MOTT MACDONALD

Draft Material Source Investigation

August 31, 2018

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Executive Summary

The Coastal Texas Protection and Restoration Feasibility study contains multiple measures that require significant amounts of clay, silt, and sand material for construction. A material source investigation was conducted to identify potential borrow sources for the Coastal Storm Risk Management (CSRM) and Ecosystem Restoration (ER) measures proposed for the Tentatively Selected Plan (TSP). A preliminary costing analysis was conducted to determine viable sediment sources. A summary of the analysis is shown below.

CSRM Alternative A:

CSRM Alternative A involves construction of levees along the Galveston Island and Bolivar Peninsula. For this analysis it was assumed that clay material would be used to construct the levees. Multiple sediment sources were investigated including commercial sourcing of material and acquiring land to source material from the Beaumont Clay formation. A summary of the advantages of each clay source is shown below in Table 1.

Table 1. Advantages and Disadvantages of CSRM Alternative A potential clay material sources

	Advantages	Disadvantages	Future Considerations
Commercial Sources	• Borrow site management and land acquisition would not be required.	• Multiple borrow sources run by multiple companies would be required. • Commercial sources may be resistant to supplying quantities required if it will exhaust their pits. • Lack of commercial sources in Chambers County to provides material to the Bolivar Peninsula resulting in high trucking costs. • Trucking duration is highly dependent on the amount of trucks available on site for transport. If there is a trucking shortage, duration of the project could increase substantially.	• Consider coordination with City of Houston on use of material from future large capital improvement projects.
Contractor Sourced Through Land Acquisition	• Potential to acquire land close to the project sites mitigating transportation costs. • Could potentially allow for trucking or barging to be options for transporting materials to the sites.	• Would require lead-time for real estate acquisition in project schedule. • Costs of Land Acquisition are unknown and will increase the estimates shown here. • Barge loading and unloading sites may be limited. • Trucking duration is highly dependent on the amount of trucks available on site for transport. If there is a trucking shortage, duration of the project could increase substantially.	• Further research and analysis should be performed to narrow down preferred land acquisition areas. • Further research should be performed on real estate land acquisition costs and time.

ER Measure G-5:

This measure involves construction of a large beach fill along portions of West Galveston Island and Bolivar Peninsula. Due to the large quantity of sand required to construct the beach fill, it was assumed that only offshore sand sources would have sufficient quantity to construct the measure. Multiple sand sources were investigated, including dredging of the Sabine Banks, Heald Banks, and shoreface sediments. The analysis showed that for Bolivar Peninsula portion of the beach fill, the Sabine bank would be the most cost effective borrow source. A summary of the advantages and disadvantages of each sand source is shown below in Table 2.

Table 2. Advantages and Disadvantages of ER Measures G-5 material sources

	Advantages	Disadvantages	Future Considerations
Sabine and Heald Banks	• Large quantities of sand available. • Multiple hoppers could be used in Sabine Bank with large dig areas to reduce duration,	• Long sail distances. • Pipeline locations restricting available dredge areas. • Offshore dredging and pump out are susceptible to weather delays. • May be safety concerns with hydraulic dredges loading to scows 30 – 50 miles offshore.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows. • Feasibility of hydraulic dredge working 30-50 miles offshore (future technologies).
Shoreface Sediment Dredging	• Closest sand source. • Lowest cost for West Galveston Island.	• Only hydraulic dredges can be used. Offshore dredging and pump out are susceptible to weather delays. • Shoreface harvesting could negatively impact adjacent beach erosion rates.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows. • Further studies on effects of shoreface excavation on nearshore coastal processes.

ER Measure G-28:

Measure G-28 involves construction of a large initial marsh fill, an out-year marsh fill in 2085, and island creation. It was assumed that silty sediments would be viable to construct these features. Multiple sand sources were investigated, including dredging of the Houston Ship Channel, GIWW, and shoreface sediments, dredging if tidal flood deltas, and placement area mining. A summary of the advantages and disadvantages of each material source is shown below in Table 3.

Table 3. Advantages and Disadvantages of ER Measures G-28 material sources

	Advantages	Disadvantages	Future Considerations
Ship Channel Dredging	• GIWW maintenance dredging event should provide sufficient material to fill all initial marsh creation and restoration areas.	• No channel maintenance event has enough quantity to fill all out-year marsh areas in one construction phase. • Highest estimated costs and durations.	• Future studies should evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel. • Maximum feasible dredge depth past authorized channel depth to increase available quantity.
Shoreface Sediment Dredging	• Large quantities of available sediment • Lowest costs • Hydraulic dredging and hopper dredging both possible	• Pipeline placement may be difficult through Galveston Island and around San Luis Pass. Both cases involve crossing the west Galveston Bay and GIWW • Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows. • Further studies on effects of shoreface excavation on nearshore coastal processes.
East Galveston Bay Tidal Flood Shoal Dredging	• Large quantities of available sediment. • Sheltered dredge area.	• Only hydraulic dredging possible. • Shallow bay areas limit sizes of dredges used. • GIWW limits size of scow to be used. • Soft material limits possible load sizes in scows. • Potential oyster beds may restrict dredging areas	• Additional geotechnical studies and research to better classify quantities and dredge dig depths
Mining Placement Areas	• Large quantities of available sediment. • Sediment replenished with maintenance dredged materials. • Could extend usable life of placement area.	• GIWW limits size of scow to be used. • Soft material limits possible load sizes in scows.	• Further research into equipment used and costs.

ER Measure B-2:

This measure involves construction of a large beach fill along portions of Follets Island. Due to the large quantity of sand required to construct the beach fill, it was assumed that only offshore sand sources would have sufficient quantity to construct the measure. Multiple sand sources were investigated, including dredging of the Sabine Banks, Heald Banks, and Incised Channels. A summary of the advantages and disadvantages of each sand source is shown below in Table 4.

Table 4. Advantages and Disadvantages of ER Measures B-2 material sources

	Advantages	Disadvantages	Future Considerations
Sabine and Heald Banks	• Large quantities of sand available. • Multiple hoppers could be used in Sabine Bank with large dig areas to reduce duration.	• Long sail distances. • Pipeline locations restricting available dredge areas. • Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows.
Incised Channels	• Potentially large quantities of sand available.	• Long sail distances • Lack of information on the locations of sandy sediments within these paleochannels. • Potentially large amounts of overburden to dredge to get to sand. • Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, overburden quantities, and dredge depths. • Environmental dredging windows.

ER Measure B-12:

Measure B-12 involves construction of a large initial marsh fill and an out-year marsh fill in 2085. It was assumed that silty sediments would be viable to construct these features. Multiple sand sources were investigated, including dredging of the GIWW, shoreface sediments, and placement area mining. A summary of the advantages and disadvantages of each source is shown below in Table 5.

Table 5. Advantages and Disadvantages of ER Measures B-12 material sources

	Advantages	Disadvantages	Future Consideration
Ship Channel Dredging	• GIWW maintenance dredging event should provide sufficient material to fill all initial marsh creation and restoration areas.	• Only has sufficient quantity for initial marsh creation.	• Future studies should evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel • Potential for filling larger marshes with maintenance material over several dredging cycles.
Shoreface Sediment Dredging	• Large quantities of available sediment • Hydraulic dredging and hopper dredging both possible is some instances. • Only source which has enough material for all out-year marsh areas.	• Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify material and dredging depths. • Environmental dredging windows. • Further studies on effects of shoreface excavation on nearshore coastal processes.
Mining Placement Areas	• Sediment replenished with maintenance dredged materials. • Could extend usable life of placement area.	None	• Further research into equipment used and costs.

ER Measure M-8:

Measure M-8 involves construction of a large initial marsh fill, an out-year marsh fill in 2085, and island creation. It was assumed that silty sediments would be viable to construct these features. Multiple sand sources were investigated, including dredging of the GIWW and mining of the Colorado River Delta. A summary of the advantages and disadvantages of each sand source is shown below in Table 6.

Table 6. Advantages and Disadvantages of ER Measures M-8 material sources

	Advantages	Disadvantages	Future Consideration
Ship Channel Dredging	• GIWW maintenance dredging event should provide sufficient material to fill all initial marsh creation and restoration areas.	• Only has sufficient quantity for initial marsh creation.	• Potential for filling larger marshes with maintenance material over several dredging cycles. • Future studies should evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel
Colorado River Delta	• Large quantities of available sediment • Only source which has enough material for all out-year marsh areas. • Material would replenish between initial marsh creation and island restoration and 2065 out-year marsh creation.	• Potential negative environmental impacts of dredging the delta.	• Additional geotechnical studies and research to better classify material and dredging depths. • Investigation into potential environmental impacts of dredging the delta.

ER Measure CA-5:

Measure CA-5 involves construction of an out-year marsh fill in 2085. It was assumed that silty sediments would be viable to construct this feature. Based on historical shoaling rates, sufficient material for construction of the out-year nourishment is expected to be available for harvesting in the adjacent Matgaorda Ship Channel. Due to its project low cost and proximity to the project site, no other sites were investigated.

ER Measure CA-6:

Measure CA-6 involves construction of an out-year marsh fill in 2085. It was assumed that silty sediments would be viable to construct this feature. Based on historical shoaling rates, sufficient material for construction of the out-year nourishment is expected to be available for harvesting in the adjacent Matgaorda Ship Channel. Due to its project low cost and proximity to the project site, no other sites were investigated.

ER Measure SP-1:

Measure SP-1 involves construction of a large island restoration adjacent to the Corpus Christi Ship Channel. Multiple sand sources were investigated, including dredging of the Corpus Christi Ship Channel and placement area mining. Due to its project low cost and proximity to the project site, no other sites were investigated. A summary of the advantages and disadvantages of each sand source is shown below in Table 7.

Table 7. Measure B-12 Conceptual Cost and Duration Source Summary

	Advantages	Disadvantages	Future Considerations
Ship Channel Dredging	• Beneficial reused of dredged material. • Potential to use both hopper and hydraulic dredges.	• Pump out locations may be draft limited. • PCCA has dredged material areas (several beneficial use) already designated for placement of new work dredged materials.	• Near future coordination with PCCA required to use new work material. • Assess more potential pump out locations in the Redfish Bay and potentially dredging access corridors to allow for deeper draft vessels. • Consider filling island areas with maintenance material over several dredging cycles.
Mining Placement Areas	• Not reliant on new work dredging schedule. • Potential to use both hopper and hydraulic dredges	• Pump out locations may be draft limited.	• Assess more potential pump out locations in the Redfish Bay and potentially dredging access corridors to allow for deeper draft vessels.

ER Measure W-3:

This alternative involves dredging of the Port Manziel Channel, and placing material on the Gulf beach or within the Bird Island adjacent to the Port Mansfield Channel. It was assumed that dredging would be conducted using an 18” hydraulic suction cutterhead dredge to excavate and pump the material to the final placement location. Due to its proximity to the Gulf Beach and Bird Island, no other sources were investigated for this measure.

1 Introduction

The following document summarizes the results of the preliminary borrow source investigation, material harvesting and placement scenarios, and cost estimates for the Coastal Texas Protection and Restoration Study. A desktop material source investigation was conducted to help develop conceptual costs for the CSRM and ER measures. The investigation included review of publicly available references including, but not limited to: previous studies of diverse material sources, review of available geotechnical data, available topographic and/or bathymetric data of borrow sources, etc.

As material requirements vary between CSRM and ER measures, the suitability of each borrow source was evaluated for each measure. Due to the limited data available on most borrow sources, several assumptions were made regarding the type, quantity, and availability of sediments within each borrow source when determining the suitability of these sources. These assumptions are described in greater detail within this report.

After the sources were identified and evaluated, scenarios for transporting the materials to construct each ER and CSRM measure were developed. The scenarios presented herein were developed based on understanding of existing equipment availability, typical contractor methodologies based on previous projects of similar type and scale, conversations with contractors, and best engineering judgement. The assumptions and driving factors for each scenario are described for each ER and CSRM alternative scenario. Feasibility of each source was evaluated based on engineering requirements, available quantities, and preliminary costs. Environmental impacts due to removal of these borrow materials were not evaluated and must be considered prior to harvesting of material from these sites.

Finally, costs were developed for each scenario using internal Mott MacDonald methodologies for cost estimation. Costs presented within this document were developed to a preliminary level for comparison purposes only and not to be used for planning or design. Costs presented herein do not include other direct costs associated with dredging such as mobilization, surveying, environmental BMP's, etc. All cost estimates provided a range and included a 40% contingency to account for any uncertainty and variability in these estimates. Specific assumptions made for each cost estimate are described later within this document.

Scenarios and estimates were limited to existing available equipment, but as the construction dates for these options are currently uncertain and, in the future, new methodologies and equipment may become available which may be utilized to optimize the construction of these projects. Also, due to the scale and size of most of these projects, new innovations may arise to help meet the specific needs for construction of the specific alternatives.

2 Material Requirements

The material source investigation includes materials to construct the Coastal Risk Management (CSRM) components: Ring levee around Galveston, levees along Bolivar and West Galveston. This document investigates materials to construct the following Ecosystem Restoration (ER) measures: G-5, G-28, B-2, B-12, M-8, CA-5, CA-6, SP-1, W-3. Three primary materials are required for construction of the measures: beach quality sand for beach nourishments, silty sand for marsh and island creation, and clay for levees. The following sections list the quantities of each material for the different measures, as provided by the United States Army Corps of Engineers (USACE).

2.1 Sand

Two ER measures require locating sand sources for beach and dune restoration, G-5: Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration, B-2- Follett's Island Gulf Beach and Dune Restoration. Sand sources for these measures require considerations for initial construction as well as renourishments occurring every 10 years for the 50 year life of the project.

Table 8. Ecosystem Restoration Measures: Sand

	Initial Beach/Dune (CY)	Total 50-Year Renourishment Beach/Dune Quantity (CY)*	Total (CY)
B-2: Folletts Island Gulf Beach and Dune Restoration	8,782,000	11,639,000 *(2,327,800 CY per cycle)	20,421,000
G-5: Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration	33,513,238 (low) – 66,889,926 (high)	27,602,760 *(5,520,552 CY per cycle)	70,458,000
*** Assumed renourishment at 10-year cycles**			

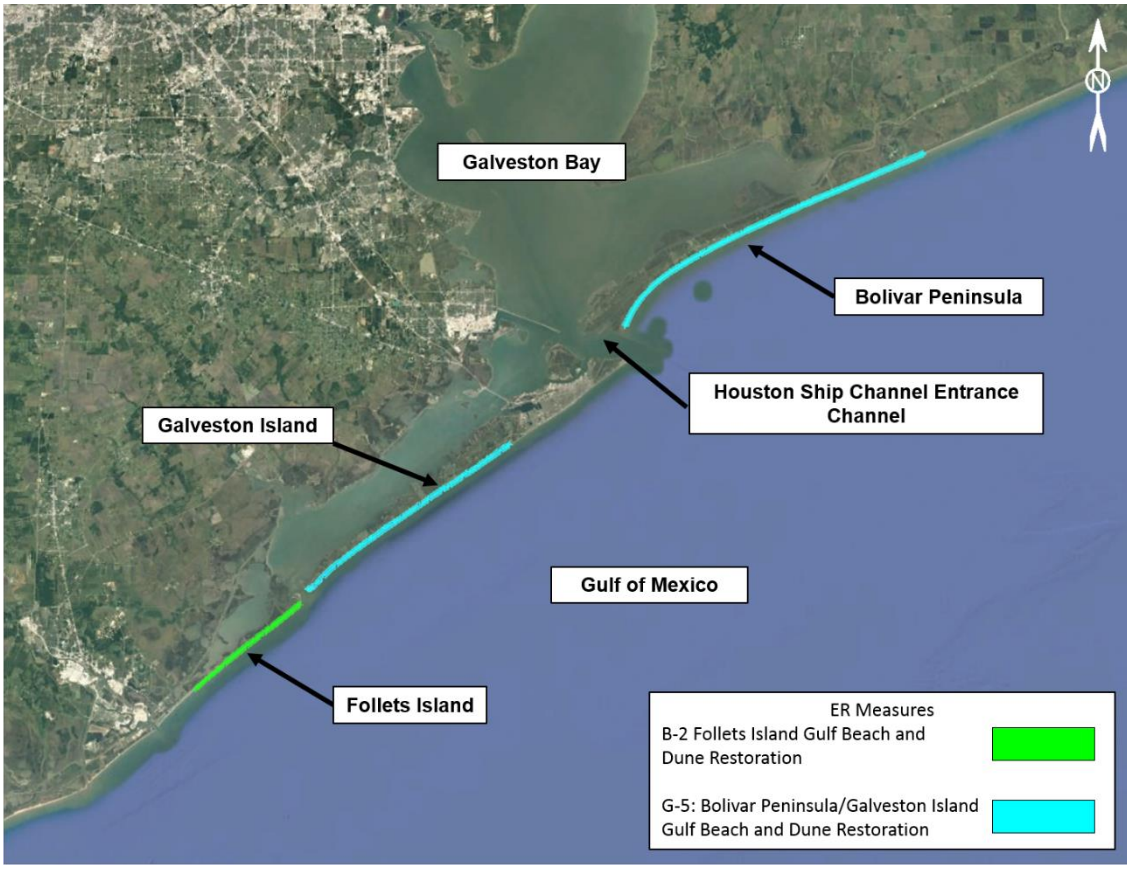


Figure 1. Overview of B-2 and G-5 ER measures

2.2 Clay

CSRM Alternative A, a storm surge protection system requiring clay materials, is made up of the following components: levees, floodwalls, barrier walls, seawalls, and gate structures for navigation channels, roadways and railroads and pump stations. The levees and seawall are to extend along the Bolivar Peninsula and along West Galveston Island. Additionally, levees may be required as part of the construction of the gate structures to be constructed at Clear Creek Channel and Dickinson Bayou. Information provided by the USACE indicated the levees are to be built with clay material at a 1V:3H side slope . Clays can be classified by their plasticity index (PI). Highly plastic clays (CH) have a PI approximately greater than 20 and medium to low plasticity clays (CL and CL-ML) have PIs ranging from 0 – 20 (Das, 2000).

According to the USACE engineering manual for the design and construction of levees (EM 1100-2-1913), almost any soil is appropriate for the construction of levees, except for very wet, fine grained soils or highly organic soils. In highly plastic clays, shallow slide failures may occur in levee slopes after heavy rainfall, potentially a result of moisture gain and water forces in cracks that developed due to shrinkage during dry weather. This risk of failure can be mitigated by using less plastic soils near the levee slope surfaces or by stabilization of the surface soils (USACE, 2000).

Figure 2 displays the locations for the reaches considered for clay and Table 9 lists the approximate amounts required for construction.

Table 9. Required Clay Quantities

	Length of levee (mi)	Quantity (CY)
East of Entrance Channel Crossing		
	Length of levee (mi)	Quantity (CY)
Eastern Tie In	2.3	776,790
Bolivar East	7.7	2,667,510
Bolivar Central	8.2	2,096,449
Bolivar West	9	2,195,467
West of Entrance Channel Crossing		
	Length of levee (mi)	Quantity (CY)
Galveston Ring Levee	5.0	515,707
Galveston East	6.8	1,285,054
Galveston Central	3.2	518,476
Galveston West	4.9	1,718,077
Gate Structures		
	Length of levee (mi)	Quantity (CY)
Clear Creek Channel	0.24	14,700
Dickinson Bayou	1.1	69,300
TOTAL		**11,857,530**

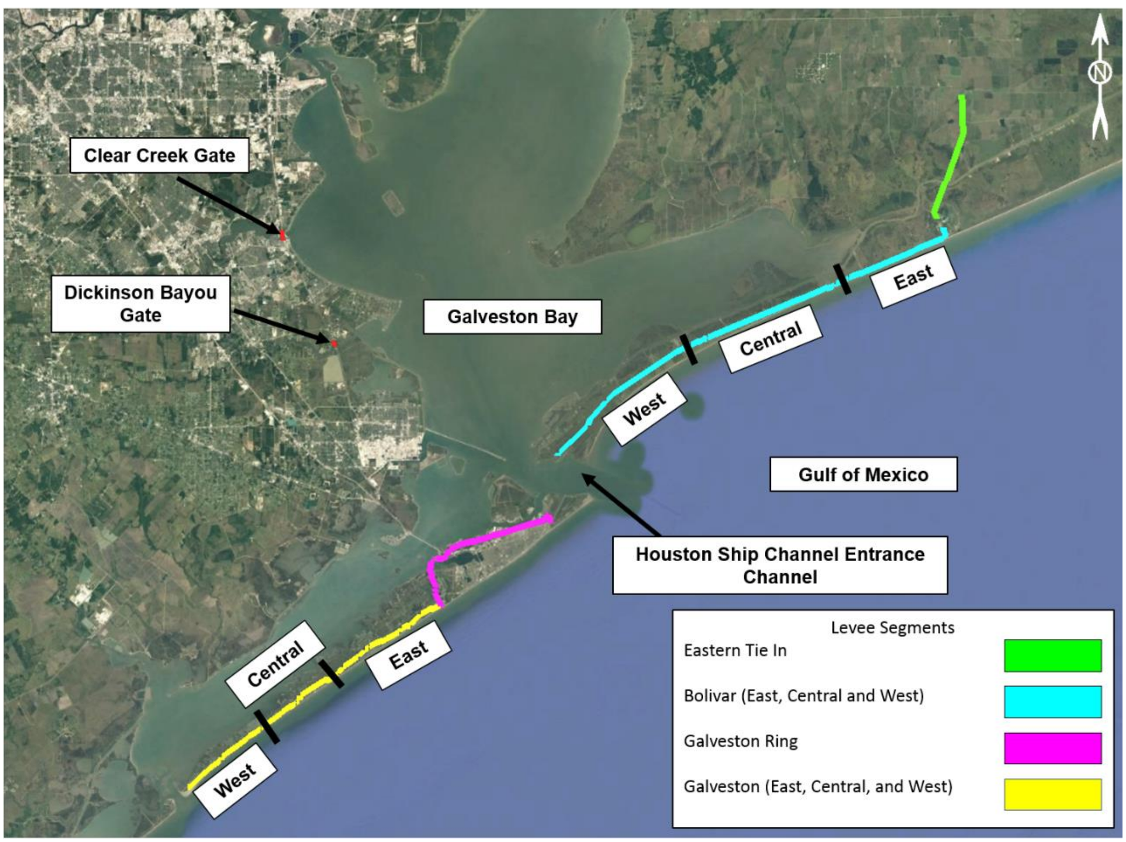


Figure 2. CSRM Alternative A feature locations

2.3 Marsh and Island Creation

For this assessment, it is assumed that soft material composed of mostly mud and clay, the type of material typically associated with maintenance dredging material, will be what is mostly used in marsh creation and the island creation restoration ER measures. The measures and their required quantities as provided by the USACE are listed in Table 10.

Table 10: Marsh Creation and Island Restoration Ecosystem Restoration Measures

	Marsh Creation and Restoration (Initial)	Marsh Creation and Restoration (Out Year 2065)	Island Creation and Restoration	Total (CY)
G-28: Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection	482,137	10,117,098	5,822,819	16,422,054
B-12: Bastrop Bay, Oyster Lake, West Bay, and GIWW Shoreline Protection	399,863	29,060,231		29,460,094
M-8: East Matagorda Bay Shoreline Protection	173,696	8,858,717	1,195,299	10,227,712
CA-5: Keller Bay Restoration		914,647		914,647
CA-6: Powderhorn Shoreline Protection and Wetland Restoration	385,760			385,760
SP-1: Redfish Bay Protection and Enhancement			6,685,556	6,685,556
W-3: Port Mansfield Channel, Island Rookery, and Hydrologic Restoration	W-3 is a measure to restore circulation in the Lower Laguna Madre. The sediment from the dredging will be placed on a bird island and north of the Mansfield Pass jetty.			

The table provides quantities for initial marsh creation and out year marsh creation. The initial marsh and island creation components are to require sources which can supply fill material in the near future (5-10 years) while the out-year marsh creation components are to be constructed in the year 2065. For this study is assumed that each component of an ER measure will be completed as a single project and will require sediment sources with enough existing volume to complete them in one construction phase.

3 Overall Assessment of Borrow Sources

3.1 Sabine and Heald Banks

The Sabine and Heald Banks are Gulf of Mexico sand banks located approximately 50 and 30 miles off the coast of east Texas respectively. The banks are mainly composed of beach quality, fine to coarse sands. The average water depth at both the Sabine and Heald Banks is approximately 30 ft. While many other offshore sand and gravel deposits are at depths nor currently feasible for use as fill, the shallower waters within the banks makes dredging of these materials feasible. Previous studies have estimated that there is potentially 1.8 billion cubic yards of sand located within the Sabine and Heald banks that could be considered compatible for beach replenishment along the Texas Gulf Coast beaches (Freese & Nichols, 2016).

The location of the banks near the Texas and Louisiana shoreline add to the viability of these areas as a potential borrow source. The material from the eastern portion of the Sabine bank has historically been used for beach nourishments along the Louisiana coast as the banks are much closer to shore in that area. The western end of the Sabine bank and the Heald Bank remain largely untouched as they are farther from shore making it less economical to harvest these materials for use on Texas beaches, but with the dwindling supply of nearshore beach quality sediments the banks will become a viable source of sand for beach nourishments. Of all the sand sources investigated as part of this study, the Sabine and Heald banks are easily capable of meeting the total sand volume requirements for the G-5 and B-2 Ecosystem Restoration Measures (approx. 91 million cubic yards).

As part of this study, Mott MacDonald has reviewed publicly available data on the Sabine and Heald banks, including geotechnical boring, grab samples, bathymetry and previous studies. Using this information, along with NOAA coastal relief model bathymetry, volume estimates for sand available were made for the banks. These estimates are conservative as they only account for areas within the banks where sand is available at the surface (no overburden). Volumes were estimated by developing a surface based on publicly available boring data for the areas within the banks where the sand extended from the seafloor down to some depth. Buffers were also placed along known pipeline locations (assumed to be approximately 1000’ on either side of pipelines) to account for actual buffers required for dredging adjacent to these structures (Michael Miner, personal communication, May 31 2018). The volume was only calculated for the area encompassed by the available borings within the banks. Based on this data the sand volume was estimated at approximately 169 million cubic yards for the Sabine Bank and 27.5 million cubic yards for the Heald banks. While previous estimates have shown much higher quantities of material available, this estimate represents a conservative volume of material that can be easily accessed with no overburden material. Further investigation is necessary for determining the exact extents, quantity, and character of the material for determining the exact location to be dredge prior to harvesting of material from these areas but the current data shows that most of the material is concentrated throughout the shallowest areas of the bank as shown in Figure 3 and Figure 4 respectively.

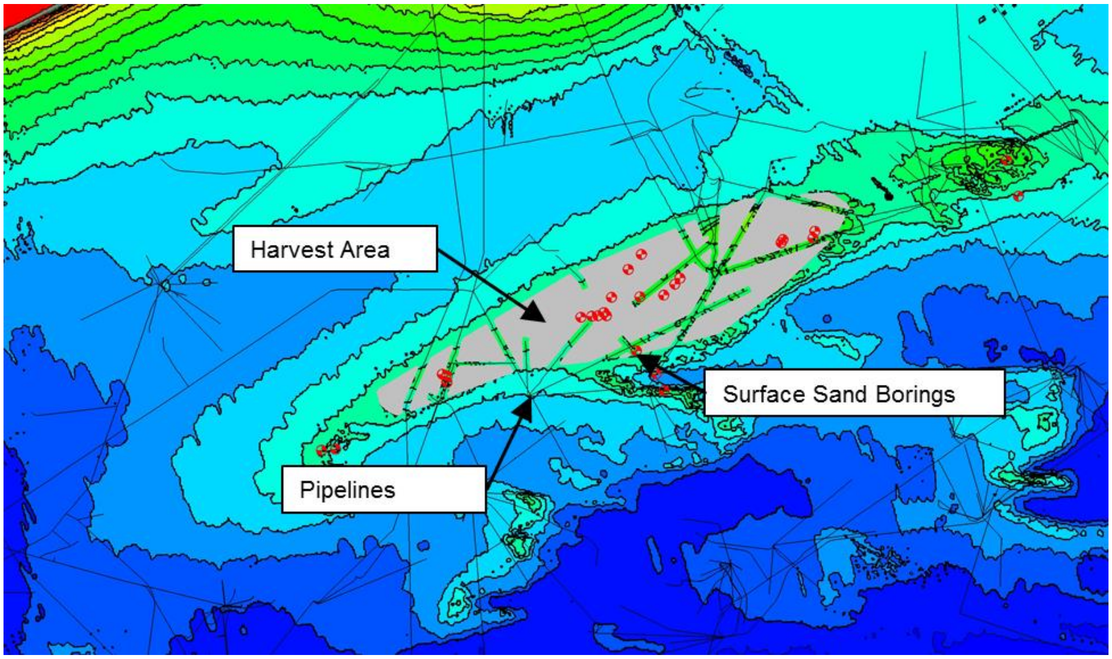


Figure 3. Sabine Bank Harvest Area

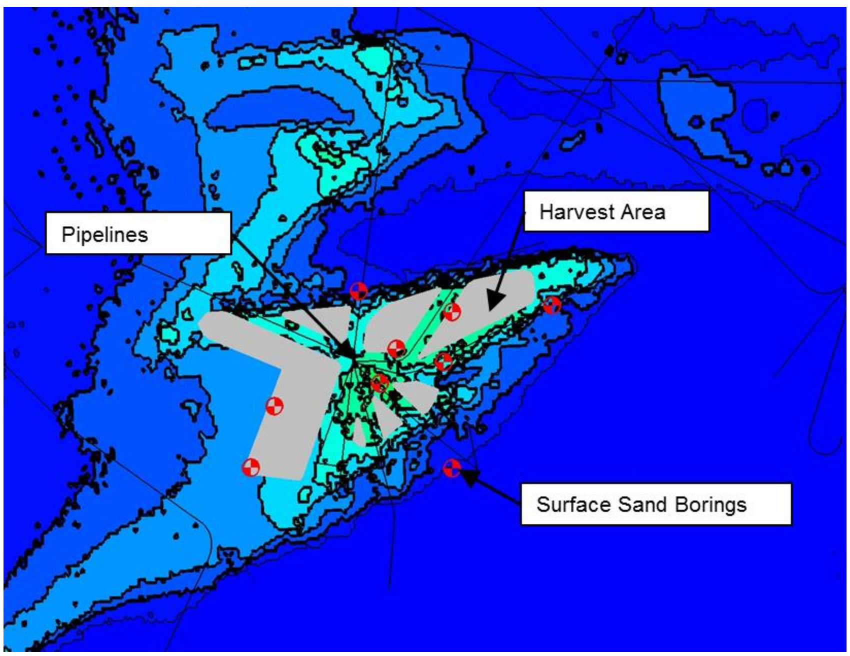


Figure 4. Heald Bank Harvest Area

While there is plenty of sandy material available at the banks, one drawback to obtaining material from these areas are the far distances from the potential project sites. The center of the Heald bank is approximately 31 nautical miles from the Galveston bay entrance while the distance to the Sabine bank varies from 45-50 nautical miles from the Galveston bay entrance. These distances are why, currently, this material has not been accessed for the nourishment of Texas beaches. The costs of dredging increase dramatically with distance and for smaller scale projects, it is not economically viable to use these sediments. However, due to growing scale of nourishment projects and dwindling quantities of nearshore beach quality sediments, the banks are becoming more appealing as borrow sources. To obtain the quantities required for large scale fill projects such as Ecosystem Restoration Measures G-5 and B-2 several borrow sites would need to be considered if the banks are not used. This would increase dredging costs as it would require the contractor must mobilize to multiple locations to source the material. Depending on the quantity of material and amount of locations to be dredged, it would become more economically viable to transport the material from a single, farther source such as the Sabine and Heald banks.

3.2 Shoreface Sediments

Shoreface sediments for this study are sediment within 10 miles of the Gulf of Mexico coastline. As part of this study, Mott MacDonald have reviewed publicly available data on shoreface sediments offshore from the Bolivar Peninsula, Galveston Island, Follett's Island, and the Brazos River Delta. The data review included examination of geotechnical borings, bathymetry surveys, and previous studies. All geotechnical borings were obtained from the Texas Coastal Sediment Geodatabase (TxSed), compiled by the Texas General Land Office, under a Coastal Impact Assistance Program (CIAP) grant (GLO, 2018). Shoreface borings were assessed on whether the material was potentially suitable for beach nourishment based on an estimated percentage of sand shown in the borings. If borings showed 70-100% sand, they were classified as potentially beach quality and were considered, for sources of sand for the ER measures which require beach and dune nourishment. Consideration was also given to the viability of each source based on the distance to a given ER measure. Sources with prohibitively long pumping distances were eliminated from consideration. Further discussion of source selection is conducted in Section 4. It should be noted that harvesting of shoreface sediments could result in a more energetic nearshore wave climate, which could have impacts on shoreline erosion. During future phases of the study, a comprehensive analysis of nearshore wave climate and shoreline retreat should be conducted if shoreface sediments are used as sources.

3.2.1 Bolivar Peninsula

Figure 5 displays the locations of the borings evaluated for the Bolivar shoreface. Boring logs were obtained for 48 boreholes with the length of the cores ranging from 0.5 to 20 FT. Many of these borings showed a high percentage of muddy, clayey sand/sand clay, and silty clay materials. Descriptions for the clay materials varied between soft to stiff. Only a few borings were described as mostly fine sand. Although a couple of borings did show a layer of fine sand beneath the clay and mud, the start depth of this layer varied considerably from 3 ft to 13 ft below the seafloor. More borings drilled to depths 10 to 20 ft below the seafloor would be required to assess whether there are nearshore areas where the clay and mud is overburden atop a potential sand source which could be used for beach nourishment. For this study the shoreface material off Bolivar Peninsula was considered largely unsuitable for nourishing the adjacent beaches and was only considered as a potential source of material for marsh creation and restoration measures. The material distribution for the shoreface materials off Bolivar Peninsula was estimated as 30% Sand, 50% mud and silt, and 20% stiff clay.

Volumes were estimated by developing a surface based on the available boring data for the areas shown on Figure 6 extended from the seafloor down to the bottom of the boring or the bottom of a layer of mud above fine sand. Buffers were also placed along known pipeline locations (approximately 1000' on either side of pipelines) to account for actual buffers required for dredging adjacent to these structures. The volume was only calculated for the area encompassed by the available borings and are shown in Table 11.

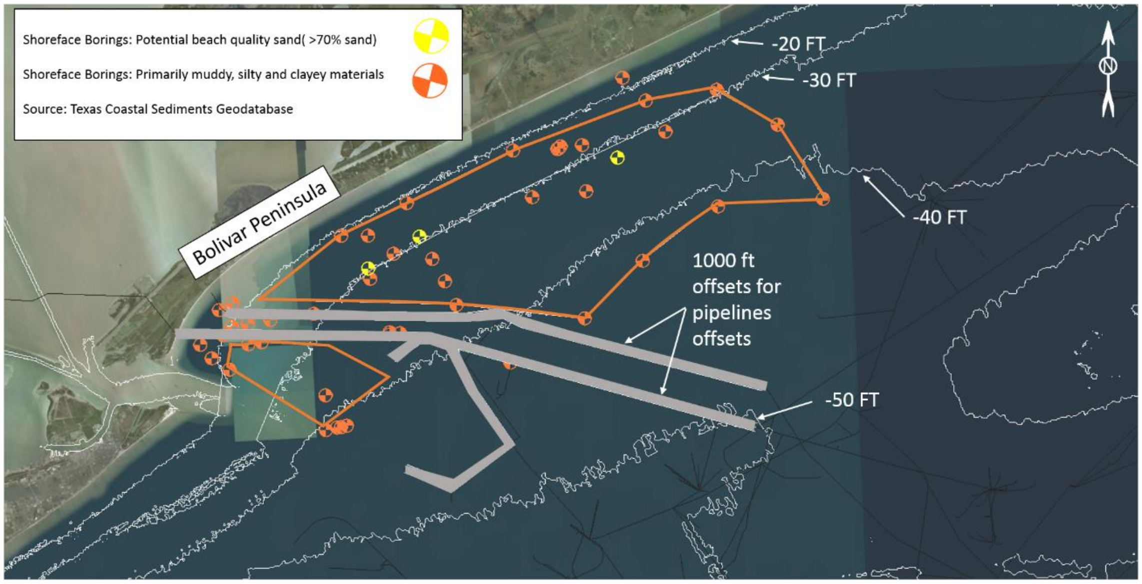


Figure 5. Bolivar Peninsula Shoreface Boring Locations

Table 11. Bolivar Peninsula Shoreface Estimated Sediment Quantities

Area [FT^2]	Volume [CY]	Average Sediment Layer Depth [FT]
3,000,000,000	401,000,000	3.6

3.2.2 Galveston Island

Figure 6 displays the locations of the borings assessed for the Galveston Island shoreface sediments. Boring logs were obtained for 78 boreholes with the length of the cores ranging from 0.5 to 20 FT. The borings show that there is potential for beach quality sand (material distribution with sand > 70%) between the -15 to -30 FT contour lines. Beyond the -30 FT contour, the borings show an increase in mud and clay sediment. For this study the areas evaluated to potentially have beach quality sand were considered as a potential sand source for the beach and dune nourishment ER measures. The available boring logs provide limited to no information regarding the grain size distribution of the potential sand and further analysis will need to be completed regarding whether the sand available is suitable for nourishment. The remaining material was considered as a potential source of material for marsh creation and restoration measures. The material distribution for the non-beach quality shoreface materials off Galveston Island was estimated as 40% Sand, and 60% mud and silt.

Volumes were estimated by developing a surface based on the available boring data for the areas shown on Figure 6 extended from the seafloor down to the bottom of the boring or the bottom of the first layer of material (either mud or sand). Buffers were also placed along known pipeline locations (approximately 1000’ on either side of pipelines) to account for actual buffers required for dredging adjacent to these structures. The volume was only calculated for the area encompassed by the available borings and are shown in Table 12.

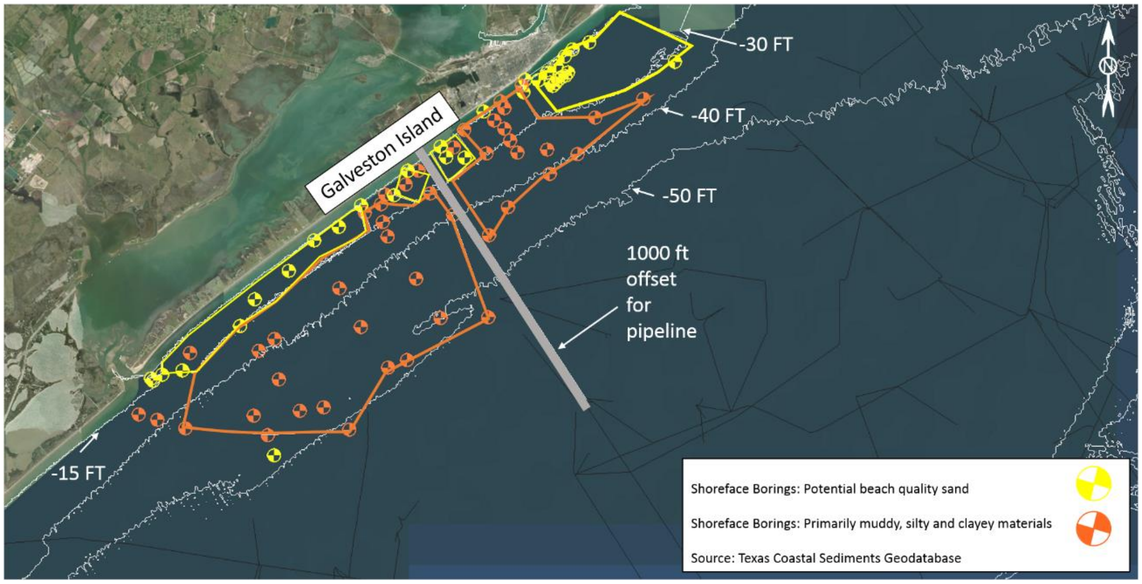


Figure 6. Galveston Island Shoreface Boring Locations

Table 12. Galveston Island Shoreface Estimated Sediment Quantities

	Area [FT^2]	Volume [CY]	Average Sediment Layer Depth [FT]
Potentially beach quality sand	1,200,000,000	402,000,000	9.0
Primarily muddy, silty, and clayey materials	3,300,000,000	674,000,000	5.5

Additional sand sources may become available for short period of time following a large storm event. Large storms may uncover sand banks by removing fine and soft sediments as well as create new sand bars due to the cross-shore transport of sand from the beaches into the deeper areas of the shoreface. Following Hurricane Ike approximately 2,300,000 to 3,900,000 cubic yards of sand was available in shoreface sand bars. These sources of sand will only be available for a short period of time after a storm (6-12 months) as natural sediment processes along the shoreline will cover and enrich the sand with fine silts and clays (Freese & Nichols, 2016).

3.2.3 Follett's Island

Figure 7 displays the locations of the borings assessed for the shoreface sediments offshore of Galveston Island. Boring logs were obtained for 8 boreholes with the length of the cores ranging from 14 to 20 FT. Threes of the borings indicated potential sand from the seafloor to depths of 4 – 9 FT firm and stiff clay beneath. The remaining borings indicated a layer of very soft mud to depths 1.5 to 6 FT below the seafloor surface with firm and stiff clay beneath. Due to the minimal boring data available, these shoreface sediments were not considered as a suitable source of sand for the beach and dune nourishment ER measures. It is possible that between the 20 FT and 30 FT contour that there are shoreface sand bars which could be used as a potential material source, however more boreholes are required to make that determination. For this study, shoreface sediments off Follett's island were only considered as a potential source of material for marsh creation and restoration measures. The material distribution for the shoreface materials off Follett's was estimated as 40% Sand, 45% mud and silt, and 15% stiff clay.

Volumes were estimated by developing a surface based on the available boring data for the areas shown on Figure 7 extended from the seafloor down to the bottom of the boring or the bottom of the first layer of material (either mud or sand). Buffers were also placed along known pipeline locations (approximately 1000' on either side of pipelines) to account for actual buffers required for dredging adjacent to these structures. The volume was only calculated for the area encompassed by the available borings and are shown in Table 13.

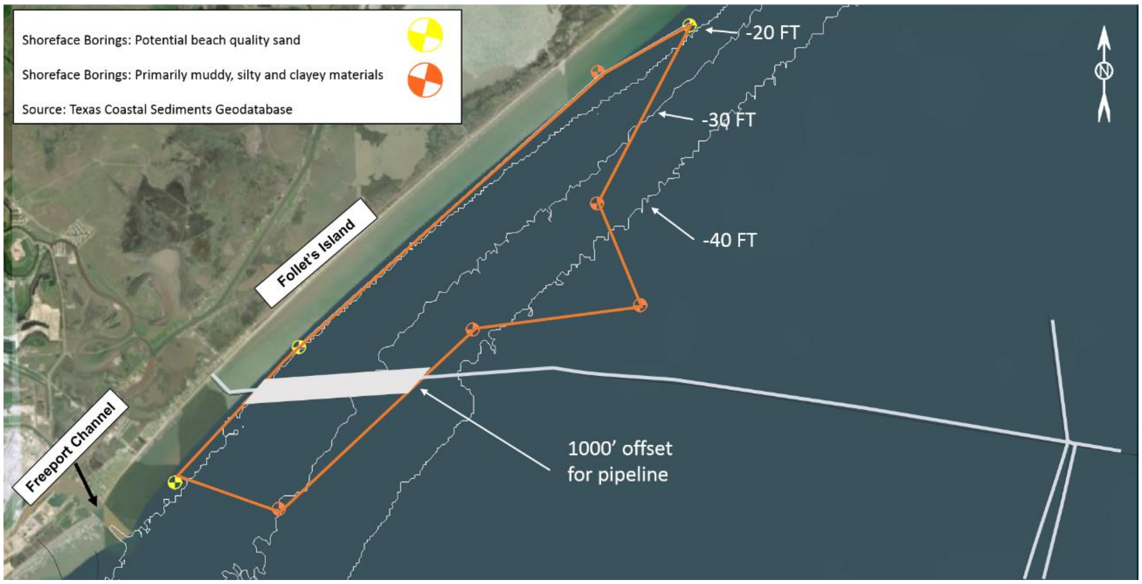


Figure 7. Follett's Island Shoreface Boring Locations

Table 13. Follett's Island Shoreface Estimated Sediment Quantities

Area [FT^2]	Volume [CY]	Average Sediment Layer Depth [FT]
537,000,000	76,000,000	3.8

3.2.4 Brazos River Delta

Figure 8 displays the locations of the borings assessed for the shoreface sediments within the Brazos River Delta. Boring logs were obtained for 33 boreholes with the length of the cores ranging from 1 to 6 FT. While a few of the borings displayed a thin layer of sand in the top 0.5 FT of the core, most of borings were described as mud/clayey silt with 5 – 20% sand. The Brazos Delta was only considered as a potential material source for marsh creation and restoration measures with the estimated material distribution as 25% sand an 75% mud & silt.

Volumes were estimated by developing a surface based on the available boring data for the areas shown on Figure 8 extended from the seafloor down to the bottom of the boring or the bottom of a the layer of material (either mud or sand). Buffers were also placed along known pipeline locations (approximately 1000' on either side of pipelines) to account for actual buffers required for dredging adjacent to these structures. The volume was only calculated for the area encompassed by the available borings and are shown in Table 14.

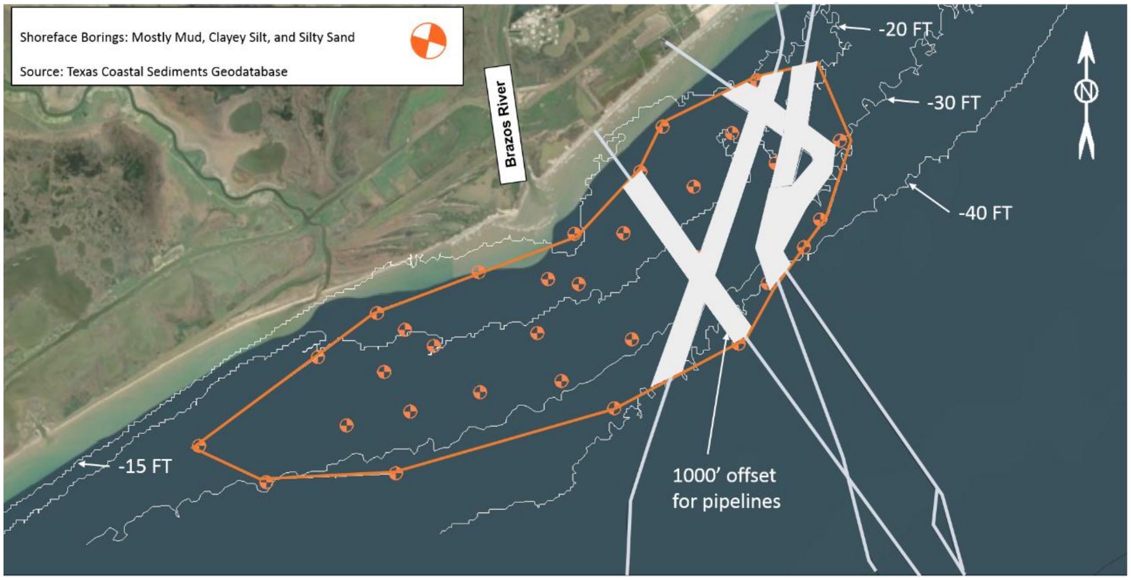


Figure 8. Brazos River Delta Shoreface Boring Locations

Table 14. Brazos Delta Shoreface Estimated Sediment Quantities

Area [FT^2]	Volume [CY]	Average Sediment Layer Depth [FT]
156,200,000	18,500,000	3.2

3.3 Sabine and Trinity Paleo Channels

The Sabine and Trinity incised paleo channels are geologic formations along the east Texas shelf which formed during the last glacial eustatic low stand where the Trinity and Sabine river valleys merged. As sea level rose and coastal transgression progressed, these valleys were filled with fluvial, bay head delta, middle bay, and lower bay marine deposits. It is currently estimated that these valleys could potentially contain more than 52,000,000,000 cubic yards of soft, mainly fine, sediments (Freese & Nichols, 2016). Figure 9 shows a graphic from Rice university (http://gulf.rice.edu/ETexas/gulfeTexasS_T_SJ_tst.html) depicting the approximate locations of the Trinity/Sabine incised valleys within Galveston Bay and the Gulf of Mexico.

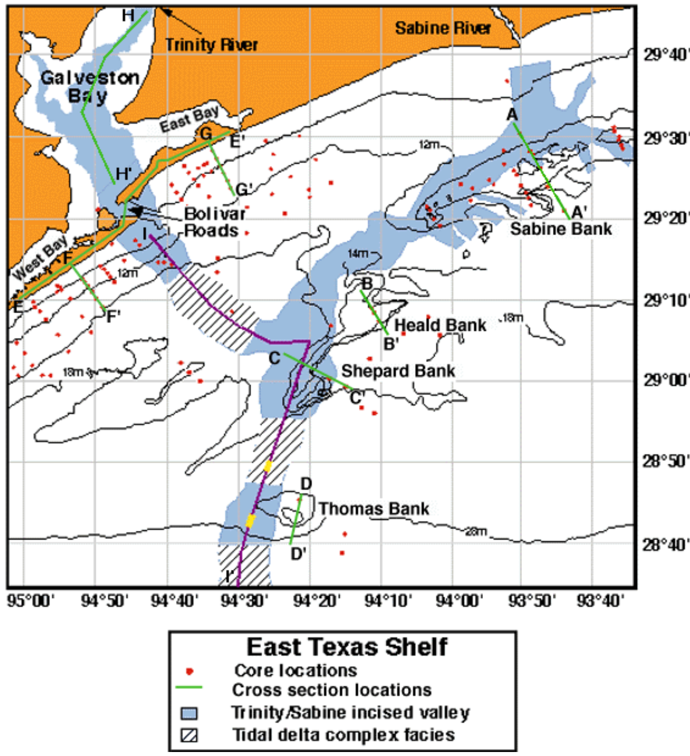


Figure 9.Trinity/Sabine incised valley

Recent investigations of the incised river system for sediment volumes showed significant amounts of valley-filled deposits. Within this system fall the Sabine and Heald banks which are a well-known source of sand as previously discussed in this report. Current field investigations have not found significant amounts of sandy materials within the other portions of the paleochannels not within the Heald and Sabine banks, thus further investigation is necessary to find any additional sources of sandy materials within the other portions of the incised valleys. If sand is found it will likely be buried under other layers of sediment which would need to be dredged to reach the sand.

3.4 The Bolivar Roads Jetties

The Bolivar Roads jetties are the north and south jetties which protect the entrance to the Houston Ship Channel between Bolivar Peninsula and Galveston Island. Several studies have been completed on the sediment transport processes around these jetties and the northern tip of Galveston Island. Four areas have been identified as potential sand sources connected to the jetties: North of the North Jetty, South of the North Jetty, Big Reef, and East Beach (South of the South Jetty). The approximate locations of these sources are shown in Figure 10 and the estimated quantities are summarized in Table 15.

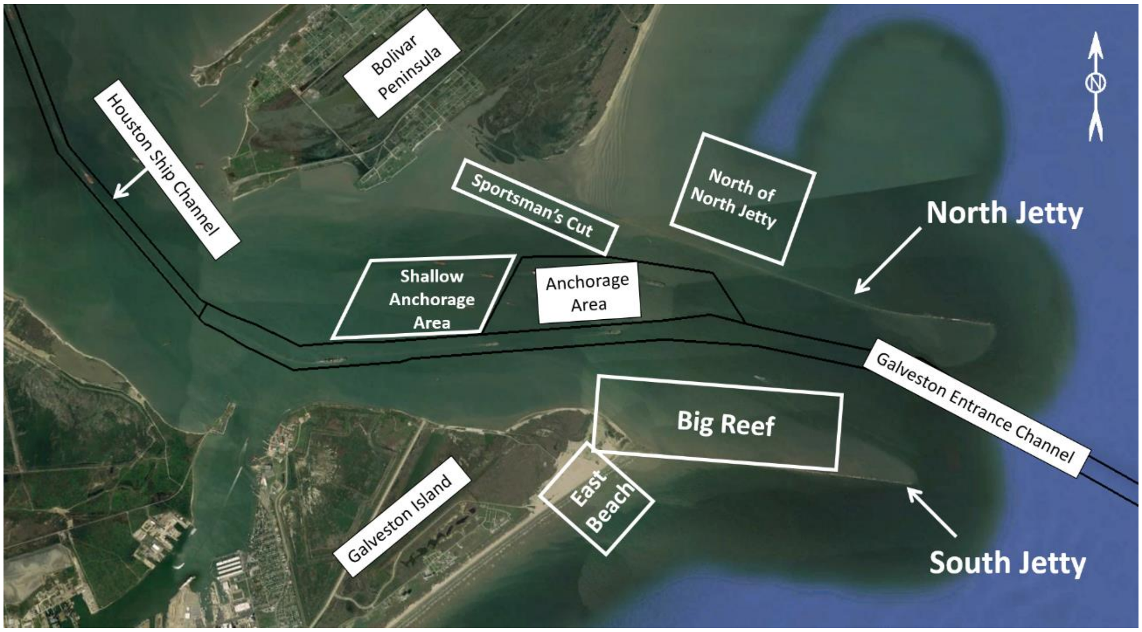


Figure 10. Bolivar Roads Jetties Sand Sources

The north jetty traps sediments moving south through longshore processes along the Bolivar Peninsula. A sand investigation conducted in 2006 collected 11 borings on the north side of the north jetty within the approximately 555-acre area outlined in Figure 10. Approximately 3,000,000 CY of sand has been estimated as the minimum quantity of sand available offshore the Bolivar Peninsula north of the north jetty (Freese & Nichols, 2016).

Sand investigations have also been performed south of the north jetty, within Sportsman's Cut in 2006 and within the Shallow Anchorage Area in 2009. The 2006 study discovered that sand available is coarser than the mean beach sand diameters found on Bolivar's beaches. Both studies identified a least 3,900,000 CY of available sand south of the north jetty (Freese & Nichols, 2016).

The net sediment transport along the northeast shoreline of Galveston Island is directed towards the north. Big Reef is a sand bank located on the north side of the south jetty which accumulates sand when sediments are transported from East Beach over the south jetty. Big reef accumulates approximately 247,000 CY of sand per year (Frey, Morang, & King, 2016). Once the sand is deposited in Big Reef, its tendency is to migrate to the Gulf (Freese & Nichols, 2016). Big Reef consists of potential surface (Figure 11) and submerged mining areas. Approximately 2,400,000 CY and 1,500,000 CY of sand is available in the submerged and surface Big Reef areas, respectively. The submerged quantity assumes dredging to -20 ft MLLW (Frey, Morang, & King, 2016).

East Beach accumulates sand due to the sediment transport to the north may be a potential source of sediment in its surface and submerged profiles, however the beach is a recreational area. Approximately 400,000 CY of sand is potentially available within Area 1 shown on Figure 10. Sand mining would not be possible all yea as the sea turtle may nest on East Beach and the sand flats south of the south jetty are piping plover habitat (Frey, Morang, & King, 2016). Submerged sand bars may also be available as a source and this quantity was captured the Section 3.2.2 where shoreface sands off Galveston Island were assessed.

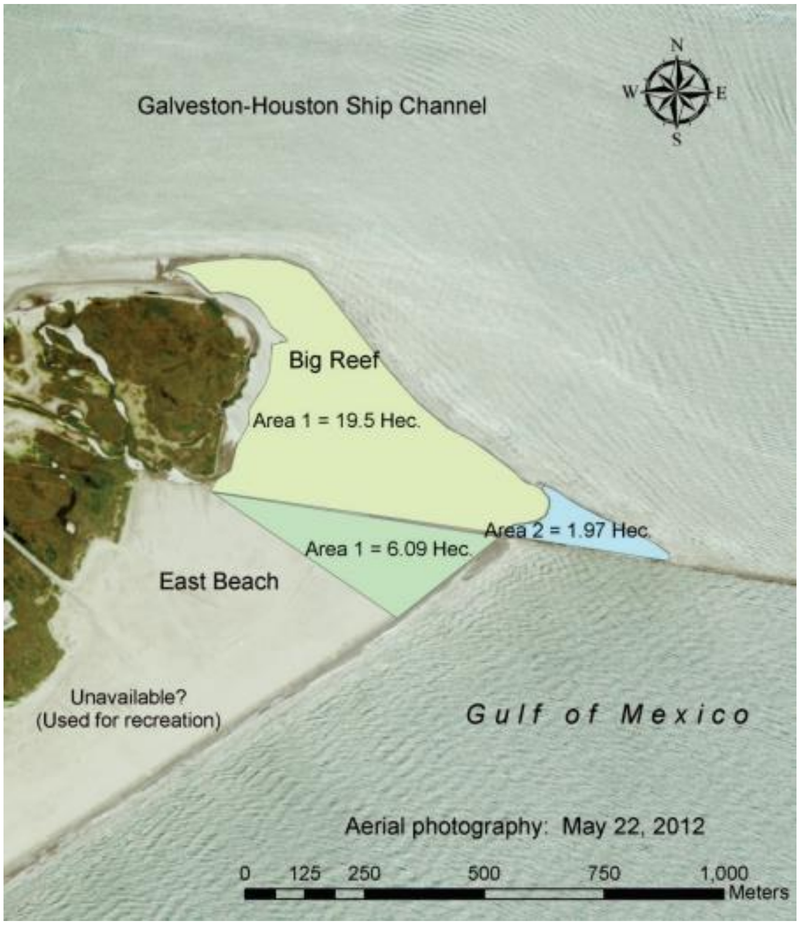


Figure 11. Big Reef Surface sand mining areas (Frey, Morang, & King, 2016).

Table 15. Bolivar Roads Jetties Estimated Sediment Quantities (Freese & Nichols, 2016) (Frey, Morang, & King, 2016)

Source	Potential Sediment Volume [CY]
North of North Jetty	3,000,000
South of North Jetty	3,900,000
Big Reef (submerged)	2,400,000
Big Reef (surface)	1,500,000
Big Reef (annual accretion)	247,000
East Beach	400,000

3.5 Colorado and Brazos Paleo Channels and Deltas

The paleo Colorado and Brazos rivers created several significant thick deltas during the last 140,000 years. The Colorado river deltas appear to be a viable source of sand for barrier island restoration projects based on geologic analysis, but there is currently not sufficient information available to pinpoint the amount, quality, and location of these sandy sediments. Additional studies will be necessary before these materials can be found and utilized for restoration projects. The most recent evolution of the delta (stage 1), which formed between approximately 11,500 and 8,000 years ago, is believed to contain high quality sands. During this stage approximately 13,000,000,000 cubic yards of sediments were deposited in the delta including high quality sands (Freese & Nichols, 2016). The approximate locations of these channels and deltas is shown in Figure 12 (http://gulf.rice.edu/sandbodies/brazosvalley.html).

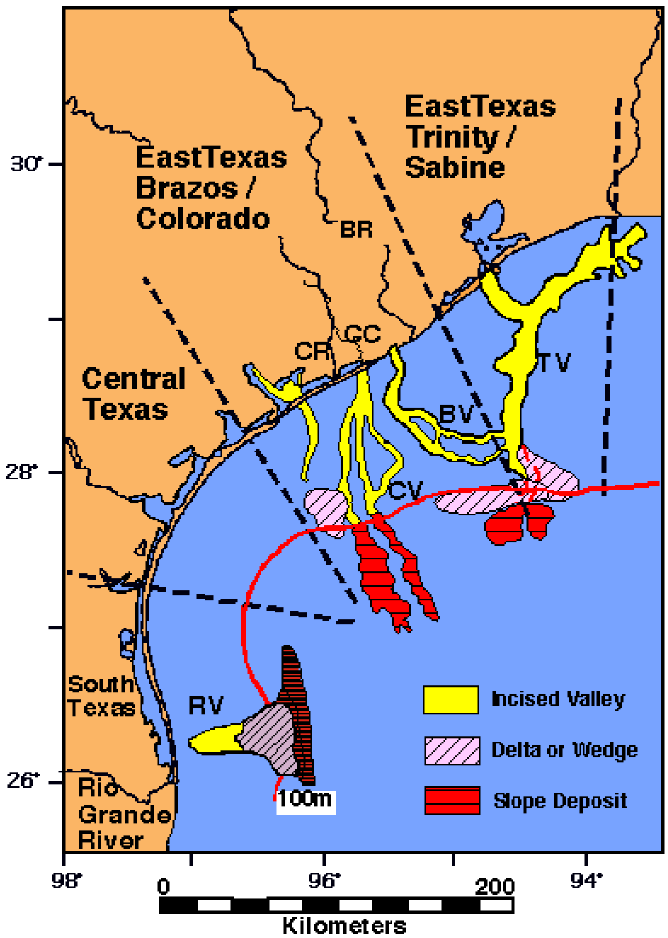


Figure 12. Colorado and Brazos Paleochannel and Deltas graphic (http://gulf.rice.edu/sandbodies/brazosvalley.html)

The Brazos river deltas formed via similar geologic processes to the Colorado River deltas. Like the Colorado River deltas, several stages of formation are observed. Information regarding the composition of the sediments deposited in these deltas is limited and a determination of the viability of this source cannot be made without additional investigation. Assuming the deltas have similar composition to the present delta, then a variety of sediments should be available within this delta. (Freese & Nichols, 2016).

3.6 East Galveston Bay Tidal Flood Delta

The Bolivar roads inlet used to be larger before it was controlled by modern structures, resulting in the formation of a large amount of flood delta deposits. Since the construction of modern structures, a smaller modern flood delta has also formed near the inlet entrance. Both deltas are shown in Figure 14 (Freese & Nichols, 2016).

39 borings from the tidal flood deltas were analyzed, 27 in the old tidal delta and 12 from the new tidal delta. The core lengths of the borings range from 3 FT to 50 FT. The borings show that the deltas are primarily soft mud, clay, and sand. Many of the borings show alternating clay and sand layers with the sand layers generally < 0.5 ft thick (see example in Only a few borings in the top 10 ft of the borings are shown as having more sand than mud and clay, however below 10 FT a sand layer appears to be more prominent as shown in Figure 15b.

Volumes were estimated by developing a surface based on the available boring data for the areas shown on Figure 15 extended from the seafloor down to the bottom of the boring or the bottom of a the layer of material (either mud or sand). Buffers were also placed along known pipeline locations (approximately 1000' on either side of pipelines) to account for actual buffers required for dredging adjacent to these structures. The volume was only calculated for the area encompassed by the available borings and are shown in Table 16. Due to the amount of overburden which would need to be dredged, the tidal deltas were not considered as a potential source of material for the sand and dune ER measures. The deltas were considered as a potential material source for the marsh creation and restoration ER measures with the estimated material distribution as 50% sand and 50% mud & silt

Some areas of the old tidal delta may be covered with oysters reefs. Generally the reefs are located more in the eastern regions of the delta but the locations of oysters reef should be explored further during future design.

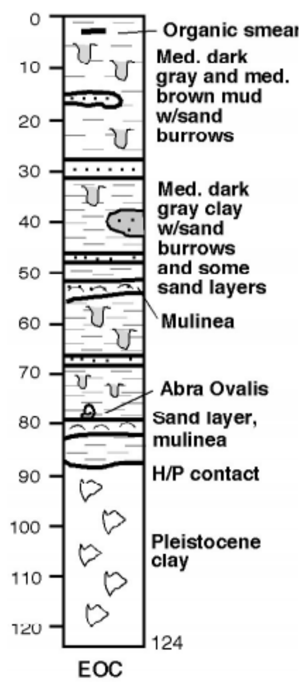


Figure 13. Example Boring RUBRETD-8 (see location on Figure 15)

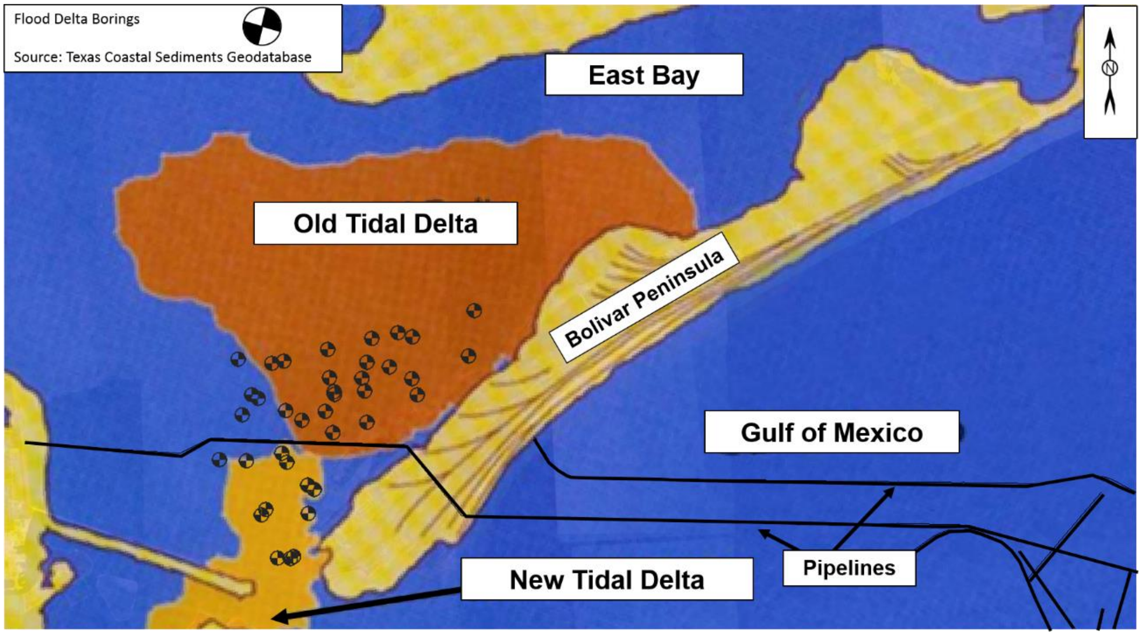


Figure 14. East Galveston Bay Tidal Deltas and Boring Locations (Freese & Nichols, 2016)

Table 16. East Galveston Bay Tidal Deltas Estimated Sediment Quantities

	Area [FT^2]	Volume [CY]	Average Sediment Layer Depth [FT]
Upper material layer (overburden)			
Old Tidal Delta	213,100,000	82,800,000	10.5
New Tidal Delta	69,500,000	30,100,000	11.7
Sand beneath overburden			
Old Tidal Delta	182,400,000	40,800,000	6.0
New Tidal Delta	27,000,000	7,300,000	7.3

The volumes in Table 16 are likely conservative as they only consider the area encompassed by the available borings. A previous study estimated approximately 520,000,000 CY of sediments, mainly sands, available within the area of the old tidal delta shown in Figure 14. More borings should be collected within other areas of the flood delta to located if there are areas that show significant volumes of sand at the surface.

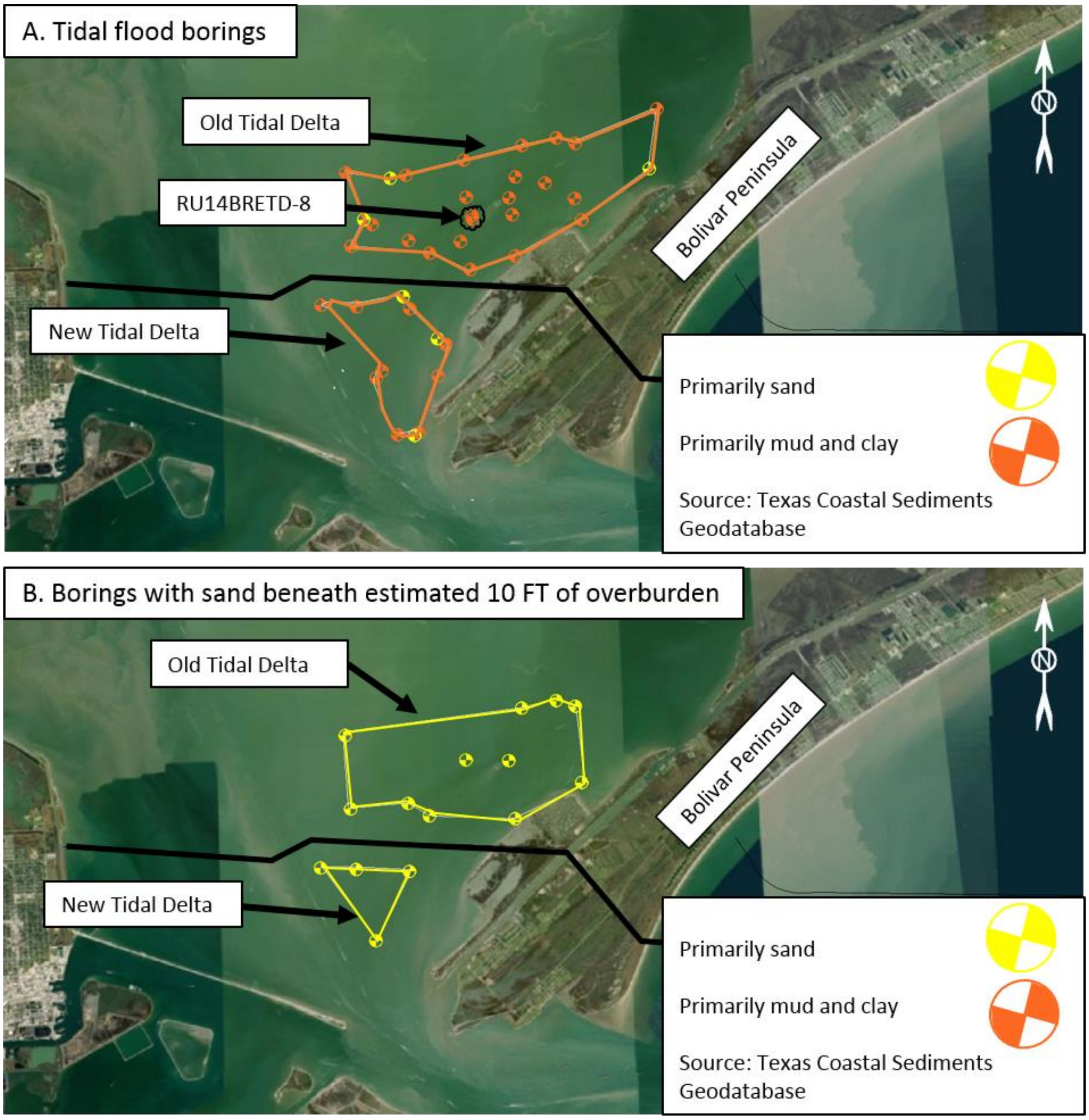


Figure 15. East Galveston Bay Tidal Deltas Estimated Available Materials

3.7 Channels

Material from maintenance dredging and planned deepening and widening projects could both act as potential sources for the marsh creation and restoration ER measures. Shoaling rates and new work volumes were taken primarily from past engineering studies. Historical dredging data was also obtained for the years 1990 to 2017 to calculate estimated shoaling rates if engineering studies were unavailable.

3.7.1 Gulf Intracoastal Waterway (GIWW)

Several of the marsh creation and restoration ER measures are adjacent to the Texas Gulf Intracoastal Waterway. Frequent maintenance dredging of the GIWW is required. Therefore, maintenance dredged material could be a potential source these measures. The GIWW channel is 125 wide and is maintained to a depth of 12 ft MLT. The frequency of maintenance dredging events depends on the shoaling rates in different segments of the channel. The extents of GIWW channel segments are shown Figure 16 and Figure 17 and their shoaling rates are summarized in Table 17. Based on these rates and estimated quantities per dredging events, the GIWW could be a potential source of sediment for ER measures with marsh and island restoration components requiring less than 2 MCY of fill sediment. These components are primarily the initial marsh creation and restoration.

Table 17. GIWW Channel Shoaling Rates and Maintenance Dredging Frequencies

Location	Start Station	End Station	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per dredge event [CY]
High Island to Port Bolivar	162+000	320+000	620,000	3,920	1.5	930,000
Port Bolivar to Galveston Causeway	320+000	360+271	380,000	9,440	2.0	760,000
Galveston Causeway to Bastrop Bayou	360+271	493+000	390,000	2,940	2.0	780,000
Bastrop Bayou to Freeport Harbor	493+000	564+000	250,000	3,520	3.0	750,000
Freeport Harbor to San Bernard River	564+000	614+000	565,000	11,300	2.0	1,130,000
San Bernard River to Matagorda Bay	614+000	901+424	1,000,000	3,480	2.0	2,000,000
Across Matagorda Bay	901+424	972+939	151,000	2,110	2.0	302,000
Port O'Connor to San Antonio Bay	972+939	1070+753	147,000	1,500	2.5	367,500
Across San Antonio Bay	1070+753	1121+000	375,000	7,460	2.0	750,000
San Antonio Bay to Aransas Bay (Light 1)	1121+000	1178+000	240,000	4,210	4-6	960,000 – 1,440,000
Across Aransas Bay	1178+000	1236+611	486,000	8,290	2-4	972,000-1,944,000
Aransas Bay to Corpus Christi Ship Channel	1236+611	1325+800	20,000	220	5.0	100,000
CCSC to Mudflats	1325+800	1679+500	515,000	1,460	1.5-2	772,500
Mudflats to Port Isabel	1679+500	1994+000	953,000	3,030	1.5-2	1,429,500

Sources: (Moffatt & Nichol, 2010; Randall, et al., 2000; USACE, 2018a; USACE, 2018b)

For this study it is assumed that the maintenance material dredged from the GIWW is majority mud/silt (90%) with some sand (10%) using engineering judgement of typical maintenance dredge materials.

Figure 16. North GIWW channel segments

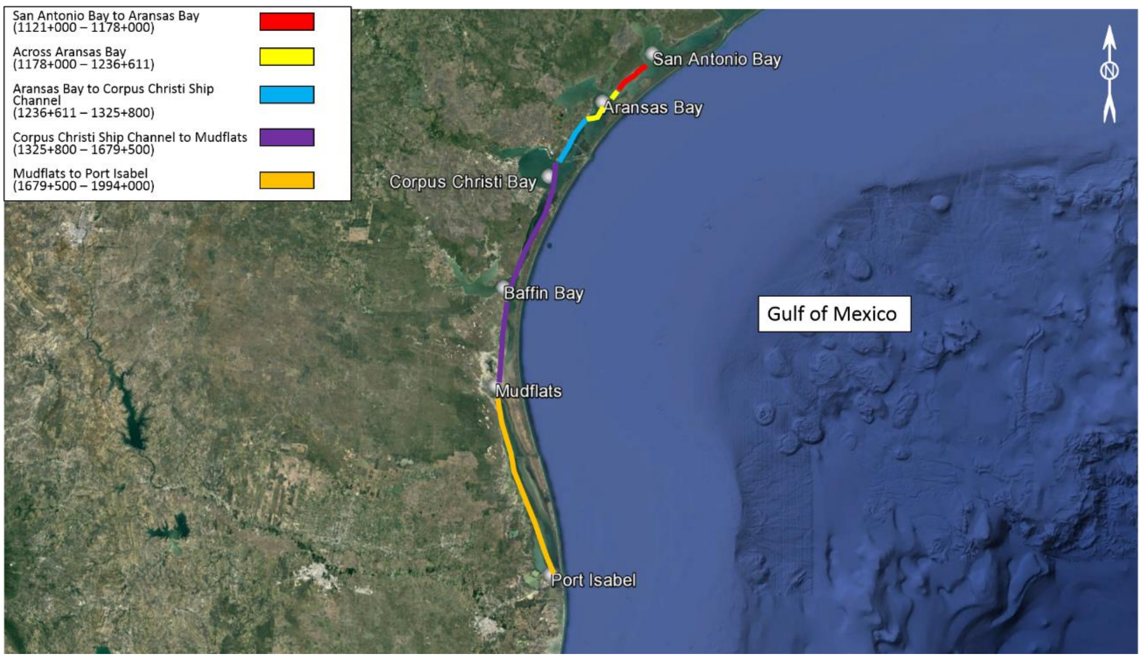


Figure 17. South GIWW channel segments

3.7.2 Houston and Galveston Area Channels

The Houston – Galveston Ship channels require regular maintenance to maintain the channels to their authorized depths. All of the existing shoaling rates for the area's channels are shown in Table 18, with the highest shoaling rates occurring in the Entrance channel, Galveston Harbor, and Houston Ship Channel (HSC) Mid Bay (Moffatt & Nichol, 2010; USACE, 2016a; USACE, 2016b; USACE, 2017a). These channels could potentially supply 13.7 MCY of dredged material if their maintenance dredging cycles all occurred in the same year.

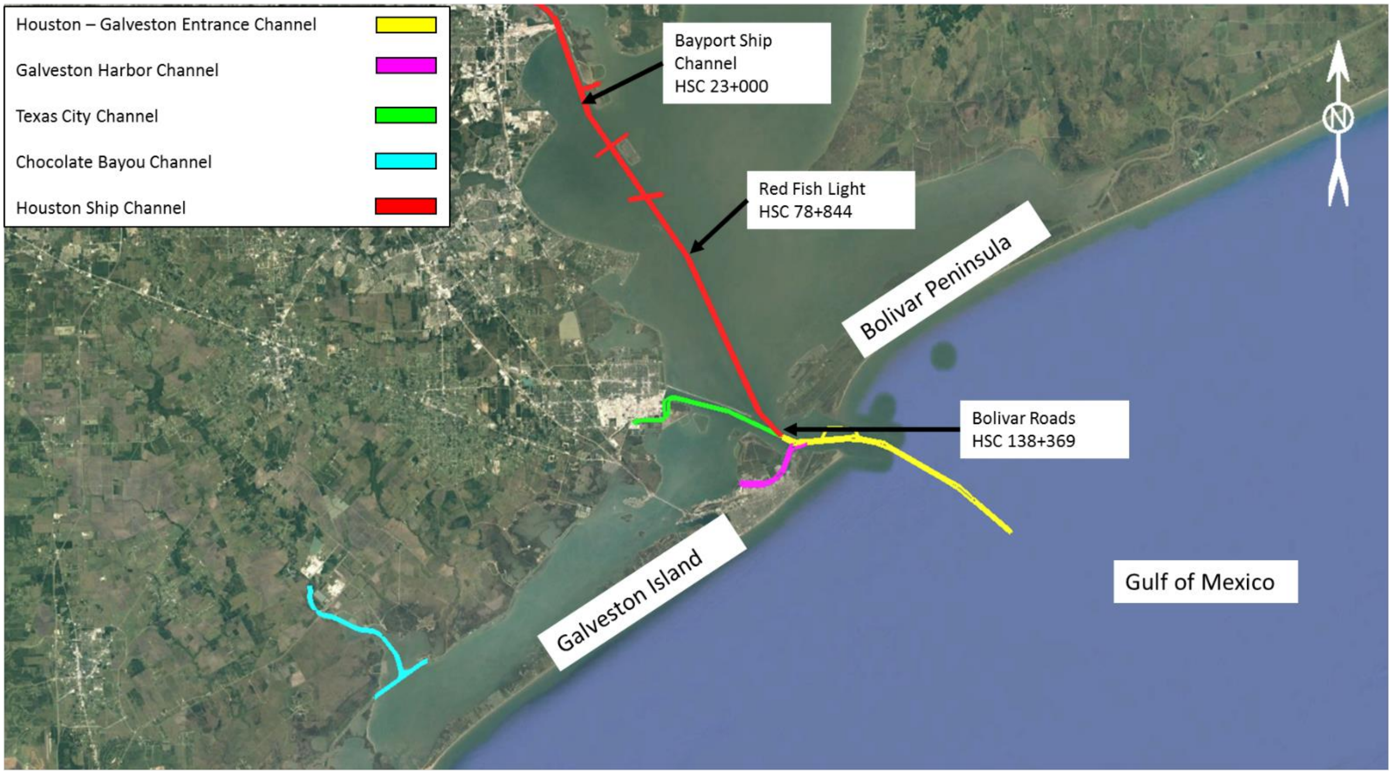


Figure 18. Houston and Galveston area potential channel sources

Table 18. Existing Shoaling rates and maintenance dredging frequencies of Houston-Galveston Channels

Location	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per Dredge Event [CY]	Material Type
Houston Ship Channel Lower Bay (138+369 to 78+844)	99,000	1,660	4	396,000	40% Silt/Clay 60% Sand
Houston Ship Channel Mid Bay (78+844 to 23+000)	1,469,000	29,240	3	4,407,000	70%Silt/Clay 30%Sand
Houston- Galveston Entrance Channel (76+000 to 0+000)	1,790,000	79,310	2	3,580,000	60% Silt/Clay 40% Sand
Galveston Harbor and Channel	2,860,000	37,630	2	5,720,000	80% Silt/Clay 20% Sand
Texas City Channel	740,000	19,660	3	2,220,000	90% Silt/Clay 10% Sand
Chocolate Bayou Channel	160,000	3,680	4	640,000	90% Silt/Clay 10% Sand
Sources: (Moffatt & Nichol, 2010; USACE, 2016a; USACE, 2016b; USACE, 2017a; USACE, 2018a)					

The new work material from future widening of the Houston Ship Channel is also a potential source of millions of cubic yards of sediment. The current tentatively selected plan is to widen the main channel from Bolivar Roads to the Barbours Cut Channel from 530 FT to somewhere between 650 to 820 FT (USACE, 2017a). The estimated new work dredging quantities and projected shoaling increases are provided in Table 19.

Table 19. Summary of Houston Ship Channel widening improvements new work quantities and estimated shoaling increases

Location	New Work Quantity [CY]	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per dredge event [CY]
Widening Channel to 650 FT					
Lower Bay (138+369 to 78+844)	2,098,000	121,000	2,030	4	484,000
Mid Bay (78+844 to 23+000)	4,527,000	1,799,000	35,810	3	5,397,000
Widening Channel to 820 FT					
Lower Bay (138+369 to 78+844	9,179,000	167,000	2,810	4	668,000
Mid Bay (78+844 to 23+000)	15,650,000	2,270,000	45,180	2	4,549,000
Sources: (USACE, 2017a; USACE, 2018a)					

3.7.3 Freeport Ship Channel

The Freeport Ship Channel extends from offshore in the Gulf of Mexico to the Port of Freeport. Existing shoaling rates for the Freeport Ship Channel are shown in Table 20. The Entrance channel requires almost yearly dredging in order to maintain the channel to its authorized depths. This material is typically disposed of in an offshore disposal site and could instead be beneficially reused in an ER measure for marsh creation.

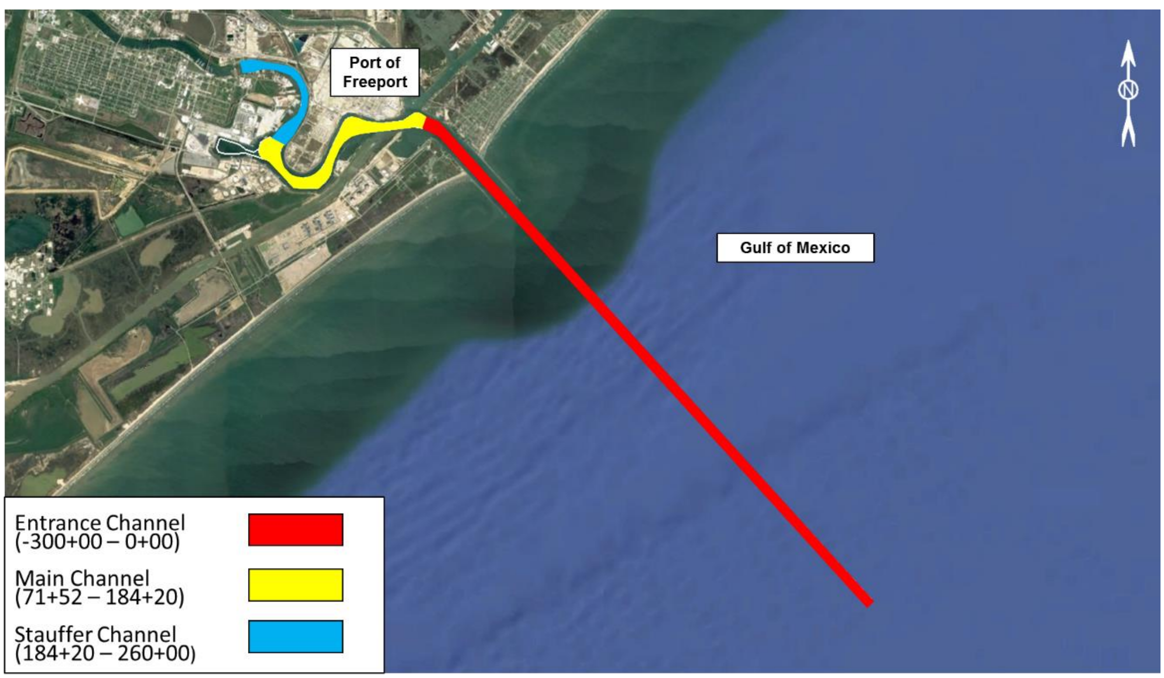


Figure 19. Freeport Ship Channel

Table 20. Existing shoaling rates in Freeport Ship Channel

Location	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per Dredge Event [CY]	Material Type
Entrance Channel (-300+00 to 71+52)	2,211,000	59,760	1	2,211,000	80% Silt/Clay 20% Sand
Main Channel (71+52 to 184+20)	261,000	23,160	3	783,000	95% Silt/Clay 5% Sand
Stauffer Channel (184+20 to 260+00)	2,500	330	12	30,000	95% Silt/Clay 5% Sand

Sources: (HDR, 2017) (USACE, 2011) (USACE, 2012) (USACE, 2018a)

Additionally, the Freeport Channel Improvement Project, which will extend the Freeport Entrance Channel into further into the Gulf of Mexico and deepen the channel from its current depth of 45 FT to authorized depths of 51 to 55 FT, is expected to begin construction in 2020 and to take approximately 5 years to complete (Dredging Today, 2018). The new work quantities for the improvements are listed in Table 21.

Table 21. Freeport Ship Channel Improvements projected new work quantities and increases in shoaling rates

Location	New Work Quantity [CY]	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per Dredge Event [CY]	Material Type
Extended Entrance Channel (-450+00 to 71+52)	9,733,000	3,188,000	86,169	1	3,188,000	80% Silt/Clay 20% Sand
Main Channel (71+52 to 184+20)	2,805,000	348,000	30,880	3	1,044,000	95% Silt/Clay 5% Sand
Stauffer Channel (184+20 to 260+00)	1,814,000	16,900	2,230	12	202,800	95% Silt/Clay 5% Sand

Sources: (HDR, 2017) (USACE, 2011) (USACE, 2012) (USACE, 2018a)

3.7.4 Matagorda Ship Channel

The Matagorda Ship Channel (MSC) extends from offshore in the Gulf through Matagorda Bay and Lavaca Bay to the Port of Port Lavaca. Existing shoaling rates for the Matagorda Ship Channel area shown in Table 22.

The Calhoun Port Authority and the USACE recently completed a feasibility study of the deepening and widening of the Matagorda Ship channel. The tentatively selected plan includes deepening the channel from 38/40FT to a depth of 47/49FT, widening the channel entrance from 300 FT to 600FT, and widening the main channel from 200 FT to 350 FT. The report estimates a total of 30.22 MCY of new work dredging will be required for the improvements (USACE, 2018d). Though neither of the ER measures near the Matagorda Ship Channel (CA – 5 and CA - 6) require quantities of this magnitude, if a need arises in the future, this potential new work material could be a potential source of fill sediment.

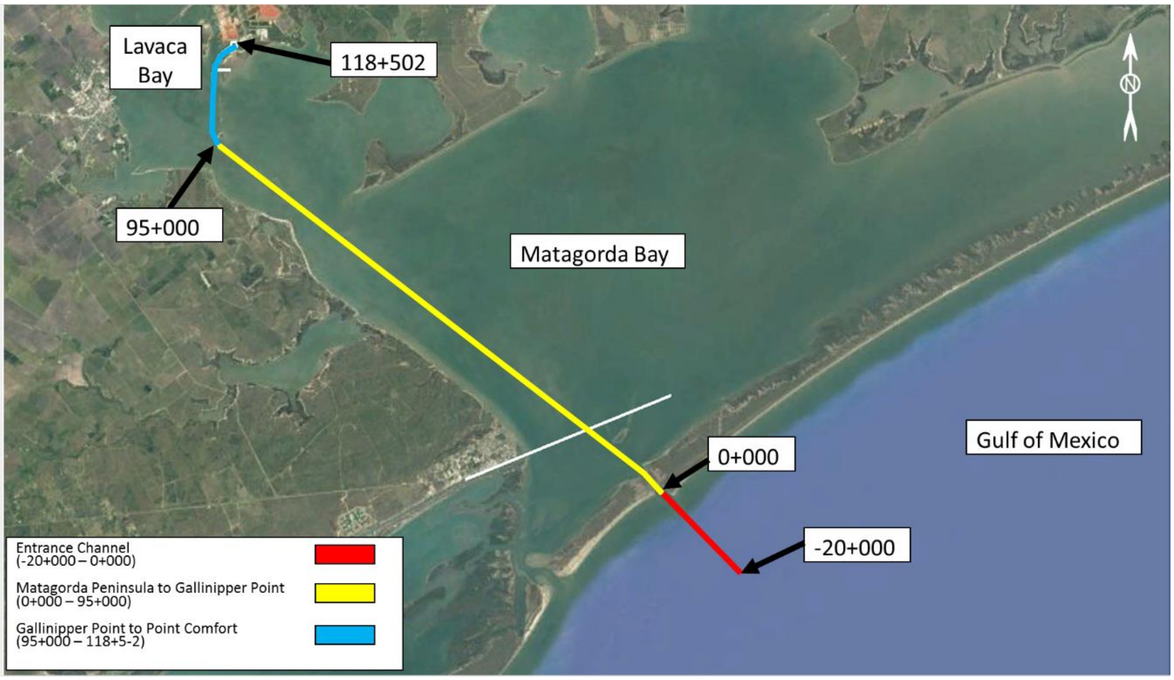


Figure 20. Matagorda Ship Channel

Table 22. Existing shoaling rates in Matagorda Ship Channel

Location	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per Dredge Event [CY]	Material Type
Entrance Channel (-20+000 to 0+000)	346,000	17,300	3	1,038,000	60% Silt/Clay 40% Sand
Matagorda Peninsula to Gallinipper Point (0+000 to 95+000)	1,302,000	13,710	2	2,604,000	78% Silt/Clay 22% Sand
Gallinipper Point to Point Comfort (95+000 to 118+502)	1,141,000	48,550	2	2,282,000	78% Silt/Clay 22% Sand

Sources: (Lambert, Willey, Thomas, Lihwa, & Welp, 2013; Wood, et al., 2017; USACE, 2018a)

3.7.5 Corpus Christi Ship Channel

The Corpus Christi Ship Channel (CCSC) extends from the Gulf of Mexico through the Corpus Christi Bay to the Inner Harbor. A major channel offshoot of the CCSC is the La Quinta Channel which allows access to the Port’s terminals along in the north of Corpus Christi Bay. The channels require regular maintenance, the Entrance Channel and Upper Bay reaches requirinng the most frequent maintenance dredging events as seen in Table 23.

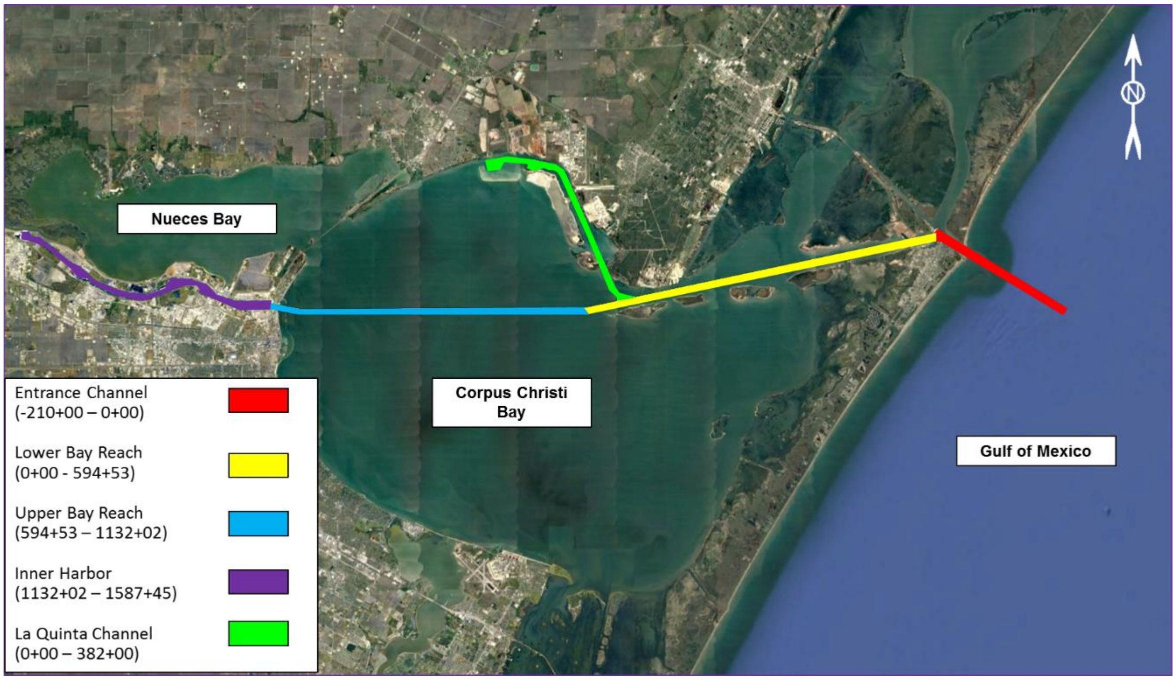


Figure 21. Corpus Christi Ship Channel

Table 23. Existing shoaling rates in the Corpus Christi Ship Channel

Location	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per Dredge Event [CY]	Material Type
Entrance Channel (-210+00 to 0+00)	598,000	34,920	2.5	1,495,000	40% Silt/Clay 60% Sand
Lower Bay Reach (0+00 to 594+53)	177,475	4,360	6	1,064,850	20% Silt/Clay 80% Sand
Upper Bay Reach (594+53 to 1132+02)	1,112,390	19,640	3	3,337,170	90% Silt/Clay 10% Sand
Inner Harbor (1132+02 to 1587+45)	331,400	7,280	4	1,325,600	70% Silt/Clay 30% Sand
La Quinta Ship Channel	166,667	4,360	3	500,000	75% Silt/Clay 25% Sand

Sources: (Parchure, Sarruff, & Brown, 2001; USACE, 2017b)

New work dredging material from the CCSC is also a potential source of marsh and island creation fill materials. Construction on the first phase of the Corpus Christi Ship Channel Improvement Project to deepen and widen the channel is expected to begin in Fall 2018 with the deepening of the Entrance Channel. The Port of Corpus Christi is aiming for the completion of all phases of the project by 2021 (Acosta, 2018). Much of the new work dredged material is expected to be beneficially used in placement areas along the channel. However, much of the new work material is slated to be disposed of in open water placement areas adjacent to the channel (see Section 3.8.3). ER measures could provide an additional location for the beneficial use of dredged material from the CCSC.

Table 24. Projected new work quantities and increases in shoaling rates of Corpus Christi Ship Channel Deepening and Widening Improvements

Location	New Work Quantity [CY]	Shoaling Rate [CY/YR]	Shoaling Rate [CY/YR/ 1000 FT]	Estimated Dredge Frequency [years]	Estimated Quantity per Dredge Event [CY]	Material Type
Entrance Channel (-210+00 to 0+00)	4,337,000	750,000	35,710	2.5	1,875,000	5% Silt/Clay 95% Sand
Lower Bay Reach (0+00 to 594+53)	8,754,000	250,000	4,360	6	1,500,000	5% Silt/Clay 95% Sand
Upper Bay Reach (594+53 to 1132+02)	14,419,000	1,700,000	20,010	3-6	5,100,000	90% Silt/Clay 10% Sand
Inner Harbor (1132+02 to 1587+45)	6,916,000	400,000	8,780	4	1,600,000	70% Silt/Clay 30% Sand

Source: (Parchure, Sarruff, & Brown, 2001; USACE, 2003; USACE, 2017a; USACE, 2018c)

3.8 Dredge Material Placement Areas (DMPAs)

3.8.1 Houston – Galveston DMPAs

There are many confined disposal sites adjacent to the GIWW which are used to dispose of maintenance dredged material. Figure 22 shows the location of the DMPAs to the G-28 marsh and island restoration areas. Mining of adjacent DMPAS was not considered as a potential source of material in this study because mining from these DMPAs is removing material that in the future will be important for shoreline and marsh protection.

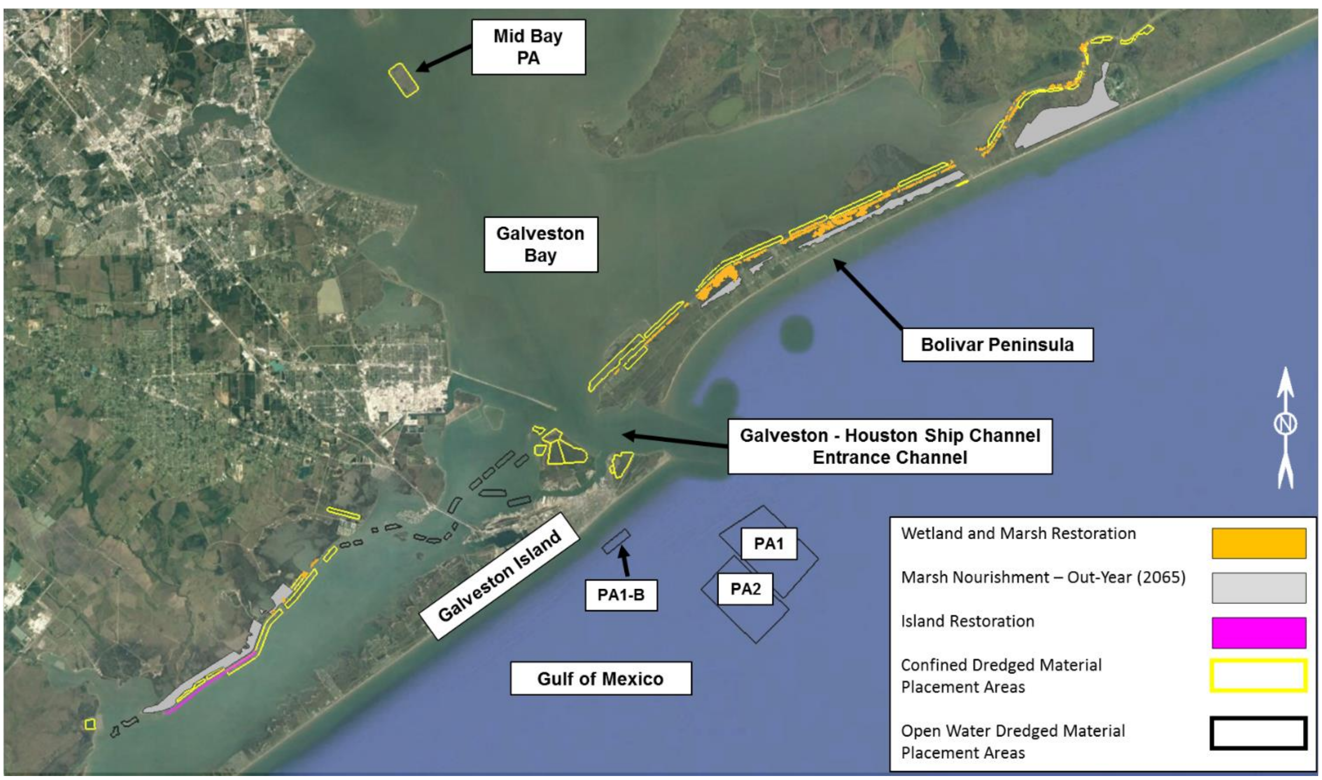


Figure 22. Houston - Galveston dredge material placement area locations

The Mid Bay Placement Area is an approximately 600-acres confined dredged material PA which typical receives material dredged from the Mid Bay segment of the Houston Ship Channel (STA 78+000 - 239+10). The ultimate capacity of Mid Bay PA is 29.3 MCY with a maximum levee elevation of +35 FT NAVD88. In 2017, the site was still considered feasible for the future placement of dredged material for approximately another 20 years (USACE, 2016b; USACE, 2017c). Mid Bay PA will likely receive some of the new work and maintenance dredged material from the proposed widening of the Houston Ship Channel in both the Lower and Mid Bay segments. The estimated dredged material quantities from Houston Ship Channel Improvements are summarized in Table 25. For either of the widening scenarios below, the estimated quantities exceed the maximum capacity of the Mid Bay PA. To maintain/increase the capacity in Mid Bay, it could potentially be mined for material to be used for marsh creation and island restoration ER measures.

Table 25. Summary of New Work and Maintenance Quantities for Mid Bay segment of Houston Ship Channel Widening Improvement

			Widening to 650 FT		Widening to 820 FT	
Houston Ship Channel Segment	Start Station	End Station	New Work Quantity [CY]	Total 50-year Maintenance Dredging Quantity [CY]	New Work Quantity [CY]	Total 50-year Maintenance Dredging Quantity [CY]
Lower Bay (Bolivar Roads to Redfish Reef)	138+369	78+844	2,098,000	6,050,000	9,178,000	8,350,000
Mid Bay (Redfish Reef to Bayport Ship Channel)	78+844	23+000	4,527,000	89,950,000	15,650,000	113,500,000

Source: (USACE, 2017a)

ODMDS 1 has historically been used for the disposal of dredged material from the Galveston Harbor and Channel, Entrance Channel, and Bolivar Roads Reach of the Houston Ship Channel. As an offshore disposal area, the site is dispersive in nature and has an unlimited placement capacity. The site is naturally sorted by storms and currents which remove muds and leave sandy sediments of the surface. Sediment within ODMDS 1 can be characterized as fine sand (60%) and silt/clay (40%) (USACE, 2016b; Freese & Nichols, 2016). More data is needed to identify whether this site could potentially be used as a source for beach quality sand, but the site could be used as a source for marsh and island restoration measures.

3.8.2 Freeport DMPAS

Similar to the Houston – Galveston area, the Freeport area contains many DMPAs adjacent to the GIWW. Mining from these DMPAs was not consider for this study for, as discussed in the previous Section, if the goal of these ER measures is to restore marshes in the surrounding area, removing sediment from these DMPAs to fill adjacent marshes is ultimately not bringing in more fill to the areas could end up increasing the area's vulnerability. However, there are a few DMPAs used for the disposal of dredged material which are not immediately adjacent to the future marshes which could potentially be mined for material, PA 1, PA 9, and PA 8 as shown in Figure 23.

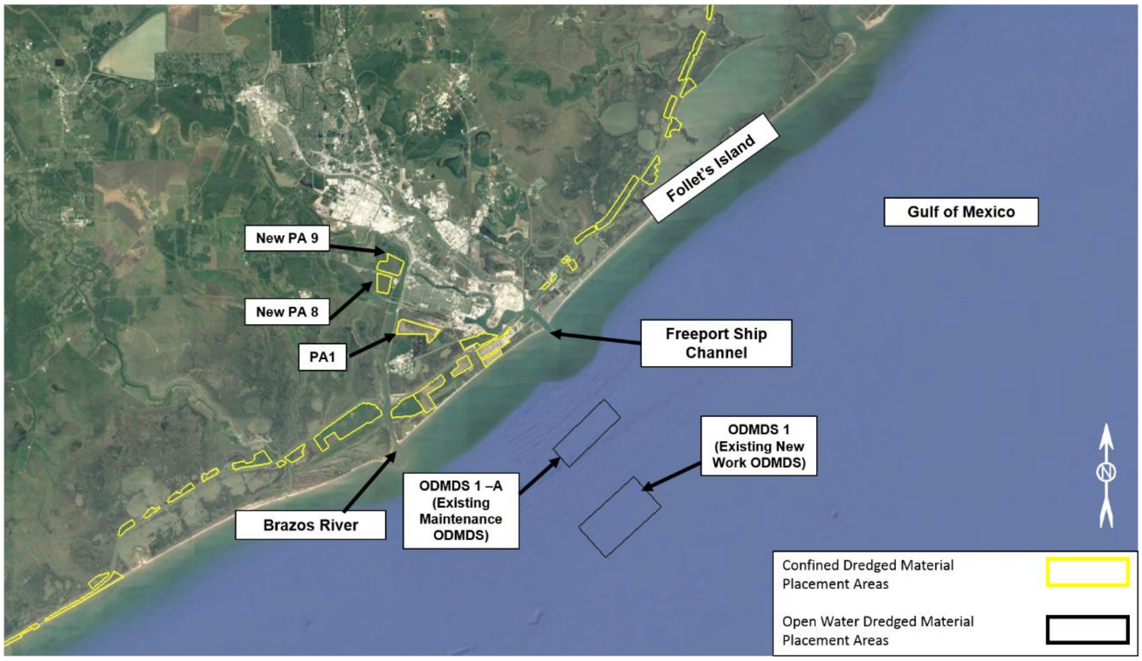


Figure 23. Freeport dredge material placement area locations

PA 1 is a confined placement area that is historically used for maintenance dredged material from the main Freeport Channel and Harbor. PAs 8 & 9 are new placement areas which will receive new work material from the deepening and widening project as well as future maintenance dredging material. Table 26 breakdown the estimated quantities to be placed in each of these placement sites in the future.

Table 26. Freeport Harbor Deepening and Widening - quantity breakdown to placements sites (CY)

Location	New Work Quantity [CY]	Total 50-year Maintenance Dredging Quantity [CY]
ODMDS 1	9,733,297	-
ODMDS 1-A	-	159,416,960
PA 1	-	1,817,240
PA 8	1,853,144	5,712,400
PA 9	2,765,559	8,993,130
Source: (USACE, 2012)		

It is anticipated that the offshore disposal sites are to be used for the majority of the new work and maintenance dredged material from the Freeport Ship Channel. As the dredged material will be soft and dispersive in nature, it will move around due to currents and likely outside the boundaries of the placement areas. However, these offshore placement areas could be mined as a potential source of sediment for marsh creation and restoration fill material, or, as discussed in Section 3.7.3, the maintenance material could instead be beneficially used in one of the ER measure marsh creation areas rather than disposed of offshore.

3.8.3 Corpus Christi DMPAS

The dredged material from the Corpus Christi and La Quinta Channels is disposed of in multiple DMPAs surrounding the channels as shown on Figure 24. Many of the island PAs are beneficial use areas and those labeled as “New Beneficial Use Areas” are beneficial use areas to be created and filled with material from the Corpus Christi Ship Channel Deepening and Widening as detailed in Table 27.

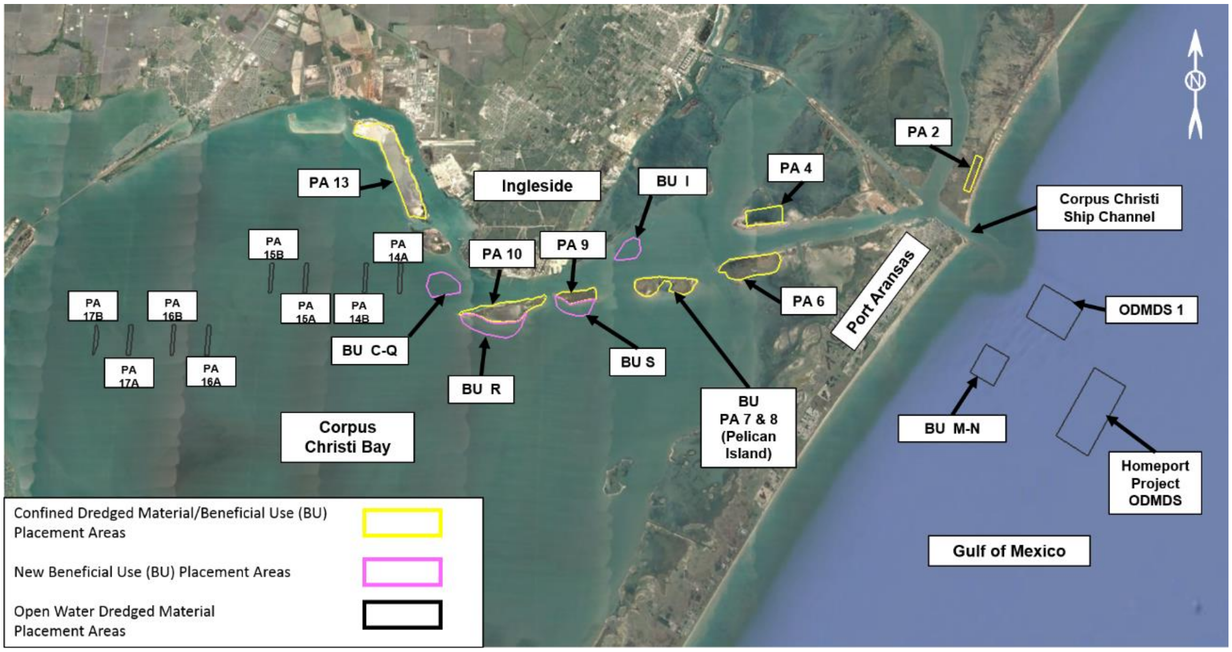


Figure 24. Corpus Christi dredge material placement area locations

Table 27. Placement Plan for New Work Material from Corpus Christi Ship Channel Improvements

Location	New Work Quantity [CY]	Total 50-year Maintenance Dredging Quantity
BU M-N	3,600,000	-
Homeport	2,600,000	-
ODMDS 1		62,000,000
PA6	2,700,000	-
BU Site I	2,100,000	-
BU PA 7 & 8	300,000	11,700,000
BU Site R	2,400,000	-
BU Site S	1,500,000	-
BU Site C-Q	2,900,000	-
17B, 17A, 16A, 16B, 15A, 15B, 14A, 14B	11,900,000	76,400,000
PA 13	2,700,000	25,200,000

Source: (USACE, 2003)

This study did not consider any DMPA that the Port of Corpus Christi is considering as a beneficial use site as potential source of material. However, PA 13, which is not a beneficial use site, could potentially be mined for material. Additionally, mining of the open water and offshore placement areas area also potential sources, or, as discussed in Section 3.7.5, the maintenance material could instead be beneficially used in one of the ER measure marsh creation areas rather than disposed of offshore.

3.9 Upland/Commercial Sources

3.9.1 Beaumont Formation

The Houston-Galveston Area largely sits atop the Beaumont Formation. The Beaumont formation, sometimes referred to as Beaumont clays, is a geologic formation formed between around 400,000 and 35,000 years ago as a fluvial delta with shallow marine deposits (Freese & Nichols, 2016). The formation is divided into two dominant sediment areas: areas predominantly sand and areas predominantly clay. The clay areas consist of “clay and mud of low permeability, high water holding capacity, high compressibility, high to very high shrink-swell potential, poor drainage, level to depressed relief, low shear strength, and high plasticity” (USGS, Texas Geologic Map Viewer, 2015). The predominantly sand areas consist of “clayey sand and silt of moderate permeability, low to moderate compressibility and shrink-swell potential, level relief with local mounds and ridges, and high shear strength” (USGS, Texas Geologic Map Viewer, 2015). Figure 25 shows the extent of these sediment areas in the greater Houston Areas. In general, the Beaumont formation is composed of 80% or more of fat and lean clays (Vipulanandan, 2008).

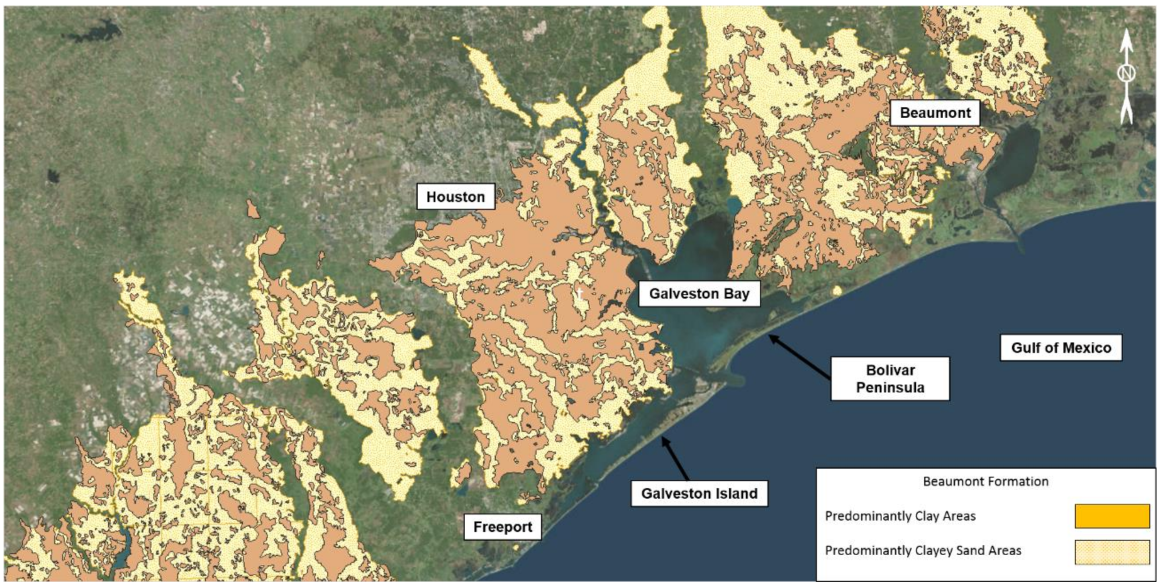


Figure 25. Houston-Galveston Area Beaumont Formation

The properties of Beaumont clays are relatively uniform, and the plasticity data typically plots within the shaded zone in Figure 26. The natural water content of the clay is typically within a few percent of the plastic limit and the clay is generally light gray, tan, and red in color (Focht & Sullivan, 1969).

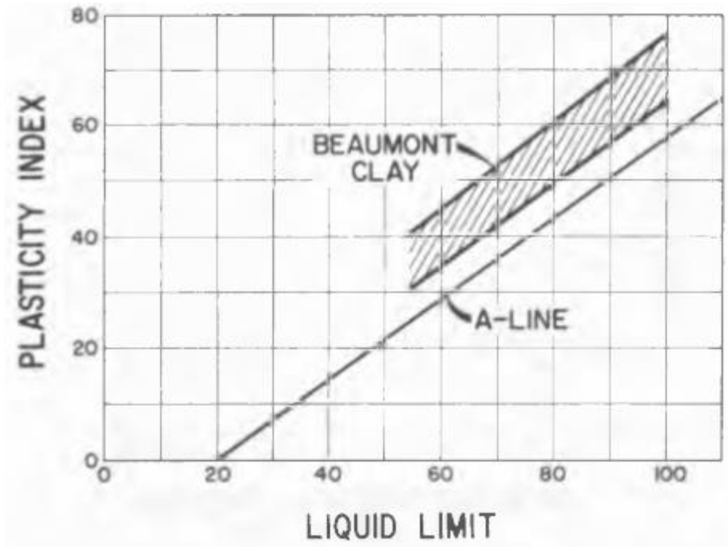


Figure 26. Beaumont clay plasticity chart (Focht & Sullivan, 1969)

Public geotechnical studies around the Houston area were obtained, one of which analyzed 116 boreholes around City of Houston (Aviles Engineering Corporation, 2010; Gorrondona & Associates, Inc., 2015; Paradigm Consultants, Inc, 2016; Vipulanandan, 2008) (Paradigm Consultants, Inc, 2016). From these boreholes it was determined that the largest percentage of soft clays is within the top 20 FT of the borings and the plasticity indexes from the samples taken in these studies ranged from 18 – 60. The groundwater level in these studies was found at approximately -10 FT below the ground surface, however this would vary depending on the time of year and annual rainfall.

For this study it was assumed that all clay materials required to construct the CSRM Alternative A could be sourced from any borrow source location within the Beaumont Formation. Further research is needed for how this soil might need to be stabilized at the surface of the levees to mitigate the risk of shallow slide failures.

3.9.2 Commercial Sources

Upland and commercial sources were evaluated for sourcing the clay required for features comprising CSRM Alternative A. Figure 27 shows the locations of existing commercial borrow pits in the greater Houston Area overlaid on the Beaumont Formation and the companies that source material from these pits. Most of the commercial pits are situated close to more populated and developed commercial, industrial, and residential land areas. This is strategic as these are areas where construction projects will need material. Very few commercial pits are located in the land east of Galveston Bay and North of the Bolivar Peninsula because the area is mostly undeveloped and unpopulated and therefore there is likely very little demand.

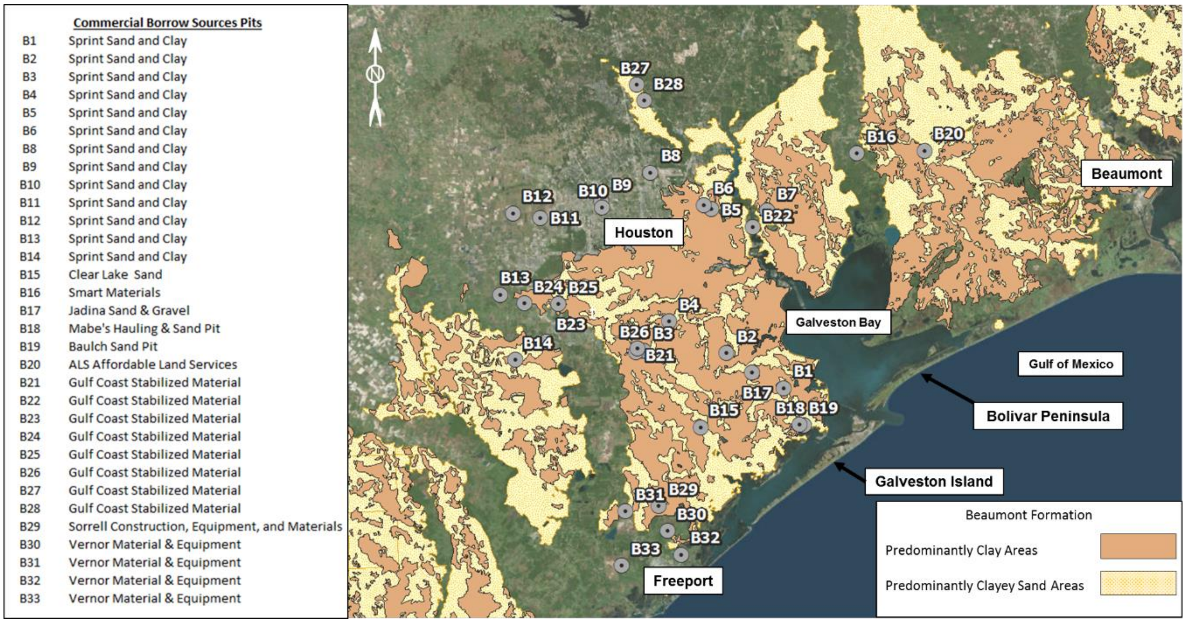


Figure 27. Available commercial borrow sites in Houston – Galveston area

Representatives of commercial borrow sites were contacted regarding the volume and quality of material available. The representatives generally did not know the quantity of material available, and mentioned that their clients will perform their own materials testing at sites to determine the material's properties. Most commercial sites offer select fill and common fill, a clay/sand mixes made to specifications by soil engineers and which generally have low to medium plasticity indices (PI). Straight clays are available though it is not a common material requested by clients. In general, clayey materials are available in the top 10 – 15 FT of the borrow pit. Commercial pit owners are able to excavate material below groundwater by using pumps to dewater the excavation area (Durwood Flora, Personal Communication, May 18, 2018).

Using aerials and publicly available property data, areas were estimated for each of the borrow sources in Figure 27. It was estimated that there is 5-10 FT of clayey material available in each of the pits, which is aa conservative estimate based on communications with commercial source representatives. Using this methodology an estimated 21,000,000 – 42,000,000 CY of clayey material is available to be sourced. While this is more than enough to construct the levees, it would require a large amount of coordination from many different sources and companies. Additionally, it would require most sources to only supply material to this project which could potentially exhaust their material supply. Most commercial sources indicated they would be resistant to supply the amount material required for a project of the scale of the levees, even if it took place over several years.

The sales representative from Gulf Coast Stabilized Materials, one of the companies with the most borrow pits, mentioned that they are able to supply approximately 4 million cubic yards of materials per year, including sand, clay, and select fill, to the Houston Area (Chris Harmon, Personal Communication, May 31, 2018).

Another potential source for clay materials could be from capital improvement projects around Houston. This would also require a lot of coordination from multiple sites but could be a viable option for reusing excavated materials.

3.9.3 Contractor Sourced Through Land Acquisition

A potential alternative to commercial borrow sites is to lease land solely for the purpose of providing clay materials to the CSRM project sites. As commercial borrow sites are limited near the Bolivar Peninsula, this would allow for a supply of material close to the proposed levees along the Bolivar Peninsula.

Figure 28 shows the land classified as “Vacant Developable” land on the Beaumont Formation in Chambers, Galveston, and Brazoria Counties, the three counties closest to Galveston and Bolivar Islands (HGAC, 2018). Note that the areas shown include farming land. The total acreage shown amounts to approximately 627,930 acres. If the farming land is removed, the amount of available vacant undeveloped land is reduced to approximately 138,000 acres. Figure 28 shows the acreage of undeveloped land available in each county.

Table 28: Available Vacant Developable Land (acres)

	Including Farming Land (acres)	Excluding Farming Land (acres)	% Reduction in Available Area
Brazoria County	308,330	16,560	95%
Galveston County	84,370	28,170	67%
Chambers County	235,230	93,320	60%
Total:	**627,930**	**138,040**	**22%**

Source: 2018 Land Use Data from Houston-Galveston Area Council (HGAC, 2018)

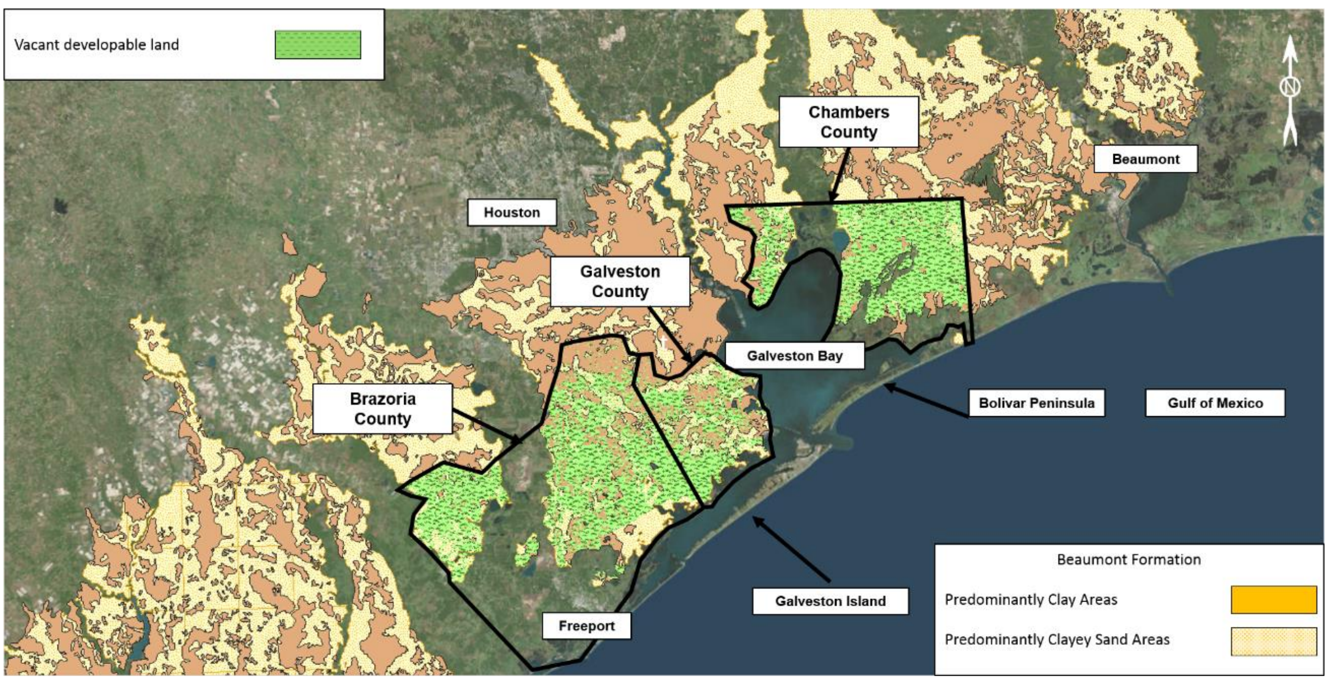


Figure 28. Available vacant developable land (including farmland)

As the Table 28 shows, there is plenty of available land for excavation of levee material. To estimate available volumes, a 5-10 FT of clayey material was assumed to keep excavation above the groundwater to avoid dewatering the excavation pit.

Table 29: Available clayey material in Vacant Developable Land (CY)

	Including Farming Land (CY) (5 – 10 FT of face)	Excluding Farming Land (CY) (5 – 10 FT of face)
Brazoria County	2,500,000,000 – 5,000,000,000	133,600,000 – 267,100,000
Galveston County	680,600,000 -1,361,100,000	227,200,000 – 454,400,000
Chambers County	1,897,500,000 – 3,798,100,000	752,800,000 – 1,505,500,000
Total:	5,100,000,000 – 10,100,000,000	1,113,500,000 – 2,227,100,000

Source: 2018 Land Use Data from Houston-Galveston Area Council (HGAC, 2018)

Even if farmland is excluded, there is more enough material available to construct the levees. Table 29 estimates the volume available for the all the available vacant land shown in Figure 28, regardless of distance from Galveston Island and Bolivar Peninsula. It is more likely that if a contractor were able to source their own material source, they would try and select a site as close as possible to the project sites.

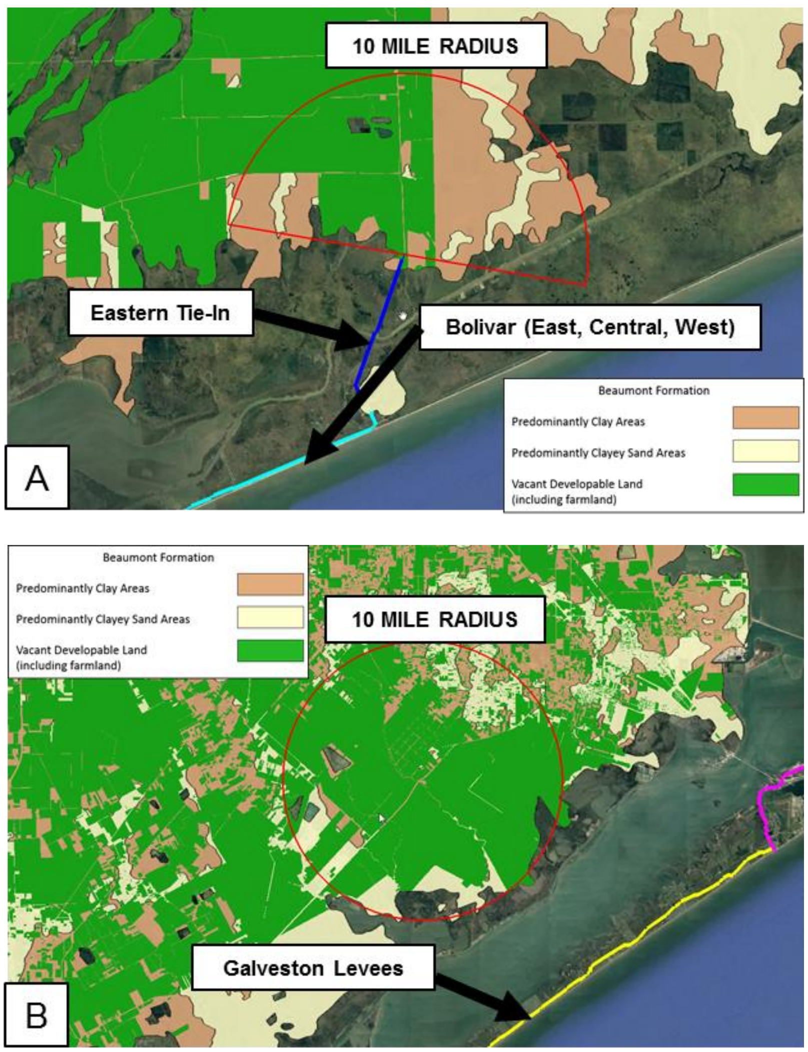


Figure 29. Available vacant developable land (including farmland) near Bolivar Peninsula levees (A) and Galveston Island levees (B)

Figure 29 displays the vacant developable land that is closer to the levee project sites and where a contractor might source material. The volumes within the 10-mile radii were calculated and are shown in Table 30. Even with the land limited to a smaller area, there is enough land available to excavate the 11.8 MCY required to construct the levees.

Table 30. Available clayey material in Vacant Developable Land near levee project sites (CY)

	Including Farming Land		Excluding Farming Land*	
	Acres	Volume (CY) (5 – 10 FT of face)	Acres	Volume (CY) (5 – 10 FT of face)
Brazoria County – near Galveston Island Levees	60,262	486,100,000 – 972,200,000	3,236	26,100,000 – 52,200,000
Chambers County – near Bolivar Peninsula Levees	16,885	136,200,000 – 272,400,000	6,698	54,000,000 – 108,100,000

* Acres and quantities based off percent reductions calculated for totals in Table 28

Further analysis should be done during future design phases to assess the vacant land close to the project sites to determine its feasibility for use as borrow sources of clay.

4 Conceptual Cost Estimates

Conceptual cost estimates were compiled for CSRM Alternative A and the ER measures. Note that the cost estimates are for material transportation only. The costs do not include levee construction costs, environmental mitigation or monitoring costs, stockpile land acquisition costs, contingency, or other costs typically associated with construction of earthen features. The following Sections present preliminary costs for comparative purposes, as well as the inputs used to obtain these costs. It is anticipated that the USACE will use the ER measure inputs provided to perform a separate cost analysis using proprietary software. Costs presented for the ER measures are for comparative purposes only between different excavation and transportation methodologies.

4.1 CSRM Alternative A

4.1.1 Commercial Sources

Trucking quotes were received from several companies and are shown in Table 31 with calculated averages. These costs include the cost to load a truck at the commercial borrow site and delivery to the levee footprint. Companies were asked to provide a range of costs if materials were delivered to 61st Street, Jamaica Beach, and San Luis Pass. One commercial source also provided an estimate to High Island on the Bolivar Peninsula. In general, the commercial sources noted that transportation of material to High Island would be cost prohibitive.

Table 31. Commercial source trucking quotes

Distance to Delivery Point (miles)	$/CY for 12 CY Trucks
10 - 20	$ 7.25
20 - 30	$ 12.27
30 - 40	$ 25.42
40 - 50	$ 17.71
50 - 60	$ 21.50
60 – 70	$ 29.00
70 – 80	$ 33.91
+80	$ 38.80
Average $/MI for 12 CY Truck	$6.56
Average $/HR for 12 CY Truck at 45 mph	$295.26
Average $/HR/CY	$24.60

*Costs shown are in 2018 dollar amounts.

If commercial sources are used for construction of the levees, it is likely that multiple sources would need to be used. The specific sources used for construction of the levees will likely be determined by the construction contractor and is unknown at this time. Therefore, to estimate the cost of trucking the material from commercial sources, the centroid of all the commercial borrow sites was calculated to establish a single point assumed as the starting point for trucking. Figure 30 shows the locations of existing commercial borrow pits in the greater Houston Area and the location of the centroid of all the points. The distance from the centroid to different reaches along the levee were calculated to estimate the typical distance a truck might travel from a commercial borrow sites. These distances are shown in Table 32. For this study it was assumed that the trucks travelling to Bolivar Peninsula would not use the ferry crossing between Galveston Island and Bolivar Peninsula. Although the distance traveled may be shorter, the wait times at the ferry are highly variable and it is assumed that truck drivers would prefer to drive around to the peninsula for delivery time consistency.

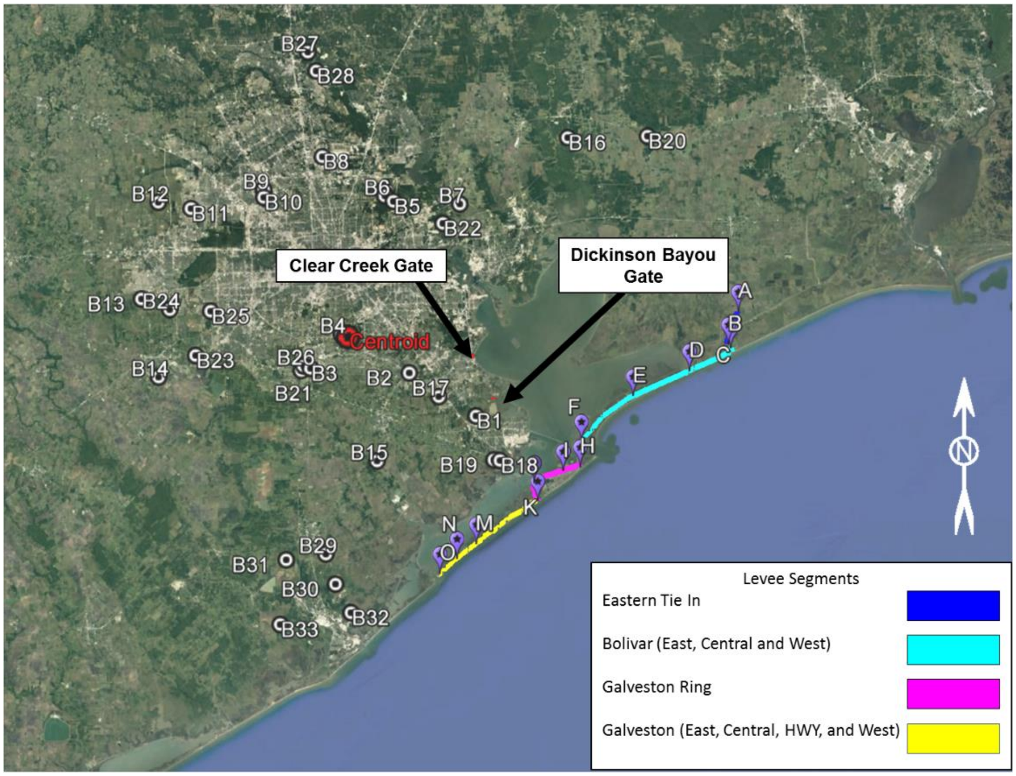


Figure 30. Centroid location of commercial borrow sources

Table 32. Distance from centroid of commercial sources to each levee reach shown in Figure 30.

Location	Distance from Centroid [mi]
East of Entrance Channel Crossing	
Eastern Tie In (A to B)	80.1 - 85.2
Bolivar East (C to D)	85.9 – 97.3
Bolivar Central (D to E)	97.3 - 102
Bolivar West (E to F)	102 – 117
West of Entrance Channel Crossing	
Galveston Ring Levee (H – K)	38.4 – 48.1
Galveston East (K – L)	48.1 – 55.4
Galveston Central (L – M)	55.4 – 59.3
Galveston HWY (M – N)	59.3 – 62.8
Galveston West (N-O)	62.8 – 66.2
Gate Structures	
Clear Creek Channel	23.6
Dickinson Bayou	27.7

The estimated costs for sourcing clay materials from commercial borrow sites was estimated using the average $/HR/CY received from commercial sources trucking quotes (Table 31) and the distances from the calculated centroid (Table 32). This analysis assumes that trucks would travel at a speed of 45 mph, including an additional 20% in the time for delays due to traffic and stops. The commercial trucking costs are shown in Table 33. It should be noted that the calculated costs only include loading the material from the commercial source into the trucks (and the additional cost of the material, if any, at the site) and transporting the material to the sites, they do not include actual construction of the levees of the additional equipment required for construction.

Table 33. Summary of estimated trucking transportation cost for commercial sources

Reach	Levee Quantity [CY]	Distance [MI]	$/CY	Total [Million $]
Eastern Tie-In	776,790	80.1 - 85.2	$54.7 - 58.2	$42.5 – 45.2
Bolivar East	2,667,510	85.9 – 97.3	$58.7 - 66.5	$156.6 – 177.4
Bolivar Central	2,096,449	97.3 - 102	$66.5 - 69.7	$139.4 -146.1
Bolivar West	2,195,467	102 – 117	$69.7 – 80	$153.0 – 175.6
Total Bolivar Peninsula East	**7,736,216**			**$491.5 – 544.3**
Galveston Ring Levee	515,707	38.4 – 48.1	$26.2 - 32.9	$13.5 – 17.0
Galveston East	1,285,054	48.1 – 55.4	$32.9 - 37.9	$42.3 – 48.7
Galveston Central	518,476	55.4 – 59.3	$37.9 - 40.5	$19.7 – 21.0
Galveston HWY	977,948	59.3 – 62.8	$40.5 - 42.9	$39.6 – 42.0
Galveston West	740,129	62.8 – 66.2	$42.9 - 45.2	$21.0 – 22.1
Total Galveston Island West	**4,037,314**			**$136.1 – 150.8**
Clear Creek Gate	**14,700**	**23.6**	**$16.10**	**$200,000**
Dickinson Bayou Gate	**69,300**	**27.7**	**$18.90**	**1,300,000**

*Costs shown are in 2018 dollar amounts and include loading trucks and delivery to site. All costs were calculated using average 26.40 $/CY/HR with trucks traveling at 45 mph and assume 20% for time delays (traffic, etc.) but do not include contingency.

As seen in Table 33, the cost of trucking is primarily dependent on the distance of the commercial site to the final levee destination. The unit costs of trucking material to the Bolivar Peninsula is almost twice as much as the unit costs to truck material to Galveston Island as most of the commercial borrow sites are located in Brazoria and Harris Counties. Figure 31 displays how the unit cost of trucking material from commercial source increases based on the delivery distance from a borrow source. The figure also compares how increases in delays might also increase the trucking unit prices. The best way to reduce costs for transportation of clay material to the levees is to find borrow sources located as close as possible to the final delivery locations. Also, commercial sourcing material from large capital improvement projects (i.e. constructing/improving storm water retention basins) around the City of Houston may also be possible. As these projects will typically already include a cost to truck the excavated material offsite, a cost share partnership could be set up where the cost for construction of the levee is the increase in costs to truck the material to levee sites. This could potentially result in overall lower trucking costs, but would require significant coordination between construction projects.

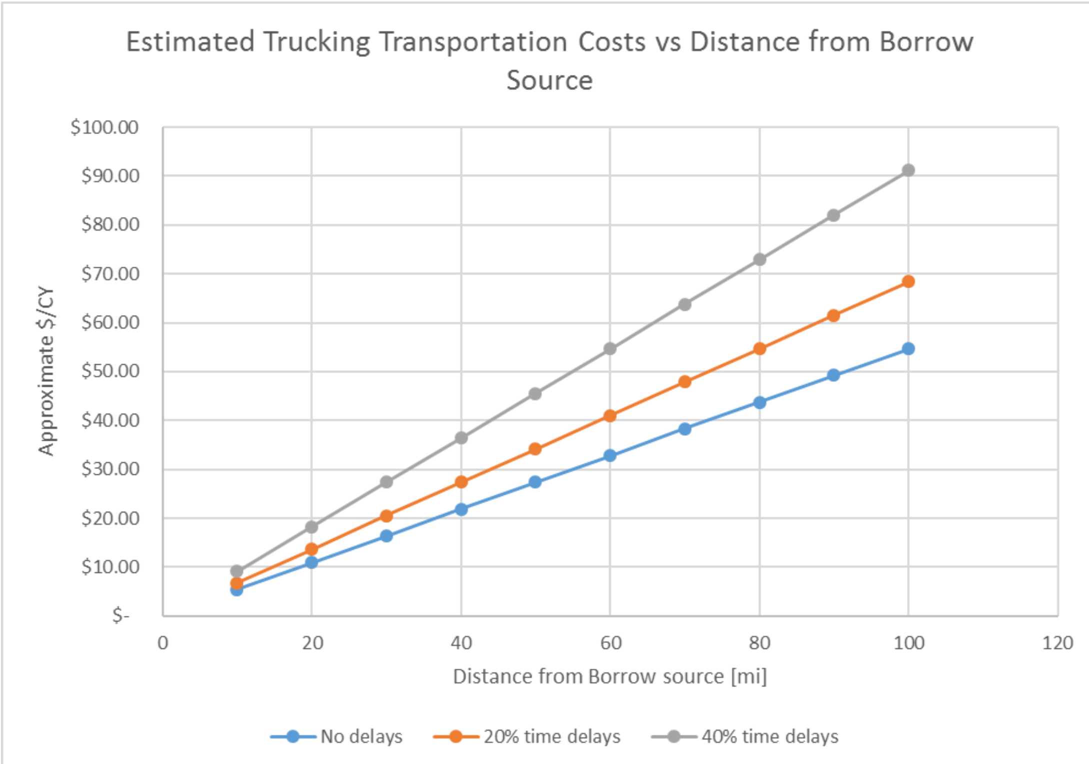


Figure 31. Estimated trucking transportation unit costs vs distance from borrow source

4.1.2 Contractor Sourced Through Land Acquisition

As discussed in the previous Section, trucking transportation costs are more economical the closer the borrow source is to the levee location. One potential way to reduce costs is to acquire vacant developable land close to the levee project sites (see Section 3.9.3). If land is acquired by a contractor, this also provides the opportunity to barge material instead of trucking material, potentially adding additional cost savings. The following two Sections detail the estimated costs of trucking and barging material to the site if the material is contractor sourced using acquired lands.

4.1.2.1 Trucking Transportation

Trucking costs were estimated using the same average trucking rate calculated from Table 31 and trucking distances assuming the contractor would source material from 10 mile radii areas shown in Figure 32. The area selected in Figure 32A for the Bolivar Peninsula levees was selected because it is the potential available land closest to the project site. The area selected in Figure 32B for the Galveston Island levees was selected because it contains the greatest amount of available developable land area. Only the available developable land within the Beaumont Formation was considered, however it is possible that there is acceptable material outside the Beaumont Formation which should be explored further in future studies. Also note that developable land data was only obtained for Chambers, Brazoria, and Galveston Counties (Figure 28). Jefferson County, the county to the east of Chambers County near the Bolivar Peninsula, likely also has the large amounts of vacant developable land available not shown and which would fill in the eastern area of the radius in Figure 32A. Despite this omission, there is sufficient material available within the current dataset to construct the levees. The estimated costs are summarized in Table 34. The calculated costs include time to excavate and load a 12 CY truck with an excavator with a 3.5 CY bucket (approximately 5 minutes), and transporting the material to the sites, and unloading the trucks (approximately 2 minutes to lift the bed of the truck). The distances range from the shortest distance between a levee reach and the 10 mile radius to the furthest distance between a levee reach and the 10 mile radius. For example, for the Eastern Tie-In, the distance between point A and point B is approximately 5.2 miles. If land is acquired close to first levee segment, a truck would have to travel approximately 0.5 – 5.2 miles to supply material to the entire segment from point A to point B, whereas if land is acquired 10 miles from the levees, a truck would have to travel 10.5 – 15.2 miles to supply material to the segment from point A to point B. Therefore, the range of distances used in estimating costs for the Eastern Tie-In levee segment was 0.5 – 15.2 miles. The unit costs are the ranges of the average costs for delivering material along the levee segments if land is acquired from the area in the radii closest to the levees and if land is acquired from the furthest distance in the radii (i.e. for the Eastern Tie-In $4.8/CY is the average of the estimated costs for the closest distance range of 0.5 – 5.2 miles, whereas $12.1/CY is the average of the estimated costs for the furthest distance range of 10.5 – 15.2 miles). The costs do not include actual construction of the levees, the additional equipment required for construction, contingency, or any land acquisition costs.

Table 34. Estimated trucking costs for material sourced from acquired land close to levee sites

Reach	Levee Quantity [CY]	Distance [MI]	$/CY	Total [Million $]
Eastern Tie-In (A to B)	776,790	0.5 - 15.2	$4.8 - 12.1	$3.7 – 9.4
Bolivar East (C to D)	2,667,510	5.8 - 23.2	$9.4 - 16.9	$25.1 – 45.1
Bolivar Central (D to E)	2,096,449	13.2 - 32.6	$15.1 - 22.6	$31.7 – 47.4
Bolivar West (E to F)	2,195,467	22.6 - 42.8	$21.8 - 29.2	$47.9 – 64.1
Total Bolivar Peninsula East	**7,736,216**			**$108.4 – 166.0**
Galveston Ring (H to K)	515,707	12.6 - 38.5	$14.1 - 27.9	$7.3 – 14.4
Galveston East (K to L)	1,285,054	18.5 - 45.6	$18 - 31.9	$23.1 – 41.0
Galveston Central (L to M)	518,476	25.6 - 49.7	$21.8 - 35.5	$11.3 – 18.4
Galveston HWY (M to N)	977,948	29.7 - 53	$24.3 - 37.8	$23.8 – 37.0
Galveston West (N to O)	740,129	33 - 56.7	$26.7 - 40.2	$19.8 – 29.8
Total Galveston Island West	**4,037,314**			**$85.3 – 140.6**

*Costs shown are in 2018 dollar amounts and include loading and unloading trucks and delivery to site. All costs were calculated using average 26.40 $/CY/HR with trucks traveling at 45 mph and assume 20% for time delays (traffic, etc.) but do not include contingency.

* $/CY does not include real estate costs for land acquisition.

Compared to Table 33 which, the costs for the Bolivar Peninsula levees in Table 34 area significantly less, primarily due to the decreased trucking distance. This confirms that there could be significant cost savings if land is acquired for excavation rather than using commercial sources. These cost savings are summarized in Table 35.

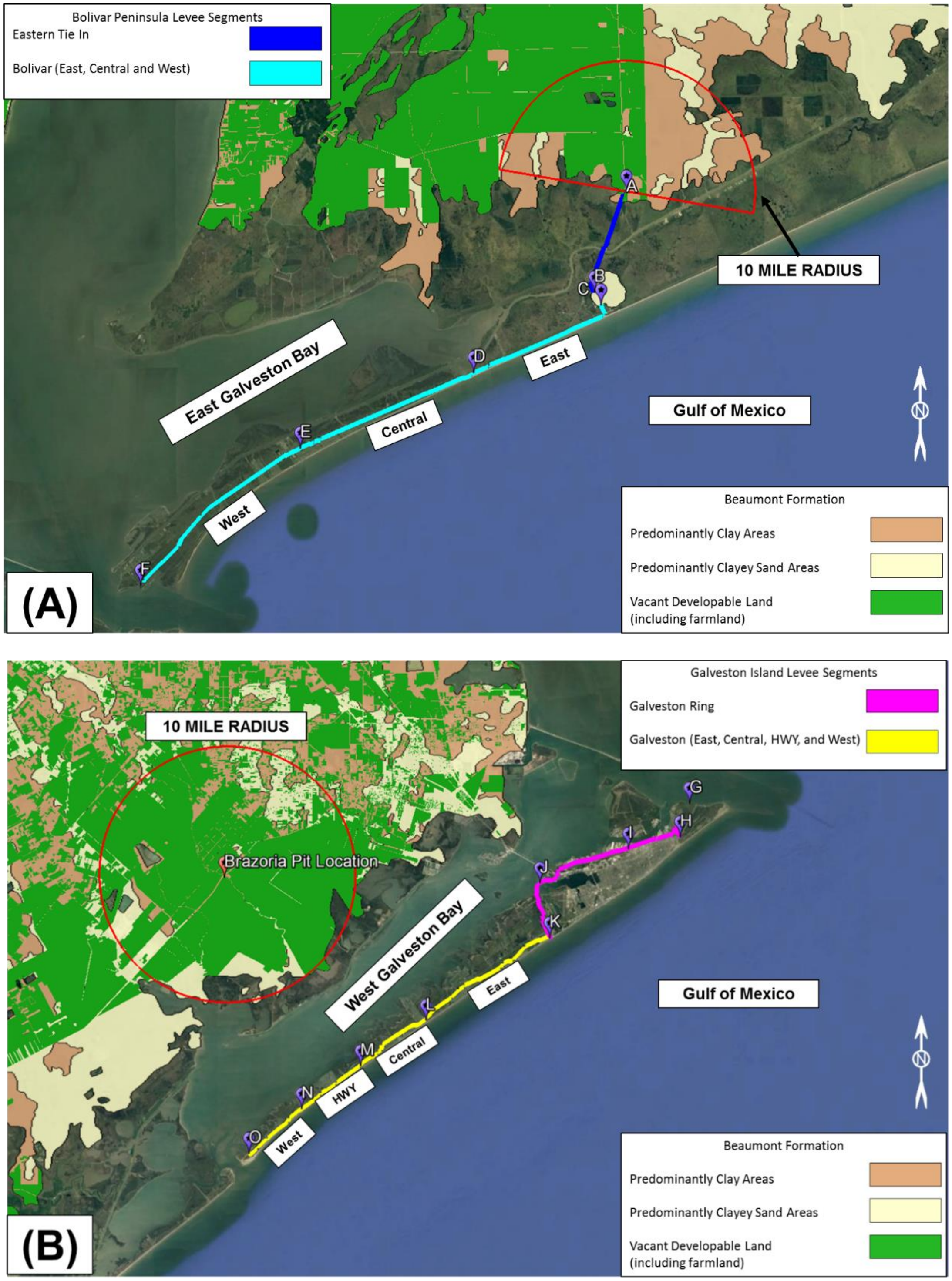


Figure 32. Contractor/Owner sourced locations (A) Bolivar Peninsula (B) Galveston Island

Table 35. Commercially sourced trucking costs vs acquire land sourced trucking costs. Percent change represents the percent cost savings or increase by switching from commercially sourced to acquired land.

Reach	Commercial Source [Million $]	Acquired Land Source [Million $]	% Change in cost
Eastern Tie-In (A to B)	$42.5 – 45.2	$3.7 – 9.4	-79 to -91%
Bolivar East (C to D)	$156.6 – 177.4	$25.1 – 45.1	-75 to -84%
Bolivar Central (D to E)	$139.4 -146.1	$31.7 – 47.4	-68 to -77%
Bolivar West (E to F)	$153.0 – 175.6	$47.9 – 64.1	-69% to 63%
Total Bolivar Peninsula East	**$491.5 – 544.3**	**$108.4 – 166.0**	**-78 to -70%**
Galveston Ring (H to K)	$13.5 – 17.0	$7.3 – 14.4	-15 to -46%
Galveston East (K to L)	$42.3 – 48.7	$23.1 – 41.0	-16 to -45%
Galveston Central (L to M)	$19.7 – 21.0	$11.3 – 18.4	-12 to -43%
Galveston HWY (M to N)	$39.6 – 42.0	$23.8 – 37.0	-12 to -40%
Galveston West (N to O)	$21.0 – 22.1	$19.8 – 29.8	-6% to +35%
Total Galveston Island West	**$136.1 – 150.8**	**$85.3 – 140.6**	**-7 to -37%**

*Costs shown are in 2018 dollar amounts and include loading trucks and delivery to site. All costs were calculated using average 26.40 $/CY/HR with trucks traveling at 45 mph and assume 20% for time delays (traffic, etc.) but do not include contingency.

* $/CY does not include real estate costs for land acquisition.

Table 36 summarizes the estimated trucking transportation durations for material sourced from acquired lands. These calculations were based on the production rate of truck loads per day. Trucking durations are estimated by assuming a production rate to be maintained each day, i.e. 100 truckloads a day to 600 truckloads a day. 100 trucks is approximately the maximum amount of 12 CY trucks which can be loaded in one day (10 hrs) with one excavator with a 3.5 CY bucket, assuming 20% for time delays throughout the day. Therefore, if 600 truckloads a day is the goal production rate, 6 excavators would be required at the excavation site to continually load trucks. For this study, 600 truckloads was selected as the maximum production rates as it was assumed that the maximum feasible number of trucks for a contractor to be able to manage and rent from trucking companies each day would range from 50 – 100 trucks. This assumption was primarily based off experience and engineering judgement and should be evaluated further in future studies.

The amount of trucks required to maintain production rates at each levee location was calculated. The further the distance from a borrow site the more trucks that would be required to maintain a daily production rate. The number of trucks required to maintain a set number of deliveries are graphically represented in Figure 33, Figure 34, Figure 35, and listed in Table 36. In order to maintain a certain production rate, more trucks are needed as the distance from the borrow site increases. Whether the levee sites are constructed simultaneously or if they are constructed sequentially, the contractor would need to maintain a production rate of 600 truckloads per day total, requiring 30 to 100 trucks on site every day depending on the distance, to complete construction within 5 years. There are several logistical issues that need to be evaluated further, such as the feasible maximum number of trucks for a contractor to be able to maintain on a project sites.

Table 36. Estimated trucking transportation durations for material sourced from land acquired in nearby sites based on production rate of truck loads per day

			Maintain Production of 100 truckloads per day		Maintain Production of 200 truckloads per day		Maintain Production of 400 truckloads per day		Maintain Production of 600 truckloads per day	
Reach	Total Truck Loads Required	Max travel distance [miles]	Max # Truck needed for loads per day	Total duration [years]	Max # Truck needed for loads per day	Total duration [years]	Max # Truck needed for loads per day	Total duration for segment	Max # Truck needed for loads per day	Total duration [years]
Eastern Tie-In	64,733	15	6	1.80	11	0.90	22	0.40	33	0.30
Bolivar East	222,293	23	8	6.10	16	3.00	31	1.50	46	1.00
Bolivar Central	174,705	33	11	4.80	21	2.40	41	1.20	62	0.80
Bolivar West	182,956	43	14	5.00	27	2.50	53	1.30	79	0.80
Total Bolivar Peninsula East	**664,687**			**17.7**		**8.8**		**4.4**		**2.9**
Galveston Ring Levee	42,976	39	12	1.20	24	0.60	48	0.30	72	0.20
Galveston East	107,088	46	14	2.90	28	1.50	56	0.70	83	0.50
Galveston Central	43,207	50	15	1.20	30	0.60	60	0.30	90	0.20
Galveston HWY	81,496	53	16	2.20	32	1.10	64	0.60	96	0.40
Galveston West	61,678	57	17	1.70	34	0.80	68	0.40	102	0.30
Total Galveston Island West	**336,445**			**8.0**		**4.0**		**2.0**		**1.4**

*Maximum travel distance is from furthest point on 10 mile radius to furthest point along levee reach

*Duration time only accounts for time to load material into trucks and to truck the material to the levee sites. It does not include real estate time for acquiring land and time to construct the levees.

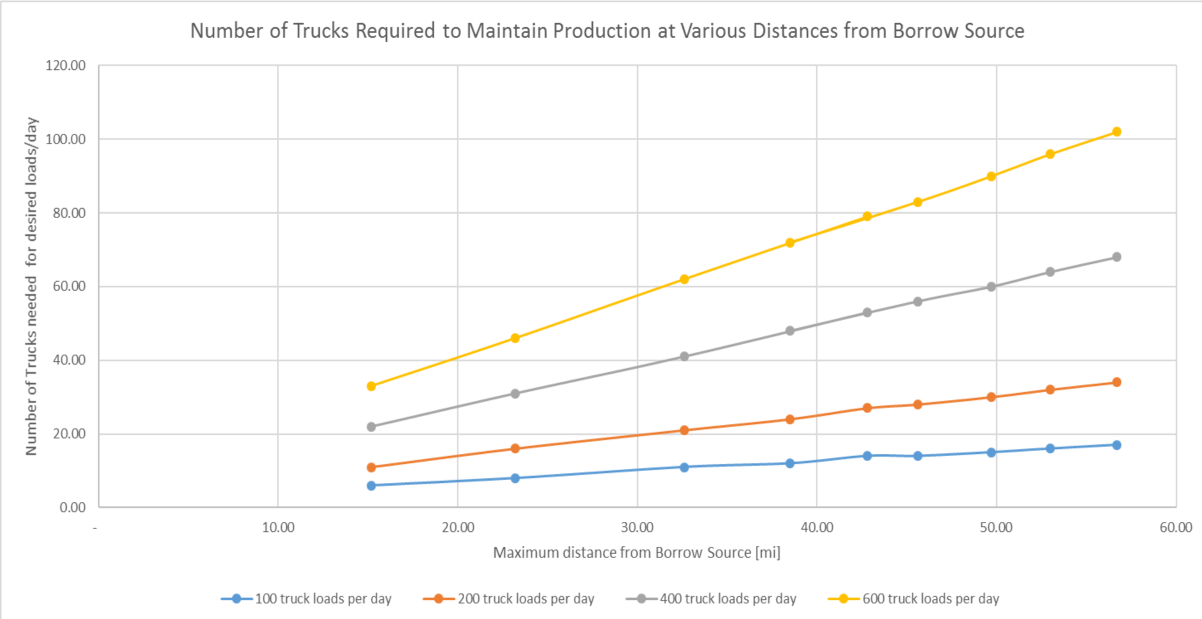


Figure 33. Number of trucks required to maintain truckload production rates vs distance from borrow source location

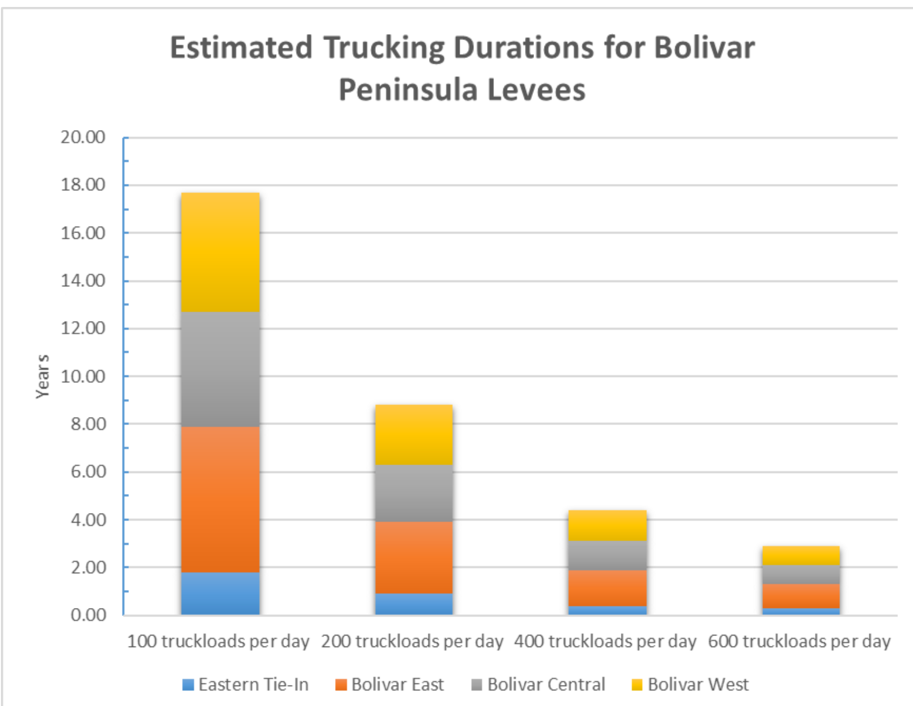


Figure 34. Estimated trucking durations for Bolivar Peninsula levees with varying truckload productions per day

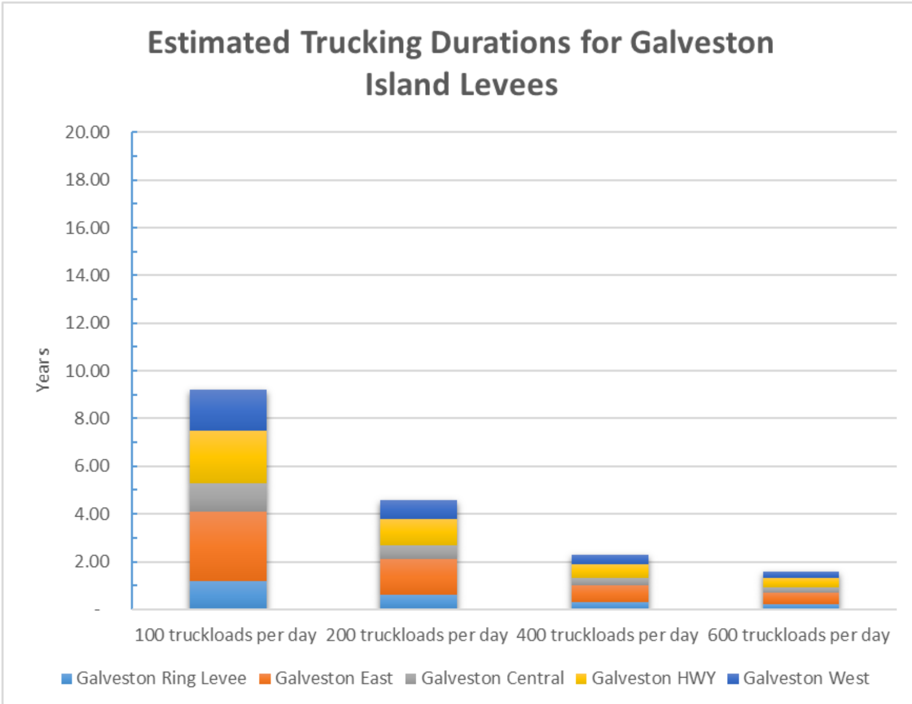


Figure 35. Estimated trucking durations for Galveston Island levees with varying truckload productions per day

4.1.2.2 Barging Transportation

As mentioned previously, if a contractor is able to source material from land that they acquire, they may be able to and source land near locations where barging material to the project site is possible. This section investigates this potential cost savings scenario.

If barging is considered, the operations would need to consider sourcing material from a borrow site from which to load the trucks. Ideally the acquired material source site nearby barge loading site. The material would have to be trucked to the barge loading site, loaded on to barges, towed to the barge offloading sites, offloaded from the barges, and trucked to the final destination along the levees. The difficulty in barging involves finding barge loading and offloading sites that minimize trucking distance to and from where the material is sourced and where the material is delivered along the levee. Figure 36 displays the barge loading and unloading sites assumed for this study. Two sites were assessed as potential barge loading sites, one near where FM 2004 crosses Chocolate Bayou as one of the commercial source providers mentioned this as a site they have delivered material to before for barging (Durwood Flora, Personal Communication, May 18, 2018), and the second near High Island Bridge as aerials show a small unimproved wharfage directly west of the bridge which barges appear to access in historical aerials. For this study it was also assumed that along the GIWW and the Bolivar Peninsula, several barge offloading sites would be possible. However, only one offloading site at the entrance of Offatt's Bayou was located as a possibility for barge offloading near Galveston Island. Barge offloading sites along Galveston Island limited due to the shallow water in West Galveston Bay. Therefore, several offloading sites along the bayside of Galveston Island are infeasible unless tow routes were dredged through the bay.

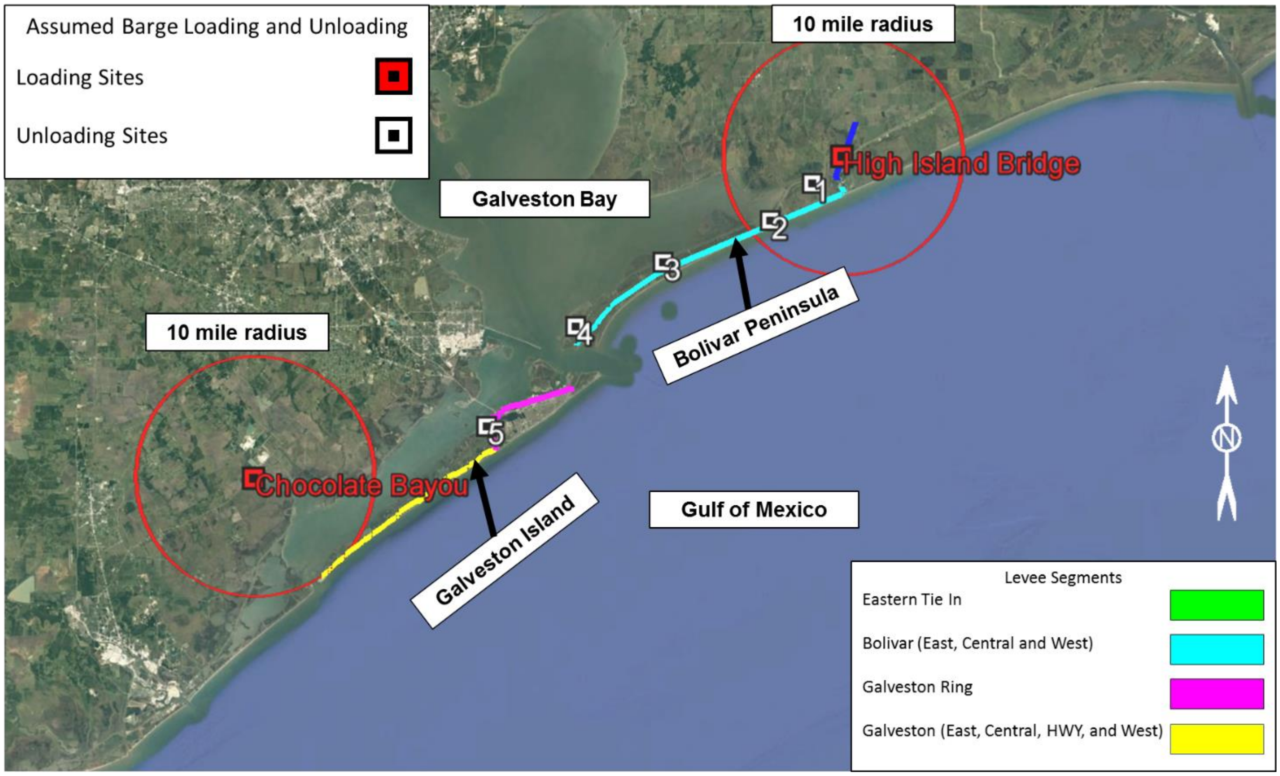


Figure 36. Assumed barge loading and offloading locations along

The parameters used to estimate barging operation costs and durations at each stage in the cycle are summarized in Table 37.

Table 37. Barge cycle operations

Load trucks and truck to barge loading sites	Load barges and tow to unloading site	Towing barges to and from sites	Offload barges	Truck material to final levee site
• Assume borrow site within 10 miles of loading area • Material can be stockpiled at site • 20 trucks (approx. 12 CY loads) • 3 excavators (3.5 CY bucket) • One bull dozer	• Six barges total • 55 ft by 250 ft barges • 35 ft by 195 ft barges • Each barge averages 945 tons each • Three excavators (3.5 CY buckets) • One bull dozer	• One 1,200 – 1,500 HP tug • Assume barges and tugs working 24 hours/day • 6 kts (heavy) • 7.5 kts (light)	• Three excavators (3.5 CY buckets) • One long reach • One bull dozer • Assumed material can be stockpiled at site	• 20 trucks (approx. 12 CY loads) • 1 excavator (3.5 CY bucket) to load trucks • Assume most trucking time occurs during other barge loading/unloading/ and sail

Two barging scenarios were considered: barging all material from the Chocolate Bayou loading site and barging all material from High Island Bridge loading site. The costs and durations for these scenarios as summarized in Table 38 and

Table 39. For most of the levee segments, if 20 trucks are used for loading and offloading, all of the time to truck material to and from the barge loading and offloading sites is able to occur during the barge loading, unloading, and sail cycle times. This is the case even if the barges and tugs work 24-hour days while the trucks work 10 hour days. Therefore, trucking distance from material source site to the loading site and from the offloading site to the levee reach largely do not influence the unit costs. The only segment where this was not the case was Galveston West, which has the longest trucking distance to the levee once material is offloaded from the barges. The time to truck all the material to the levee in Galveston West is slightly longer than the total barging cycle times when the barges were sailing from Chocolate Bayou and thus the unit cost slightly increases towards the end of the levee in this scenario.

Table 38. Barging from Chocolate Bayou

Reach	Levee Quantity [CY]	Offloading Site	Tow distance [NM]	$/CY	Total (Million $)	Years
Eastern Tie-In	776,790	High Island Bridge	52	$42.9	$33.3	0.9
Bolivar East	2,667,510	1 & 2	48 - 52	$39.3 - 41.1	$104.8 - 109.6	2.9
Bolivar Central	2,096,449	2 & 3	40 - 48	$36.7 - 39.3	$74.8 – 82.3	2.1
Bolivar West	2,195,467	3 & 4	32 - 40	$32.0 – 35.7	$70.3 – 78.3	2.0
Total Bolivar Peninsula East	**7,736,216**				**$283.1 – 303.5**	**8.0**
Galveston Ring Levee	515,707	5	21	$27.1	$14.0	0.4
Galveston East	1,285,054	5	21	$27.1	$34.9	0.9
Galveston Central	518,476	5	21	$27.1	$14.1	0.4
Galveston HWY	977,948	5	21	$27.1	$26.5	0.7
Galveston West	740,129	5	21	$27.1 – 28.1	$20.1 – 20.8	0.5
Total Galveston Island West	**4,037,314**				**$109.6 – 110.3**	**3.0**

*Costs shown are in 2018 dollar amounts and only include costs for equipment and labor for barge cycle operations assumed in Table 30, they do not include actual construction of the levees of the additional equipment required for construction.

* $/CY does not include real estate costs for land acquisition.

Table 39. Barging from High Island Bridge

Reach	Levee Quantity [CY]	Offloading Site	Tow distance [NM]	$/CY	Total (Million $)	Years
Eastern Tie-In	776,790			N/A		
Bolivar East	2,667,510	1 & 2	3.4 – 7.7	$19.1 – 21.0	$50.9 – 56.0	1.5
Bolivar Central	2,096,449	2 & 3	7.7 - 16	$21.0 – 24.8	$44.0 – 51.9	1.3
Bolivar West	2,195,467	3 & 4	16 - 24	$24.8 – 28.4	$54.4 – 62.3	1.6
Total Bolivar Peninsula East	**7,736,216**				**$149.3 - 177.6**	**4.4**

Reach	Levee Quantity [CY]	Offloading Site	Tow distance [NM]	$/CY	Total (Million $)	Years
Galveston Ring Levee	515,707	5	35.6	$33.7	$17.4	0.5
Galveston East	1,285,054	5	35.6	$33.7	$43.2	1.2
Galveston Central	518,476	5	35.6	$33.7	$17.4	0.5
Galveston HWY	977,948	5	35.6	$33.7	$32.9	0.9
Galveston West	740,129	5	35.6	$33.7	$24.9	0.7
Total Galveston Island West	**4,037,314**				**$135.8**	**3.7**

* Costs shown are in 2018 dollar amounts and only include costs for equipment and labor for barge cycle operations assumed in Table 30, they do not include actual construction of the levees of the additional equipment required for construction.
* $/CY and duration times do not include real estate costs and time for land acquisition.
*Costs and time do not include Eastern Tie-In. Trucking from barge site to Eastern Tie-In would be more cost effective

4.1.3 Summary of Source Scenarios

Table 40 compares the total costs for each of the sourcing and transportation scenarios. In all cases, the commercial sources have the highest estimated costs. This, compounded with the fact that sourcing from commercial source would require coordination from multiple sources and sites run managed by different companies, strengthen the case for acquiring land for borrow sources rather than relying on commercial sources. For the scenarios assuming the material would be sourced from acquired land, the trucking and barging costs with the shortest sail distance have reasonably similar costs and should also be compared for estimated duration times as shown in Figure 37 and Figure 38.

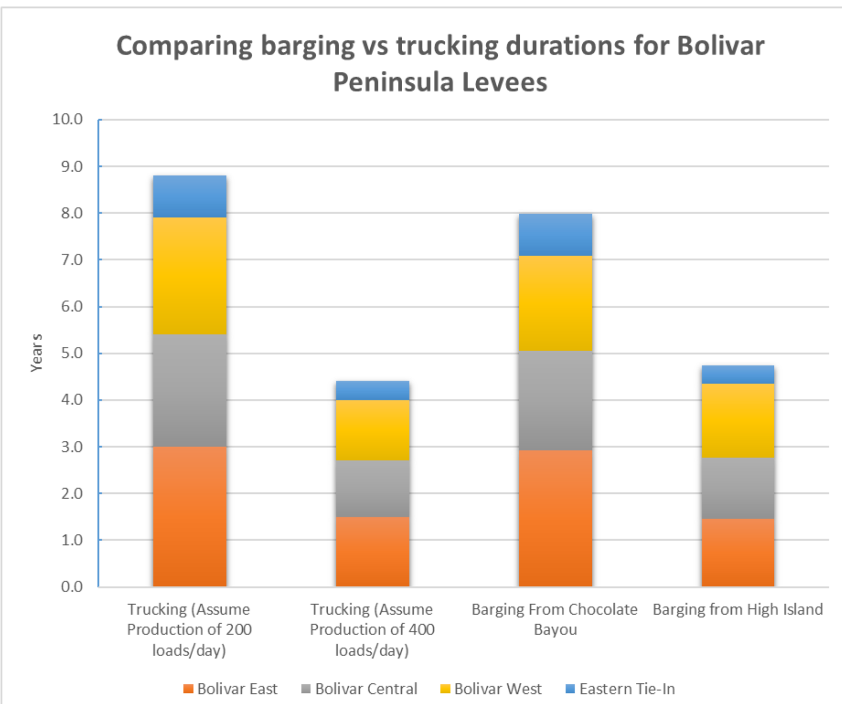
Table 40. Comparison of CSRM Alternative A borrow source conceptual costs

	Commercial Borrow Source	Borrow Source Through Land Acquisition		
Reach	Trucking [Million $]	Trucking [Million $]	Barging from Chocolate Bayou [Million $]	Barging from High Island Bridge [Million $]
Eastern Tie-In	$42.5 – 45.2	$3.7 – 9.4	$33.3	N/A
Bolivar East	$156.6 – 177.4	$25.1 – 45.1	$104.8 - 109.6	$50.9 – 56.0
Bolivar Central	$139.4 -146.1	$31.7 – 47.4	$74.8 – 82.3	$44.0 – 51.9
Bolivar West	$153.0 – 175.6	$47.9 – 64.1	$70.3 – 78.3	$54.4 – 62.3

	Commercial Borrow Source	Borrow Source Through Land Acquisition		
Total Bolivar Peninsula East	**$491.5 – 544.3**	**$108.4 – 166.0**	**$283.1 – 303.5**	**$149.3 - 177.6**
Galveston Ring Levee	$13.5 – 17.0	$7.3 – 14.4	$14.0	$17.4
Galveston East	$42.3 – 48.7	$23.1 – 41.0	$34.9	$43.2
Galveston Central	$19.7 – 21.0	$11.3 – 18.4	$14.1	$17.4
Galveston HWY	$39.6 – 42.0	$23.8 – 37.0	$26.5	$32.9
Galveston West	$21.0 – 22.1	$19.8 – 29.8	$20.1 – 20.8	$24.9
Total Galveston Island West	**$136.1 – 150.8**	**$85.3 – 140.6**	**$109.6 – 110.3**	**$135.8**

* Costs shown are in 2018 dollar amounts and only include costs transporting the material to the sites, they do not include actual construction of the levees of the additional equipment required for construction.

* $/CY does not include real estate costs for land acquisition.



Note: Barging cost not calculated for Eastern Tie-In Barging from High Island. Time used in graphs is Trucking cost assuming a production rate of 400 trucks per day.

Figure 37. Comparing barging vs trucking durations for Borrow Source Through Land Acquisition scenarios for Bolivar Peninsula Levees

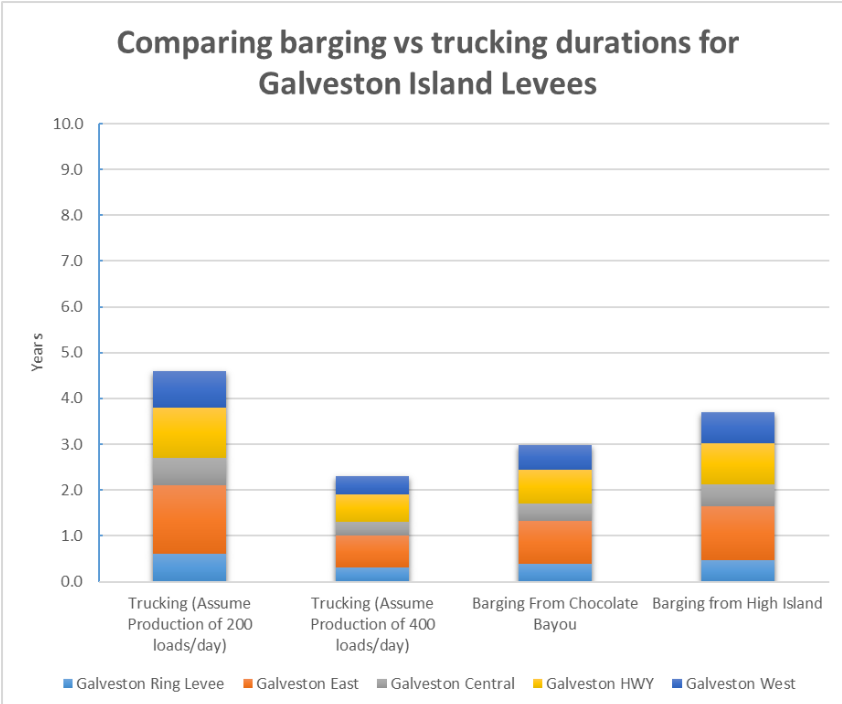


Figure 38. Comparing barging vs trucking durations for Borrow Source Through Land Acquisition scenarios for Galveston Island Levees

The figures show that the barging durations for the scenarios with the shortest sail times are similar to trucking if a contractor is able to maintain 400 truckloads per day. It will likely be up to the contractor whether or not they will barge or truck material to the sites, but it depends mostly on the locations of the barge loading and unloading sites and if the approximate locations and distances in this study are feasible. The advantages and disadvantages of the different scenarios are summarized below:

Table 41. Advantages and Disadvantages of CSRM Alternative A potential clay material sources

	Advantages	Disadvantages	Future Considerations
Commercial Sources	• Borrow site management and land acquisition would not be required.	• Multiple borrow sources run by multiple companies would be required. • Commercial sources may be resistant to supplying quantities required if it will exhaust their pits. • Lack of commercial sources in Chambers County to provides material to the Bolivar Peninsula resulting in high trucking costs. • Trucking duration is highly dependent on the amount of trucks available on site for transport. If there is a trucking shortage, duration of the project could increase substantially.	• Consider coordination with City of Houston on use of material from future large capital improvement projects.
Contractor Sourced Through Land Acquisition	• Potential to acquire land close to the project sites mitigating transportation costs. • Could potentially allow for trucking or barging to be options for transporting materials to the sites.	• Would require lead-time for real estate acquisition in project schedule. • Costs of Land Acquisition are unknown and will increase the estimates shown here. • Barge loading and unloading sites may be limited. • Trucking duration is highly dependent on the amount of trucks available on site for transport. If there is a trucking shortage, duration of the project could increase substantially.	• Further research and analysis should be performed to narrow down preferred land acquisition areas. • Further research should be performed on real estate land acquisition costs and time.

4.2 ER Measure G-5

Ecosystem restoration measure G-5 consists of placing beach quality borrow material along the western Bolivar Peninsula and west Galveston Island for beach and dune restoration. Approximately 39.4 and 27.5 million cubic yards of sand would be placed along Bolivar and West Galveston Island respectively for the initial beach re-nourishment (USACE, Personal Comm. Ecosystem Restoration Sediment Volume Required, 2018). An additional 3.6 and 1.9 million cubic yards of sand would be placed every 10 years after the initial nourishment along Bolivar and West Galveston Island respectively.

4.2.1 Heald and Sabine Banks

Currently, the only verified sources of material vast enough to meet this demand for sand are the Heald and Sabine Banks with an estimated 28 and 169 million cubic yards available, respectively. See Section 3.1 for further discussion of how these volume estimates were compiled.

Due to the quantity of material required for the Bolivar Peninsula portion of G-5, the Heald bank was not considered as a viable source, as the current estimate indicates that sufficient material is not available at these banks to meet the demand. While more material may be available in the Heald Bank, the material would still be better utilized for other areas such as West Galveston Island and Follett's Island which are much farther west. The Sabine bank has an ample quantity of material available, and scenarios considering it as a borrow source for both portions of G-5 were considered in this analysis. The distances from the Heald and Sabine banks to the G-5 placement areas and the Galveston Bay entrance are shown in Figure 39.

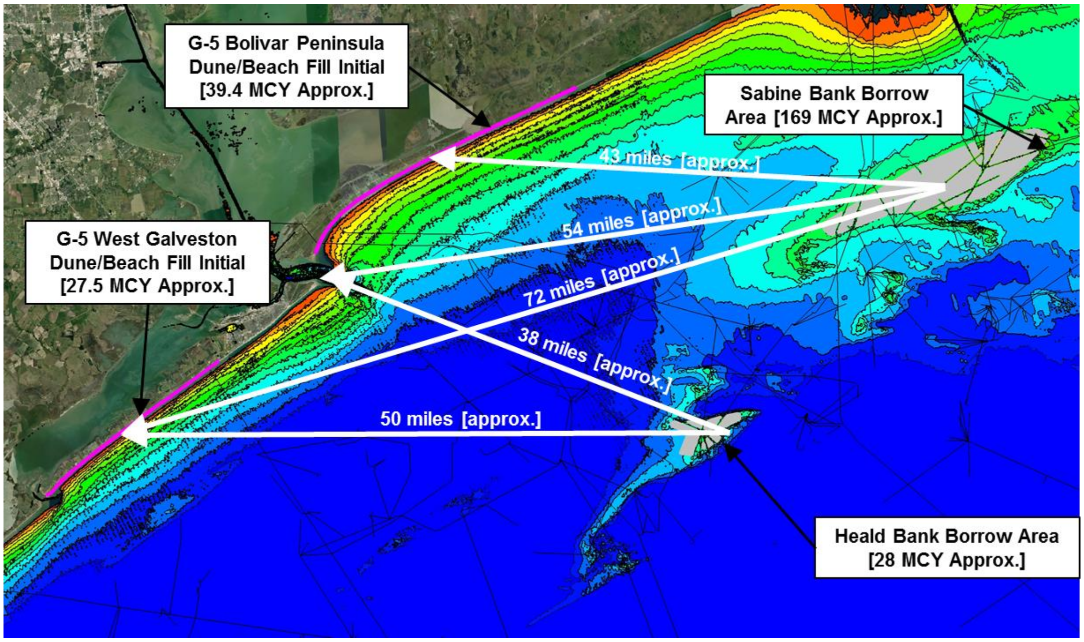


Figure 39. Heald and Sabine Bank distances to G-5 placement areas.

4.2.1.1 Hopper Dredge Scenarios

In order to estimate the costs for these projects, assumptions regarding the methodology for harvest, transport, and placement of the material must be made. Upon further review and research, it was determined that trailing suction hopper dredges are the most viable option for dredging, transporting, and placement of the material. Using these dredges, the material is pumped into the dredge from the harvest site and transported to the site. At the site, the material is pumped from the dredge to the shoreline using the necessary pipeline and booster pumps. For this estimate, the dredge parameters shown in Table 42 were used. These were based on some of the currently largest available trailing suction hopper dredges in the United States

Table 42: Trailing Suction Hopper Dredge Parameters.

Type:	Trailing Suction Hopper Dredge
Hopper Capacity	14,800 CY
Loaded Draft:	30'
Suction Diameter:	2@36"
Discharge Diameter:	34"
Dredge Pump Power:	10,000 HP
Estimated Speed:	14 Knots

Once the dredge was selected, scenarios for the dredging, transport, and placement of the material were developed. Several scenarios were developed for both the Bolivar and West Galveston portions of this project. The scenarios were developed based on discussions with dredging contractors and engineering judgement based on previous experience with harvesting and beach nourishment projects in the Gulf of Mexico. For Bolivar, only dredging material from the Sabine Bank was considered due to the total volume requirement and the closer proximity to the project site. For West Galveston Island both the Heald and Sabine banks were considered in the development of scenarios. In addition to the borrow sources, the placement locations were assessed for both locations. Two main placement options were considered for both West Galveston and Bolivar; offloading material at the Galveston Bay entrance and pumping it to the desired location via pipeline and offloading the material via offshore pipeline adjacent to the placement areas.

Table 43: Approximate distances from borrow sources.

G-5

Location	Distance to Sabine Bank [mi]	Distance to Heald Bank [mi]
Bolivar Peninsula	43 miles	35 miles
West Galveston Island	72 miles	38 miles
Galveston Bay Entrance	54 miles	50 miles

Galveston bay offloading was considered as an option to reduce potential downtime at the offloading site due to waves and would involve the dredge connecting to a pipeline at the Galveston bay entrance and pumping the material to the project location. Although there would be minimum downtime at the entrance as it is protected from waves, the total pumping distance would be much greater than the shore offloading option. Therefore, offloading in Galveston Bay was not considered a viable option and removed from consideration. As the pumping distance increases, additional booster pumps may be required, increasing the cost of this option. Figure 40 and Figure 41 show the approximate layout and pipeline lengths for the bay entrance scenarios for Bolivar and West Galveston respectively. For this pump out scenario it is assumed that one pump out location would be used, and the shore pipeline would be extended as necessary to build the beach eastward from the western edge of the beach fill template.

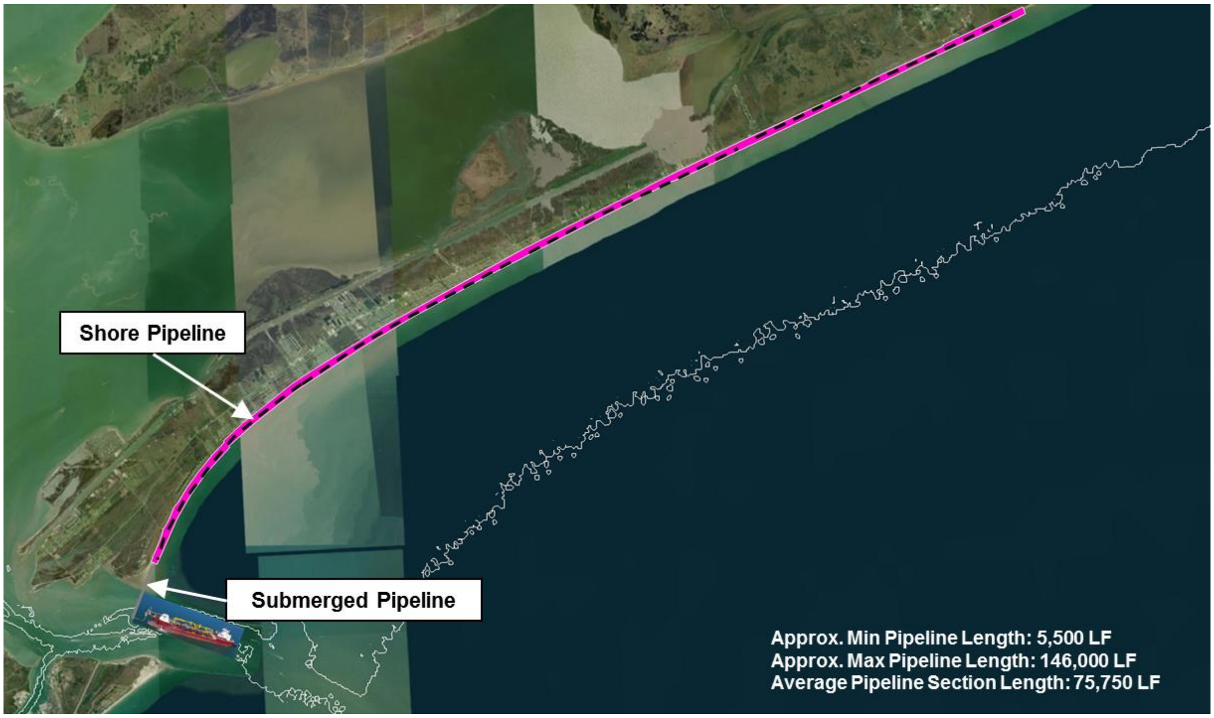


Figure 40. Bolivar bay entrance offload

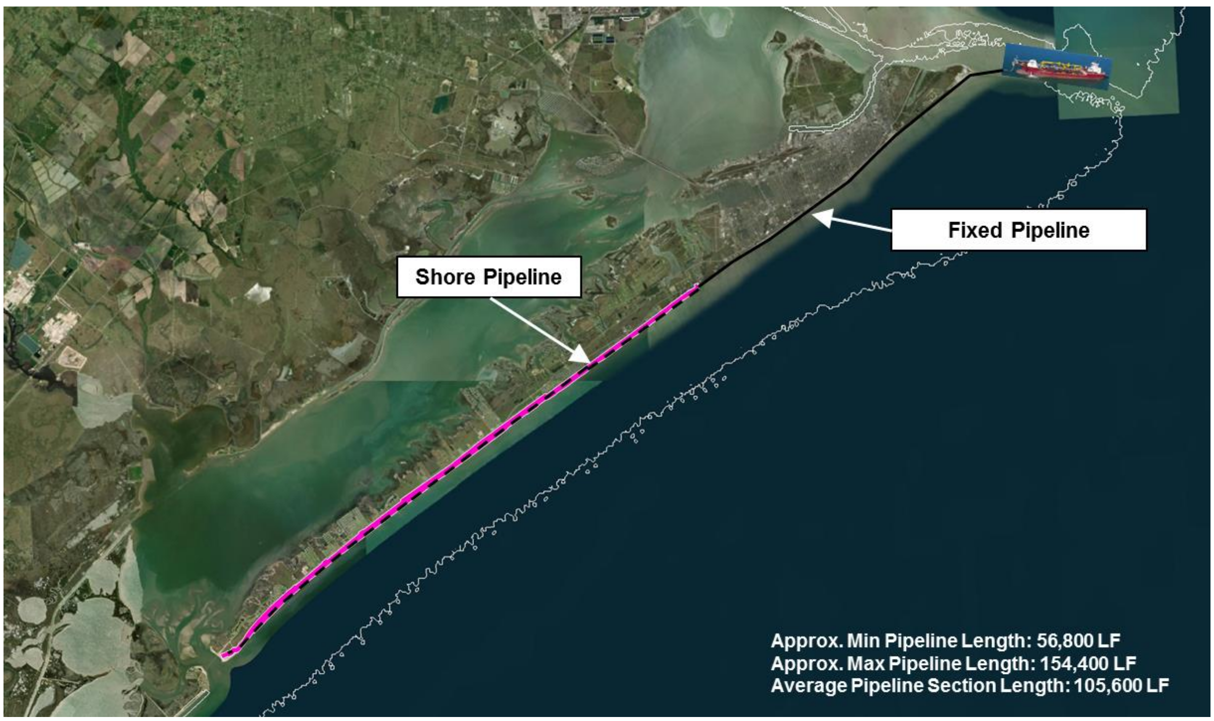


Figure 41. West Galveston bay entrance offload.

Shore offloading would involve the dredge reaching an area adjacent to the placement location and connecting to a submerged pipeline leading to the placement site. The length of submerged pipeline would be dictated by the draft of the dredge and the bathymetry offshore. It is estimated that for the hopper dredge considered the minimum depth at the pipeline location would need to be 36' to account for the draft of the dredge (30') and allowing for an under keel clearance of 6' to accommodate at least 2' of clearance in the trough of 3-4' waves. For the offshore placement option, the placement sites were divided into four equal sections to reduce the total pumping distance for the dredge. The placement area could be divided further as necessary, but this would depend on the amount of pipeline and boosters available to the contractor and how quickly they could relocate the pipeline. This offloading scenario assumes multiple pumpout locations. The shore pipeline would be extended as necessary to build the beach fill template.

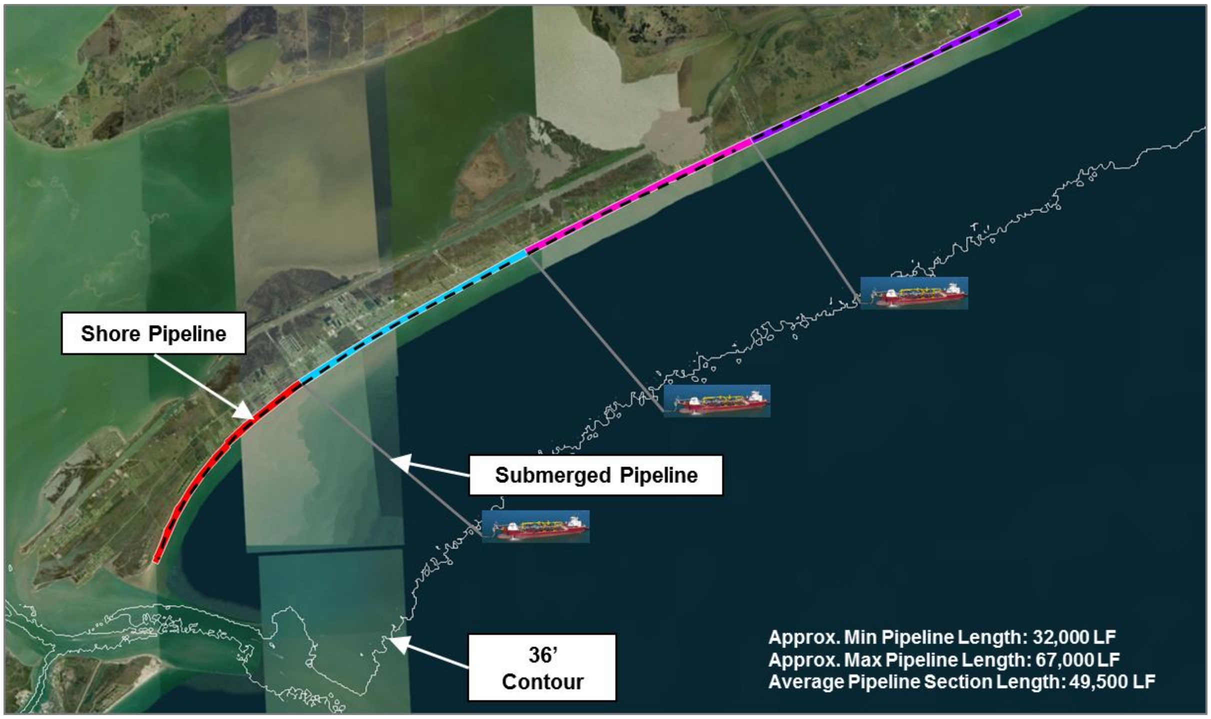


Figure 42. Bolivar shore offload. Dredge images represent assumed offload locations. Grey lines show submerged pipeline, and black dashed lines represent the necessary shore pipeline lengths.

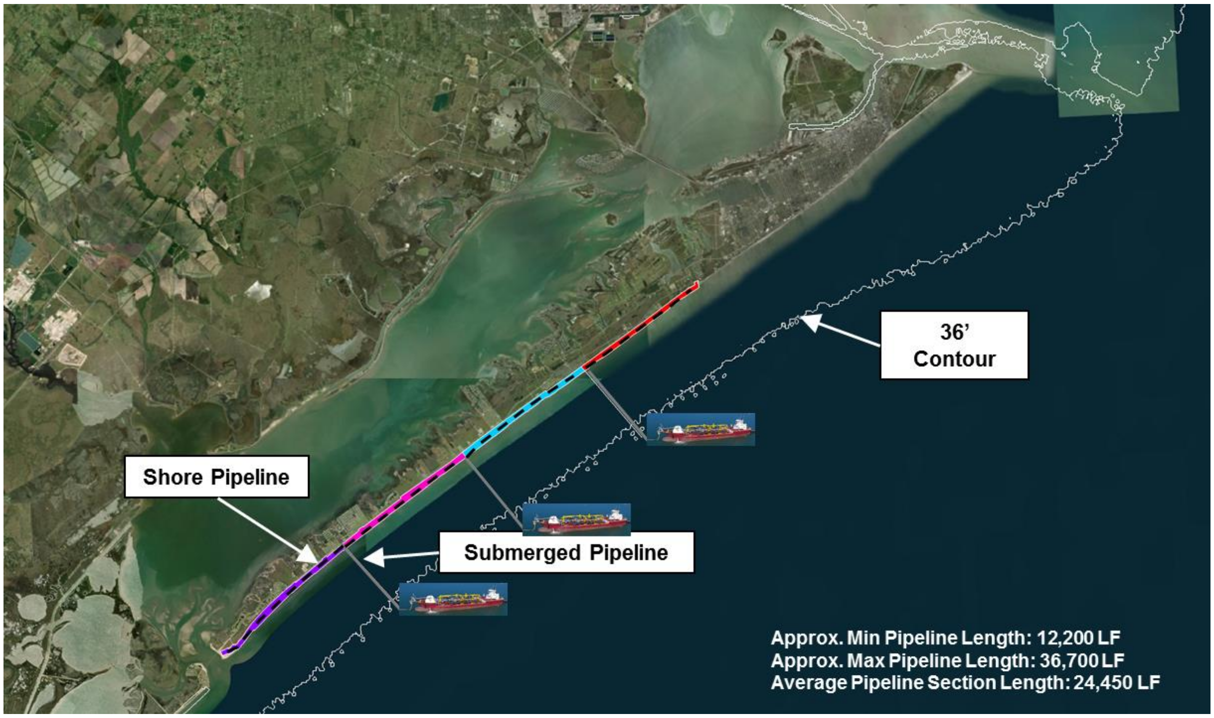


Figure 43. West Galveston shore offload. Dredge images represent assumed offload locations. Grey lines show submerged pipeline, and black dashed lines represent the necessary shore pipeline lengths.

Using the scenarios described previously, the parameters listed in Table 44 were determined to be the driving factors behind the dredging costs for this alternative. The amount of shore pipeline used, and the haul distance had the most significant impacts to the cost as they directly impact the efficiency of the dredge operations. Preliminary costs were developed for comparison purposes between the different scenarios and are shown in Table 44. Other factors which impact the cost such as downtime were also considered.

Estimates for weather downtime at the harvest site and placement location were made based on statistical analysis of historical hind cast wave data at the corresponding locations along the coast. Data was downloaded from the USACE Wave Information Studies (WIS) site, a site which provides a database of wave hindcast data at “virtual” offshore gauges developed using discrete spectral wave models (WIS, 2018). It was assumed that dredging at the harvest site would not occur in wave heights greater than 6’ and offloading operations would not occur in wave heights greater than 3’ at the offloading site. Pump out operations require lower wave heights due to the shallower depths at pump out resulting in reduced under keel clearance. High wave conditions also make connection of the pump out pipeline more difficult.

Table 44: G-5 hopper dredging scenarios and costs

G-5						
	Bolivar Peninsula		**West Galveston Island**			
Scenario Description	Bay Entrance Offload	Shore Offload	Bay Entrance Offload	Bay Entrance Offload	Shore Offload	Shore Offload
Total Fill Volume [MCY]	39.4	39.4	27.5	27.5	27.5	27.5
Borrow Source	Sabine Bank	Sabine Bank	Sabine Bank	Heald Bank	Sabine Bank	Heald Bank
Haul Distance [mi]	54	43	54	38	72	50
Average Pipeline Used [LF]	75,750	49,500	105,600	105,600	24,450	24,450
Average Number of Boosters Required	5	3	6	6	2	2
Weather Downtime [%]	4%	6%	4%	5%	9%	9%
Maintenance and Breakdowns [%]	10%	10%	10%	10%	10%	10%
Effective Working Time [%]	86%	84%	86%	85%	81%	81%
Dredging Unit Cost* [$/CY]	$19-$26	$15-$21	$20-$28	$18-$25	$18-$25	$15-$21
Total Costs* [Millions]	$749-$1025	$591-$827	$550-$770	$495-$688	$495-$688	$413-$578

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools.

The results of the preliminary cost analysis indicate that, for Bolivar peninsula, pumping the material from offshore is more cost effective primarily due to the decreased pumping distance for offloading of the material and also due to the slightly shorter haul distance. A similar trend is observed for the West Galveston portion of the project, where the shore offload scenarios for both the Sabine and Heald bank harvesting were less expensive. Heald bank harvesting would be most cost effective for West Galveston Island as the Heald bank is closer to the project site than the Sabine bank.

In addition to costs, efficiencies were evaluated to determine the approximate time it would take to complete both portions of the project based on the estimated production rates and total volumes to be dredged (Table 45). These estimates are for comparison purposes only and do not include time for mobilization, pipeline relocation, or any other construction aspects that would increase the duration of construction. The estimates assume that a single hopper dredge would perform the work.

Table 45: G-5 hopper dredging scenario durations

G-5						
	Bolivar Peninsula		**West Galveston Island**			
Scenario Description	Bay Entrance Offload	Shore Offload	Bay Entrance Offload	Bay Entrance Offload	Shore Offload	Shore Offload
Borrow Source	Sabine Bank	Sabine Bank	Sabine Bank	Heald Bank	Sabine Bank	Heald Bank
Weather Downtime [%]	4%	6%	4%	5.%	9%	9%
Maintenance and Breakdowns [%]	10%	10%	10%	10%	10%	10%
Effective Working Time [%]	86%	84%	86%	85%	81%	81%
Total Volume [MCY]	39.4	39.4	27.5	27.5	27.5	27.5
Loads Per Day [1 Dredge]	1.6	1.7	1.6	1.9	1.2	1.5
Total Duration [Years]	9	9	7	6	9	7

Table 45 shows similar durations for both dredging scenarios for the Bolivar Peninsula portion of the project with a slightly longer duration for the bay entrance offload scenario. This increased time for the bay entrance scenario is likely due to the reduced pump out efficiency due to the longer pipeline required to transport the material to the project location. For West Galveston island, construction durations are decreased slightly for the bay entrance offload option as the area sees more wave energy at the shoreline than Bolivar Peninsula, the increased down time for the shore offload results in a slightly longer construction duration than the bay entrance offload despite the loss in efficiency from the much longer shore pipeline required. Overall, the construction durations have shown that, to complete the work within a reasonable time frame (1-5 years), additional hopper dredges will be necessary to complete the work in a shorter construction duration. In practice, the G-5 project can be divided into several smaller projects that can be completed simultaneously by several dredging companies to complete the work more efficiently and reduce the construction timeframe.

4.2.1.2 Hydraulic Suction Cutterhead Dredge Scenarios

Based on the distances from the borrow sites, depths, and wave conditions offshore, it was quickly determined that hydraulic dredging using cutter suction dredges with pipelines would not be feasible with the current technology available. The length of pipeline and quantity of booster pumps necessary to pump the material over such vast distances is currently not possible. Therefore, hydraulic dredging would have to utilize scows or hopper barges to transport the material from the banks to the project site. For these scenarios it was assumed that two 30” to 34” hydraulic suction cutterhead dredges would be used. One dredge at the borrow site would dredge the material and pump it into a SCOW which then transports the material and places it just offshore of the project site where another dredge can re-dredge the material and pump it to the project site. For this analysis it was assumed that 6,000 CY split hull SCOWs would be used to transport the material to the site. Larger SCOWs or a collection of barges may be used, but the size and number of SCOWs required depends on the actual production rates of the dredges used.

As was done for the hopper dredge scenarios, the projects were divided into four separate sections to reduce the total quantity of pipeline required to increase the overall efficiency of the operation.

Preliminary costs were developed for comparison purposes between the different scenarios and are shown in Table 46. Other factors which impact the cost such as downtime were also considered. Estimates for weather downtime at the harvest site and placement location were made based on statistical analysis of historical hind cast wave data at the corresponding locations as described previously. Suction cutter head dredges are more limited than hopper dredges as to the wave climates in which they can operate as higher waves cause uncontrollable motions of the dredge which can damage the cutterhead and the dredge ladder. It was assumed that the dredges cannot operate in wave heights greater than 3' at both the harvest and placement locations.

Table 46: G-5 hydraulic suction cutterhead dredging scenarios and costs

G-5			
	Bolivar Peninsula	**West Galveston Island**	
Scenario Description	Shore Offload	Shore Offload	Shore Offload
Total Fill Volume [MCY]	39.4	27.5	27.5
Borrow Source	Sabine Bank	Sabine Bank	Heald Bank
Haul Distance [mi]	54	72	50
Average Pipeline Used [LF]	75,750	24,450	24,450
Number of SCOWs Required	3	4	3
SCOW Capacity [CY]	6,000	6,000	6,000
SCOW Round Trip Travel Time [hrs]	11.5	19.3	13.4
Average Shore Pipeline Used [LF]	24,500	15,950	15,950
Dredging Unit Cost* [$/CY]	$11-$16	$13-$19	$10-$14
Total Costs* [Millions]	$433-$631	$358-$523	$275-$385

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

These preliminary estimates show that hydraulic dredging can potentially be less costly than using existing available hopper dredges assuming the dredges can work nonstop while the material is transported to the project site. For West Galveston Island, harvesting from the Heald Bank is more cost effective as it is closer to the project site than the Sabine Bank.

Construction durations for these scenarios (Table 47) are similar to the hopper dredge scenarios discussed previously. While production rates may be higher for these scenarios than the hopper, as dredging does not cease to transport material to the site, additional downtime is expected for this operation due to waves, maintenance, anchor movement, and breakdowns which impact the total cost. Additional down time can also be expected for repairs of the dredge at the borrow site due to breakdowns as, depending on the severity of the breakdown, the dredge may need to return to port for repairs. There is also a higher risk with this operation as the dredge cannot be transported as quickly to port to avoid an incoming storm.

Table 47: G-5 hydraulic suction cutterhead dredging scenario durations

G-5			
	Bolivar Peninsula	**West Galveston Island**	
Scenario Description	Galveston Bay Entrance Offload	Shore Offload	Shore Offload
Borrow Source	Sabine Bank	Sabine Bank	Heald Bank
Haul Distance [mi]	54	72	50
Weather Downtime [%]	6%	9%	9%
Maintenance, Breakdowns, Dredge moves [%]	34%	34%	34%
Effective Working Time [%]	60%	57%	57%
Total Volume [MCY]	39.4	27.5	27.5
Number of SCOWS Required	3	4	3
Production Rate [CY/hr]	469	280	403
Total Duration [Years]	8	6	6

As with the hopper scenarios, due to the large quantity of material to be dredged, if the project is to be completed within a reasonable time period, several dredges would need to be employed to execute the work.

4.2.2 Shoreface Sediment Sources

As previously discussed, shoreface sediments have been identified as a potential source of sandy material for this alternative. This analysis assumes that dredging of this material will not impact the stability of the adjacent shoreline and that there is sufficient material available within the shoreface for completion of this project. Based on the analysis of shoreface sediment availability, the west Galveston island Shoreface was divided into Eastern and Western portions separated by an existing pipeline as shown in Figure 44. The Bolivar peninsula shoreface was not considered for this analysis as investigation of this area did not show significant quantities of sandy materials available for harvesting at that location.

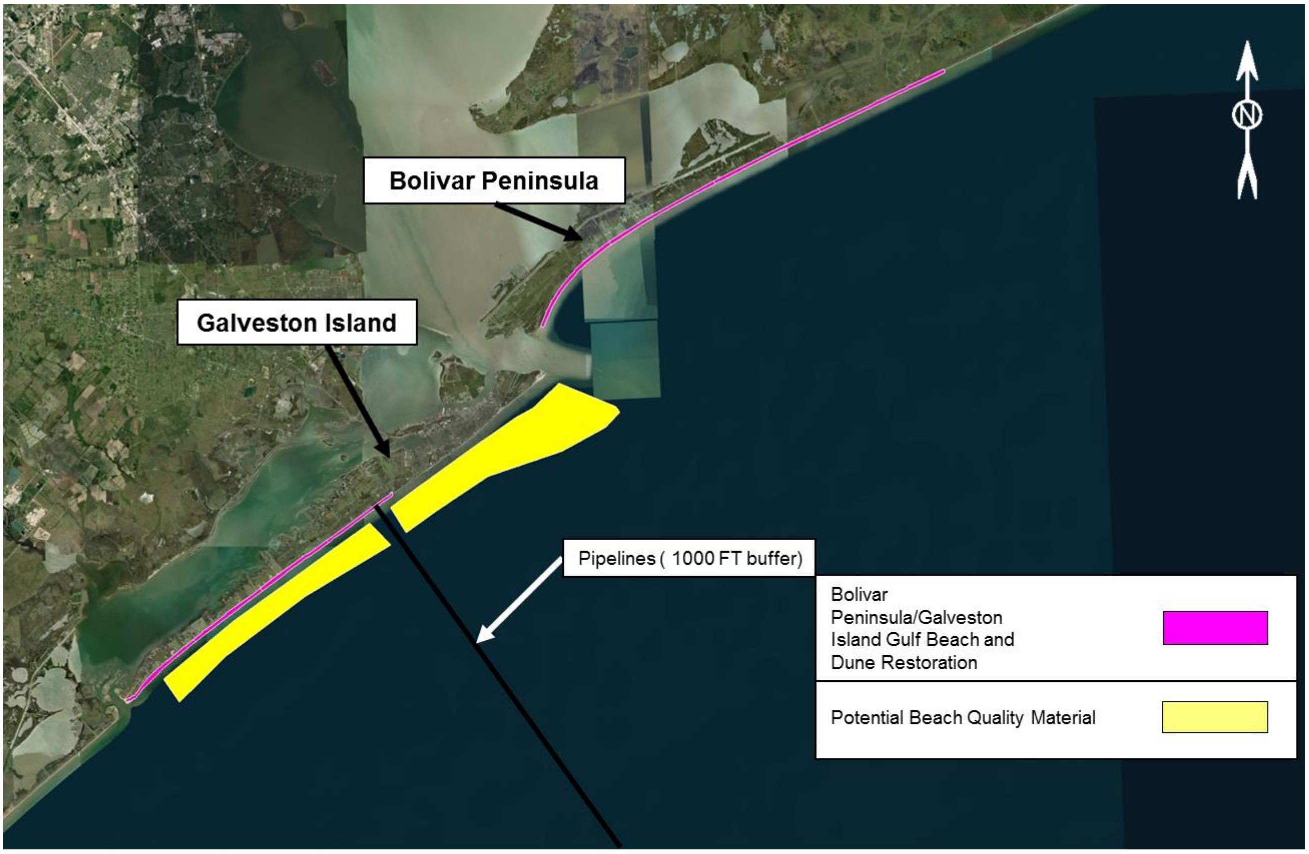


Figure 44 G-5 Shoreface dredging scenarios

Table 48 shows the shoreface dredging scenarios developed for this analysis. These scenarios assume the material is dredged using a 34" hydraulic suction cutterhead dredge to excavate the material and transport it to the site. Hopper dredges were not considered as the close proximity to the project site and shallow water along the shoreface makes cutterhead dredges the more viable option. Only the East Shoreface was considered for Bolivar Peninsula as it is closest to the project site.

Table 48: G-5 Shoreface dredging scenarios and costs

G-5			
	Bolivar Peninsula	**West Galveston Island**	
Scenario Description	East Shoreface Harvesting	West Shoreface Harvesting	East Shoreface Harvesting
Total Fill Volume [MCY]	39.4	27.5	27.5
Borrow Source	Galveston East Shoreface	Galveston West Shoreface	Galveston East Shoreface
Average Pipeline Used [LF]	116,500	25,250	87,000
Average Number of Boosters Required	6	0	4
Weather Downtime [%]	4%	9%	9%
Maintenance and Breakdowns [%]	10%	10%	10%
Effective Working Time [%]	86%	81%	81%
Dredging Unit Cost* [$/CY]	$26-$37	$8-$11	$22-$31
Total Costs* [Millions]	$1025-1458	$220-$303	$605-$853

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

The analysis shows that the driving factor behind the costs for these scenarios are the total pipeline lengths and distances of the borrow source from the project site. The bolivar peninsula portions would be the most expensive portion as the pipeline would have to cross the ship channel and reach several miles to the end of the fill template. West Shoreface harvesting would be the most cost-effective option for the West Galveston portion of the project as it is the closest to the project site.

Table 49: G-5 Shoreface dredging scenario durations

G-5			
	Bolivar Peninsula	**West Galveston Island**	
Scenario Description	East Shoreface Harvesting	West Shoreface Harvesting	East Shoreface Harvesting
Borrow Source	Galveston East Shoreface	Galveston East Shoreface	Galveston East Shoreface
Weather Downtime [%]	4.3%	8.8%	8.8%
Maintenance and Breakdowns [%]	10%	10%	10%
Effective Working Time [%]	85.7%	81.2%	81.2%
Total Volume [MCY]	39.4	27.5	27.5
Production Rate[CY/hr]	481	531	480
Total Duration [Years]	32	11	18

The durations shown in Table 49 indicate that several dredges would be required to complete these projects within a reasonable timeline as the duration is driven by the dredge production rate and total volume to be dredged. This would increase the costs as additional contractors' equipment, and pipeline would need to be mobilized to complete the work. During final design, detailed wave and shoreline morphology modeling should be conducted to determine whether shoreface sediment harvesting could increase erosion.

4.2.3 Summary of Source Scenarios

A summary of all the source scenarios for all of the G-5 ER measure components is provided in Table 50. Note that the costs shown are midpoint of the cost range estimate. It is evident that for Bolivar peninsula, the Sabine bank would be the most cost effective borrow source and hydraulic dredging to scows may be the more cost effective despite the potential increase in weather downtime. This option presents more risk as this type of dredging has not been executed at this scale for such a large quantity and over such long sail distances which could potentially drive the cost up. For the west Galveston portion, dredging from the adjacent shoreface would be the most cost effective option as this area is closes to the project site, but this assumes that the necessary quantities of material are available and can be harvested without any detriment to the shoreline. Additional investigation is necessary to evaluate the feasibility of this option. Further detail regarding the advantages and disadvantages of the different alternatives are shown in Table 51.

Table 50. ER Measure G-5 Conceptual Cost and Duration Source Summary

Source	Dredge Scenario	$/CY	Duration [years]
G-5 Beach and Dune nourishment Bolivar Peninsula			
Sabine Bank	15,000 CY Hopper with bay entrance offload	$22.50	9
Sabine Bank	15,000 CY Hopper with shore offload	$18.00	9
Sabine Bank	34" Hydraulic dredge to scows and shore offload	$13.50	8
Galveston Shoreface	34" Hydraulic dredge with direct pump out	$31.50	32
G-5 Beach and Dune nourishment West Galveston Island			
Sabine Bank	15,000 CY Hopper with bay entrance offload	$24.00	7
Heald Bank	15,000 CY Hopper with bay entrance offload	$21.50	6
Sabine Bank	15,000 CY Hopper with shore offload	$21.50	9
Sabine Bank	15,000 CY Hopper with shore offload	$18.00	7
Sabine Bank	34" Hydraulic dredge to scows and shore offload	$16.00	6
Heald Bank	34" Hydraulic dredge to scows and shore offload	$12.00	6
Galveston Shoreface (west of pipeline)	34" Hydraulic dredge with direct pump out	$9.50	11
Galveston Shoreface (east of pipeline)	34" Hydraulic dredge with direct pump out	$26.50	18

Table 51. Advantages and Disadvantages of ER Measures G-5 material sources

	Advantages	Disadvantages	Future Considerations
Sabine and Heald Banks	• Large quantities of sand available. • Multiple hoppers could be used in Sabine Bank with large dig areas to reduce duration,	• Long sail distances. • Pipeline locations restricting available dredge areas. • Offshore dredging and pump out are susceptible to weather delays. • May be safety concerns with hydraulic dredges loading to scows 30 – 50 miles offshore.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows. • Feasibility of hydraulic dredge working 30-50 miles offshore (future technologies).
Shoreface Sediment Dredging	• Closest sand source. • Lowest cost for West Galveston Island.	• Only hydraulic dredges can be used. Offshore dredging and pump out are susceptible to weather delays. • Shoreface harvesting could negatively impact adjacent beach erosion rates.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows. • Further studies on effects of shoreface excavation on nearshore coastal processes.

4.3 ER Measure G-28

Ecosystem restoration measure consists of initial marsh creation and restoration, out – year marsh creation ad restoration, and island creation and restoration. The measures can be broken out into east and west with the east areas on the Bolivar Peninsula and the West areas along the northern shoreline of the West Galveston Bay.

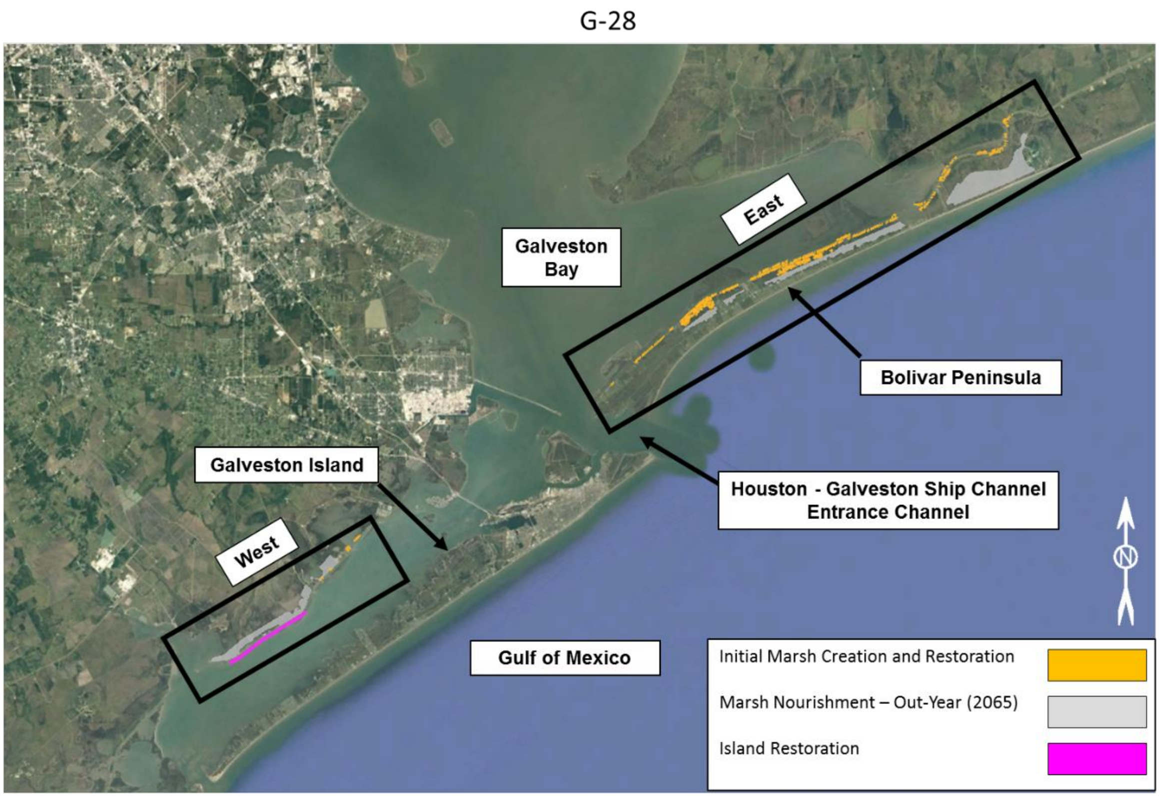


Figure 45. ER Measure G-28 Overview

Table 52. ER Measure G-28 quantities separated by area

Construction Element	Estimated Volumes (CY)			Areas (acres)				
	Total	East	West	Total	East		West	
Initial Marsh Creation and Restoration	482,137	459,265	22,872	664	633	95%	32	5%
Marsh Creation and Restoration (2065 Out-year)	10,117,098	7,273,564	2,843,534	6,891	4954	72%	1,937	28%
Island Creation and Restoration	5,822,917		5,822,917	298			298	100%

4.3.1 Initial Marsh Creation

G-28 has initial marsh areas adjacent to the GIWW along Bolivar Peninsula and the northern shoreline of the West Galveston Bay. The initial marsh creation was separated into different areas as shown in Figure 46.

Figure 46. G-28 Initial Marsh Creation East and West Areas

4.3.1.1 Ship Channel Dredging

Based on the shoaling rates in the GIWW (see Table 17 in Section 3.7.1) maintenance dredging material from one dredging cycle in the GIWW will provide a sufficient supply of material to fill the initial marsh area. As there is sufficient material and maintenance dredging is routinely conducted, sourcing from the GIWW was the only scenario considered for ER measure G-28's initial marsh creation and restoration. In order to estimate the costs, assumptions regarding the methodology for harvest, transport, and placement of the material must be made. It was assumed that 18" - 24" hydraulic suction cutterhead dredges would be used to dredge the marsh restoration material. These dredges are frequently used for the dredging, transporting, and placement of the maintenance material in the GIWW. In channel dredging with a hydraulic cutterhead dredge, the material in pumped directly from the dredge to the placement area. The dredge typically has several hundred feet of floating/pontoon pipe behind it attached to a submerged pipe. The submerged pipe comes up on shore at the placement area where shoreline pipe added as marsh areas are filled. Therefore, when calculating average pipeline lengths, the both addition of pipeline behind the dredge as it moves down a channel and, on the shore, the addition of shoreline as it fills marsh areas were considered.

The acreage of each areas was estimated off aerials and the total volume in each of the areas was calculated based on the percentage of the total area. Average pipelines were then measured by estimating the length of the channel which would need to be dredged to supply the fill volume required in each area. For the purpose of this conceptual cost estimate, it was also assumed that shoaled material in the channel would be evenly distributed. This will not be the case during an actual maintenance dredging event and future studies should evaluate past before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel. It was also assumed that a contractor would try and limit the average pipe to line lengths which would not require a booster dredge, approximately 15,000 LF. The volumes and estimated pipeline lengths used in this study are shown in Table 53.

Preliminary costs were developed for comparison purposes between the different scenarios and are shown in Table 54. Since dredging of the GIWW is routinely conducted, it is possible that this funding could come from the standard GIWW maintenance budget. In addition, advanced maintenance dredging could be conducted if necessary.

Table 53. G-28 Initial Marsh Creation separated by area

Areas	Acres	% of Total	Volume [CY]	Average pipeline [FT]
East	**664**	**100%**	**459,270**	**14,100**
1	1.1	0.2%	740	1,760
2	25	3.8%	17,300	10,100
3	275	41.4%	190,200	14,900
4	275	41.4%	190,200	16,700
5	54	8.1%	32,260	6,025
6	34	5.1%	23,570	2,250
West	**31.5**	**100%**	**22,900**	**4,240**

Table 54. G-28 Initial Marsh Creation Ship Channel Dredging Costs

G-28 Initial Marsh Creation and Restoration			
Scenario Description	**East Areas (Bolivar Peninsula)**	**West Areas (West Galveston Bay)**	**Total**
Total Fill Volume [CY]	459,270	22,900	482,170
Borrow Source	GIWW	GIWW	GIWW
Average Pipeline Used [LF]	14,100	4,250	13,600
Average Number of Boosters Required	0	0	0
Material Classification [%]	90% Mud, 10% Sand	90% Mud, 10% Sand	90% Mud, 10% Sand
Dredging Rate [CY/hr]	1,000	1,200	1,010
Time to Complete Dredging [Months]	3.5 - 5	0.4 – 0.6	3.9 – 5.6
Dredging Unit Cost* [$/CY]	$3.20 – 4.50	$2.00 – 2.80	$2.00 – 4.50
Total Costs* [Millions]	$1.5 - 2.1	$0.05 – 0.06	$1.55 – 2.16

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools.

4.3.2 Out Year 2065 Marsh Creation

G-28 has out-year marsh areas adjacent to the GIWW along Bolivar Peninsula and the northern shoreline of the West Galveston Bay. These are marsh areas that are projected to be restored in 2065. The out-year marsh creation was separated into different areas as shown in Figure 47. The acreage of each areas was estimated off aerials and the total volume in each of the areas was calculated based on the percentage of the total area as shown in Table 55. During future analysis, topography survey should be taken of each area to determine the true breakdown of volumes by area.

Table 55. G-28 Out – year marsh creation separated by area

Areas	Acres	% of Total	Volume [CY]
East	**4,655**	**100%**	**7,273,570**
7	3,110	62.8%	4,567,450
8	1,370	27.7%	2,011,380
9	135	2.7%	196,730
10	340	6.9%	497,710
West	**1,940**	**100%**	**2,843,530**
11	400	20.6%	568,710
12	1,540	79.4%	2,274,820

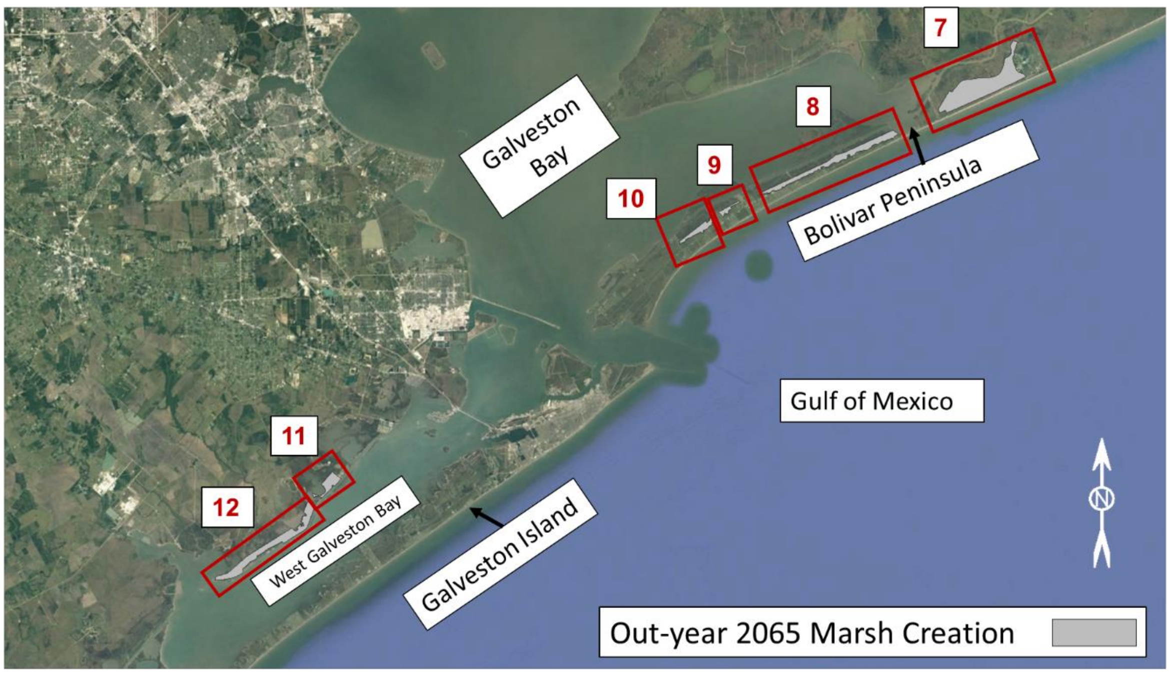


Figure 47. G-28 Out - year 2065 marsh creation and restoration areas

Several sediment sources were identified as potential sources for the east and west out-year marsh areas and they are detailed in the following Sections. The primary constraint for a sediment source were if it contained enough material for to fill the ER measure marsh areas during one construction phase. This eliminated most maintenance dredging channel sources as the maintenance dredging quantities were typically not sufficient to fill entire marsh areas.

4.3.2.1 Shoreface Sediment Dredging

Shoreface sediments were considered as a large source of sediment for fill material. As discussed in Sections 3.2.1 and 3.2.2, the sediment offshore the Bolivar Peninsula and seaward of -30 FT offshore Galveston Island are generally not suitable for use in beach nourishment. Therefore, these areas have millions of cubic yards of material which could be used to fill marshes. The eastern out-year marsh areas are located along the GIWW and landward of the

Bolivar Peninsula beaches while the western out-year marsh areas are located along the GIWW in the north of West Galveston Bay. Two dredging scenarios were considered for the shoreface sediment dredging: offshore dredging with a 34" hydraulic dredge with the dredging pumping out directly to the marsh areas, and dredging with a 15,000 hopper dredge (see Section 4.2.1.1, Table 42) with offshore pump out locations.

This study estimated dredging scenarios with only one dredge working at a time and assumed dredging would be able to occur year-round. In the future studies environmental windows should be taken into consideration for how they might affect dredging durations. In addition, future studies should investigate any negative impacts to shoreline erosion caused by the dredging of shoreface sediments.

Hydraulic Suction Cutterhead Dredge Scenarios

The primary constraint for hydraulic dredges harvesting material from shoreface sediment areas is the exposure to offshore waves. Generally hydraulic dredges have difficulty working in waves greater than 3 – 4 FT, however several U.S. dredging companies have experience safely dredging offshore with hydraulic dredges. In the costs estimated in Table 56, it is assumed hydraulic dredges working dredging offshore of the Bolivar Peninsula will have a slightly higher effective work time due to less weather delays. The same weather delays calculated with WIS data for the Bolivar Peninsula and Galveston Island offshore pump out scenarios for G-5 were used for the offshore pump outs for ER measure G-28. The effective work time also includes estimated loss in time due to moving the dredge, shutting down the dredge to add pipe at the shore, and to perform maintenance. In addition to the length of the submerged pipeline, the maximum amount of pipe which would need to be added behind the hydraulic dredge in the dig area to reach the furthest reaches, and the maximum shoreline were also included the average pipeline calculation for each marsh area.

Along the Bolivar Peninsula, it was estimated that four submerged sublines would be used to pump material in each eastern out-year marsh creation area (Figure 49). The estimated dredge dig areas were placed within the boundaries of the boring locations shown in Section 3.2.1, Figure 5 and production rates were calculated assuming an estimated dig face as calculated in Table 4. This study did not take into account the potential effects of removing large amounts of shoreface sediment on the coastal processes of the adjacent shoreline. These effects should be examined in further studies.

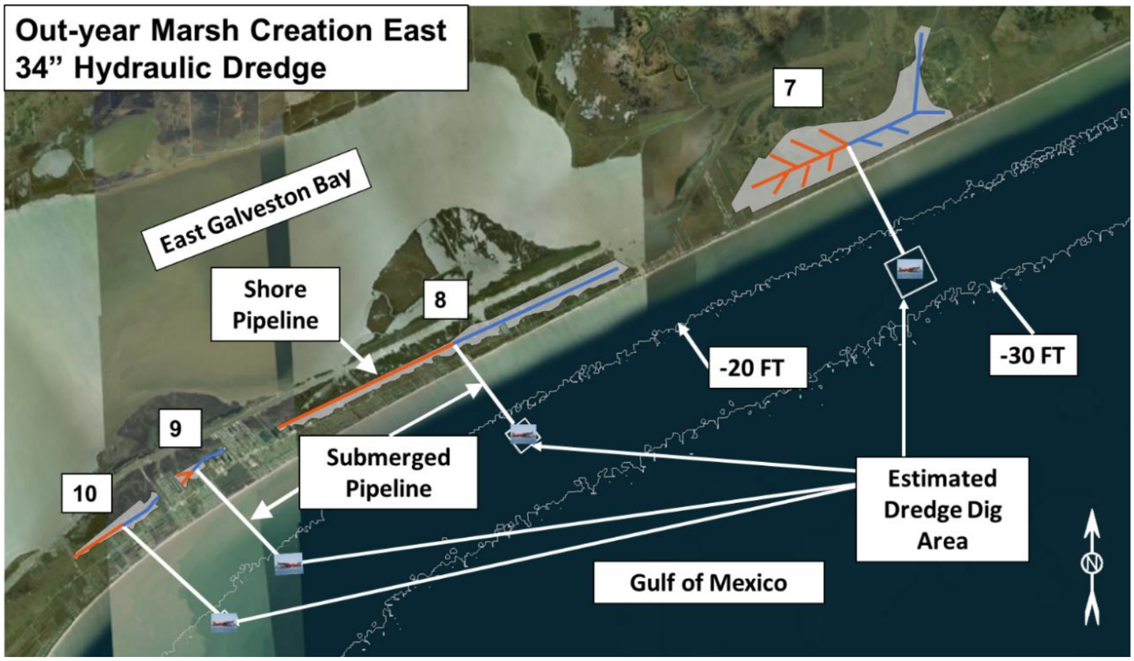


Figure 48. G-28 out-year marsh creation east – Shoreface sediment Hydraulic dredging Bolivar Peninsula

Pumping material from the Galveston Island shoreface to the out-year marsh creation west areas would require a submerged pipe to cross the West Galveston Bay and GIWW, requiring multiple boosters and pipeline elevation changes. Two submerged pipeline scenarios were considered, the first with the pipeline crossing Galveston Island, which would be the shortest length but would require installing the pipeline underneath the highway and could impact private properties, and the second with the pipeline running through San Luis Pass. It was assumed shoreface dredging for the marshes would occur seaward of the -30 FT contour to avoid areas with potential beach quality sand. See Section 3.2 for a full description of the sediment composition of all shoreface sediments.

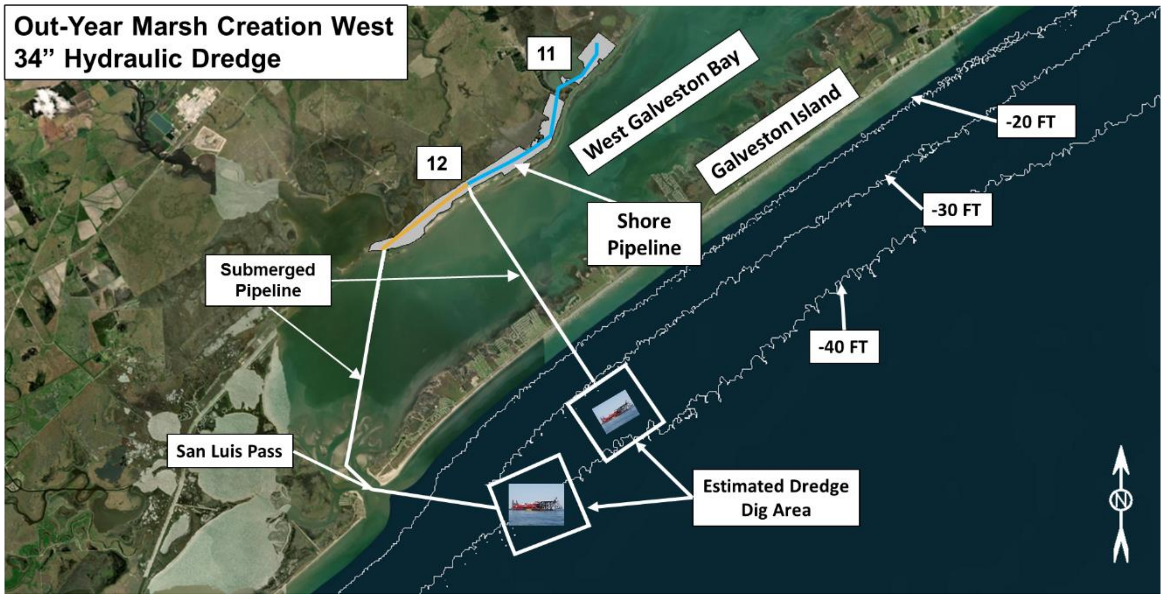


Figure 49. G-28 out-year marsh creation west – Shoreface sediment Hydraulic dredging Galveston Island

Table 56. G-28 out-year marsh creation – Shoreface sediment hydraulic dredging

	Out Year 2065 East (Bolivar Peninsula)	Out Year 2065 West (West Galveston Bay)	
Scenario Description	**Shore Offload**	**Shore Offload Galveston Pipeline**	**Shore Offload San Luis Pass Pipeline**
Total Fill Volume [MCY]	7.3	2.8	2.8
Borrow Source	Bolivar Peninsula shoreface	Galveston Island shoreface	Galveston Island shoreface
Average Pipeline Used [LF]	24,000	54,150	82,200
Average Number of Boosters Required	1-2	4	6
Material Classification [%]	50% Mud/silt 30% Sand 20% Clay	60% Mud/silt 40% Sand	60% Mud/silt 40% Sand
Effective Working Times	60%	55%	55%
Dredging Rate [CY/hr]	1,560	1,560	1,430
Time to Complete Dredging [Months]	11.75	5.7	7.8
Dredging Unit Cost* [$/CY]	$3.9 – 5.5	$7.6 – 10.7	$11.3 – 15.9
Total Costs* [Millions]	$28.4 – 39.8	$21.7 – 30.3	$32.2 – 45.1

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

Hopper Dredge Scenarios

Hopper dredge pump out locations are constrained by the loaded draft of the hopper. It is estimated that for the large hopper dredge considered (See Table 42), which has an estimated loaded draft of 30 feet. The minimum depth at the pipeline location would need to be 36 feet to account for the draft of the dredge and allow for proper under keel clearance. It was assumed that the dig area would be adjacent to the hopper's pump out location so as to minimize the hopper's sail time to the and from the dig area. While the dig areas shown are approximate, it was assumed that the hopper would dredge an area which will allow it to dig a full load with one turn. It was assumed that the hopper would stage dredging in such a manner that the hopper would be sailing towards the pumpout one the hopper is full.

Due to the soft material type in both shoreface dig areas, the hopper would be unable to reach full loads as softer material does not settle out in a hopper resulting in a point in production where it is more efficient to to stop digging and pumping out light loads rather than spending the additional time trying to reach maximum draft with the soft material. For this study it was estimated that the maximum hopper volumes per load would be 5,700 CY and 6,000 CY for the east and west areas respectively. The Galvestion Island shoreface sediments have slightly more sand, hence the slightly larger load sizes. It is possible that the hopper would be able to safely come in closer to shore than the -36 feet. This should be researched further in future cost estimates if shoreface sediments are identified as the primary source of material.

Effective dredge working time was estimated to be higher for the hopper dredges than the hydraulic dredges as hoppers do not have downtime to move the dredge to different cuts and generally have less downtime on the shoreside due to the shore crew being able to add shore pipe during the hopper's dig and sail times.

Compared to the hydraulic dredging scenarios, the unit costs calculated for hopper dreding Table 57 are approximately 80% higher than those calculated for hydraulic dredging, however the duration of the dredging is shown to decrease as a result of the higher effective work times.

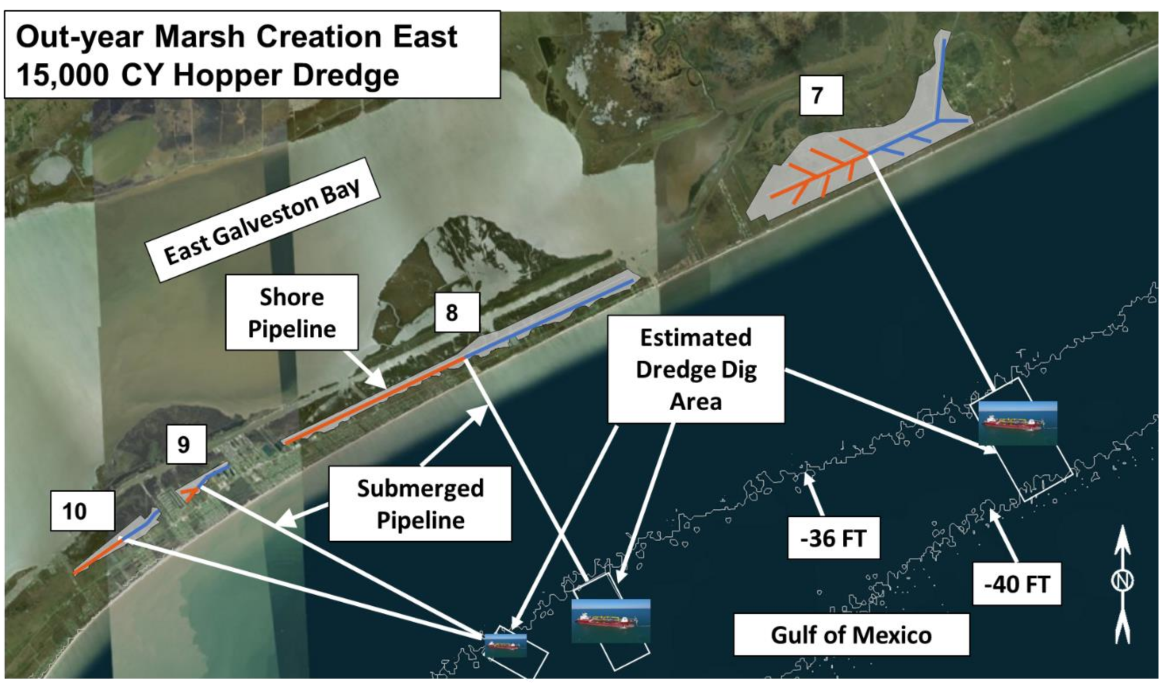


Figure 50. G-28 out-year marsh creation east – Shoreface sediment Hopper dredging Bolivar Peninsula

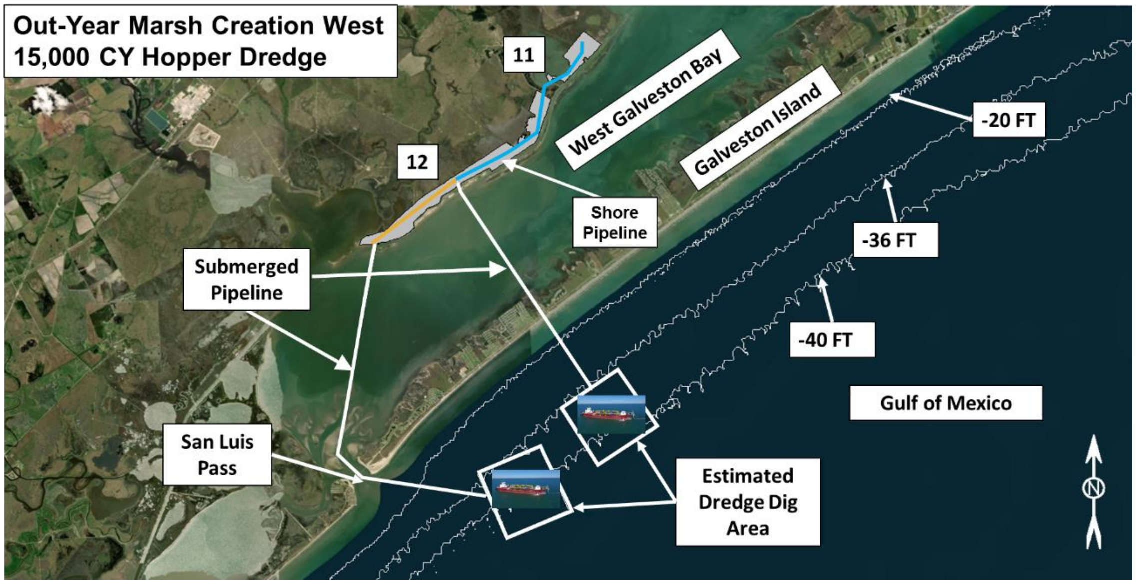


Figure 51. G-28 out-year marsh creation west – Shoreface sediment Hopper dredging Galveston Island

Table 57. G-28 out-year marsh creation – Shoreface sediment hopper dredging

	Out Year 2065 East (Bolivar Peninsula)	Out Year 2065 West (West Galveston Bay)	
Scenario Description	**Shore Offload**	**Shore Offload Galveston Pipeline**	**Shore Offload San Luis Pass Pipeline**
Total Fill Volume [MCY]	7.3	2.8	2.8
Borrow Source	Bolivar Peninsula shoreface	Galveston Island shoreface	Galveston Island shoreface
Haul Distance [mi]	2	2	2
Average Pipeline Used [LF]	39,040	52,050	77,250
Average Number of Boosters Required	2-3	3	5
Weather Downtime [%]	4%	9%	9%
Maintenance and Breakdowns [%]	15%	15%	15%
Effective Working Time [%]	81%	76%	76%
Loads per day [1 dredge]	5.4	4.5	4.3
Time to Complete Dredging [Months]	8.3	3.5	4.5
Dredging Unit Cost* [$/CY]	$7.1 – 9.9	$8.2 – 11.5	$10.3 – 14.5
Total Costs* [Millions]	$51.4 – 71.9	$23.4 – 32.8	$29.4 – 41.2

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.3.2.2 East Galveston Bay Tidal Flood Delta Dredging

Two dredging scenarios were considered for harvesting material from the East Galveston Bay for placement in the out – year marsh areas, direct hydraulic pumping from the old tidal delta to the east out-year marsh area (Figure 53) and hydraulic pumping to fill scows (Figure 54 and Figure 55) which are towed to an offloader and pumped out to the marsh areas. There are two main constraints to harvesting material in the East Galveston Bay, the first is the shallow elevation in the bay and the second is the GIWW channel depth of -12 MLT. As seen in Figure 52, the elevation in the old tidal flood delta ranges from -10 feet to -5 feet which limits the size of the hydraulic dredge which can dig in the delta due to draft and clearance limitations. The second constraint limits the size of the scow which can sail up the GIWW due to draft limitations. For the first scenario, a 24” cutterhead dredge was assumed as this is potentially the largest size cutterhead dredge which can work in the old tidal delta. 24” hydraulic dredges typically draft 5 FT and the dredge dig area would have to allow for the dredge to dig into the shallower bay areas.

For the second scenario, only small scows with a maximum draft of 10 feet were considered for this study with an average maximum tonnage of 1,750 (Canal Barge, 2011). Using an density conversion of 1.3 ton/cy for a mixture of mud/silt and fine sand, this amount to a maximum CY of approximately 1,350 CY per scow (HR Wallingford, 1996). However, as the material is estimated at 50% mud/silt and 50% sand, the scows will not be able to reach their full loaded tonnage due to the inability for mud/silt to settle out in a hopper. Assuming fine sand will fill a scow to 80% capacity and mud/silt is able to fill a scow to 30% capacity, a maximum usable scow capacity was calculated at approximately 750 CY per scow per load by for material with 50% mud/silt and 50% sand estimated material distribution (approximately 55% of the total scow capacity). Due to the small size of each scow load, a large cutterhead dredge may have too much power and too strong of a discharge to fill the small scows. In this study it was assumed a 16” hydraulic dredge would be used to fill the scows and an 800 HP tug would be required to tow the scow to the offloading location and Production rates were calculated assuming an estimated 5 feet of dig face. In order to calculate an offloading rate, it was assumed the hydraulic equipment used to pump out the scows would have equivalent power to a 24” hydraulic dredge. Tug towing distances were calculated from the old tidal flood to the east out-year areas and from the new tidal flood delta to the west out-year areas to slightly reduce the hauling distances to the west.

The estimated costs for the scenarios are summarized in Table 58. From the conceptual costs the direct pump out scenarios can be eliminated as an option as the unit costs and duration are twice as much as the hydraulic to scow scenario.

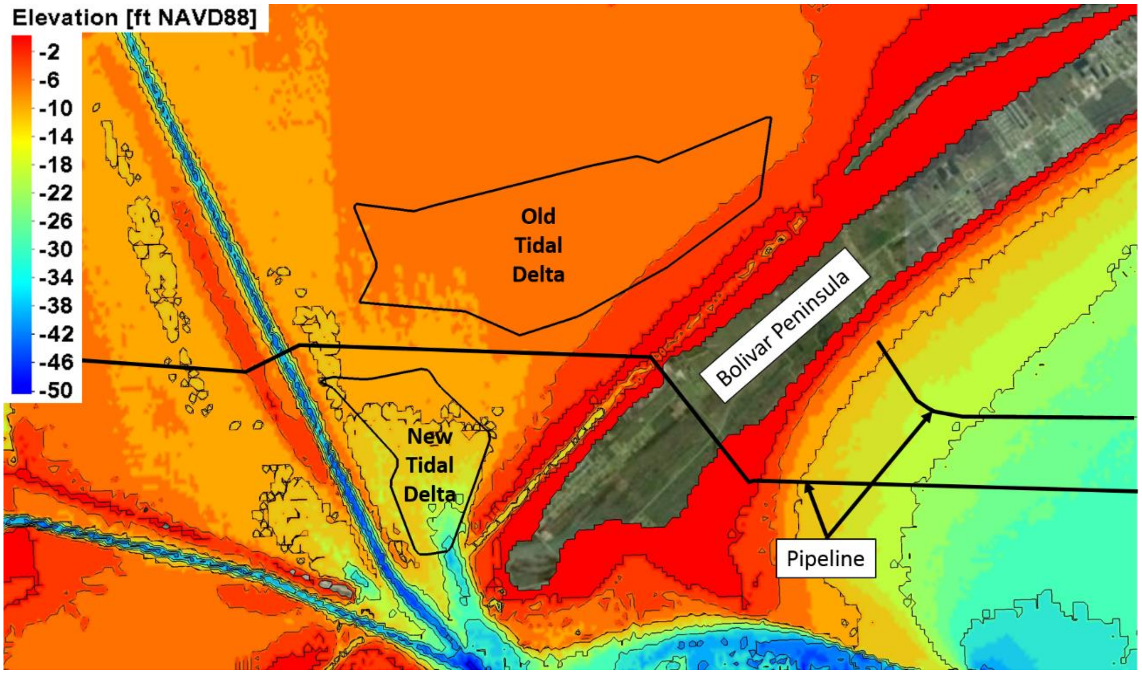


Figure 52. East Galveston Bay Tidal Flood Delta Elevation

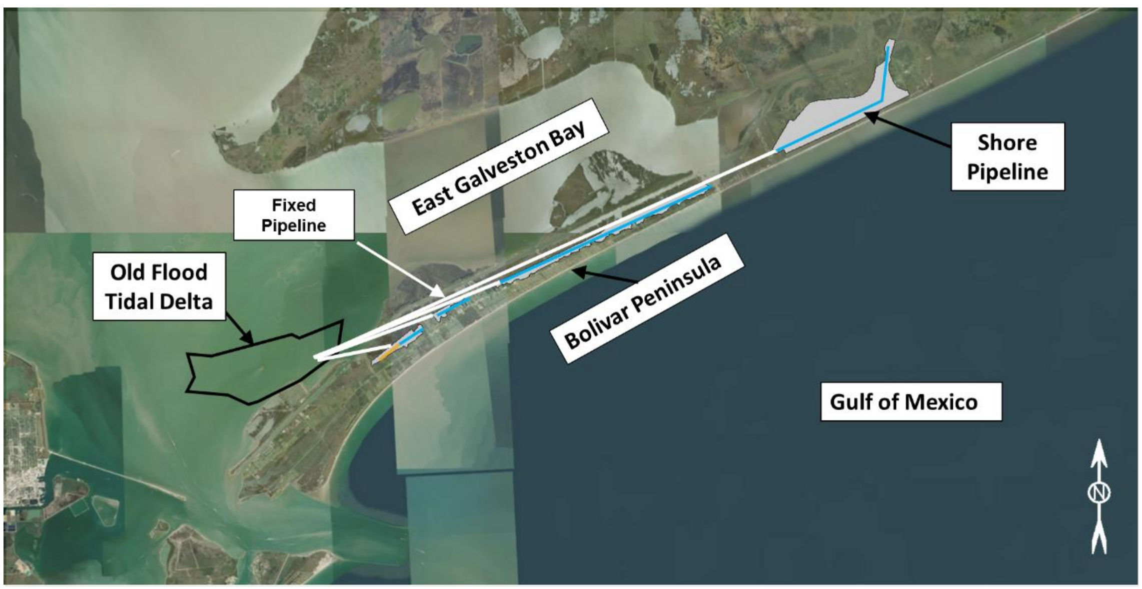


Figure 53. G-28 out-year marsh creation east – East Galveston Bay Tidal Flood Delta Hydraulic dredging with direct pump out

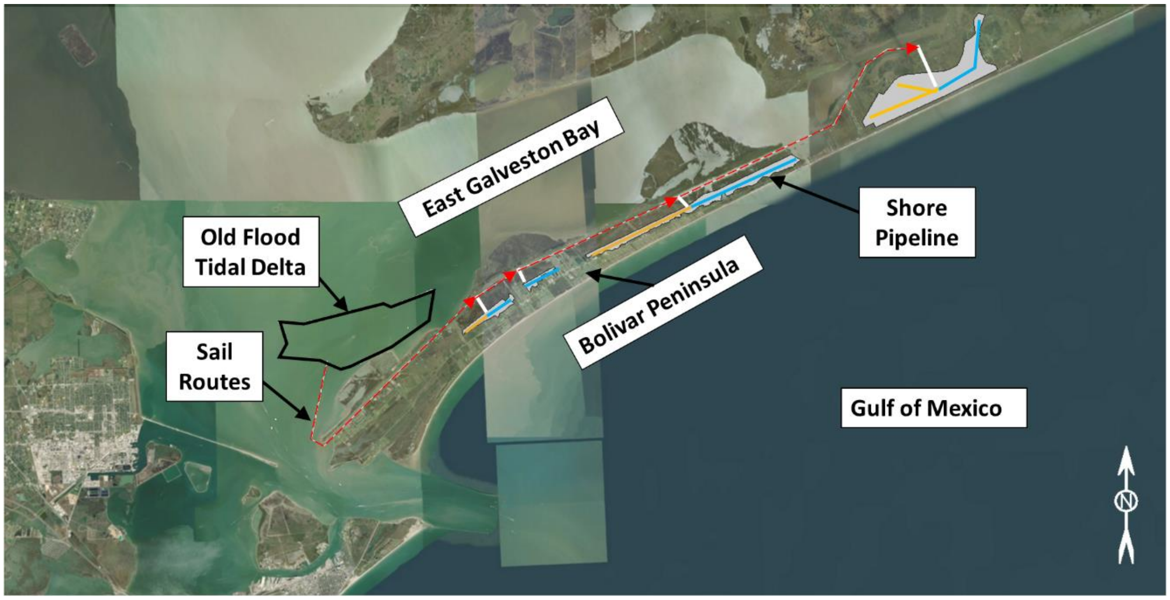


Figure 54. G-28 out-year marsh creation east – East Galveston Bay Tidal Flood Delta Hydraulic dredging to scows

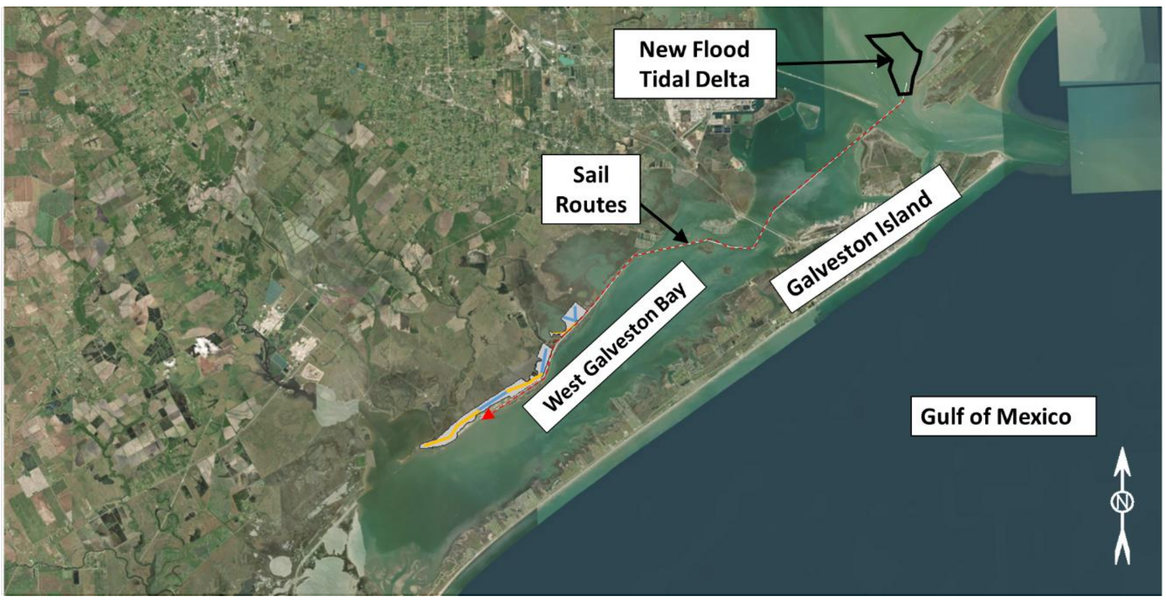


Figure 55. G-28 out-year marsh creation west – East Galveston Bay Tidal Flood Delta Hydraulic dredging to scows

Table 58. G-28 out-year marsh creation – East Galveston Bay Tidal Flood Delta

	Out Year 2065 East (Bolivar Peninsula)		Out Year 2065 West (West Galveston Bay)
Scenario Description	**Old Tidal Delta 24" Hydraulic Pumpout**	**Old Tidal Delta 16" Hydraulic Dredge to Scows**	**New Tidal Delta 16" Hydraulic Dredge to Scows**
Total Fill Volume [MCY]	7.3	7.3	2.8
Borrow Source	Galveston Bay Old Tidal Flood Delta	Galveston Bay Old Tidal Flood Delta	Galveston Bay New Tidal Flood Delta
Haul Distance [mi]	N/A	24	20.9
Number of SCOWs Required	N/A	11	10
SCOW Capacity [CY]	N/A	1,350	1,350
SCOW Round Trip Travel Time [hrs]	N/A	6.2	5.4
Average Pipeline Used [LF]	89,400	17,300	12,500
Average Number of Boosters Required	8	0 - 1	0
Material Classification [%]	50% Mud/silt 50% Sand	50% Mud/silt 50% Sand	50% Mud/silt 50% Sand
Dredging Rate [CY/hr]	1,020	1,350	1,340
Time to Complete Dredging [Months]	49	24	9.5
Dredging Unit Cost* [$/CY]	$14.9 – 20.9	$8.6 – 12.1	$7.55 – 10.6
Total Costs* [Millions]	$108.4 – 151.8	$62.7 – 87.8	$21.5 – 30.1

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.3.2.3 Mining Placement Areas

The only placement area that was considered as potential source of material was the Mid Bay Placement Area. By the year 2065, this placement area, which has an ultimate capacity 29.3 MCY, will likely be filled. That quantity is twice the amount of the volume required to fill the out-year marsh areas. If the Mid Bay Placement area is emptied to construct the G-28 out-year marsh creation and restoration areas then it could possibly extend its life as an active DMPA for maintenance materials from the Houston Ship Channel. The scenarios were estimated assuming that the PA would be mined hydraulically, using a pump to hydraulically pump water to the placement area to create a slurry mix, and another pump to excavate the placement area and to pump the slurry to scows which are towed to offloading site and pump out with an unloader or submersible pump. To estimate conceptual costs, it was assumed that the equipment used to excavate the placement areas would have a production rate and power similar to a 16” hydraulic cutterhead dredge and the offloading equipment would have a production rate and power similar to a 24” hydraulic dredge. As the scows would be towed up the GIWW, the same draft constraints and scow capacities were applied as discussed previously.

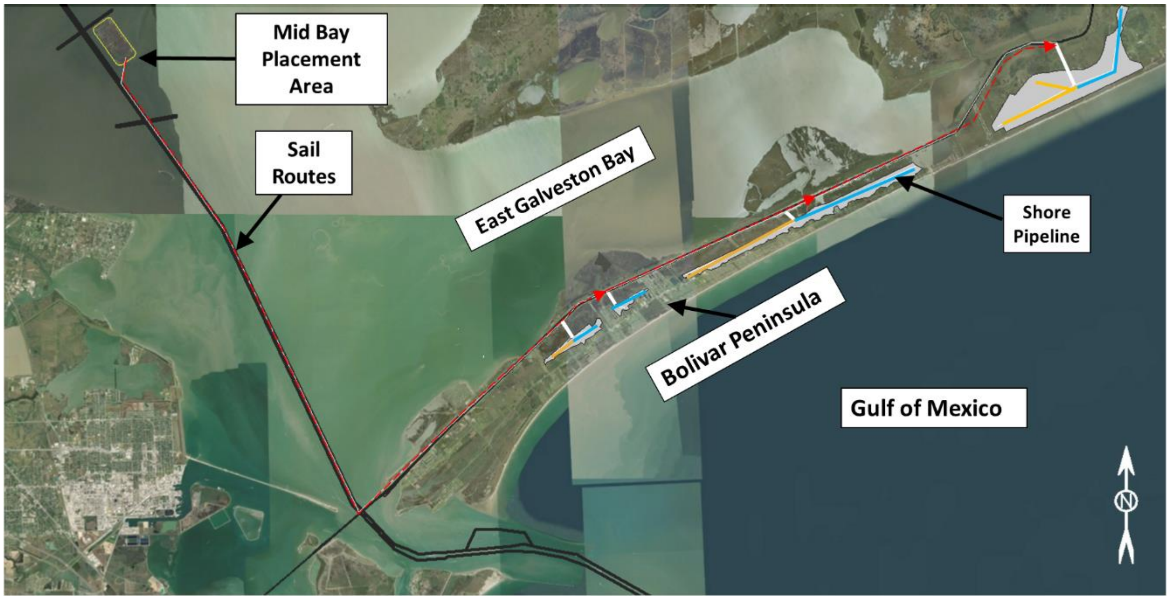


Figure 56. G-28 out-year marsh creation east –Mid Bay placement area mining

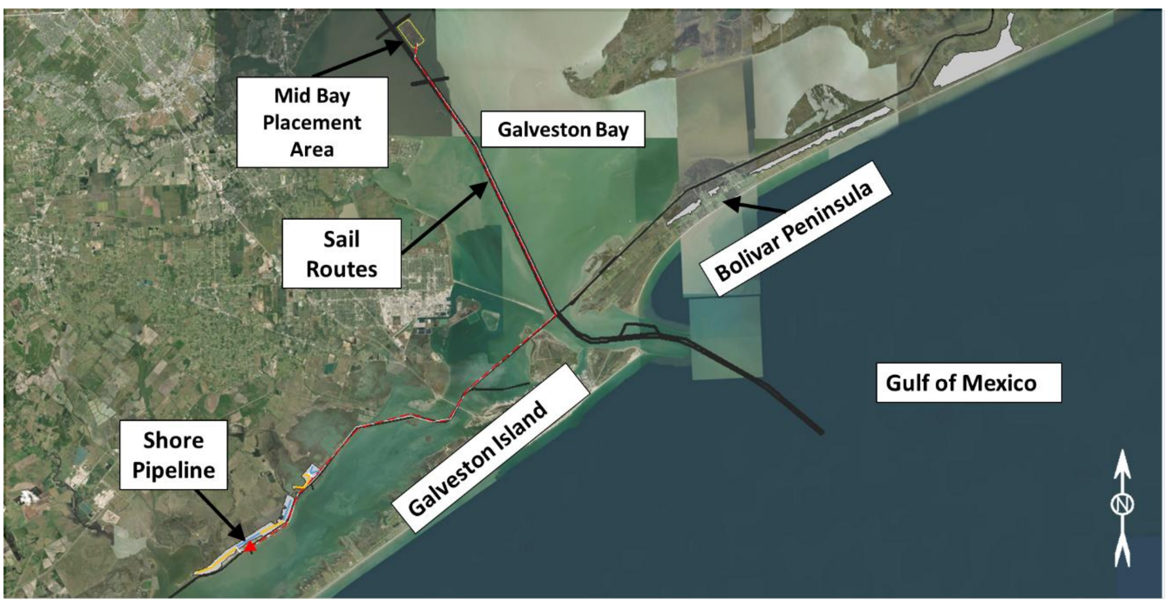


Figure 57. G-28 out-year marsh creation west – Mid Bay placement area mining

Table 59. G-28 out-year marsh creation – Mid Bay placement area mining

	G-28 Out Year East (Bolivar Peninsula)	G-28 Out Year 2065 West (West Galveston Bay)
Scenario Description	**Hydraulic Mining of PA to Scows**	**Hydraulic Mining of PA to Scows**
Total Fill Volume [MCY]	7.3	2.8
Borrow Source	Mid Bay PA	Mid Bay PA
Haul Distance [mi]	38	35
Average Pipeline Used [LF]	14,200	7,800
Number of SCOWs Required	10	5
SCOW Capacity [CY]	1350	1,480
SCOW Round Trip Travel Time [hrs]	9.2	9.2
Material Classification [%]	58% Mud/silt 27% Sand 15% Stiff clay	58% Mud/silt 27% Sand 15% Stiff clay
Time to complete dredging [months]	20.2	11.8
Dredging Unit Cost* [$/CY]	$7.5 – $10.5	$11.2 - $15.6
Total Costs* [Millions]	$53.9 – $75.5	$21.2 – $38.0

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.3.2.4 Ship Channel Dredging

If advanced maintenance dredging below the authorized depth is allowed, the Galveston Entrance could potentially provide a channel source of for the eastern out-year marsh areas. This scenario was estimated with hydraulic dredge and scow operations and the conceptual costs were calculated assuming that the channel would be dredged with a 34” hydraulic dredge and pump the material to fill 6000 CY scows. The scows would be towed with a 3000 HP tug to a location near the shore where they would dump the material. Another hydraulic dredge would at the disposal site to dig the material and pump it out to shore. Based on the material composition, the maximum usable scow capacities were estimated at 2,640 CY per scow per load. In order to provide sufficient material for the eastern out-year marsh area, approximately 1-2 feet of material past the authorized dredging depth would need to be dredged in addition to a maintenance dredging event in the Entrance Channel. There would not be sufficient volume for this scenario to able to fill the western marsh areas unless an additional 1-2 feet were dredged past the authorized channel depth.

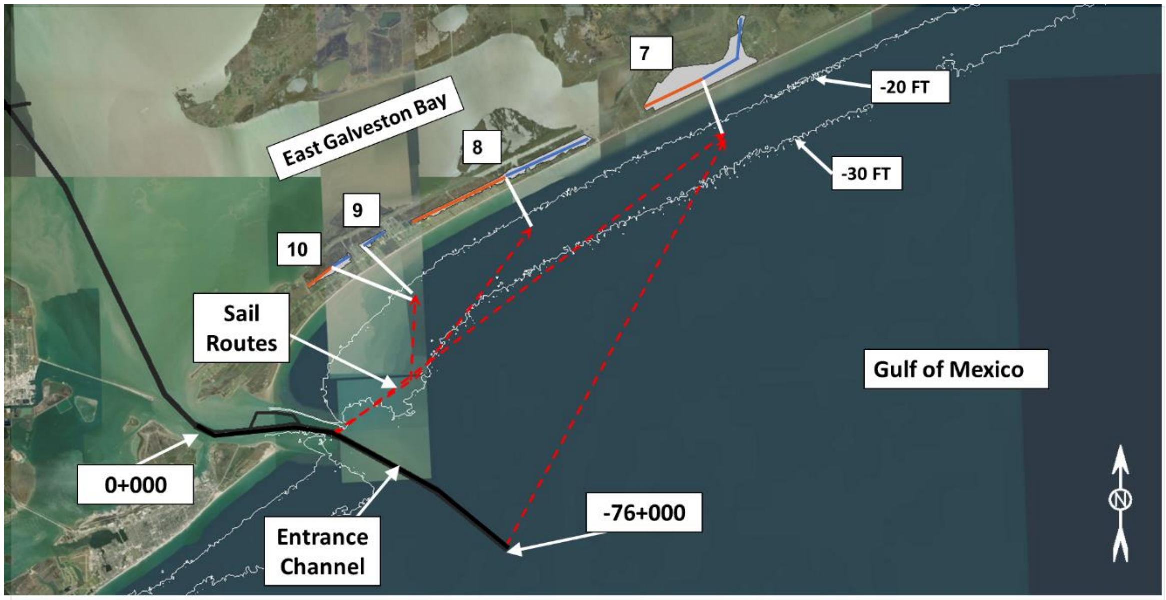


Figure 58. G-28 Out-year marsh creation east - Entrance Channel cutterhead dredging to large scows

Table 60: G-28 hydraulic suction cutterhead dredging to scows scenarios and costs

G-28 Out Year Marsh Creation and Restoration

Scenario Description	East (Bolivar Peninsula) 34" Hydraulic dredge filling large scows
Total Fill Volume [MCY]	7.3
Borrow Source	Galveston Entrance Channel
Haul Distance [mi]	17.7
Average Pipeline Used [LF]	22,300
Number of SCOWs Required	2 - 3
SCOW Capacity [CY]	6,000
SCOW Round Trip Travel Time [hrs]	4.6
Material Classification [%]	30% Mud/silt 40% Sand 30% Stiff clay
Time to complete dredging [months]	20.7
Dredging Unit Cost* [$/CY]	$15.3 - $17.5
Total Costs* [Millions]	$111 - $156

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.3.3 Island Creation and Restoration

G-28 has an island restoration component which will require an estimated 5.8 MCY of material. The island restoration is located to the south of the GIWW that runs across the West Galveston Bay. Much of the same material sources that were considered for the western out-year marsh areas were considered as potential material sources for the island restoration.

Figure 59. G-28 Out - year 2065 Island creation and restoration area

4.3.3.1 Shoreface Sediment Dredging

The Galveston Island shoreface sediments could supply material to the area designated for island restoration. Conceptual cost estimates were developed for two dredging scenarios, dredging offshore with a 34" hydraulic dredge and 15,000 CY hopper dredge with a pump out through a long pipeline to the island creation area. The same pipeline alignment and dredge dig areas were assumed as detailed in Section 4.3.2.1. The conceptual costs are detailed in the tables in the following two Sections.

Hydraulic Suction Cutterhead Dredge Scenarios

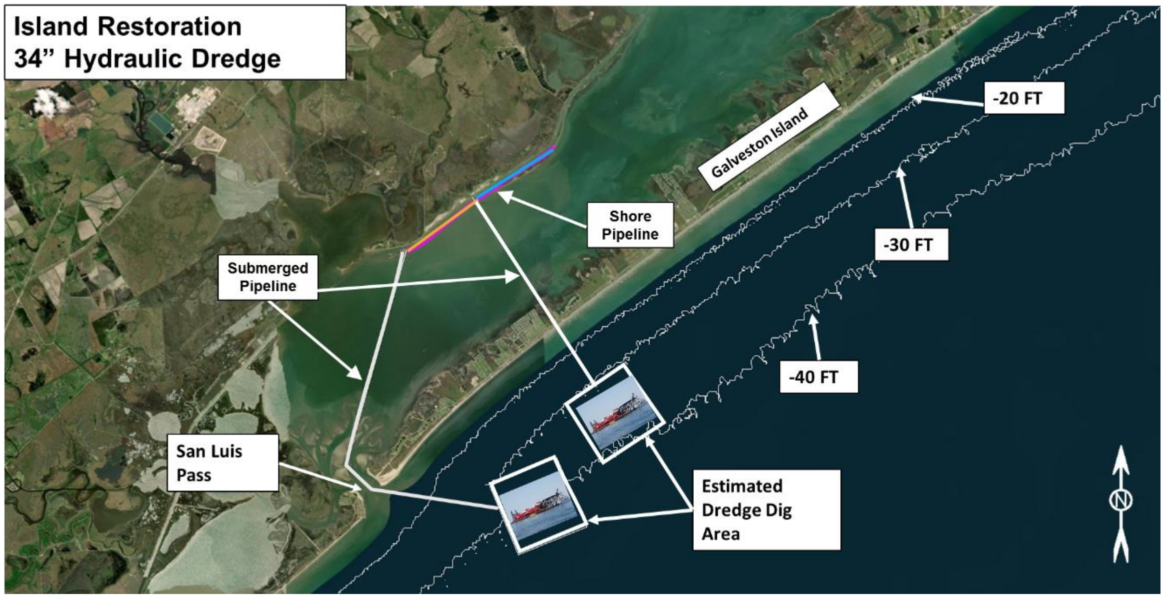


Figure 60. G-28 Island Creation and Restoration – Shoreface sediment Hydraulic dredging

Table 61. G-28 Island Creation and Restoration – Shoreface sediment Hydraulic dredging

G-28 Island Creation and Restoration		
Scenario Description	**Shore Offload Galveston Pipeline**	**Shore Offload San Luis Pass Pipeline**
Total Fill Volume [MCY]	5.8	5.8
Borrow Source	Galveston Island shoreface	Galveston Island shoreface
Average Pipeline Used [LF]	43,360	73,060
Average Number of Boosters Required	3	5
Material Classification [%]	60% Mud/silt 40% Sand	60% Mud/silt 40% Sand
Effective work time [%]	55%	55%
Dredging Rate [CY/hr]	1,560	1,400
Time to Complete Dredging [Months]	12.5	17.6
Dredging Unit Cost* [$/CY]	$6.3 – $8.8	$10.1 – $14.1
Total Costs* [Millions]	$36.7 – $51.4	$58.8 – $82.3

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

Hopper Dredge Scenarios

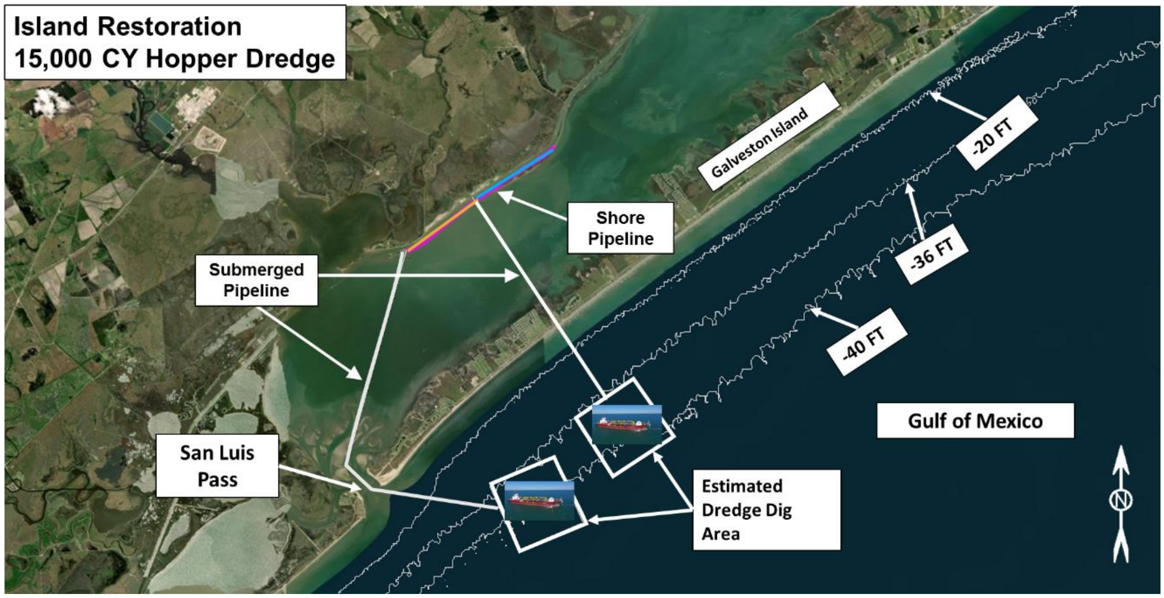


Figure 61. G-28 Island Creation and Restoration – Shoreface sediment Hopper dredging

Table 62. G-28 Island Creation and Restoration – Shoreface sediment Hopper dredging

	G-28 Island Creation and Restoration	
Scenario Description	**Shore Offload Galveston Pipeline**	**Shore Offload San Luis Pass Pipeline**
Total Fill Volume [MCY]	5.8	5.8
Borrow Source	Galveston Island shoreface	Galveston Island shoreface
Haul Distance [mi]	2	2
Average Pipeline Used [LF]	41,235	68,090
Average Number of Boosters Required	3	4
Weather Downtime [%]	9%	9%
Maintenance and Breakdowns [%]	15%	15%
Effective Working Time [%]	76%	76%
Loads per day [1 dredge]	4.3	4.3
Time to Complete Dredging [Months]	7.4	9.6
Dredging Unit Cost* [$/CY]	$8.1 – $11.4	$9.5 – $13.3
Total Costs* [Millions]	$47.2 – $66.1	$55.3 – $77.4

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.3.3.2 East Galveston Bay Tidal Flood Delta Dredging

The new flood tidal delta could also be a potential source of material for the island restoration area. The material would have to be dredged with a hydraulic dredge and loaded into small scows that are towed through the GIWW to an offloading location. The same constraints as detailed in Section 4.3.2.2 were assumed to develop the conceptual cost estimate in Table 63.

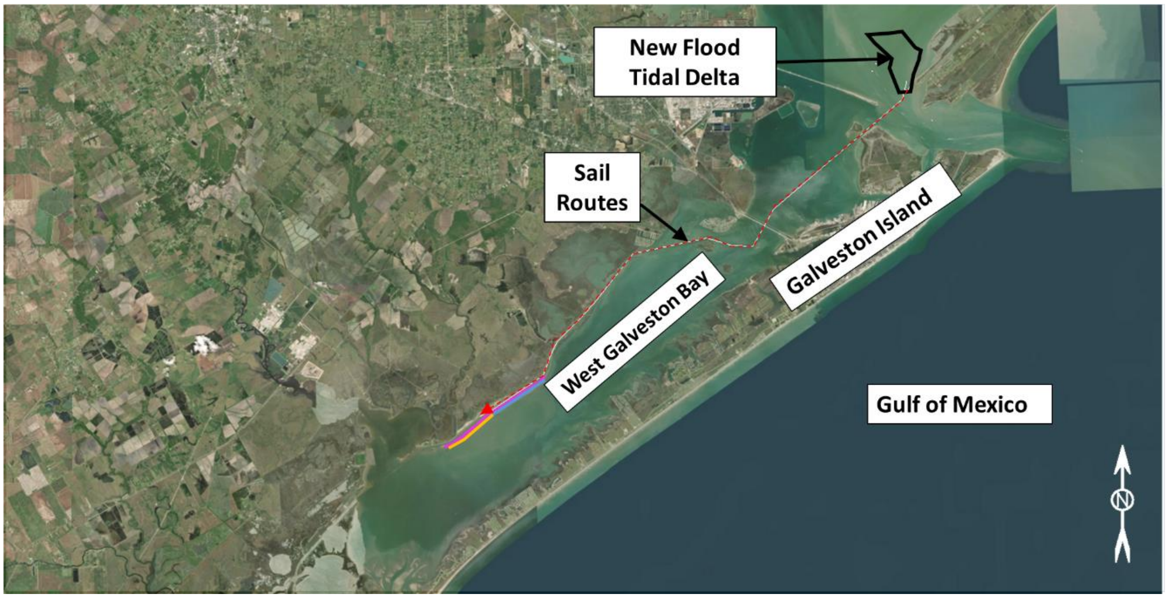


Figure 62. G-28 Island Creation and Restoration – East Galveston Bay Tidal Flood Delta Hydraulic dredging to scows

Table 63. G-28 Island Creation and Restoration – East Galveston Bay Tidal Flood Delta Hydraulic dredging to scows

	G-28 Island Restoration
Scenario Description	**New Tidal Delta 16" Hydraulic Dredge to Scows**
Total Fill Volume [MCY]	5.8
Borrow Source	Galveston Bay New Tidal Flood Delta
Haul Distance [mi]	22.6
Number of SCOWs Required	10
SCOW Capacity [CY]	1,350
SCOW Round Trip Travel Time [hrs]	5.9
Average Pipeline Used [LF]	3,700
Average Number of Boosters Required	0
Material Classification [%]	50% Mud/silt 50% Sand
Dredging Rate [CY/hr]	1,616
Time to Complete Dredging [Months]	9.5
Dredging Unit Cost* [$/CY]	$8.5 – $11.9
Total Costs* [Millions]	$49.7 – $69.5

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.3.3.3 Mining Placement Areas

The Mid Bay Placement Areas could also be a potential source of material for the island restoration area. The placement site would have to be hydraulically excavated into small scows that are towed through the GIWW to an offloading location. The same constraints as detailed in Section 4.3.2.3 were assumed to develop the conceptual cost estimate in Table 64. It is assume the island restoration component to the ER measure will be constructed prior to the 2065 Out-year marsh constructions, therefore the Mid Bay placement area would have enough capacity to fill both as after the island restoration is constructed the PA will continue as a disposal site for maintenance dredging events and be replenished by the time the out-year marsh areas are constructed.

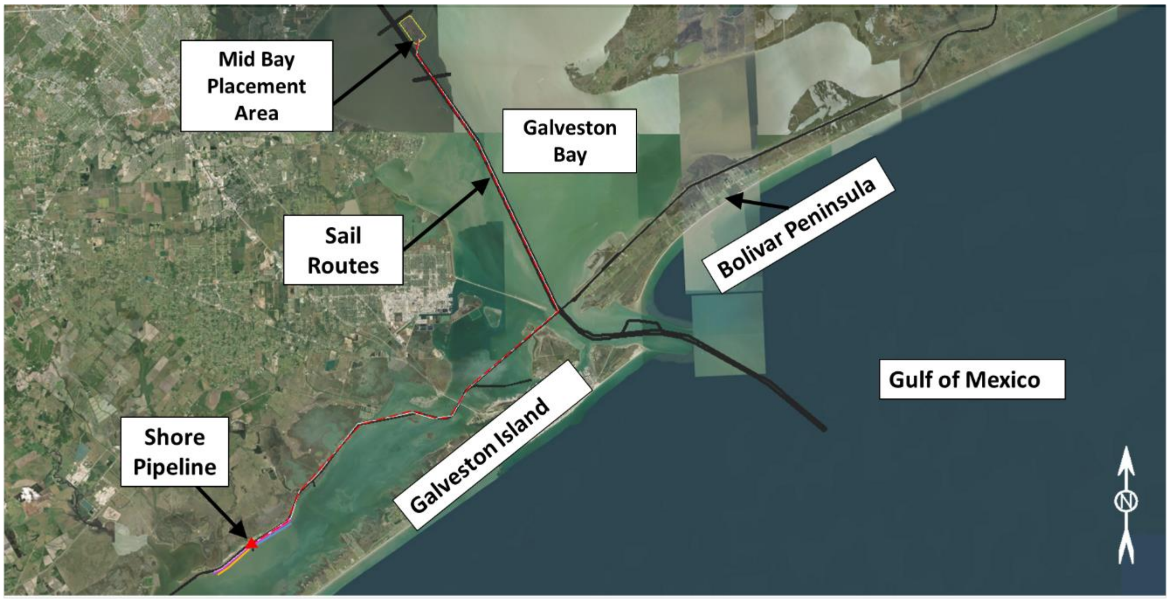


Figure 63. G-28 Island Creation and Restoration – Mid Bay placement area mining

Table 64. G-28 Island Creation and Restoration – Mid Bay placement area mining

	G-28 Island Restoration
Scenario Description	**Hydraulic Mining of PA to Scows**
Total Fill Volume [MCY]	5.8
Borrow Source	Mid Bay PA
Haul Distance [mi]	38
Average Pipeline Used [LF]	3,700
Number of SCOWs Required	8
SCOW Capacity [CY]	1,350
SCOW Round Trip Travel Time [hrs]	9.7
Material Classification [%]	58% Mud/silt 27% Sand 15% Stiff clay
Time to complete dredging [months]	16.2
Dredging Unit Cost* [$/CY]	$8.8 – $12.3
Total Costs* [Millions]	$38.6 - $54.1

4.3.3.4 Ship Channel Dredging

A maintenance dredging event in the Galveston Harbor and Entrance Channel could also be a potential source of material for filling the island restoration area. The conceptual costs for this scenario were developed assuming that the channel would be dredged using 34" hydraulic directly pumping to the island restoration area. Pipeline lengths were calculated by assuming the dredge would start dredging in the Harbor Channel digging towards the entrance channel and then proceed to dig out into the Gulf in the Entrance Channel. Such a scenario requires an extremely long pipeline with an estimated 7-11 booster pumps required. It should be explored further whether the existing US dredging market has sufficient equipment available to complete such a dredging scenario.

Dredging to scows was not considered as a feasible dredge scenario for this source as the size of the scow would have to be as small as the scows used to estimate the East Galveston Bay Tidal Flood source scenarios. The discharge from a 34" dredge may be too much to control to fill such small scows and a smaller hydraulic dredge would not be an optimal dredge to dig in the Entrance Channel offshore.

Figure 64. G -28 Island Creation and Restoration - 34" Hydraulic Direct Pump out

Table 65. G -28 Island Creation and Restoration - 34" Hydraulic Direct Pump out

G -28 Island Creation and Restoration

Scenario Description	34" Hydraulic Direct Pump out		
	Galveston Harbor Dredging	Entrance Channel Dredging	Total
Total Fill Volume [MCY]	1.8	2.8	4.6
Borrow Source	Galveston Harbor	Entrance Channel	Galveston Harbor and Entrance Channel
Average Pipeline Used [LF]	101,200	148,220	136,935
Average Number of Boosters Required	7	11	7-11
Material Classification [%]	80% Mud/silt 20% Sand	60% Mud/silt 40% Sand	
Effective Working Times	60%	55%	
Dredging Rate [CY/hr]	1,045	830	913
Time to Complete Dredging [Months]	8.1	47.3	55.4
Dredging Unit Cost* [$/CY]	$13.8 - $19.3	$29.4 – $41.2	$23.4 – 32.8
Total Costs* [Millions]	$24.7 – $35.6	$84.1 – $117.8	$108.8 – 152.4

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.3.4 Summary of Source Scenarios

A summary of all the source scenarios for all of the G-28 ER measure components is provided in Table 66. Note that the costs shown are midpoint of the cost range estimate.

Table 66. ER Measure G-28 Conceptual Cost and Duration Source Summary

Source	Dredge Scenario	$/CY	Duration [months]
G-28 Out-year marsh creation and restoration EAST			
Shoreface Sediment	34" Hydraulic	4.7	11.75
Shoreface Sediment	15,000 CY Hopper with pump out	8.5	8.3
Old Tidal Delta	24” Hydraulic Pump out	17.9	49
Old Tidal Delta	16” Hydraulic Dredge to small scows	10.4	24
Mid Bay PA Mining	N/A	8.9	20.2
Entrance Channel	34” Hydraulic dredge filling large scows	16.4	20.7
G-28 Out-year marsh creation and restoration WEST			
Shoreface Sediment	34 " Hydraulic dredge Galveston Island Pipeline	9.15	5.7
Shoreface Sediment	34 " Hydraulic dredge San Luis Pipeline	13.6	7.8
Shoreface Sediment	15,000 CY Hopper Galveston Island Pipeline	9.8	3.5
Shoreface Sediment	15,000 CY Hopper San Luis Pipeline	12.4	4.5
New Tidal Delta	16” Hydraulic Dredge to small scows	9.1	9.5
Mid Bay PA Mining	N/A	11.5	11.8
G-28 Island creation and restoration			
Shoreface Sediment	34 " Hydraulic dredge Galveston Island Pipeline	7.55	12.5
Shoreface Sediment	34 " Hydraulic dredge San Luis Pipeline	12.1	17.6
Shoreface Sediment	15,000 CY Galveston Island Pipeline	9.75	7.4
Shoreface Sediment	15,000 CY Galveston Island San Luis Pipeline	11.4	9.6
New Tidal Delta	16” Hydraulic Dredge to small scows	10.2	9.5
Mid Bay PA Mining	N/A	7.95	16.2
Entrance Channel	34" Hydraulic direct pump out	28.1	55.4

The shoreface sediments, East Galveston Bay tidal flood shoal, and mining from Mid Bay PA have costs within 30% of each other. The shoreface sediment scenarios are estimated to have the lowest costs with the shoreface hopper dredge estimated to have the shortest durations. The scenarios which require dredging through the longest pipelines and sourcing material from the Galveston Harbor and Entrance Channel were estimated to both the highest costs and durations.

Table 67. Advantages and Disadvantages of ER Measures G-28 material sources

	Advantages	Disadvantages	Future Considerations
Ship Channel Dredging	• GIWW maintenance dredging event should provide sufficient material to fill all initial marsh creation and restoration areas.	• No channel maintenance event has enough quantity to fill all out-year marsh areas in one construction phase. • Highest estimated costs and durations.	• Future studies should evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel. • Maximum feasible dredge depth past authorized channel depth to increase available quantity.
Shoreface Sediment Dredging	• Large quantities of available sediment • Lowest costs • Hydraulic dredging and hopper dredging both possible	• Pipeline placement may be difficult through Galveston Island and around San Luis Pass. Both cases involve crossing the west Galveston Bay and GIWW • Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows. • Further studies on effects of shoreface excavation on nearshore coastal processes.
East Galveston Bay Tidal Flood Shoal Dredging	• Large quantities of available sediment. • Sheltered dredge area.	• Only hydraulic dredging possible. • Shallow bay areas limit sizes of dredges used. • GIWW limits size of scow to be used. • Soft material limits possible load sizes in scows. • Potential oyster beds may restrict dredging areas	• Additional geotechnical studies and research to better classify quantities and dredge dig depths
Mining Placement Areas	• Large quantities of available sediment. • Sediment replenished with maintenance dredged materials. • Could extend usable life of placement area.	• GIWW limits size of scow to be used. • Soft material limits possible load sizes in scows.	• Further research into equipment used and costs.

4.4 ER Measure B-2

Ecosystem restoration measure B-2 consists of a beach nourishment and dune restoration along 10.1 miles of Gulf shoreline on Follett's island in Brazoria County. An initial quantity of approximately 8.8 million cubic yards would be placed with an approximately 11.7 million cubic yards placed in 10-year renourishment cycles for a period of 50 years. It is anticipated that Hopper barges would collect the sand from offshore sources and transport it to floating hydraulic pumping stations nearshore. The material would then be pumped to the shoreline and spread with bulldozers.

4.4.1 Sabine and Heald Bank Harvesting

As discussed previously in this report, the Heald and Sabine banks are the largest presently identified sources of sandy material in the Gulf with approximately 169 million cubic yards and 28 million cubic yards of easily accessible sand located within the Sabine and Heald Banks respectively. The methodology for harvesting and placement of the material would be similar to the methodologies discussed for ER measure G-5 using hopper dredges, but due to the geographic location of Follett's island distances to the sources are significantly increased. Figure 65 shows the approximate distances from the Sabine and Heald Banks to the project site and to Freeport Channel.

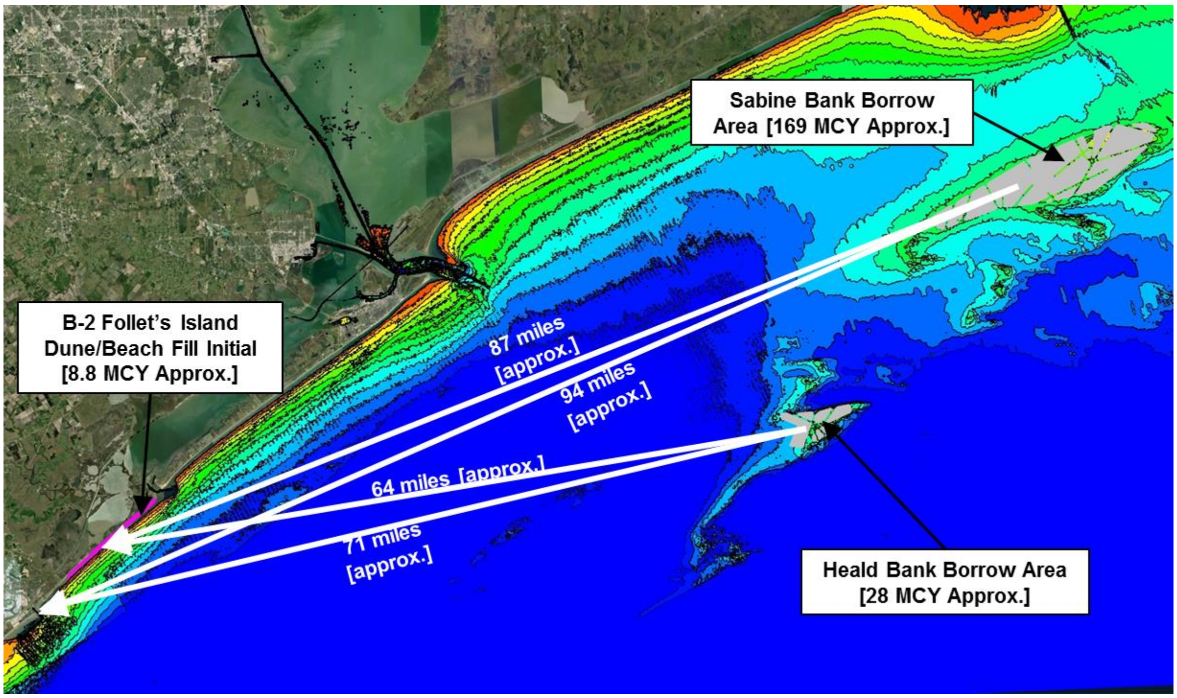


Figure 65. Heald and Sabine Bank distances to B-2 placement & offloading areas.

Two offloading scenarios were considered for this measure including pumping the material to the project site via pipeline from offshore (Figure 66) or from the Freeport inlet (Figure 67). Offshore placement would require much less pipeline, but there is a potential for additional down time due to wave conditions nearshore. The same dredge parameters used for the hopper dredge scenarios for ER Measure G-5 shown in Table 42 were used for this estimate. These were based on some of the currently largest available trailing suction hopper dredges in the United States.

Shore offloading would involve the dredge reaching an area adjacent to the placement location and connecting to a submerged pipeline leading to the placement site. The length of submerged pipeline would be dictated by the draft of the dredge and the bathymetry offshore. It is estimated that for the hopper dredge considered the minimum depth at the pipeline location would need to be 36' to account for the draft of the dredge and allow for proper under keel clearance. For the offshore placement option, the placement sites were divided into four equal sections to reduce the total pumping distance for the dredge. The placement area could be divided further as necessary, but this would depend on the amount of pipeline and boosters available to the contractor and how quickly they could relocate the pipeline.

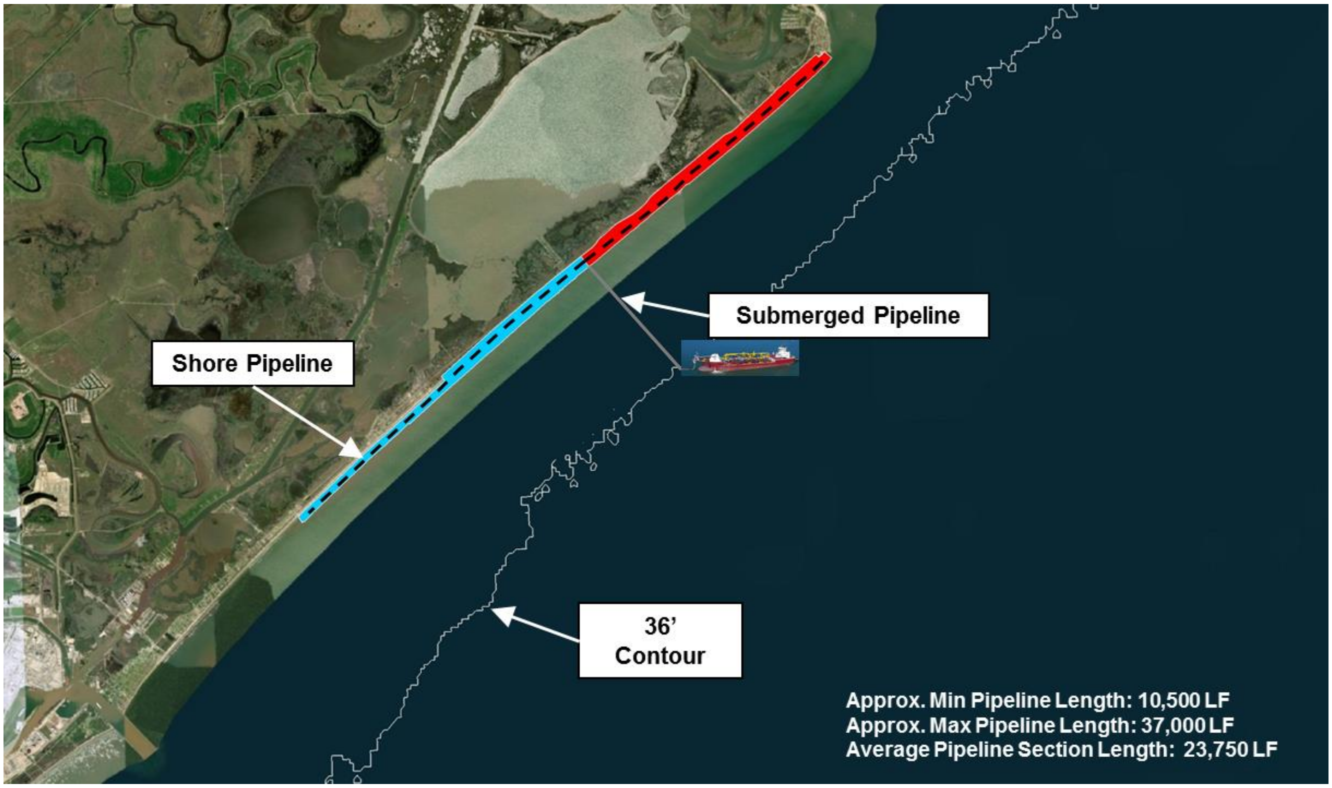


Figure 66. Follett’s Island shore offload.

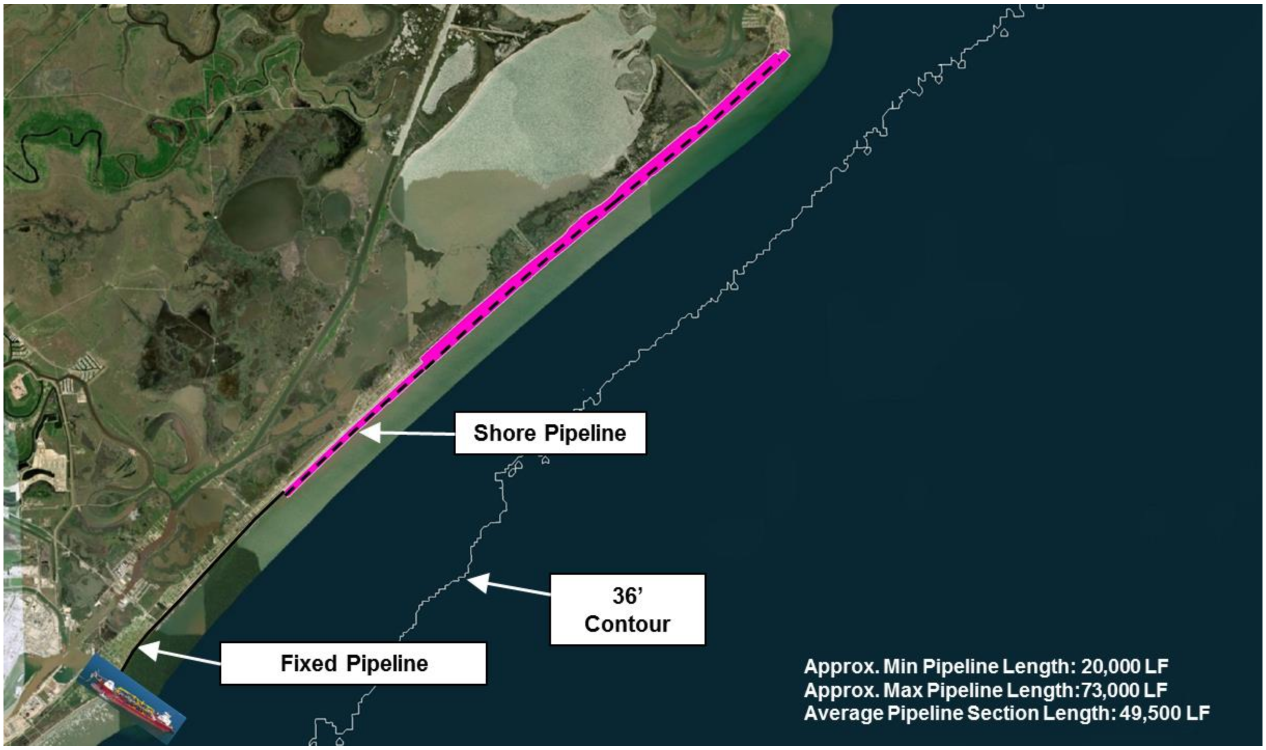


Figure 67. Follett’s Island Freeport offload.

Cost estimates for the scenarios described in this section were developed and compiled in Table 68. Cost were primarily driven by the distance from the borrow source to the project site, average length of shore pipeline used, and downtime due to weather. Weather downtime was determined based on statistical analysis of wave conditions at the borrow source and at the project site using data downloaded from the USACE Wave Information Studies (WIS) site for a "virtual" gauge location offshore Follett's Island (WIS, 2018). It was assumed that the dredge would cease dredging operations at the borrow sites in wave heights greater than 6' and offloading operations would not occur in wave heights greater than 3'.

Table 68: B-2 dredging scenarios and costs

B-2				
	Heald Bank		**Sabine Bank**	
Scenario Description	Freeport Offload	Shore Offload	Freeport Offload	Shore Offload
Total Fill Volume [MCY]	8.8	8.8	8.8	8.8
Borrow Source	Heald Bank	Heald Bank	Sabine Bank	Sabine Bank
Haul Distance [mi]	71	64	94	87
Average Pipeline Used [LF]	46,500	23,750	46,500	23,750
Average Number of Boosters Required	3	2	3	2
Weather Downtime [%]	5%	10%	5%	10%
Maintenance and Breakdowns [%]	10%	10%	10%	10%
Effective Working Time [%]	85%	80%	85%	80%
Dredging Unit Cost* [$/CY]	$19-$27	$17-$24	$23-$32	$21-$29
Total Costs* [Millions]	$167-$238	$150-$211	$203-$282	$185-$255

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

The analysis shows that, for this measure, the Heald Bank would be the preferred borrow source as it is closer to the project site resulting in shorter haul times which reduces the overall dredging costs. The shore offload alternative would be more cost effective as the shorter pipeline allows for quicker offloading of the material. This increased production from the shorter pipeline is enough to counteract the increase in down time from the shore offload option.

In addition to the costs, project durations were estimated for each alternative and summarized in Table 69. The durations show that this project can be completed within a reasonable time line, but overall construction durations can be reduced if additional dredges are used to increase production.

Table 69: B-2 dredging scenario durations.

B-2				
	Heald Bank		Sabine Bank	
Scenario Description	Freeport Offload	Shore Offload	Freeport Offload	Shore Offload
Borrow Source	Heald Bank	Heald Bank	Sabine Bank	Sabine Bank
Haul Distance [mi]	71	64	94	87
Weather Downtime [%]	5.0%	10%	5.0%	10%
Maintenance and Breakdowns [%]	10%	10%	10%	10%
Effective Working Time [%]	85%	80%	85%	80%
Total Volume [MCY]	8.8	8.8	8.8	8.8
Loads Per Day [1 Dredge]	1.3	1.3	1.1	1.1
Total Duration [Years]	2.5	2.6	3.1	3.2

Based on the preliminary costs for each scenario, harvesting of material from the Heald Bank would be preferred as it is closer than the Sabine Bank to the project site. Also, shore offloading of the material would allow for faster production which in turn reduces the costs assuming downtime due to wave action at the offloading site is not substantial.

4.4.2 Incised Channels

As discussed previously in this report, Several Paleo Incised Channels exist throughout the Gulf which may contain sandy material to be used for beach nourishment (See Figure 68). While most of the currently identified sandy material currently identified within the Sabine/Trinity incised paleochannels fall within the Sabine and Heald banks, geologic evidence points to additional sandy material within other portions of the Brazos and Colorado River incised paleochannels (Freese & Nichols, 2016). Unfortunately, there is currently not enough data available to determine the exact locations, quantity, overburden, and character of all sandy sediments within these channels.

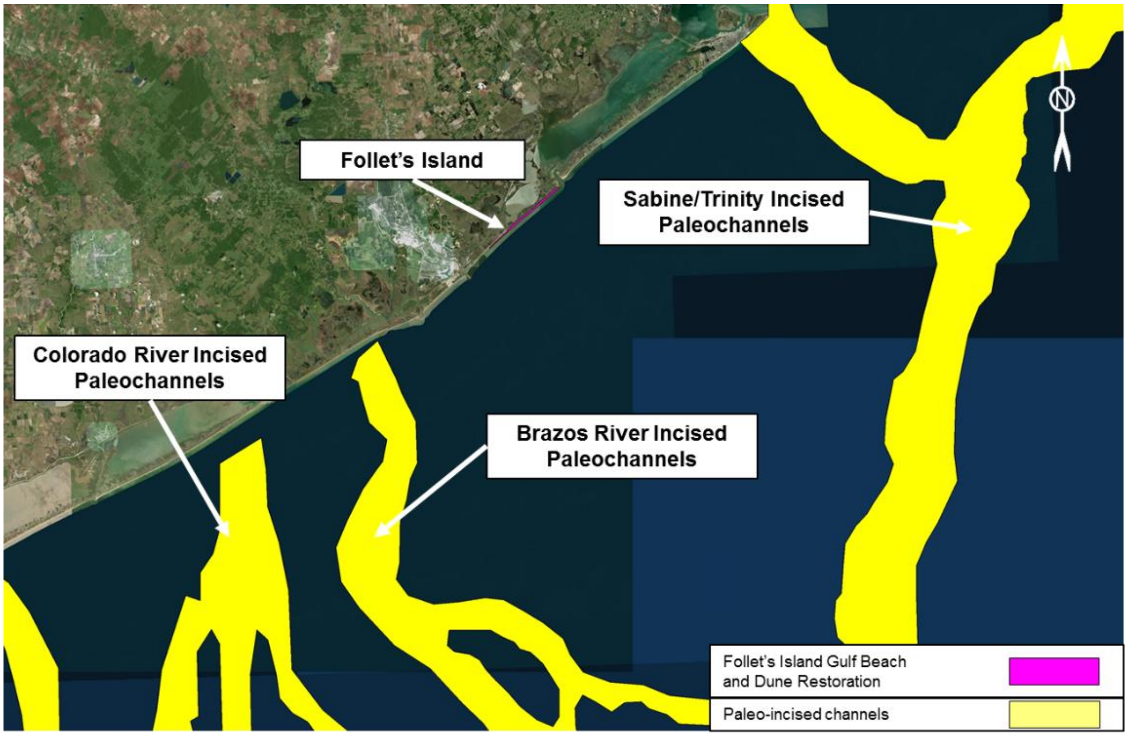


Figure 68: B-2 Paleo Incised Channel approximate locations

Due to current the lack of information on the locations of sandy sediments within these paleochannels, several assumptions must be made in order to estimate the costs of dredging of these materials for beach nourishment. It was assumed that the sandy materials within the Trinity/Sabine Incised Valleys would be found between 45 and 65 miles away from the project site. Likewise, it was assumed that the sandy materials within the Colorado and Brazos Deltas and Valleys could be found between 15 and 35 miles from the project site. Finally, it was also assumed that the sandy materials would be found under layers of overburden materials which would need to be removed to access the beach quality sand. (Freese & Nichols, 2016) As overburden can vary significantly depending on the location and how the material was deposited, it was assumed that dredging of overburden would account for 50% of the dredging time, meaning that the volume of overburden material is equal to the volume of beach quality fill required. This is a conservative assumption which partially accounts for the overall variability in overburden expected and the spatial variability in sand deposits.

It is assumed that dredging will be performed using trailing suction hopper dredges of similar dimensions as described throughout this report. The dredge would remove any overburden, then dredge the sandy material, transport the material to the site, and pump it to the shore via offshore pipeline. It was also assumed that all of the sandy material necessary for the completion of this project is located within the same area, thus haul distances would not vary significantly throughout construction.

Using the assumptions described herein, the costs shown in Table 70 were developed for comparison of the dredge alternatives. These comparisons show that the amount of overburden and haul distances have a significant impact on the total dredging costs.

Table 70: B-2 incised channel dredging scenarios and costs

B-2				
	Trinity/Sabine Incised Valleys		**Colorado/Brazos Deltas and Valleys**	
Scenario Description	Shore Offload	Shore Offload	Shore Offload	Shore Offload
Total Fill Volume [MCY]	8.8	8.8	8.8	8.8
Borrow Source	Trinity/Sabine Paleo Channels and Deltas	Trinity/Sabine Paleo Channels and Deltas	Colorado/Brazos Paleo Channels and Deltas	Colorado/Brazos Paleo Channels and Deltas
Haul Distance [mi]	45	65	15	35
Average Pipeline Used [LF]	23,750	23,750	23,750	23,750
Average Number of Boosters Required	2	2	2	2
Weather Downtime [%]	10%	10%	10%	10%
Maintenance and Breakdowns [%]	10%	10%	10%	10%
Over Burden Time [% of Total Dredge Time]	50%	50%	50%	50%
Effective Working Time [%]	30%	30%	30%	30%
Dredging Unit Cost* [$/CY]	$24-$34	$31-$44	$16-$23	$22-$31
Total Costs* [Millions]	$211-$300	$273-$387	$141-$203	$194-$273

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

Based on the preliminary estimates in Table 70, the Colorado/Brazos Paleo Channels and Deltas would be the preferred over the Trinity/Sabine Paleo Channels and deltas as they are geographically much closer to the project site. Further investigation is necessary to identify the actual locations and quantities beach quality sand within these paleochannels.

Estimates of construction durations are shown in Table 71 for the scenarios identified in this section. These durations are also subject to change based on the actual overburden and distance from the project site. If overburden is less than assumed herein then a single dredge may be able to complete the project

Table 71: B-2 incised channel dredging scenario durations.

B-2				
	Heald Bank		Sabine Bank	
Scenario Description	Freeport Offload	Shore Offload	Freeport Offload	Shore Offload
Borrow Source	Heald Bank	Heald Bank	Sabine Bank	Sabine Bank
Haul Distance [mi]	45	65	15	35
Weather Downtime [%]	9.7%	9.7%	9.7%	9.7%
Maintenance and Breakdowns [%]	10%	10%	10%	10%
Overburden Time [% of Total Dredge Time]	50%	50%	50%	50%
Effective Working Time [%]	30%	30%	30%	30%
Total Volume [MCY]	8.8	8.8	8.8	8.8
Loads Per Day [1 Dredge]	0.6	0.5	1.0	0.7
Total Duration [Years]	5	7	3	5

4.4.3 Summary of Source Scenarios

A summary of all the source scenarios for all of the B-2 ER measure components is provided in Table 72. Note that the costs shown are midpoint of the cost range estimate. For this alternative all options have similar costs, but these do not include the additional costs for investigation necessary to pinpoint the exact quantities and types of materials available within each borrow source. This cost would likely be substantially higher for the Paleochannel and delta alternatives as more investigation would be necessary to find the necessary materials which may not be within the assumed distances from the project site. Also, overburden may be more than assumed or the target material may be within smaller pockets which would require relocation of the dredge and additional dredging of overburden materials which would incur higher costs.

Table 72. ER Measure B-2 Conceptual Cost and Duration Source Summary

Source	Dredge Scenario	$/CY	Duration [years]
Heald Bank	15,000 CY Hopper with Freeport entrance offload	$21.50	2.5
Heald Bank	15,000 CY Hopper with shore offload	$20.50	2.6
Sabine Bank	15,000 CY Hopper with Freeport entrance offload	$27.50	3.1
Sabine Bank	15,000 CY Hopper with shore offload	$25.00	3.2
Trinity/Sabine Paleo Channels and Deltas	15,000 CY Hopper with shore offload- 45 mile haul	$29.00	5
Trinity/Sabine Paleo Channels and Deltas	15,000 CY Hopper with shore offload- 65 mile haul	$37.50	7
Colorado/Brazos Paleo Channels and Deltas	15,000 CY Hopper with shore offload- 15 mile haul	$19.50	3
Colorado/Brazos Paleo Channels and Deltas	15,000 CY Hopper with shore offload- 35 mile haul	$26.50	5

Table 73. Advantages and Disadvantages of ER Measures B-2 material sources

	Advantages	Disadvantages	Future Considerations
Sabine and Heald Banks	• Large quantities of sand available. • Multiple hoppers could be used in Sabine Bank with large dig areas to reduce duration.	• Long sail distances. • Pipeline locations restricting available dredge areas. • Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, quantities, and dredge depths. • Environmental dredging windows.
Incised Channels	• Potentially large quantities of sand available.	• Long sail distances • Lack of information on the locations of sandy sediments within these paleochannels. • Potentially large amounts of overburden to dredge to get to sand. • Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify potential beach quality sand locations, overburden quantities, and dredge depths. • Environmental dredging windows.

4.5 ER Measure B-12

Ecosystem restoration measure B-12 consists of initial marsh creation and restoration & out – year marsh creation and restoration. The measure is shown in Figure 69 with required quantities summarized in Table 74.

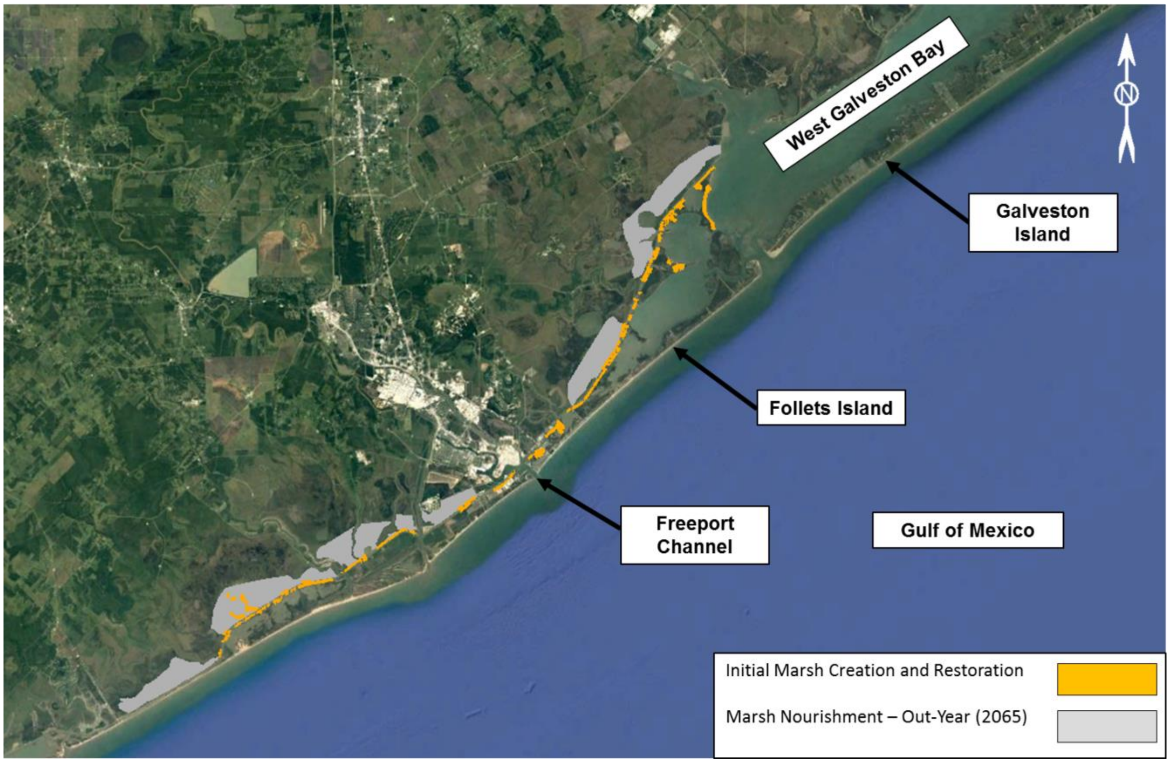


Figure 69. Ecosystem restoration measure B-12

Table 74. Ecosystem restoration measure B-12 required quantities

	Marsh Creation and Restoration (Initial) (CY)	Marsh Creation and Restoration (Out Year 2065) (CY)	Total (CY)
B-12: Bastrop Bay, Oyster Lake, West Bay, and GIWW Shoreline Protection	399,863	29,060,231	29,460,094

4.5.1 Initial Marsh Creation

ER measure B-12's initial marsh creation and restoration areas are located along the adjacent shorelines between GIWW channel stations 470+000 and 650+000. The initial marsh creation was separated into different areas as shown in Figure 70.

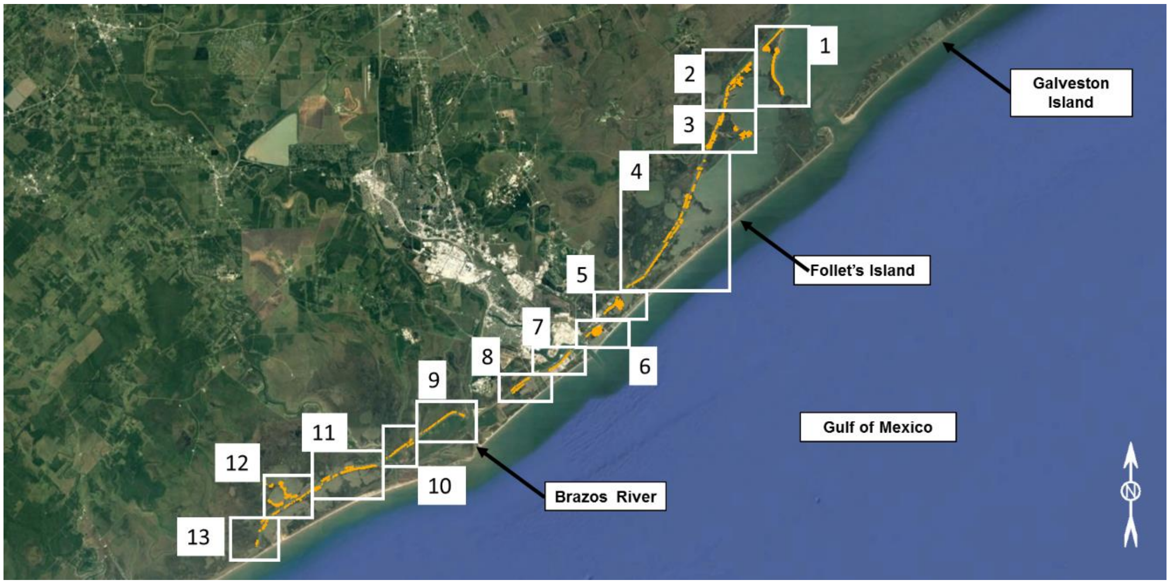


Figure 70. B-12 Initial Marsh Creation and Restoration Areas

4.5.1.1 Ship Channel Dredging

Based on the shoaling rates in the GIWW (see Table 17 in Section 3.7.1) maintenance dredging material from one dredging cycle in the GIWW will provide a sufficient supply of material to fill the initial marsh area. As there is sufficient material and maintenance dredging is routinely conducted, sourcing from the GIWW was the only scenario considered for ER measure B-12's initial marsh creation and restoration. In order to estimate the costs, assumptions regarding the methodology for harvest, transport, and placement of the material must be made. It was determined that 18" - 24" hydraulic suction cutterhead dredges would be used to dredge the marsh restoration material. These dredges are frequently used for the dredging, transporting, and placement of the maintenance material in the GIWW. In channel dredging with a hydraulic cutterhead dredge the material in pumped directly from the dredge to the placement area. The dredge typically as several hundred feet of floating/pontoon pipe behind it attached to a submerged pipe. The submerged pipe comes up on shore at the placement area where shoreline pipe added as marsh areas are filled. Therefore, when calculating average pipeline lengths, the both addition of pipeline behind the dredge as it moves down a channel and, on the shore, the addition of shoreline as it fills marsh areas were considered.

The acreage of each areas was estimated off aerials and the total volume in each of the areas was calculated based on the percentage of the total area. Average pipelines were then measured by estimating the length of the channel which would need to be dredged to supply the fill volume required in each area. For the purpose of this conceptual cost estimate, it was also assumed that shoaled material in the channel would be evenly distributed. This will not be the case during an actual maintenance dredging event and future studies should evaluate past before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel. It was also assumed that a contractor would try and limit the average pipe to line lengths which would not require a booster dredge, approximately 15,000 LF. The volumes and estimated pipeline lengths used in this study are shown in Table 75. A total preliminary cost was developed from various areas volumes and pipelines and is shown in Table 76

Table 75. B-12 Initial Marsh Creation separated by area

Areas	Acres	% of Total	Volume [CY]	Average pipeline [FT]
1	90	14.7	58,720	14,000
2	82	13.3%	53,210	8,950
3	72	11.8%	47,060	10,050
4	74	12.0%	48,030	9,850
5	57	9.4%	37,420	8,150
6	56	9.2%	36,760	6,000
7	12	1.9%	7,600	2,500
8	15	2.5%	10,060	2,500
9	9	1.5%	6,130	2,500
10	15	2.5%	9,990	2,500
11	44	7.1%	28,490	7,250
12	73	11.9%	47,620	13,000
13	13	2.2%	8,770	3,500
	613	**100%**	**399,860**	**9,280**

Table 76. B-12 Initial Marsh Creation Ship Channel Dredging Costs

B-12 Initial Marsh Creation and Restoration	
	All reaches
Total Fill Volume [CY]	399,863
Borrow Source	GIWW
Average Pipeline Used [LF]	9,280
Average Number of Boosters Required	0
Material Classification [%]	90% Mud/silt 10% Sand
Dredging Rate [CY/hr]	900
Time to Complete Dredging [Months]	1.2
Dredging Unit Cost* [$/CY]	$3.5 – $4.9
Total Costs* [Millions]	$1.4 – $1.9

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.5.2 Out Year 2065 Marsh Creation

B-12 has out-year marsh areas along the shoreline adjacent to the GIWW between channel stations 470+000 and 650+000 in much of the same area as the initial marsh creation. These are marsh areas that are projected to be restored in the year 2065. The out-year marsh creation was separated into different areas as shown in Figure 71. The acreage of each areas was estimated off aerials and the total volume in each of the areas was calculated based on the percentage of the total area as shown in Table 77.

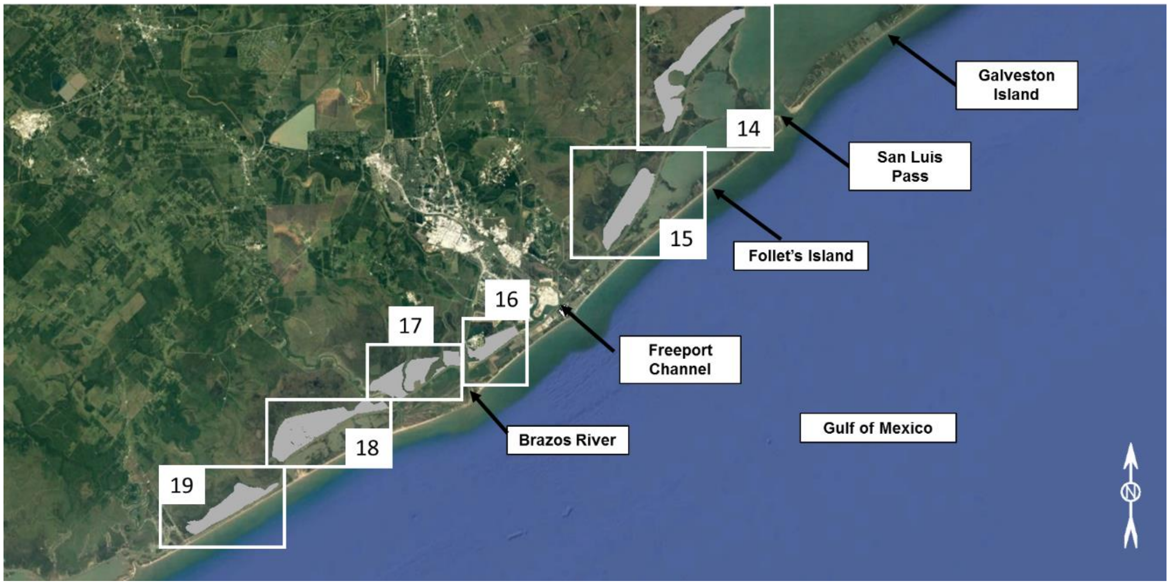


Figure 71. B-12 Out - year 2065 marsh creation and restoration areas

Table 77. B-12 Out – year marsh creation separated by area

Areas	Acres	% of Total	Volume [CY]
14	3,930	24.5	7,126,300.00
15	2,510	15.7%	4,548,600.00
16	1,050	6.5%	1,895,900.00
17	2,590	16.1%	4,691,700.00
18	3,760	23.5%	6,816,600.00
19	2,200	13.7%	3,981,100.00
	16,070	**100%**	**29,060,200**

Several sediment sources were identified as potential sources for the east and west out-year marsh areas and they are detailed in the following Sections. The primary constraint for a sediment source were if it contained enough material for to fill the ER measure marsh areas during one construction phase. This eliminated most maintenance dredging channel sources as the maintenance dredging quantities were typically not sufficient to fill entire marsh areas.

4.5.2.1 Shoreface Sediment Dredging

Shoreface sediments were considered as a large source of sediment for fill material. B-12's out-year marsh areas are too spread out to feasible use a single shoreface source for all the areas. The three shoreface sources identified as potential sources for the B-12 out years marshes are the offshore Galveston Island shoreface, the Follett's Island shoreface, and the Brazos River Delta. These sources are detailed in Section 3.2 and were found to have millions of cubic yards of material which could be used to fill marshes. Two dredging scenarios were considered for the Galveston Island shoreface sediment dredging: offshore dredging with a 34" hydraulic dredge with the dredging pumping out directly to the marsh areas, and dredging with a 15,000 hopper dredge (see Section 4.2.1.1, Table 42). However, the bathymetric depths of the shoreface sediment offshore Follett's Island and within the Brazos Delta are too shallow for a 15,000 CY hopper dredges and only hydraulic dredges were considered for these locations. Future studies should assess the potential for digging these two areas with smaller hopper dredges.

Hydraulic Suction Cutterhead Dredge Scenarios

The primary constraint for hydraulic dredges for harvesting material from shoreface sediment areas is the exposure to offshore waves. Generally hydraulic dredges have difficulty working in waves greater than 3 – 4 feet, however several U.S. dredging companies have experience safely dredging offshore with hydraulic dredges.

The effective work time also includes estimated loss in time due to weather, moving the dredge, shutting down the dredge to add pipe at the shore, and to perform maintenance. In addition to the length of the submerged pipeline, the maximum amount of pipe which would need to be added behind the hydraulic dredge in the dig area to reach the furthest reaches, and the maximum shoreline were also included the average pipeline calculation for each marsh area.

Out – year marsh area 14 could potentially source material from either the Galveston Island shoreface or Follett's Island shoreface. Out – year marsh area 15 is a location where it would be optimal to source material from the Follett Island shoreface. The Brazos Delta is the optimal shoreface sediment source for out-year marsh areas 16 – 19. The estimated dredge dig areas were placed within the boundaries of the boring locations shown in Figure 6, Figure 7, Figure 8 and production rates were calculated assuming an estimated dig face as calculated in Table 12, Table 13, and Table 14 (see Section 3.2) . This study did not take into account the potential effects of removing large amounts of shoreface sediment on the coastal processes of the adjacent shoreline. These effects should be examined in further studies.

For the Galveston Island scenario, it was assumed shoreface dredging for the marshes would occur seaward of the -30 FT contour so as to avoid areas with potential beach quality sand. Substantial quantities of Beach quality sand were not located in either of the two shoreface sources and the pipeline buffers were the primary constraint when approximating the dredge dig areas. Note that in the Follet's Island pipeline scenario, the pipeline would need to cross over or under CR257. This could create a potential logistical concern that should be analyzed further if this scenario is selected.

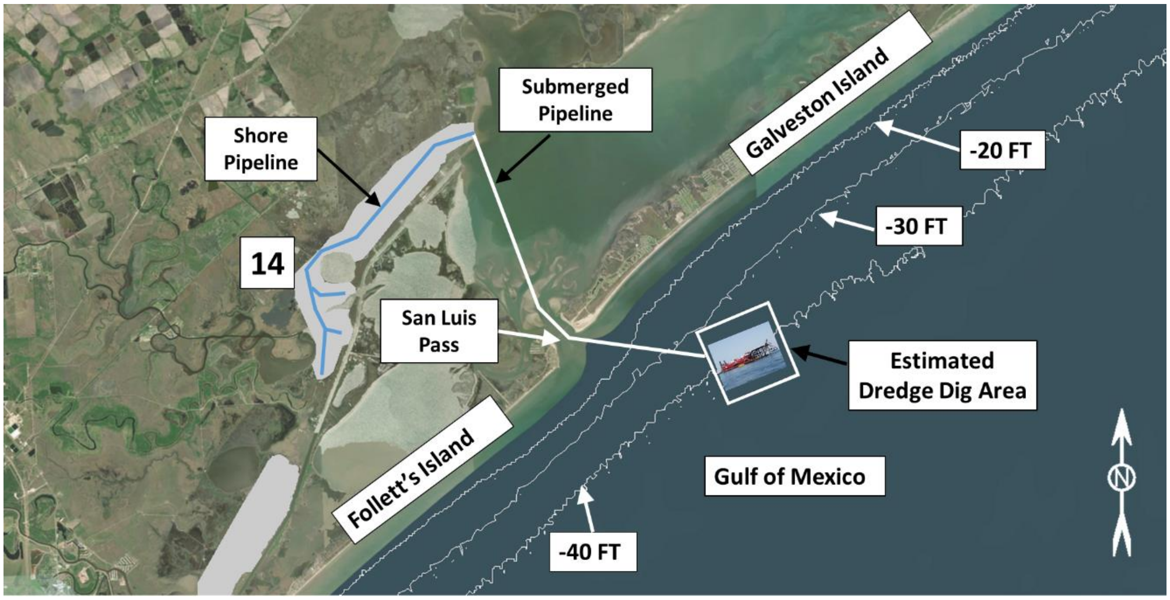


Figure 72. B-12 out-year marsh creation – Shoreface sediment Hydraulic dredging Galveston Island

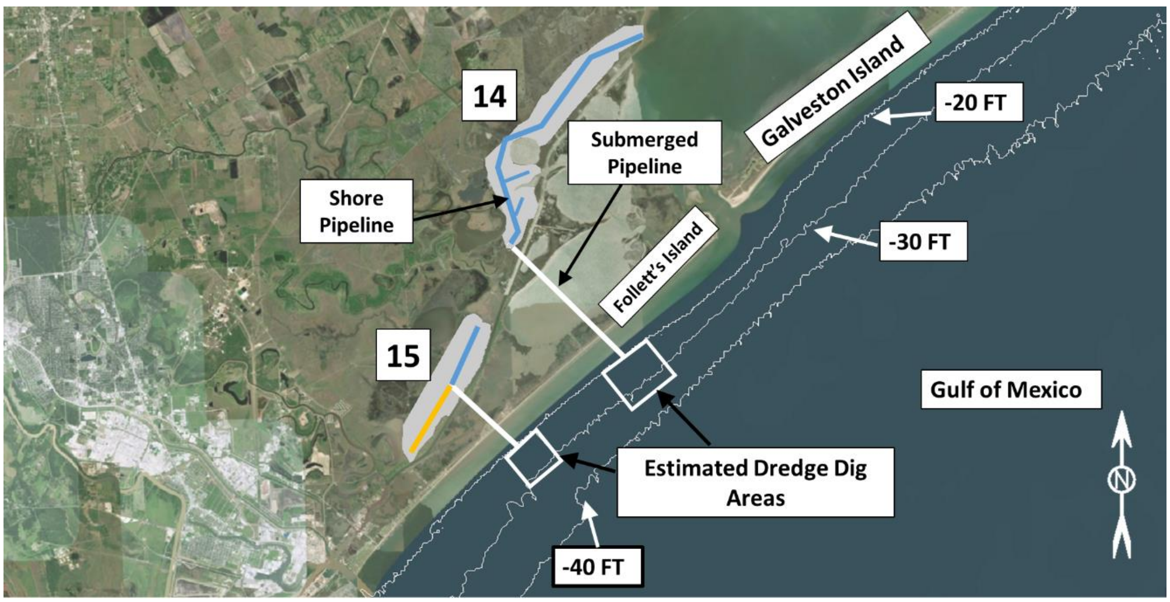


Figure 73. B-12 out-year marsh creation – Shoreface sediment Hydraulic dredging Follett's Island

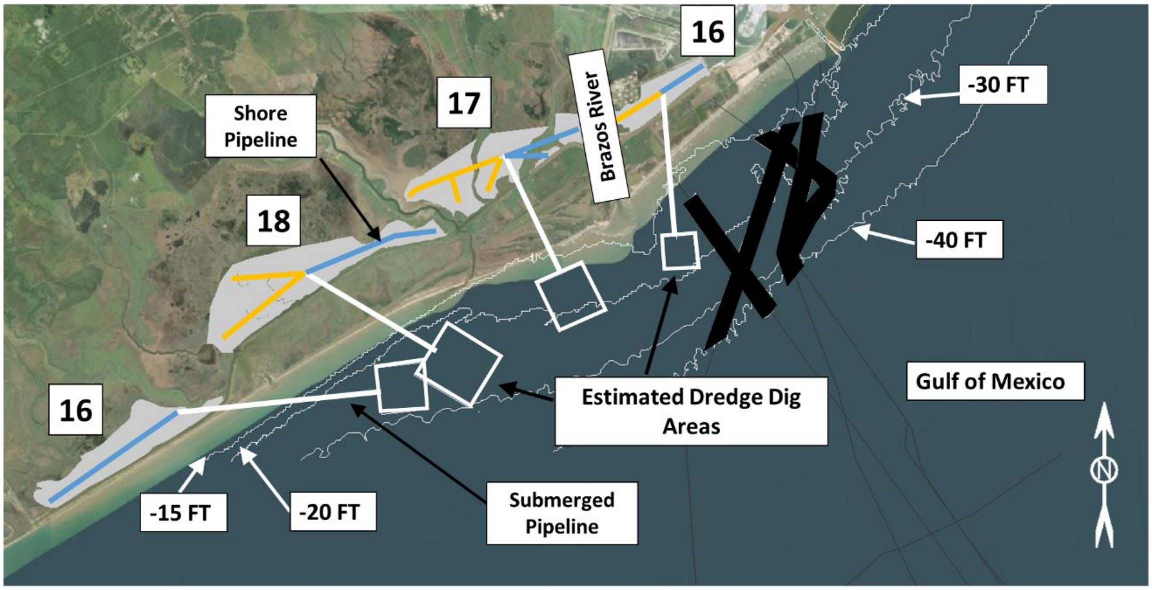


Figure 74. B-12 out-year marsh creation – Shoreface sediment Hydraulic dredging Brazos Delta

Table 78. B-12 out-year marsh creation – Shoreface sediment hydraulic dredging

B-12 Out Year 2065 Marsh Creation and Restoration

Scenario Description	Reach 14 Direct hydraulic pumpout	Reaches 14 & 15 Direct hydraulic pumpout	Reaches 16 - 19 Direct hydraulic pumpout
Total Fill Volume [MCY]	7.1	11.7	17.4
Borrow Source	**Galveston Island shoreface**	**Follett's Island shoreface**	**Brazos Delta**
Average Pipeline Used [LF]	72,100	38,975	28,155
Average Number of Boosters Required	5	2 - 3	1 - 2
Material Classification [%]	60% Mud/silt 40% Sand	45% Mud/silt 40% Sand 15% Clay	75% Mud/silt 25% Sand
Effective Working Times	55%	55%	55%
Dredging Rate [CY/hr]	1,430	1,150	1,350
Time to Complete Dredging [Months]	21.8	35.5	33.0
Dredging Unit Cost* [$/CY]	$9.75 – $13.65	$8.3 – $11.6	$5.00 – $7.00
Total Costs* [Millions]	$69.5 – $97.3	$96.4 - 135	$87.2 – $122.4

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

Hopper Dredge Scenarios

Hopper dredge pump out locations area constrained by the loaded draft of the hopper. It is estimated that for the large hopper dredge considered (See Table 42),, which has an estimated loaded draft of 30 feet the minimum depth at the pipeline location would need to be 36 feet to account for the draft of the dredge and allow for proper under keel clearance. It was assumed that the dig area would be adjacent to the hopper's pump out location so as to minimize the hopper's sail time to the and from the dig area. While the dig areas shown are approximate, for this study it was assumed that the hopper would dredge an area which will allow it to dig a full load with one turn. It was assumed that the hopper would stage dredging in such a manner that the hopper would be sailing towards the pumpout one the hopper is full.

Due to the soft material type in both shoreface dig areas, the hopper would be unable to reach full loads as softer material does not settle out in a hopper resulting in a point in production where is more efficient to stop digging and pumping out light loads rather than spending the additional time trying to reach maximum draft with the soft material. For this study it was estimated that the maximum hopper volumes per load would be 6,000 CY for material dredged from the Galveston Island shoreface. It is possible that the hopper would be able to safely come in closer to shore than the -36 feet, and this should be researched further in future cost estimates if shoreface sediments are identified as the primary source of material.

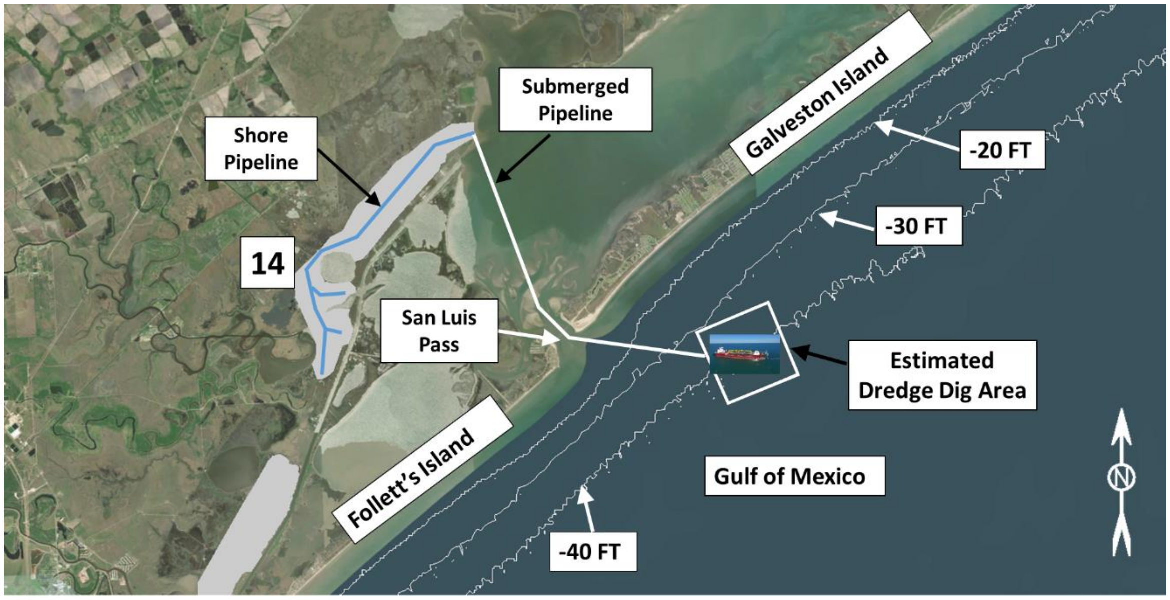


Figure 75. B-12 out-year marsh creation – Shoreface sediment hopper dredging Galveston Island

Table 79. B-12 out-year marsh creation – Shoreface sediment hopper dredging

B-12 Out Year 2065 Marsh Creation and Restoration	
Scenario Description	**Areas 14 Offshore pump out**
Total Fill Volume [MCY]	7.1
Borrow Source	Galveston Island Shoreface
Haul Distance [mi]	2
Average Pipeline Used [LF]	69,000
Average Number of Boosters Required	4
Weather Downtime [%]	10%
Maintenance and Breakdowns [%]	15%
Effective Working Time [%]	75%
Loads per day [1 dredge]	4.2
Time to Complete Dredging [Months]	9.2
Dredging Unit Cost* [$/CY]	$9.7 – $13.4
Total Costs* [Millions]	$68.1 – $95.4

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.5.2.2 Mining Placement Areas

All of the new work dredged material for the main channel Freeport channel deepening and widening is to be placed in PAs 8 and 9, 1.8 and 2.8 MCY respectively. Additionally, PA 1 and ODMDS 1-A are expected to receive 5.7 and 9 MCY respectively of maintenance dredged material from the Freeport Entrance and Main Channels in the next 50 – years (see Section 3.8.2). These placement areas could potentially be mined in the year 2065 to fill the out-year marsh areas.

Confined Placements Areas

Due to their locations and the locations of the out-year marsh creation areas, only area 16 and 17 were considered for potential areas to be filled with material from the confined disposal areas. To avoid the logistical concerns of placing a pipeline in the Brazos River, it was assumed that area 16 would be filled with material from PA 1 and area 17 from PAs 8 and 9. The scenarios were estimated assuming that the PA would be mined hydraulically, using a pump to hydraulically pump water to the placement area to create a slurry mix, and another pump to excavate the placement area and to pump the slurry to the out-year marsh areas. To estimate conceptual costs, it was assumed that the equipment used to excavate the placement areas would have a production rate and power similar to a 16” hydraulic cutterhead dredge.

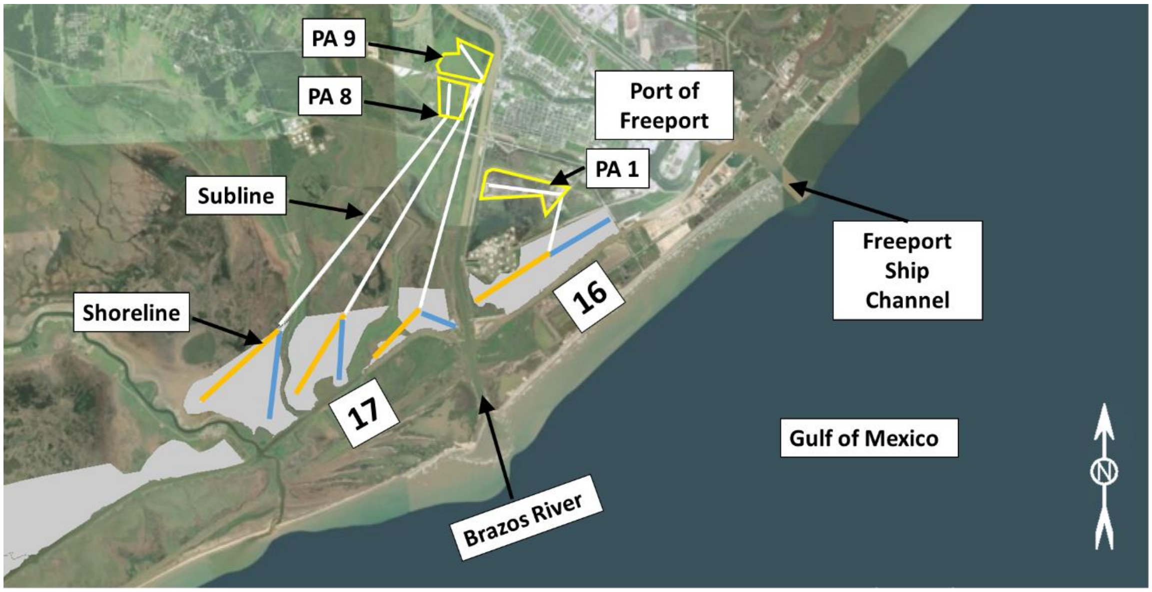


Figure 76. B-12 out-year marsh creation – Confined disposal site mining

Table 80. B-12 out-year marsh creation – Confined disposal site mining

B-12 Out Year 2065 Marsh Creation and Restoration

Scenario Description	Area 16 Hydraulic Mining	Area 17 Hydraulic Mining	Total Areas 16&17 Hydraulic Mining
Total Fill Volume [MCY]	1.9	4.7	6.6
Borrow Source	PA 1	PA8 and PA 9	PA 1, PA 8, PA 9
Average Pipeline Used [LF]	13,000	29,730	24,900
Average Number of Boosters Required	2	4	2-4
Material Classification [%]	80% Mud/clay 20% Sand	80% Mud/clay 20% Sand	80% Mud/clay 20% Sand
Dredging Rate [CY/hr]	734	705	714
Time to Complete Dredging [Months]	7.3	23.9	31.2
Dredging Unit Cost* [$/CY]	$3.5 - $5.0	$5.5 - $7.7	$4.9 – $6.9
Total Costs* [Millions]	$6.7 – $9.4	$25.8 – $36.1	$32.5 – $45.5

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

Offshore Placement Areas

A 15,000 hopper dredge was assumed to for developing a conceptual cost estimate for mining ODMDS 1-A for marsh fill. To minimize line lengths, it was also assumed the dredge would be able to sail in to through the Freeport Ship Channel and pump out the hopper from within the Freeport Harbor as shown on Figure 77. Pumping out the hopper from within the Freeport Harbor would minimize the dredge's vulnerability to weather delays compared to offshore dredging were waves greater than 3 – 4 feet may create an unsafe environment for hooking up a hopper to its submerged pipeline and result in delays.

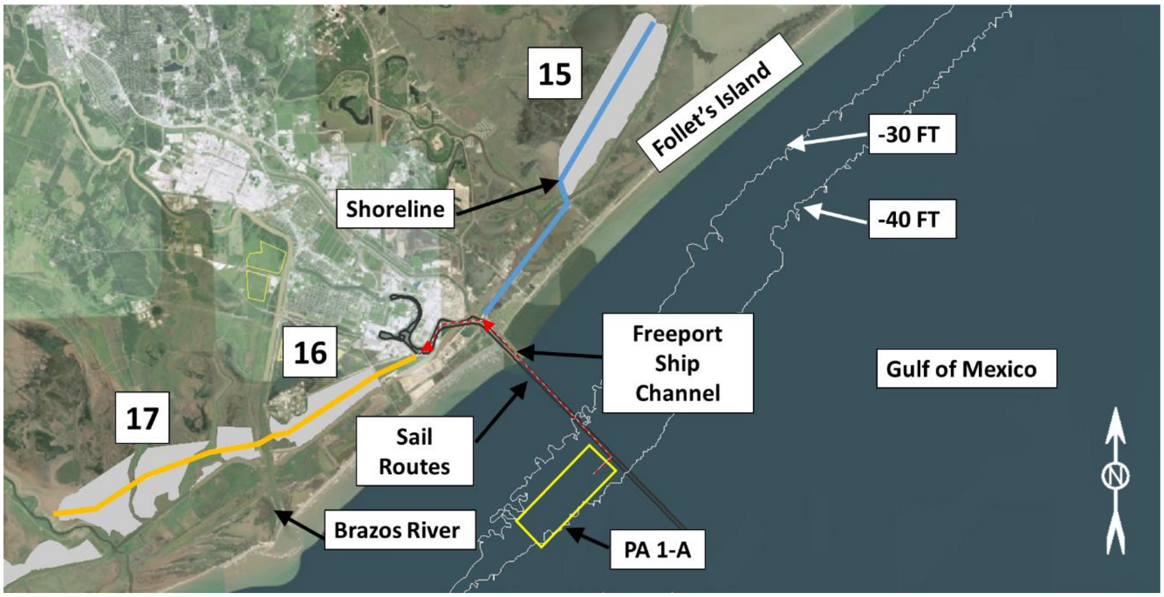


Figure 77. B-12 out-year marsh creation – PA 1-A Offshore disposal site mining

Table 81. B-12 out-year marsh creation – PA 1-A Offshore disposal site mining

B-12 Out Year 2065 Marsh Creation and Restoration

Scenario Description	Areas 15 – 17 Freeport pumpout
Total Fill Volume [MCY]	11.1
Borrow Source	ODMDS 1-A
Haul Distance [mi]	6.2
Average Pipeline Used [LF]	30,260
Average Number of Boosters Required	1 – 2
Weather Downtime [%]	0%
Maintenance and Breakdowns [%]	15%
Effective Working Time [%]	85%
Loads per day [1 dredge]	4
Time to Complete Dredging [Months]	15
Dredging Unit Cost* [$/CY]	$7.7 – $10.8
Total Costs* [Millions]	$86.1 – $120.6

4.5.3 Summary of Source Scenarios

A summary of all the source scenarios for all of the B-12 ER measure components is provided in Table 82. Note that the costs shown are midpoint of the cost range estimate.

Table 82. Measure B-12 Conceptual Cost and Duration Source Summary

Reach	Source	Dredge Scenario	$/CY	Duration [months]
14	Galveston Shoreface	34" Hydraulic direct pump out	$11.70	21.8
14	Galveston Shoreface	15,000 CY Hopper with offshore pump out	$11.55	9.2
14 & 15	Follet's Shoreface	34" Hydraulic direct pump out	$9.95	35.5
16 - 19	Brazos Delta	34" Hydraulic direct pump out	$6.00	33
16 & 17	PAs 1, 8, and 9 Mining	N/A	$5.90	31.2
15 - 17	ODMDS 1-A	15,000 CY Hopper with Freeport Harbor pump out	$9.25	15

Overall the unit costs for the different areas do not differ substantially. It is difficult to compare durations as most the scenarios combine different reaches, however, the hopper dredge scenario for pumping material to the reach 14 estimated to take have the time compared to the hydraulic dredge due to the higher effective work time. Only the shoreface sediment, spread out over in several locations, is able to provide enough fill material for all the out-year marsh areas. For out-year marsh areas 14-17 there are at least two options for sourcing material. However only the Brazos Delta was located as a potential source for areas 18 and 19, which comprise 37% of the total out-year marsh creation. Maintenance material from the Freeport Ship Channel could also be a potential source of material. This source was not considered for the out-year marshes in this study as multiple maintenance dredging events would be required to fill an out – year marsh areas and this study focused on sources which could fill an area in a single dredging event. However, this an option for future consideration if significant advanced maintenance dredging below the authorized depth is allowed.

Table 83. Advantages and Disadvantages of ER Measures B-12 material sources

	Advantages	Disadvantages	Future Consideration
Ship Channel Dredging	• GIWW maintenance dredging event should provide sufficient material to fill all initial marsh creation and restoration areas.	• Only has sufficient quantity for initial marsh creation.	• Future studies should evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel • Potential for filling larger marshes with maintenance material over several dredging cycles.
Shoreface Sediment Dredging	• Large quantities of available sediment • Hydraulic dredging and hopper dredging both possible is some instances. • Only source which has enough material for all out-year marsh areas.	• Offshore dredging and pump out are susceptible to weather delays.	• Additional geotechnical studies and research to better classify material and dredging depths. • Environmental dredging windows. • Further studies on effects of shoreface excavation on nearshore coastal processes.
Mining Placement Areas	• Sediment replenished with maintenance dredged materials. • Could extend usable life of placement area.	None	• Further research into equipment used and costs.

4.6 ER Measure M-8

ER measure M-8 (East Matagorda Shoreline Protection) involves the construction of shoreline protection, island restoration, and oyster reef creation. Sediments would be used to restore a 92.7-acre island that once protected approximately 3.5 miles of shoreline directly in front of Big Boggy National Wildlife Refuge. An initial marsh restoration would be constructed to restore approximately 239 acres in several areas behind the breakwaters to be constructed. An out-year marsh nourishment would occur in 2065 in the areas shown on Figure 78, which would convert to open water or unconsolidated shoreline due to relative sea level rise. The out-year nourishment would create approximately 6,034 acres of marsh area. Sediments would need to be obtained for three portions of this project: island creation, initial marsh creation, and out-year marsh restoration.

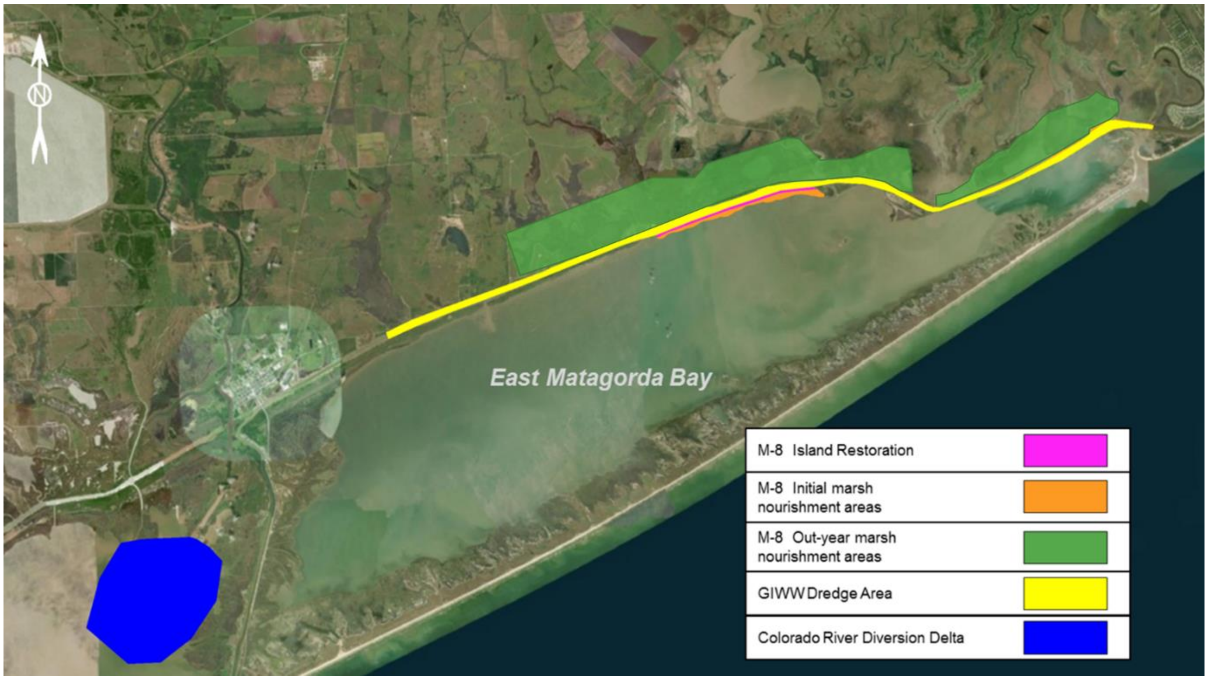


Figure 78. Ecosystem restoration M-8

Table 84. Ecosystem restoration measure M-8 required quantities

	Island Creation and Restoration (CY)	Marsh Creation and Restoration (Initial) (CY)	Marsh Creation and Restoration (Out Year 2065) (CY)	Total (CY)
M-8: East Matagorda Bay Shoreline Protection	1,195,299	173,696	8,858,717	10,227,712

Three sources of sediments were identified to satisfy the material needs for this alternative; maintenance dredging of the adjacent GIWW, dredging of the Colorado River Diversion Delta, and harvesting of materials from the Paleo Colorado and Brazos Deltas.

4.6.1 Ship Channel Dredging

Due to the low quantity of material necessary for marsh creation, it was determined that dredging of the GIWW would be preferred for the initial marsh creation portion of the project. The quantity requirements for the initial island creation and out-year marsh creation far exceed the expected amount available to dredge from the adjacent portion of the GIWW, this channel dredging was not considered for these options.

For the initial marsh creation, it was assumed that an 18” dredge would be used to excavate and pump the material to the project site. Larger dredges would not be recommended due to the depth and size constraints within the GIWW. Shoaling rates for the GIWW were reviewed and it was determined that maintenance dredging of the adjacent portions of the GIWW would be sufficient to satisfy the volume requirements for this portion of the project. Pipeline lengths would be minimized as the dredge pipeline would be relocated as the dredge progresses along the channel. It was also assumed that the material to be dredged from this area would be mostly silt or other fine-grained materials based on review of geotechnical borings for the area. Based on these assumptions the costs shown in Table 85 were developed.

Table 85: M-8 ship channel dredging costs

M-8	
	Initial Marsh Creation
Total Fill Volume [CY]	173,696
Borrow Source	GIWW
Average Pipeline Used [LF]	1,750
Average Number of Boosters Required	0
Material Classification [%]	90% Mud, 9% Sand, 1% Gravel
Dredging Rate [CY/hr]	1,267
Time to Complete Dredging [Months]	0.21
Dredging Unit Cost* [$/CY]	$1.10-$1.54
Total Costs* [Millions]	$0.2-$0.3

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

The initial marsh creation portion of the project is the least costly portion of the project as material requirements are minor. Unit costs described herein do not include any lump sum costs associated with dredging such as mobilization which would increase the total cost of the project significantly.

4.6.2 Colorado River Diversion Delta Mining

The second option considered is mining of the Colorado River Diversion delta. While limited data is available regarding the quantity and type of material available within this delta, preliminary estimates indicate that the delta contains sufficient material to construct all portions of this project. Assuming the entire area of the delta may be dredged, it would only need to be excavated down 2’ from the ground surface to obtain sufficient material to construct all project features. In addition, as the out-year marsh placement is far into the future from the initial portions of the project, material dredged from the delta for the initial work would have replenished well before additional material dredged for the out-year marsh placement.

As with the channel dredging, it was assumed that an 18” hydraulic suction cutterhead dredge would be used to excavate and transport the material to the project site as it would be difficult for larger dredges to work in the shallow waters within this portion Matagorda bay. It is assumed that the material would be pumped hydraulically to the site via pipeline. Results from the cost estimate for the three portions of this project are shown in Table 86.

Table 86: M-8 ship Colorado River Diversion Delta Mining

M-8			
	Initial Marsh Creation	**Island Restoration**	**Out-Year Marsh Placement**
Total Fill Volume [CY]	173,696	1,195,299	8,858,717
Borrow Source	Colorado River Delta	Colorado River Delta	Colorado River Delta
Average Pipeline Used [LF]	96,500	78,500	86,000
Average Number of Boosters Required	8	7	7
Material Classification [%]	90% Mud, 9% Sand, 1% Gravel	90% Mud, 9% Sand, 1% Gravel	90% Mud, 9% Sand, 1% Gravel
Dredging Rate [CY/hr]	402	544	400
Time to Complete Dredging [Months]	2	7	70
Dredging Unit Cost* [$/CY]	$26.05-$36.50	$12.91-$18.07	$14.84-$20.78
Total Costs* [Millions]	$4.5-$6.4	$15.4-$21.6	$132-$184

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

While the initial marsh creation has the lowest total cost, due to the much lower dredge volume, unit costs are much highest as overall the longest length of pipeline would be required to reach every marsh area. The island restoration has the lowest unit costs as it is concentrated within a smaller area closer to the harvest site. Finally, the out-year marsh placement has slightly lower costs than the initial marsh creation as the area does not extend as far east as the initial marsh creation and most of the area to be filled is concentrated slightly closer to the borrow area than the initial marsh creation.

4.6.3 Summary of Source Scenarios

A summary of all the source scenarios for all of the M-8 ER measure components is provided in Table 87. Note that the costs shown are midpoint of the cost range estimate.

Table 87. Measure M-8 Conceptual Cost and Duration Source Summary

Source	Dredge Scenario	$/CY	Duration [months]
GIWW	18” Hydraulic Dredge - Initial marsh creation	$1.3	0.2
Colorado River Delta	18” Hydraulic Dredge - Initial marsh creation	$31.3	2
Colorado River Delta	18” Hydraulic Dredge – Island Restoration	$15.5	7
Colorado River Delta	18” Hydraulic Dredge – Out-Year Marsh Placement	$17.8	70

Based on these preliminary costs, Colorado River Delta mining would not be recommended for the initial marsh creation as channel dredging would satisfy the material requirements and is far less costly than this option. Delta mining is the preferred option for the island restoration and out-year marsh placement portions of this project as this source should have sufficient material to meet the demand for these projects. In addition, there are potential environmental impacts involved with dredging the delta that should be investigated further if this option is selected. Also, the delta is much closer to the project site than potential offshore material sources which would be far costlier to transport to the project site. These recommendations are based on the information presented herein based on current data available, additional investigation will be necessary to evaluate the true feasibility for mining these materials in the future.

Table 88. Advantages and Disadvantages of ER Measures M-8 material sources

	Advantages	Disadvantages	Future Consideration
Ship Channel Dredging	• GIWW maintenance dredging event should provide sufficient material to fill all initial marsh creation and restoration areas.	• Only has sufficient quantity for initial marsh creation.	• Potential for filling larger marshes with maintenance material over several dredging cycles. • Future studies should evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel
Colorado River Delta	• Large quantities of available sediment • Only source which has enough material for all out-year marsh areas. • Material would replenish between initial marsh creation and island restoration and 2065 out-year marsh creation.	• Potential negative environmental impacts of dredging the delta.	• Additional geotechnical studies and research to better classify material and dredging depths. • Investigation into potential environmental impacts of dredging the delta.

4.7 ER Measure CA-5

ER Measure CA-5 (Keller Bay Restoration) involves the construction of miles of rock breakwaters and oyster reef along the Matagorda Bay shoreline adjacent to Keller Bay. An out-year marsh nourishment would occur in 2065 in areas that would otherwise be impacted by relative sea level rise. The out-year marsh nourishment would cover approximately 623 acres. A one-time placement of approximately 915,000 cubic yards of material would be required for the marsh nourishment occurring in 2065. The focus of this section is to identify the anticipated costs for the 2065 marsh restoration using sediments dredged from the upper half of the Matagorda ship channel for nourishment. Based on the quantity of material necessary, borrow sources were selected based on the feasibility and availability of material.

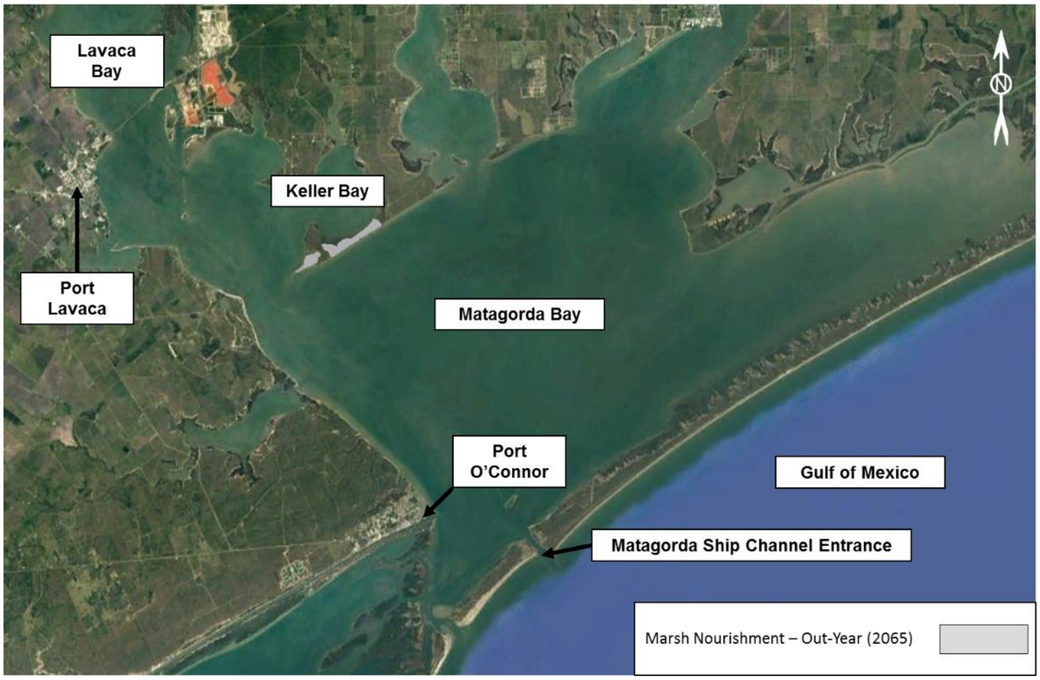


Figure 79. ER Measure CA-5

4.7.1 Ship Channel Dredging

Based on the historical shoaling rates of the Matagorda ship channel, approximately 7 miles of channel would need to be dredged to meet the volume requirements after 1 year of anticipated shoaling. For the purpose of this conceptual cost estimate, the estimate assumes that the channel shoaling is uniform throughout the 7-mile length. For the purpose of this conceptual cost estimate, the estimate assumes that the channel shoaling is uniform throughout the 7-mile length. This will not be the case during an actual maintenance dredging event and future studies should evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel. It was also assumed that the material would be dredged using an 18" hydraulic cutter suction dredge to excavate the material and pump it to the project site via pipeline. It was estimated that a minimum 8,000 LF and maximum 45,000 LF of pipeline would be necessary to pump material to the project site throughout the dredging of the channel. Studies of the shoaling materials within the Matagorda Ship channel showed that the materials within the channel tend to be a mixture of muddy sands, thus for this estimate it was assumed that the material dredged was 78% mud and 22% sand (see paragraph 3.7.4). Using these assumptions, the parameters in Table 89 were estimated to determine the approximate cost. The costs shown are in 2018 dollars.

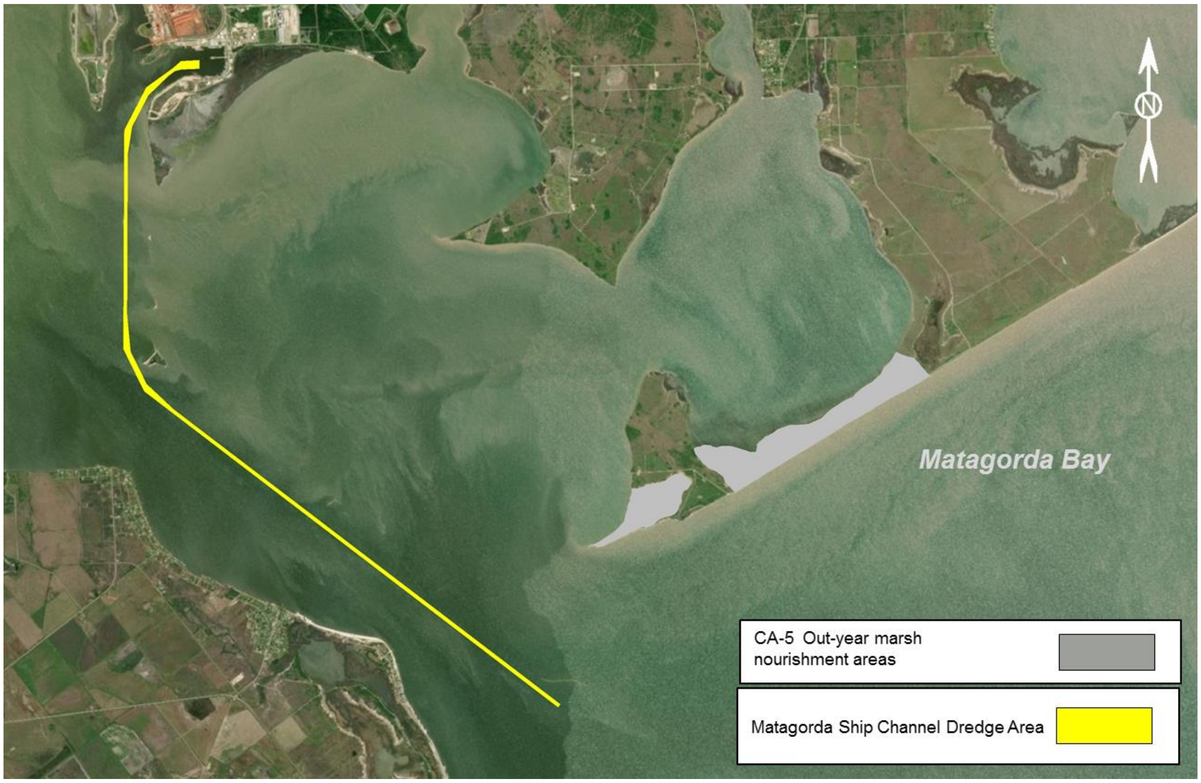


Figure 80. ER Measure CA-5 Ship Channel Dredging

Table 89: CA-5 ship channel dredging costs

CA-5	
	Matagorda Ship Channel
Total Fill Volume [CY]	915,000
Borrow Source	Matagorda Ship Channel
Average Pipeline Used [LF]	26,500
Average Number of Boosters Required	2
Material Classification [%]	78% Mud, 22% Sand
Dredging Rate [CY/hr]	674
Time to Complete Dredging [Months]	2.6
Dredging Unit Cost* [$/CY]	$3.29-$4.60
Total Costs* [Millions]	$3-$4.2

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

Maintenance dredged material from the Matagorda Ship Channel was the only source considered for ER Measure CA-5 as the channel should be able to supply a sufficient volume required to fill the out-year marsh area. If the quantity required for the fill material increases, other sources may need to be located in the futures, such as new work dredging material or open water DMPAs. Future studies should also evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel. Knowing the typical areas for shoaling will allow for a better estimate of pipe placement and pipeline lengths.

4.8 ER Measure CA-6

ER Measure CA-6 (Powderhorn Shoreline Protection and Wetland Protection) involves the restoration of approximately 6.7 miles of Matagorda Bay shoreline fronting portions of the community of Indianola, the Powderhorn Lake estuary, and Texas parks and Wildlife's Powderhorn Ranch. For the marsh restoration portion of the project, approximately 386,000 cubic yards of material will be required to restore four adjacent marsh areas covering approximately 531 acres.

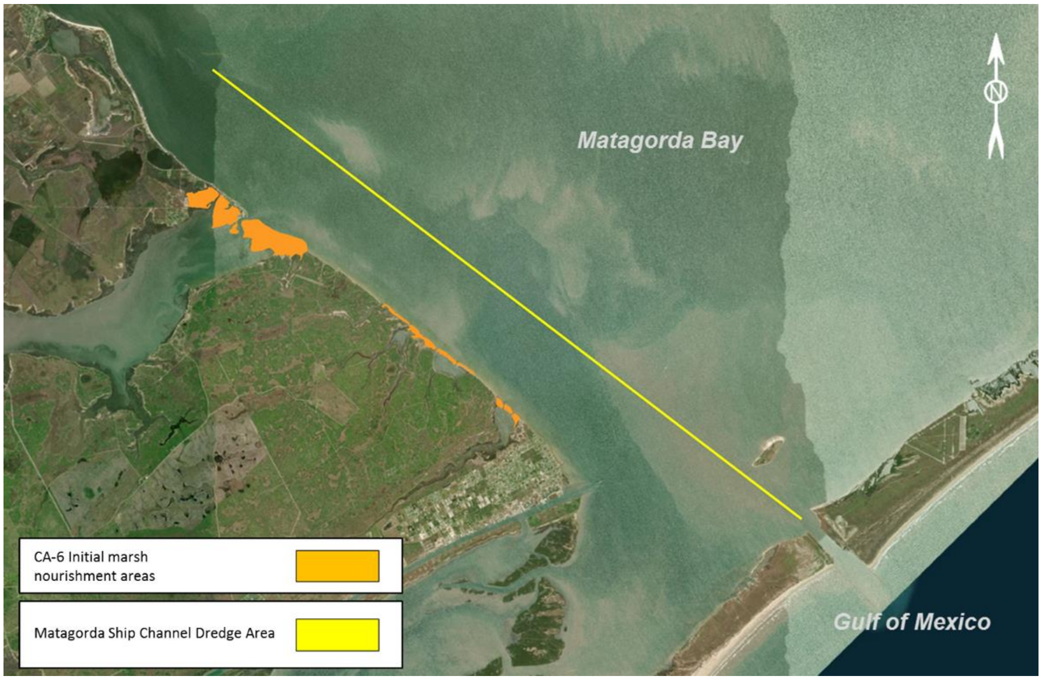


Figure 81. ER Measure CA-6

4.8.1 Ship Channel Dredging

The fill for the marsh restoration will be harvested from maintenance dredging of the adjacent Matagorda Ship Channel. Based on the anticipated shoaling and approximate volumes for fill of each restoration area, dredging would occur along the sections of channel adjacent to the marsh restoration area. It was assumed that an 18" hydraulic cutter suction dredge would be used to excavate the material and a minimal amount of pipeline would be used to pump the material to the restoration areas. Due to the short distance it is assumed that a booster pump would not be required to pump the material and the pipeline would be moved along as the dredge progresses with dredging of the channel. Based on the assumptions, the costs shown in Table 90 were estimated.

Table 90: CA-6 ship channel dredging costs

CA-6	
	Matagorda Ship Channel
Total Fill Volume [CY]	386,000
Borrow Source	Matagorda Ship Channel
Average Pipeline Used [LF]	9,850
Average Number of Boosters Required	0
Material Classification [%]	78% Mud, 22% Sand
Dredging Rate [CY/hr]	583
Time to Complete Dredging [Months]	1
Dredging Unit Cost* [$/CY]	$2.50 - $3.25
Total Costs* [Millions]	$1 - $1.3

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

Costs for this measure are relatively low due to the minimal pipeline lengths required. Due to the proximity to the project site, the resulting low cost, and the fact that it shoaling rates suggest a sufficient amount of quantity, only the Matagorda Ship Channel sediment source was investigated for this measure.

If the quantity required for the fill material increases, other sources may need to be located in the future, such as new work dredging material or open water DMPAs. Future studies should also evaluate before dredge surveys from past maintenance dredging events to assess typical shoaling patterns and maintenance material locations throughout the channel. Knowing the typical areas for shoaling will allow for a better estimate of pipe placement and pipeline lengths.

4.9 ER Measure SP-1

The sediment source portion of ER Measure SP-1 only consists of Island Creation and Restoration of islands in Red Fish Bay to the north of the Corpus Christi Ship Channel. The measure also involves oyster reef and breakwater construction, however no sediment is anticipated to be required during construction of these features. The restoration will require an estimated quantity of 6.7 MCY of material.

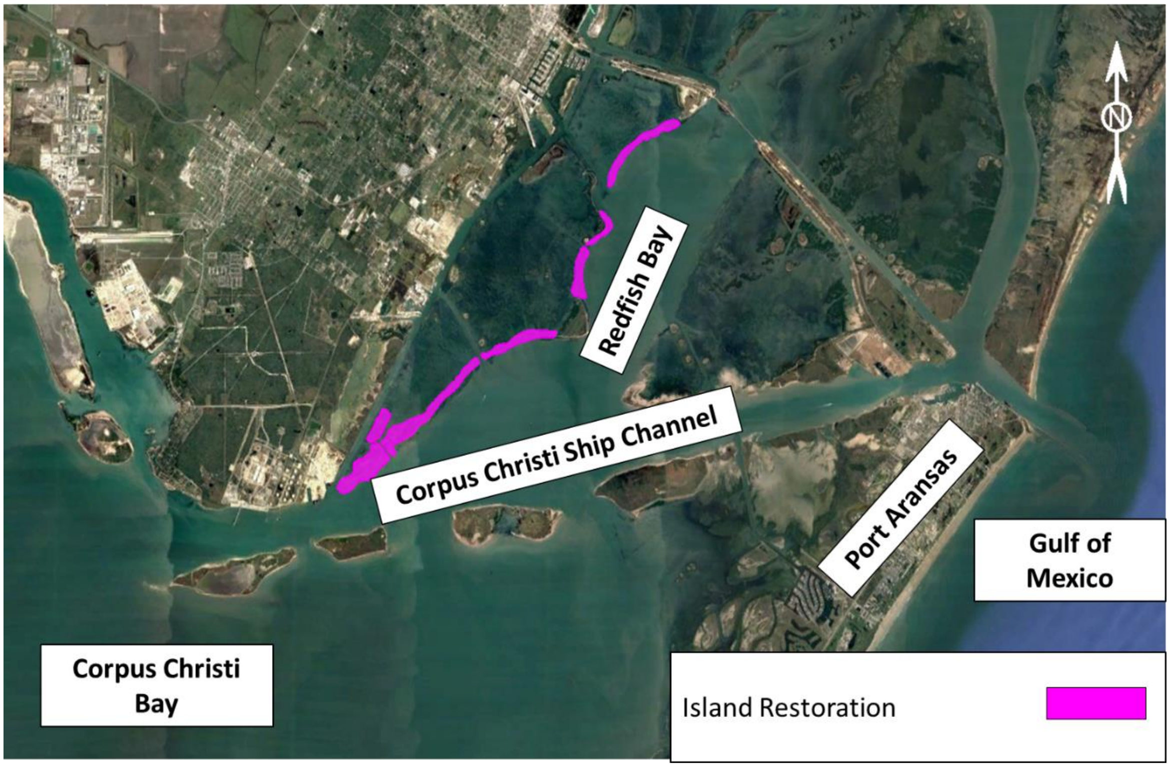


Figure 82. Ecosystem restoration measure SP-1

Only two sources were considered as potential sources of fill material for the island restoration, new work material from the Corpus Christ Ship Channel deepening and widening and mining material from offshore placement areas.

4.9.1 Ship Channel Dredging

The CCSC deepening and widening quantities from either the Lower Bay or Mid Bay would provide enough material to fill the island restoration area. The Port of Corpus Christi Authority (PCCA) has an aggressive schedule and is aiming for all phases of the project to be completed by the year 2021. Coordination with the PCCA will need to occur very quickly to consider using some of this new work material as fill for the island restoration. Additionally, the PCCA is already planning to beneficially reuse much of the new work material in surrounding placement areas, especially the material from the Lower Bay. If there is more new work quantity than previously estimated this extra amount could potentially be used in the island restoration areas. Also, most of the new work dredged material from the Mid Bay is slated to be disposed in adjacent open water disposal areas (see Section 3.8.3). If coordination is able to occur with the PCCA prior to the project, this material could potentially be beneficially reused for the island restoration instead.

It should also be noted that maintenance dredging material is also a potential source for fill, however multiple dredging cycles would be required to provide sufficient quantities for the fill. Maintenance dredging material was not considered for the SP-1 island restoration in this study as this study focused on sources which could fill an area in a single dredging event. However, this an option for future consideration if significant advanced maintenance dredging below the authorized depth is allowed.

Both hydraulic and hopper dredging scenarios were considered for using dredged material from the new work deepening and widening channel improvements.

4.9.1.1 Hydraulic Dredging Scenarios

Conceptual cost estimates were developed for two hydraulic dredge scenarios in the Lower Bay. These scenarios include dredging with a 34” hydraulic dredge and pumping directly to the restoration site or pumping to scows which are towed to site to where the scows are hydraulically offloaded throughout the project site. For the scenario where the dredge is pumping directly the island restoration site, it was assumed that the furthest reaches of the island area would be filled initially, and fill would proceed south as the hydraulic dredge digs towards the Entrance Channel. This would ideally limit the amount of pipeline the dredge would have to pump through as shoreline would be removed as pipeline is added behind the dredge down the channel.

For the scenario where the hydraulic dredge is dredging to scows which are towed to the site and unloaded, it was assumed the dredge would fill 3,000 CY scows towed with a 2,400 HP tug. The southernmost point of the island restoration area was selected as the pump out location. This location is just north of the CCSC and would be in fairly shallow water, which is the reason a 3,000 CY scow was assumed instead of a larger 6,000 CY scow. Further consideration should be given to other potential pump out sites as this location adjacent to the CCSC would be exposed to a lot of passing ship traffic. It may be required to dredge access to a pump out location through Red Fish Bay.

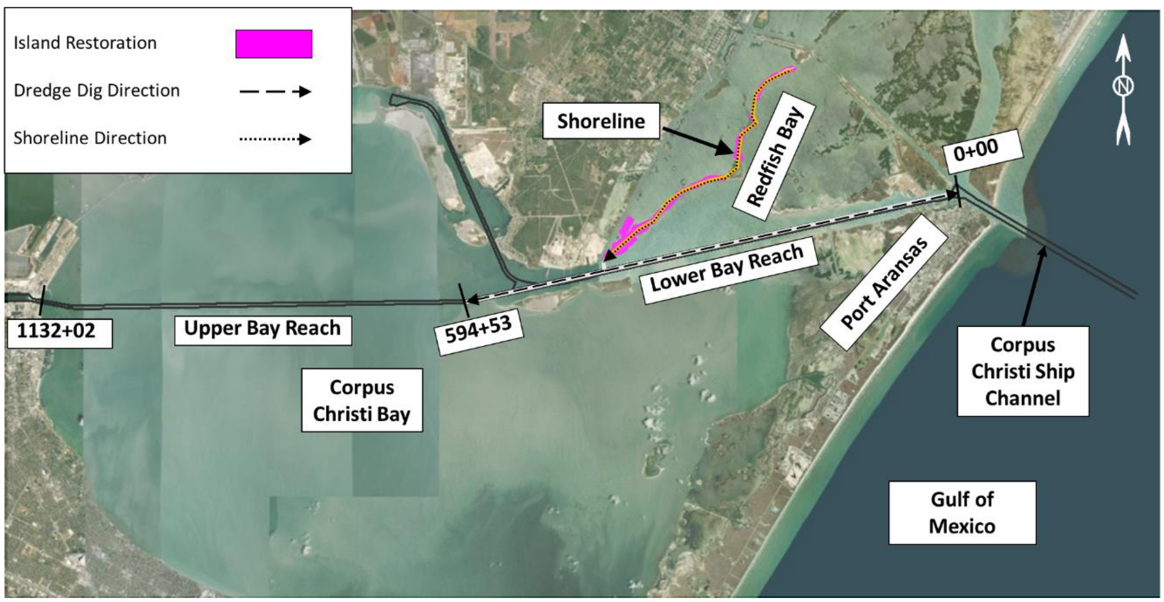


Figure 83. SP-1 Island Creation and Restoration – Hydraulic dredge channel dredging

Table 91. Island Creation and Restoration – Hydraulic dredge channel dredging

SP – 1 Island Creation and Restoration

Scenario Description	Deepening and Widening New Work	
	34" Hydraulic Dredge Direct Pumpout	34" Hydraulic Dredge to scows
Total Fill Volume [MCY]	6.7	6.7
Borrow Source	CCSC Lower Bay New Work	CCSC Lower Bay New Work
Haul Distance [mi]	N/A	6
Number of SCOWs Required	N/A	2
SCOW Capacity [CY]	N/A	3,000
SCOW Round Trip Travel Time [hrs]	N/A	1.45
Average Pipeline Used [LF]	30,250	18,275
Average Number of Boosters Required	3	0 - 1
Material Classification [%]	10% Mud/silt 90% Sand	10% Mud/silt 90% Sand
Dredging Rate [CY/hr]	1,540	1,200
Time to Complete Dredging [Months]	13.5	13
Dredging Unit Cost* [$/CY]	$6.32 - $8.8	$7.74 – $10.84
Total Costs* [Millions]	$42.3 – 59.2	$45.1 – 63.2

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.9.1.2 Hopper Dredging Scenarios

Two hopper dredge channel scenarios were considered, the first sourcing material from the Lower Bay channel segment and the second sourcing material from the Mid Bay channel segment. Both hopper dredge scenarios were developed assuming a 15,000 CY hopper. The primary difference between the two scenarios were the estimated pipeline lengths and material classifications. The finer material in the Mid Bay will result in smaller hopper loads for that segment and the duration for the project would be longer than if the material were sourced from the Lower Bay as seen in Table 92. The pump out location was again assumed at the southernmost point of the island restoration site, however access to this location with this size of dredge would likely have to be dredged. As mentioned in the previous Section, further consideration should be given to other potential pump out sites as this location adjacent to the CCSC would be exposed to a lot of passing ship traffic. It may be required to dredge access to a pump out location through Red Fish Bay.

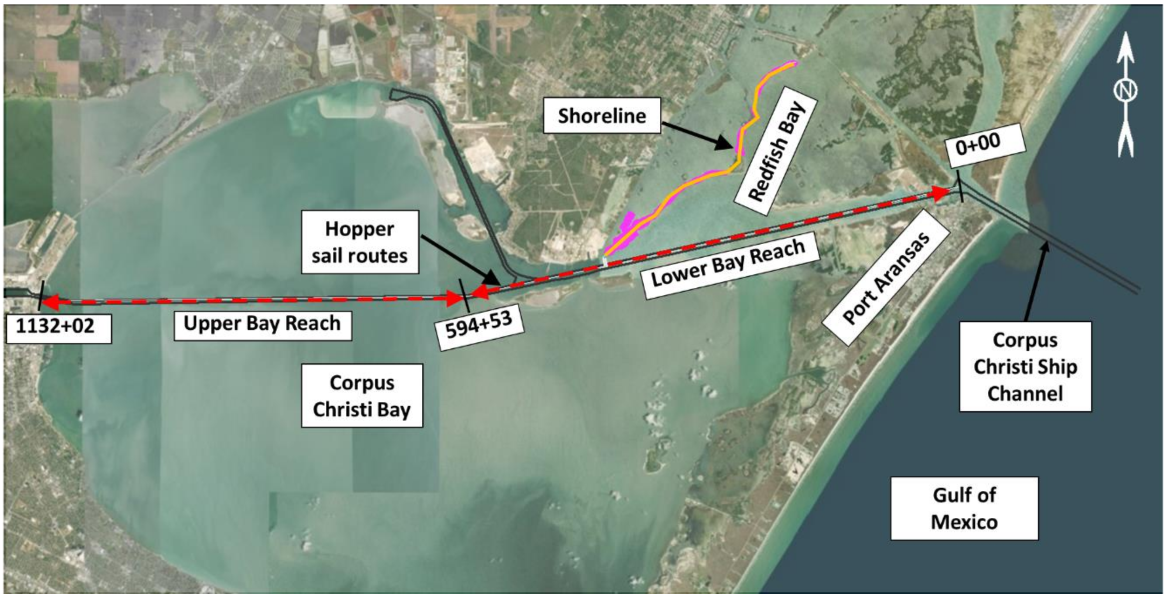


Figure 84. SP-1 Island Creation and Restoration – Hopper dredge channel dredging

Table 92. SP-1 Island Creation and Restoration – Hopper dredge channel dredging

SP – 1 Island Creation and Restoration

Scenario Description	Deepening and Widening New Work	
Total Fill Volume [MCY]	6.7	6.7
Borrow Source	CCSC Lower Bay New Work	CCSC Upper Bay New Work
Haul Distance [mi]	6	8
Average Pipeline Used [LF]	18,275	18,275
Average Number of Boosters Required	1	1
Weather Downtime [%]	0%	0%
Maintenance and Breakdowns [%]	15%	15%
Effective Working Time [%]	85%	85%
Material Classification [%]	10% Mud/silt 90% Sand	80% Mud/silt 20% Sand
Loads per day [1 dredge]	3.5	3.5
Time to Complete Dredging [Months]	8.8	12.3
Dredging Unit Cost* [$/CY]	$6.9 – 9.6	$9.1 - $12.7
Total Costs* [Millions]	$46 - 64	$60.8 – 85.2

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.9.2 Mining Placement Areas

Besides channel sources, the material could be sources from ODMDS 1. This offshore placement area is the disposal site for the maintenance dredged material from Entrance Channel. Conceptual cost estimates were developed for two dredging scenarios: 34” hydraulic dredging to scows with pump out and 15,000 CY hopper dredging with pump out. The equipment is the only difference in the two scenarios as they would follow the same sail route inside the CCSC to the pump out location. The material is classified as primarily sandy material which implies that the hopper and scows would be able to be fully loaded.

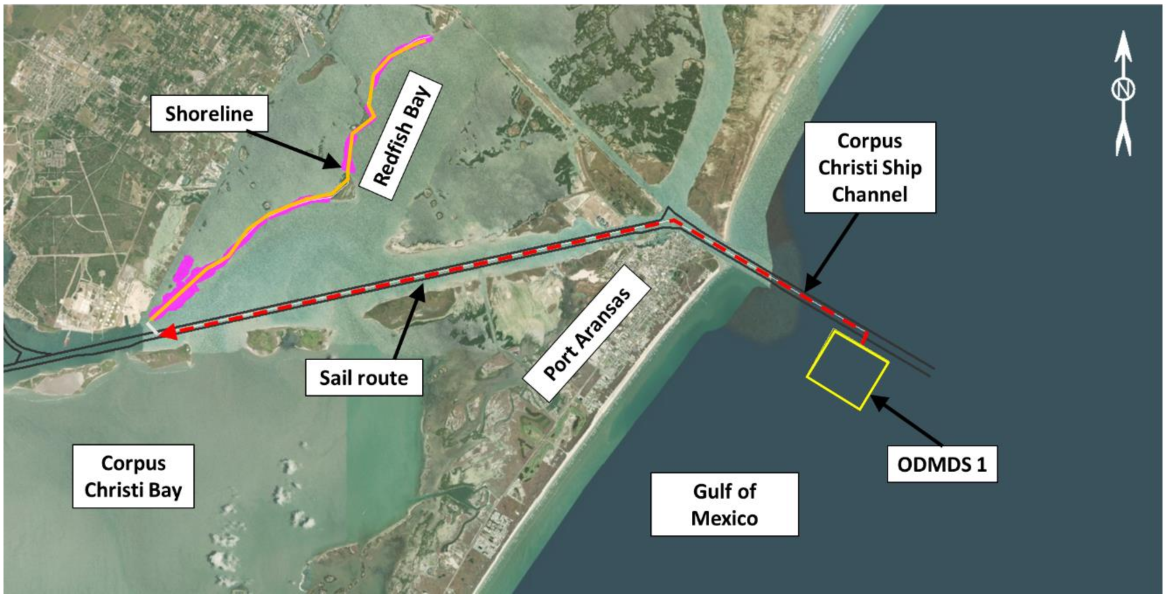


Figure 85. SP-1 Island Creation and Restoration – Dredging offshore placement area

4.9.2.1 Hydraulic Dredging Scenarios

This scenario assumes a 34" hydraulic dredge digging offshore to 3,000 CY scows which are then towed using a 2,400 HP tug to the offloading site. 3,000 CY scows were assumed due to potential draft restrictions at the offloading sites. The pump out location was again assumed at the southernmost point of the island restoration site. Further consideration should be given to other potential pump out sites as this location adjacent to the CCSC would be exposed to a lot of passing ship traffic. It may be required to dredge access to a pump out location through Red Fish Bay. If an access corridor is dredged, that material could also be used as a small source of fill, and the access corridor could be dredged to a depth allowing larger scows.

Table 93. SP-1 Island Creation and Restoration – Hydraulic Dredging offshore placement area

SP – 1 Island Creation and Restoration

Scenario Description	34" Hydraulic Dredge to scows
Total Fill Volume [MCY]	6.7
Borrow Source	ODMDS PA 1
Haul Distance [mi]	12
Number of SCOWs Required	3
SCOW Capacity [CY]	3,000
SCOW Round Trip Travel Time [hrs]	3.1
Average Pipeline Used [LF]	18,275
Average Number of Boosters Required	1
Material Classification [%]	10% Mud/silt 90% Sand
Dredging Rate [CY/hr]	1,175
Time to Complete Dredging [Months]	13
Dredging Unit Cost* [$/CY]	$7.6 - $10.6
Total Costs* [Millions]	$50.7 – $71.0

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.9.2.2 Hopper Dredging Scenarios

The hopper dredge scenario assumed that a 15,000 CY hopper dredge would be utilized with the pump out location again assumed at the southernmost point of the island restoration site, and, as mentioned in previous sections, access to this location with this size of dredge would likely have to be dredged. Further consideration should be given to other potential pump out sites as this location adjacent to the CCSC would be exposed to a lot of passing ship traffic. It may be required to dredge access to a pump out location through Red Fish Bay.

Table 94. SP-1 Island Creation and Restoration – Hydraulic Dredging offshore placement area

SP – 1 Island Creation and Restoration	
Scenario Description	**15,000 CY Hopper**
Total Fill Volume [MCY]	6.7
Borrow Source	ODMDS PA 1
Haul Distance [mi]	12
Average Pipeline Used [LF]	18,275
Average Number of Boosters Required	1
Weather Downtime [%]	0%
Maintenance and Breakdowns [%]	15%
Effective Working Time [%]	85%
Loads per day [1 dredge]	2.5
Time to Complete Dredging [Months]	12.0
Dredging Unit Cost* [$/CY]	$8.86 - $12.4
Total Costs* [Millions]	$59.2 – $82.9

*Costs shown are for a conceptual level and may not reflect the actual construction costs as they do not include several costs such as mobilization, contractor overhead and profit, environmental considerations, etc. Costs were developed using Mott MacDonald internal estimation tools

4.9.3 Summary of Source Scenarios

A summary of all the source scenarios for all of the G-28 ER measure components is provided in Table 95. Note that the costs shown are midpoint of the cost range estimate.

Table 95. Measure SP-1 Conceptual Cost and Duration Source Summary

Source	Dredge Scenario	$/CY	Duration [Months]
CCSC Lower Bay New Work	34” Hydraulic Dredge direct pump out	$7.55	13.5
CCSC Lower Bay New Work	34” Hydraulic Dredge to scows	$9.25	13
CCSC Lower Bay New Work	15,000 CY Hopper with pump out	$8.25	8.8
CCSC Upper Bay New Work	15,000 CY Hopper	$10.9	12.3
ODMDS PA 1	34” Hydraulic Dredge to scows	$9.1	13
ODMDS PA 1	15,000 CY Hopper with pump out	$10.65	12

Overall the costs and durations are very close to one another. The scenario with the shortest duration is hopper dredging in the Lower Bay, and the scenario with the lowest cost is the hydraulic dredge pumping directly to the island restoration area. However, the Lower Bay dredged material is already slated for several beneficial use areas around the CCSC, though this scenario is included in this report, future reports need to determine the actually feasibility for use of this material.

Table 96. Measure B-12 Conceptual Cost and Duration Source Summary

	Advantages	Disadvantages	Future Considerations
Ship Channel Dredging	• Beneficial reused of dredged material. • Potential to use both hopper and hydraulic dredges.	• Pump out locations may be draft limited. • PCCA has dredged material areas (several beneficial use) already designated for placement of new work dredged materials.	• Near future coordination with PCCA required to use new work material. • Assess more potential pump out locations in the Redfish Bay and potentially dredging access corridors to allow for deeper draft vessels. • Consider filling island areas with maintenance material over several dredging cycles.
Mining Placement Areas	• Not reliant on new work dredging schedule. • Potential to use both hopper and hydraulic dredges	• Pump out locations may be draft limited.	• Assess more potential pump out locations in the Redfish Bay and potentially dredging access corridors to allow for deeper draft vessels.

4.10 ER Measure W-3

ER measure W-3 will consist of recurring dredging of the Mansfield navigation channel to complete three elements which include: 1) recurring nourishment of the Gulf shoreline north of the Port Mansfield Channel; 2) protect and restore Mansfield island with 3,696 feet of riprap breakwater and 27.8-acre footprint island restoration; and 3) restore and maintain the hydraulic connection between Brazos Santiago Pass and the Port Mansfield Channel with dedicated dredging of a portion of the Port Mansfield ship channel. For this study, the dredging and placement aspects of the alternative were considered. These consist of dredging of the Port Mansfield channel to provide fill material for the Mansfield Island restoration and for nourishment of the Gulf beach north of the channel.

Figure 86. ER Measure W-3

4.10.1 Ship Channel Dredging

For this alternative, it was assumed that shoaling of the Mansfield channel is uniform, and the entire channel would be dredged to provide the sediment sources for the two placement options. For both placement options it was assumed that the dredged material would either be placed on the Gulf beach or within Mansfield Island. Costs for each option were based on dredging using an 18” hydraulic suction cutterhead dredge to excavate and pump the material to the final placement location. It was assumed that the material dredged would be mostly sand based on existing borings within the area. Dredge distances were calculated based on the approximate footprints provided by the USACE for the beach and Mansfield Island placement and Mansfield Navigation Channel Dredge template. The assumptions and cost estimates for both placement options are shown in Table 97.

Table 97: W-3 ship channel dredging costs

W-3		
	Beach Placement	**Mansfield Island Placement**
Total Fill Volume [CY]	500,268	500,268
Borrow Source	Port Mansfield Channel	Port Mansfield Channel
Average Pipeline Used [LF]	42,138	29,788
Average Number of Boosters Required	3	2
Material Classification [%]	100% Sand	100% Sand
Dredging Rate [CY/hr]	251	309
Time to Complete Dredging [Months]	4.3	3.2
Dredging Unit Cost* [$/CY]	$11.75-$16.50	$7.75-$11.00
Total Costs* [Millions]	$5.9-$8.3	$3.9-$5.5

As shown in Table 97, dredging costs for beach placement are higher primarily due to the average length of pipeline utilized. It is important to note that the costs for beach placement assume that material is pumped throughout the entire beach placement template during each event which results in higher average pipeline lengths.

5 Future Work

Several areas for future investigation were mentioned throughout this report but the following is a list of some of the major areas for future work:

- Offshore sand investigations
  Further investigation is necessary to find additional sources of sandy materials within portions of the Trinity/Sabine incised valley which do not include the Heald and Sabine banks. Geotechnical borings should be collected within these other portions, enough to develop an idea of the depth of the potential sand in the incise valley and to estimate overburden quantities.

- Real estate land acquisition costs and time
  The analysis completed for this study concluded that acquiring land close to the levees project sites could significantly reduce the transportation costs of materials. However, real estate costs and time should be take into consideration for this alternative. If real estate prices are high, this may negate the cost decreases provided with closer excavation sites. The time it takes to search for and purchase land should also be research because if it is the contractor’s responsibility to acquire and purchase land prior to starting construction, this would need to be included in the project schedule.

- Cost of CSRM Material Placement
  Further investigation into the cost of placement costs for the clay levee material should be conducted. The analysis shown in this report only investigates transportation costs for the CSRM material and does not include costs for grading or placing the material into the levee template.

- Effects of shoreface excavation adjacent shoreline coastal processes
  For many of the ER measures requiring large quantities of material for marsh and island creation, the cheapest and quickest scenarios involved sourcing materials from shoreface sediment sources. The effects of removing such large quantities from the shoreface should be evaluated further as negative effects to sediment transport or changes in wave energy influencing the shoreline could negate the use of these sediment sources. This is especially important if shoreface sediments such as sand bars are considered as a potential source for beach nourishment.

- Future technologies
  Further research should be done into possible advances in technologies which could improve dredging efficiencies, especially for offshore hydraulic dredging.

6 References

Acosta, T. (2018, 4 17). *Port of Corpus Christi pressing aggressive channel expansion schedule.* Retrieved from Corpus Christi Caller Times: https://www.caller.com/story/news/2018/04/17/port-corpus-christi-pressing-aggressive-channel-expansion-schedule/525840002/

Aviles Engineering Corporation. (2010). *Geotechnical Investigation City of Houston Surface Water Transmission Program Report No. G137-10.* Houston: LAN, Inc.

Canal Barge. (2011). *Resources: Hopper Barge Draft Table.* Retrieved August 2018, from Canal Barge Web site: http://www.canalbarge.com/resources/barges/hopperBargeDraft.php

Das, B. M. (2000). *Fundamentals of Geotechnical Engineering.* Pacific Grove: Brooks/Cole a division of Thomson Learning.

Dredging Today. (2018, February 19). *Port Freeport Commissioners Push for Channel Improvement Project*. Retrieved from Dredging Today: https://www.dredgingtoday.com/2018/02/19/port-freeport-commissioners-push-for-channel-improvement-project/

Focht, J., & Sullivan, R. (1969). *Two Slides in Overconsolidated Pleistocene Clays.* Houston: McClelland Engineers, Inc.

Freese & Nichols. (2016). *Texas Coastal Sediment Sources General Evaluation Study.* Austin: Texas General Land Office.

Frey, A. E., Morang, A., & King, D. B. (2016). *Galveston Island, Texas, Sand Managemen Strategies.* Vicksburg: USACE Engineer Research and Development Centers.

GLO. (2018). *Texas Coastal Sediments Geodatabase*. Retrieved July 2018, from TxSED Mapping Viewer: http://gisweb.glo.texas.gov/txsed/index.html

Gorrondona & Associates, Inc. (2015). *Geotechnical Engineering Report HCAD - 13013 Northwest Freeway Houston, Texas.* Houston: Harris County Appraisal District.

HDR. (2017). *Freeport Harbor Channel Improvement Project, Draft Integrated General Reevaluation Report and Environmental Assessment: Appendix K Dredge Material Management Plan.* Galveston: USACE Galveston District.

HGAC. (2018). *Land Use & Land Cover Data*. Retrieved 2018, from Houston-Galveston Area Council: https://www.h-gac.com/home/residents.aspx

HR Wallingford. (1996). *Guidelines for the Beneficial Use of Dredged Material. Report SR 488.* London: Environment Agency (now part of DEFRA).

Lambert, S. S., Willey, S. S., Thomas, R. C., Lihwa, H. L., & Welp, T. L. (2013). *Regional Sediment Management Studies of Matagorda SHip Channel and Matagorda Bay System, Texas.* Galveston: USACE Engineer Research and Development Center.

Moffatt & Nichol. (2010). *Galveston Bay Regional Sediment Management: Programmatic Sediment Management.* Galveston: USACE Galveston District.

Paradigm Consultants, Inc. (2016). *Geotechincal Study CR48 From FM 1462 to CR 52 Brazoria County, Texas.* Houston: Binkley & Barfield, Inc.

Parchure, T. M., Sarruff, S., & Brown, B. (2001). *Desktop Study for Shoaling Prediction in Corpus Christi Navigation Channel, Texas.* Vicksburg: USACE Engineer Research and Development Center.

Randall, R., Edge, B., Basitotto, J., Cobb, D., Qi He, S. G., & Miertschin, M. (2000). *Texas Gulf Intracoastal Waterway (GIWW) Dredged Material: Benefical Uses, Estimating Costs, Disposal Analysis Alternatives, and Separation Techniques.* Austin: Texas Department of Transportation.

TXDOT. (2018). *Geotechnical Manual.* Austin: Texas Department of Transportation.

USACE. (2000). *EM 1110-2-1913 Design and Construction of Levees.* Washington, DC: U.S. Army Corps of Engineers.

USACE. (2003). *Corpus Christi Ship Channel, Texas Channel Improvement Project, Volume II Appendices.* Galveston: USACE Galveston District.

USACE. (2011). *Freeport Harbor Deepening and Widening Channel Improvement Project, ODMDS Site Management and Monitoring Plan.* Galveston: USACE Galveston District.

USACE. (2012). *Freeport Harbor Channel Improvement Project Volume I Final Environmental Impact Statement.* Galveston: USACE Galveston District.

USACE. (2016a, June). *Engineering Appendix Galveston Harbor Channel Extension Feasibility Study Houston-Galveston Navigation Channels.* USACE Galveston District. Retrieved from NOAA: Geospatial Data and Services.

USACE. (2016b). *Galveston, Texas, Ocean Dredged Material Disposal Site, Site Management & Monitoring Plan.* Galveston, Texas: U.S. Army Corps of Engineers Galveston District.

USACE. (2017a). *Houston Ship Channel Expansion Channel Improvement Project, Harris, Chambers, and Galveston Counties, Texas. Engineering Appendix.* Galveston: US Army Corp of Engineers Galveston District.

USACE. (2017b). *Site Management and Monitoring Plan for the Corpus Christi Maintenance and New Work Ocean Dredged Material Disposal Sites.* Galveston: USACE Galveston District.

USACE. (2017c). *Houston Ship Channel Feasibility Real Estate Appendix.* Galveston: USACE Galveston District.

USACE. (2018). *Personal Comm. Ecosystem Restoration Sediment Volume Required.*

USACE. (2018a). *Dredging statistics: Corps owned dredges and dredging contracts*. Retrieved from USACE Digital Library: https://usace.contentdm.oclc.org/digital/collection/p16021coll2/id/2640/rec/1

USACE. (2018b). *Gulf Intracoastal Waterway: Brazos River Floodgates and Colorado River Locks Systems Feasibility Study Appendix A: Draft Report.* Galveston: USACE Galveston District.

USACE. (2018c, June 01). Amendment No. 0003 To Solicitation No. W91226G18B0013. Galveston, Texas: US Army Corps of Engineers Fort Worth.

USACE. (2018d). *Matagorda Ship Channel Feasibility Report and Environment Impact State, Review of Completed Projects, Matagorda Counties.* Galveston: USACE Galveston District.

USGS. (2007). *Texas Geologic map data*. Retrieved 2018, from U.S. Geological Survey: https://mrdata.usgs.gov/geology/state/state.php?state=TX

USGS. (2015). *Texas Geologic Map Viewer*. Retrieved 2018, from https://txpub.usgs.gov/dss/texasgeology/

Vipulanandan, C. (2008). Geotechnical Engineering Challengers in the Houston Area. *CIGMAT - Conference & Exhibition.* Houston.

WIS. (2018). *Gulf of Mexico Data*. Retrieved August 2018, from Wave Hindcast Model Domains for U.S. Coasts: http://wis.usace.army.mil/hindcasts.html?dmn=gulf

Wood, E., Campbell, T., Duke, M., Olson, L., Dunkin, L., & Lin, L. (2017). *Identification of Alternatives to Reduce Shoaling in the Lower Matagorda Ship Channel, Texas.* Galveston: USACE Engineer Research and Development Center.