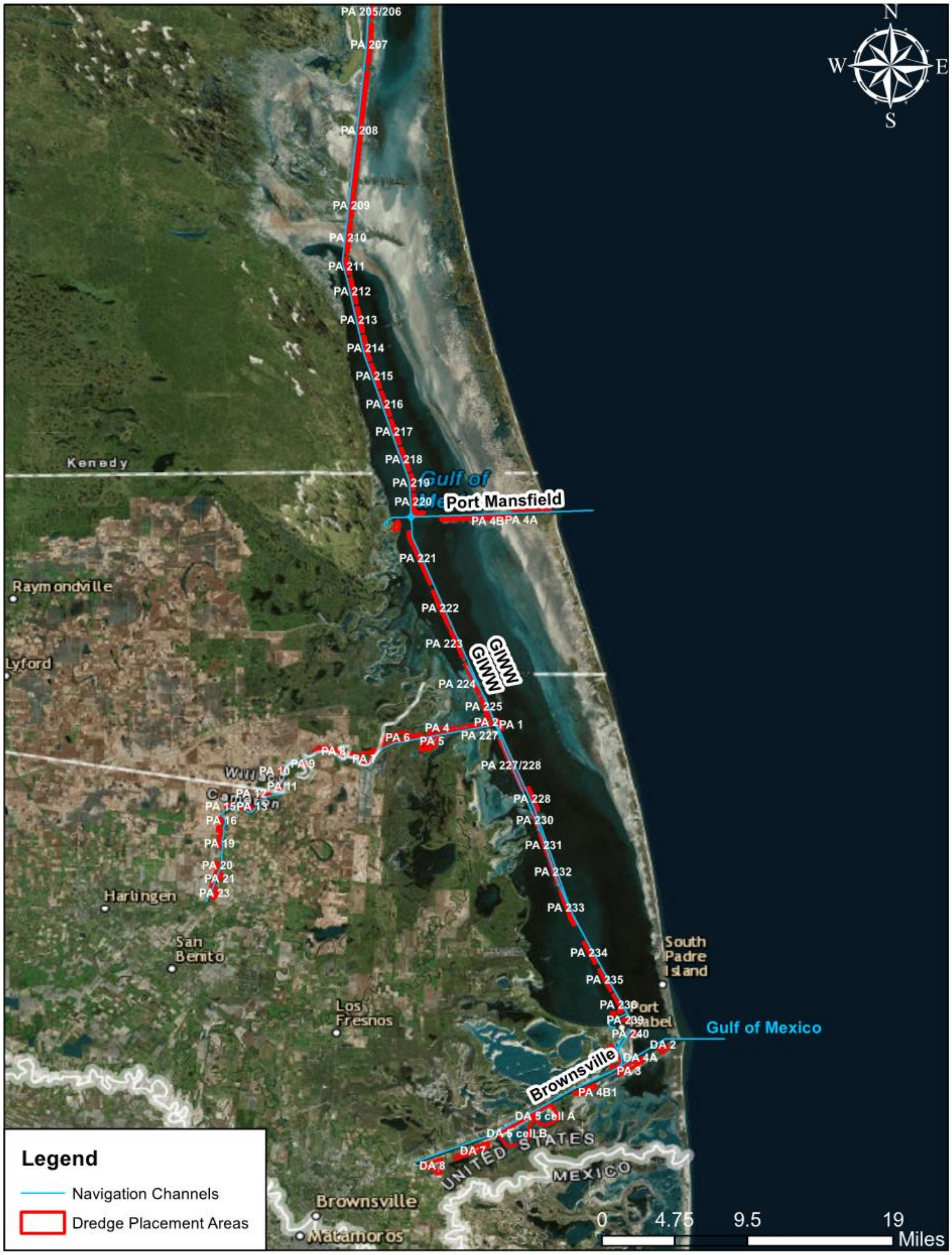

Figure 13-11, Dredge Placement Areas in the Lower Laguna Madre