Jefferson County Ecosystem Restoration Feasibility Study

Final Integrated Feasibility Report and
Environmental Assessment

Appendix B: Engineering

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1 INTRODUCTION

1.1 Study Overview and Purpose

The Jefferson County Ecosystem Restoration feasibility study is a partnership between the U.S. Army Corps of Engineers (USACE) Galveston District, and the Sabine-Neches Navigation District and Jefferson County. Broadly, the study is intended to identify the ecosystem-related problems throughout coastal Jefferson County, review ecosystem restoration (ER) opportunities within the study area, and identify a plan that improves, preserves, and sustains ecosystem resources.

Identified problems include: (1) land loss along the coastal shoreline and inland marshes related to erosion and relative sea level change (RSLC), (2) altered and interrupted hydrology, and (3) a sediment-starved condition along the gulf shoreline. In terms of significance, the chenier plains of the study area are unique and threatened geomorphic feature in the US. This area is within the Central Flyway and acts as year-round habitat for species such as mottled ducks, whistling ducks, and purple gallinule. The main report provides a full elucidation of the national significance, problems, opportunities, objectives, and constraints identified for this study.

1.2 Study Area

A focused study area of approximately 184,115 acres was delineated based on the location of coastal marsh and the incumbent ER opportunities (fig. 1). The focused study area contains approximately 124,000 acres of marsh and about 32 miles of Gulf of Mexico shoreline. There are managed lands in the area owned and operated by the US Fish and Wildlife Service (USFWS), i.e., McFaddin National Wildlife Refuge (NWR) and Texas Point NWR, and lands owned and operated by Texas Parks and Wildlife Department (TPWD), i.e., J.D. Murphree Wildlife Management Area (WMA) and Sea Rim State Park. There are two federal navigation projects in the study area: the Sabine Neches Waterway (SNWW) and Gulf Intracoastal Waterway (GIWW). Figure 2 shows elevation information in and around the study area with profiles through two sections.

1.3 Overview of Other ER Projects

Other agencies and land management organizations have undertaken ER measures in the study area. These include: beach nourishment at McFaddin NWR (permit SWG-2015-00444), a clay berm along McFaddin NWR (permit SWG-2013-00102), terracing at Mud Lake (permit SWG-2012-00675), and other terracing and flow control measures on McFaddin NWR (permit SWG-2009-00343). The former three measures are shown in figure 3; the last is not because the available maps were of insufficient quality to accurately georeference the project.

The beach nourishment on McFaddin NWR identified in figure 3 is the first phase of a larger effort to nourish the extents of the NWR. The borrow source for this work is nearshore sediment approximately 1.5 miles from the coast. Prior to the beach nourishment, a clay berm was constructed along the extents of the McFaddin gulf shoreline to reduce overwash inundation in marshland landward of the berm. The borrow material for this measure was just landward of the constructed berm. Terracing, such as that near Mud Lake and on McFaddin NWR, is undertaken in various areas to help entice runoff and sediment transport to areas needing those resources.

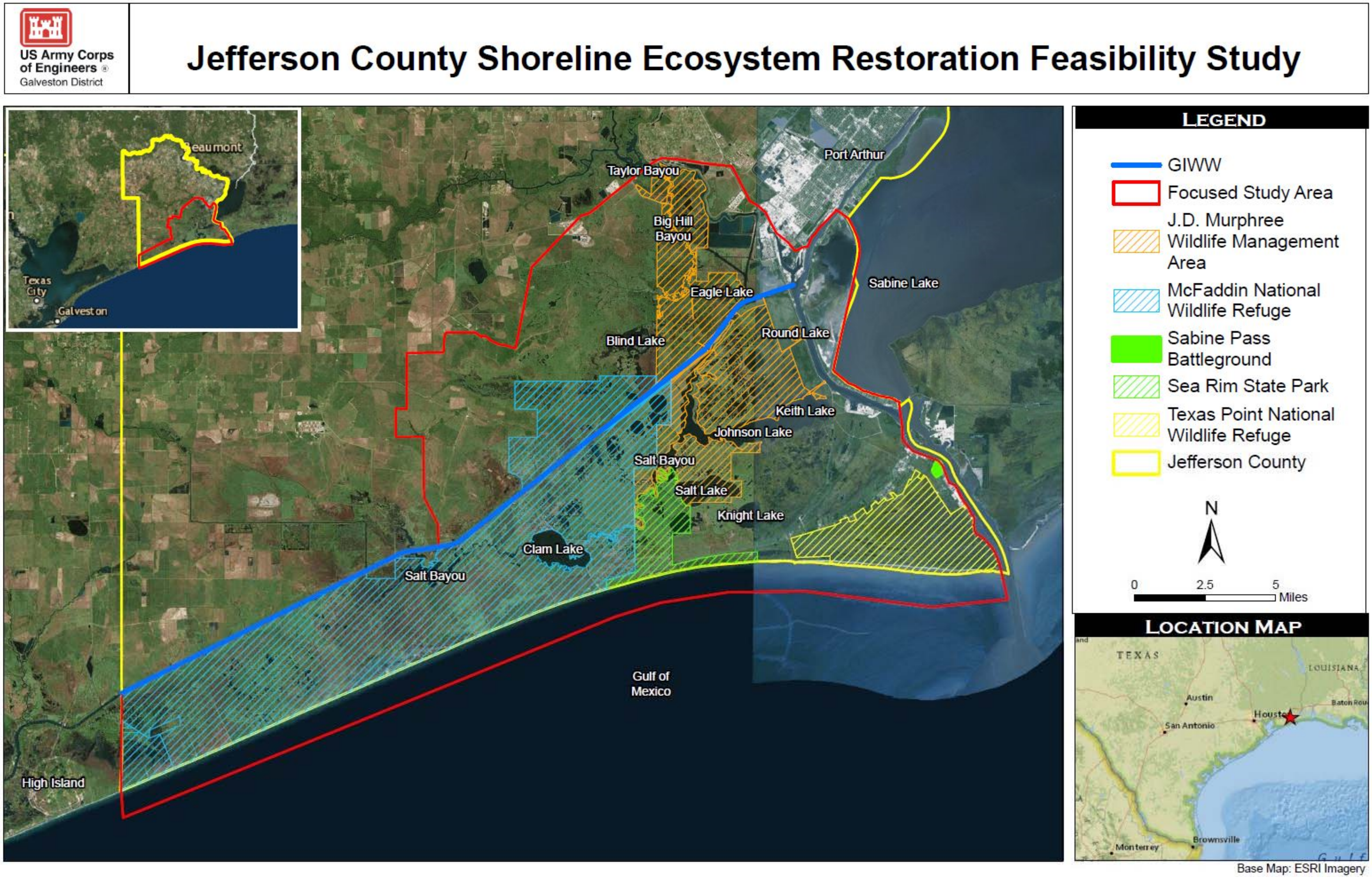


Figure 1: Jefferson County Ecosystem Restoration Feasibility Study Area

Inverted siphons are a measure in the area intended to restore hydrologic connection currently interrupted by the GIWW. Given the actions already undertaken by, and clear intentions of, other agencies/entities in the area, these are considered part of the no-action condition. Additionally, the extents of the McFaddin beach nourishment will be considered as part of the no-action condition though only a few miles are currently constructed. Lastly, several miles of breakwaters have been constructed along the GIWW shoreline (fig. 3). These are meant to reduce ship-wake-induced erosion of marshland adjacent to the GIWW. Additional breakwaters are included in this study in areas where not currently in place.

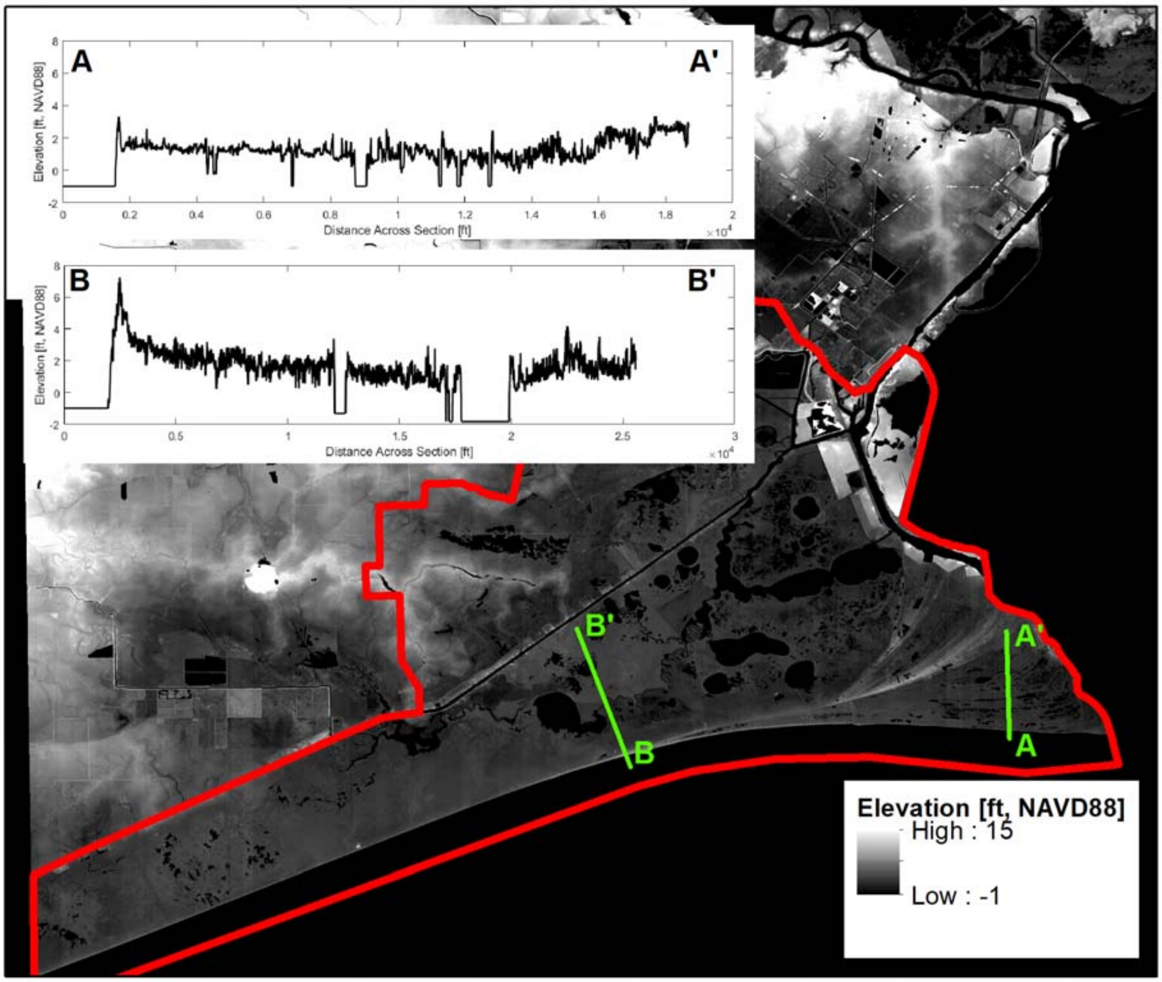


Figure 2: Elevation data throughout the study area with selected profiles

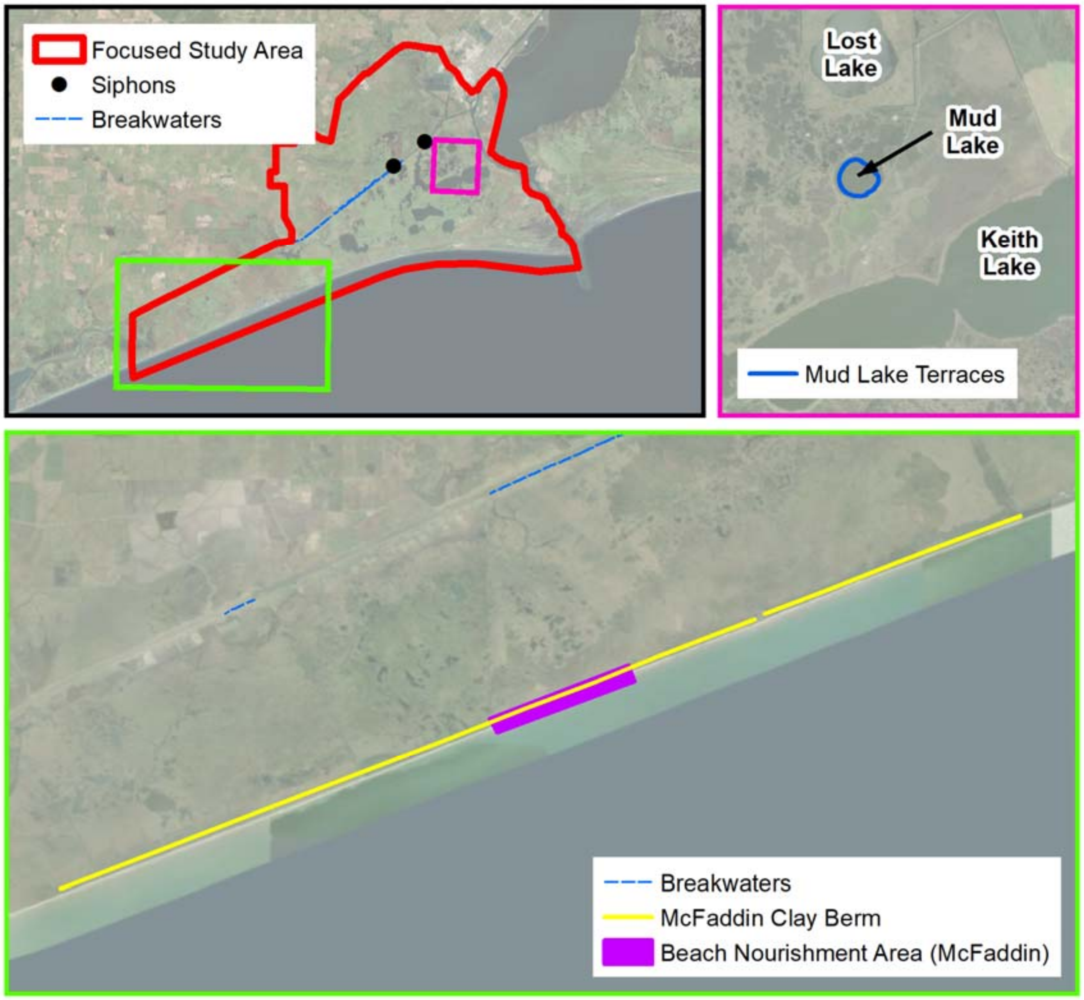


Figure 3: Other restoration measures in and around the study area

2 ALTERNATIVES

2.1 Focused Alternatives Array

An initial array of alternatives was generated based on a series of formulation strategies. Preliminary screening identified those alternatives that most completely addressed the problems and objectives identified in the study area; those retained constituted the final focused array of alternatives for evaluation and comparison. The focused array of alternatives is shown in figures 4-14.

Broadly, the measures included in the alternatives are threefold: (1) armoring along the GIWW shoreline, (2) marsh restoration and nourishment, and (3) gulf shoreline protection. These were combined in various permutations into fully-formed alternatives.

The focused array of alternatives includes:

No Action: No action would be taken in the study area.

Alternative 1A and 1Abu (Passive Restoration): This alternative takes a more passive approach to restoration including 71,818 feet of nearshore berm (nearshore nourishment in the littoral zone) and 11,595 acres of marsh elevation modifications (fig. 4).

Alternative 1B and 1Bbu (Passive Restoration): Like Alternative 1A, this alternative takes a more passive approach to restoration. The difference from Alternative 1A is that a sand engine is used for the gulf shoreline protection (fig. 5).

Alternative 2A and 2Abu (Engineered Restoration): This alternative takes a more aggressive and engineered approach to restoration. The measure includes 56,455 feet of shoreline armoring along the GIWW, 13,925 acres of marsh elevation modification with invasive species removal and plantings, and 71,818 feet of beach and dune nourishment along the gulf shoreline with offshore segmented breakwaters for sediment retention (fig. 6).

Alternative 2B and 2Bbu (Engineered Restoration): This alternative focuses on shoreline stabilization by including 56,455 feet of armoring along the GIWW and 71,818 feet of beach and dune nourishment along the gulf shoreline. Marsh nourishment measures are excluded from this alternative (fig. 7).

Alternative 3 and 3bu (Complimentary Restoration): This alternative includes measures that specifically compliment other restoration activities being pursued in and around the study area such that synergy is maximized. The measures included are 56,455 feet of GIWW shoreline armoring, 12,695 acres of marsh nourishment, and 55,413 feet of beach nourishment along McFaddin NWR (fig. 8).

Alternative 4A and 4Abu (Keith Lake Restoration): This is a location-centric alternative that focuses on the area in and around Keith Lake. The measures are 6,592 feet of shoreline armoring along the south side of the GIWW adjacent to the Keith Lake area and 8,421 acres of marsh nourishment in the area (fig. 9).

Alternative 4B and 4Bbu (Keith Lake Restoration): Unlike the protective measures undertaken in Alternative 4A, this alternative takes an indirect approach toward protecting the Keith Lake area by fortifying the gulf shoreline defending the area. Like Alternative 4A, the armoring along the south shoreline of the GIWW is retained. No marsh nourishment is included (fig. 10).

Alternative 6A (Beneficial Use of Dredged Material): This alternative was formulated with the express goal of maximizing the use of BUDM from the SNWW. The measures included are generally within a 5 mile distance from the SNWW and include 16,400 feet of beach nourishment and 10,638 acres of marsh nourishment (fig. 11).

Alternative 6B (Beneficial Use of Dredged Material): This alternative had the same purpose and scope of Alternative 6A but substitutes sand engine style placement at the gulf shoreline instead of shore-attached nourishment (fig. 12).

Alternative 10 and 10bu (South of GIWW Restoration): This alternative focuses on the portion of the study area south of the GIWW. The measures include 38,237 feet of armoring along the south shoreline of the GIWW, 12,347 acres of marsh nourishment, and 71,818 feet of beach and dune nourishment with offshore segmented breakwaters to aid in sediment retention (fig. 13).

Alternative 13 and 13bu (Hybrid Restoration): This alternative was developed after the AMM milestone as a blended approach between the passive and engineered approaches used in Alternatives 1 and 2 respectively. The difference from Alternative 2 is that a sand engine style placement is used at Texas Point in lieu of beach nourishment and offshore breakwaters. There was also a concern that the substrate near Texas Point would not support breakwaters and could experience substantial settlement (fig. 14).

The final array consists of several using the suffix ‘bu,’ e.g., 1A and 1Abu. This difference is not explicitly called out throughout this document. Generally, the principle difference between #X and #Xbu, where ‘#’ represents an alternative number and ‘X’ represents a possible scale, is that those identified as #X were originally formulated to use sediment from the SNWW upland confined placement areas (PA), while #Xbu specifically uses beneficial use of dredged material (BUDM) from the SNWW. This difference in sediment source is applicable for measures in the eastern portion of the study area; offshore sources were identified for those in the western portion of the study. Sediment sources are more fully discussed in a subsequent section.

2.2 Alternatives Evaluation, Comparison, and Selection

Quantities and costs were developed for each of the alternatives in the focused array using pre-TSP feasibility-level designs. This was done using available existing data, engineering assumptions, and best professional judgment. The feature design is discussed in a subsequent section.

The ecological benefits of each alternative were evaluated using the Wetland Value Assessment (WVA) models. Benefits are reflected as a number of average annual habitat units (AAHUs) that an alternative generates over the no-action alternative. Details regarding determination of benefits are in the Environmental Appendix.

Using the cost generated from the engineering and the benefits from the habitat modeling, a cost effective/incremental cost analysis (CE/ICA) was performed to identify the cost effective and best buy alternatives. The results of this analysis is in the main report.

Lastly, an “is it worth it” analysis was done to compare the plans amongst themselves to determine a selected plan. This analysis captures some of the benefits not treated quantitatively. Further, it aids plan selection since AAHUs do not have a monetary value. The analysis provides the justification for one plan over another and the additional investment. This discussion is in the main report.

2.3 Description of Selected Alternative

The selected plan is Alternative 4Abu. Based on the analysis, it partially meets the study objectives, reasonably maximizes benefits for the associated costs, and includes important features to restore and sustain the ecological and geomorphic form and function of the coastal system in the study area. The plan includes measures addressing the marsh platform elevation and drainage, and measures to mitigate shoreline erosion along the GIWW shoreline. The marsh nourishment component aims to improve terrestrial wildlife habitat, hydrologic behavior, water quality, and fish nurseries. The GIWW shoreline component combats the shipwake-induced shoreline erosion by constructing breakwaters to protect the adjacent wetlands.

The plan includes restoration activities on J.D. Murphree WMA owned and managed by TPWD, on McFaddin NWR owned and managed by USFWS, and on private lands (table 1). The source material for these measures is BUDM from the SNWW. The maintenance dredging volumes from the SNWW are of sufficient quantity and proximity as to serve the borrow needs for the plan without having to utilize other sources.

Table 1: Scale and scope of 4Abu measures in as a function of Land Ownership

Ownership	Marsh Measures [ac]	GIWW Shoreline Measures [ft]
JD Murphree WMA	5,365	5,170
McFaddin NWR	683	0

The marsh nourishment activities in the plan encompass six restoration cells and approximately 6,048 acres of habitat toward the east of the study area. The areas would be constructed using BUDM from the SNWW by pumping the material to low-lying areas in the marsh cells assuming that 65% of each cell will have a post-construction settlement target elevation of +1.6 feet (NAVD88). Earthen dikes will be used, as necessary, to contain dredged material; the dikes will be breached following construction to allow for dewatering settlement to the ecological target elevation. The estimated material required for initial construction is 5.1 million cubic yards (MCY).

GIWW armoring would involve constructing 5,170 linear feet of breakwater structures. The structures would be built in shallow water (approximately 3 feet deep) along the southern edge of the GIWW, at varying distances from the shoreline and where soils are conducive to supporting the weight of the stone without significant subsidence. The distance from the shoreline would be determined during PED, after site specific surveys have been completed, but sufficiently offset from the boundaries of the GIWW navigation channel to ensure continued safe navigation.

Additional detail and refinement was done on this alternative during final feasibility design. A description of this work is at the end of section 6.

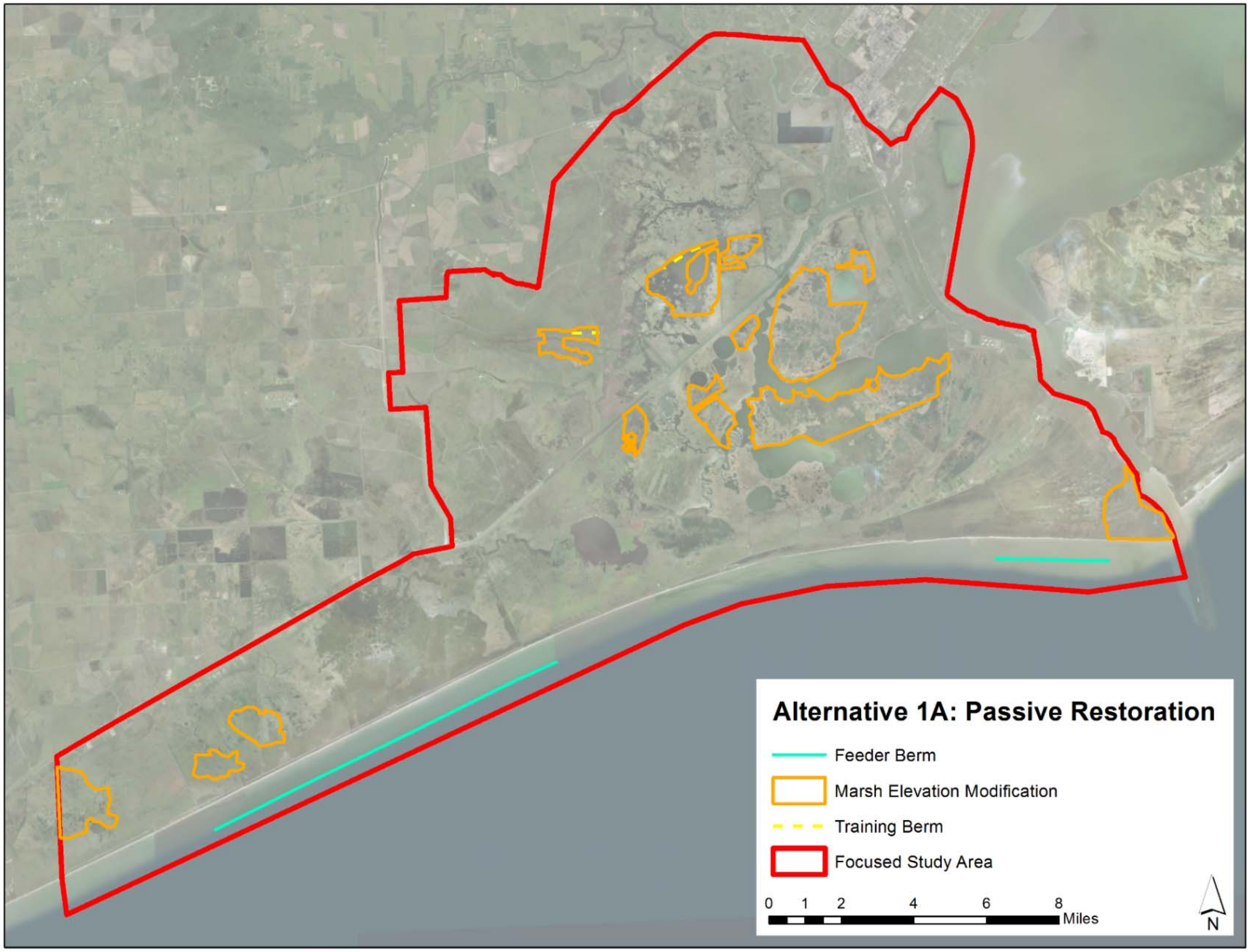


Figure 4: Alternative 1A (Passive Restoration) including nearshore berms, marsh nourishment, and training berms

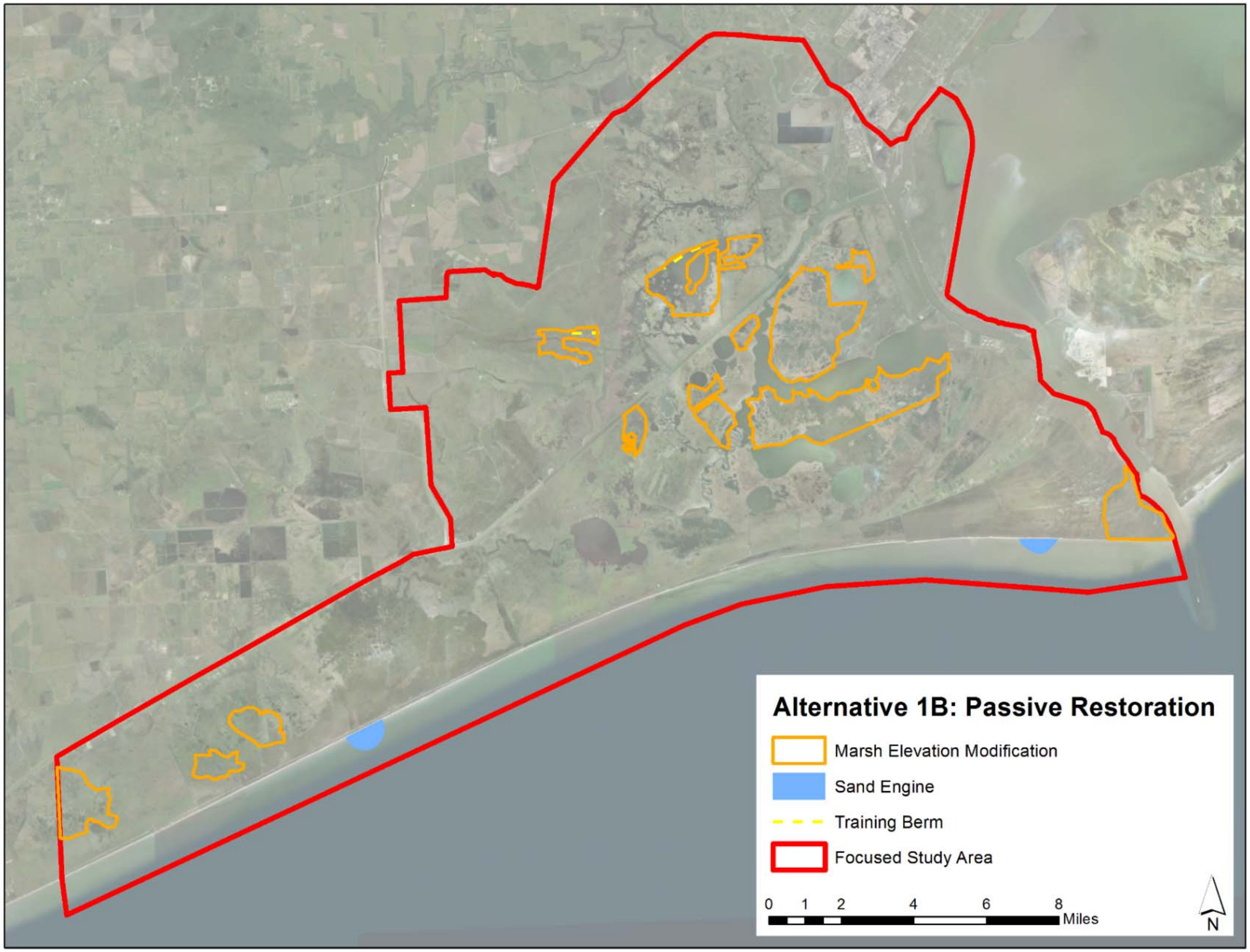


Figure 5: Alternative 1B (Passive Restoration) including marsh nourishment, sand engines, and training berms

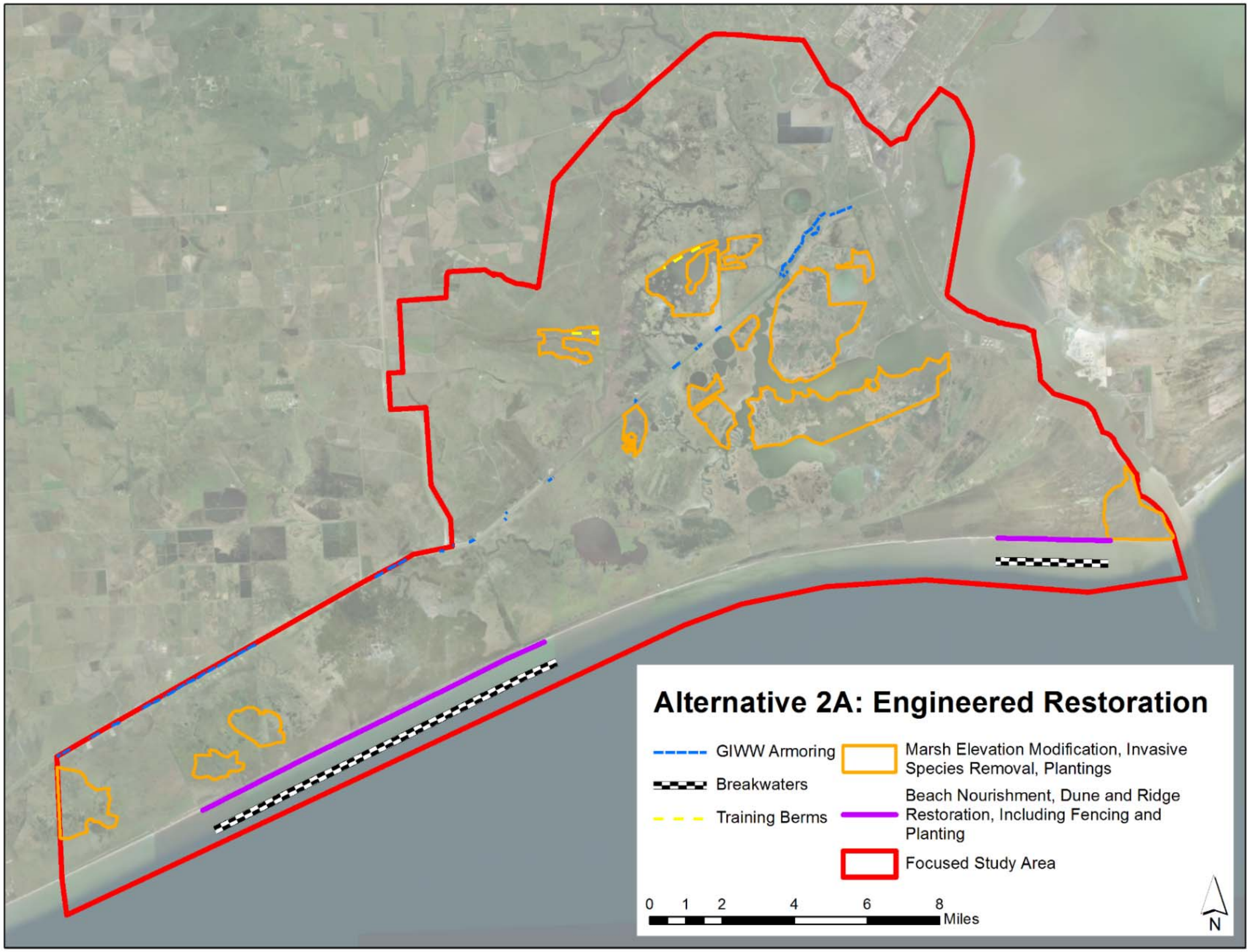


Figure 6: Alternative 2A (Engineered Restoration) including GIWW shoreline armoring, marsh nourishment, training berms, beach and dune nourishment, and segmented emergent offshore breakwaters

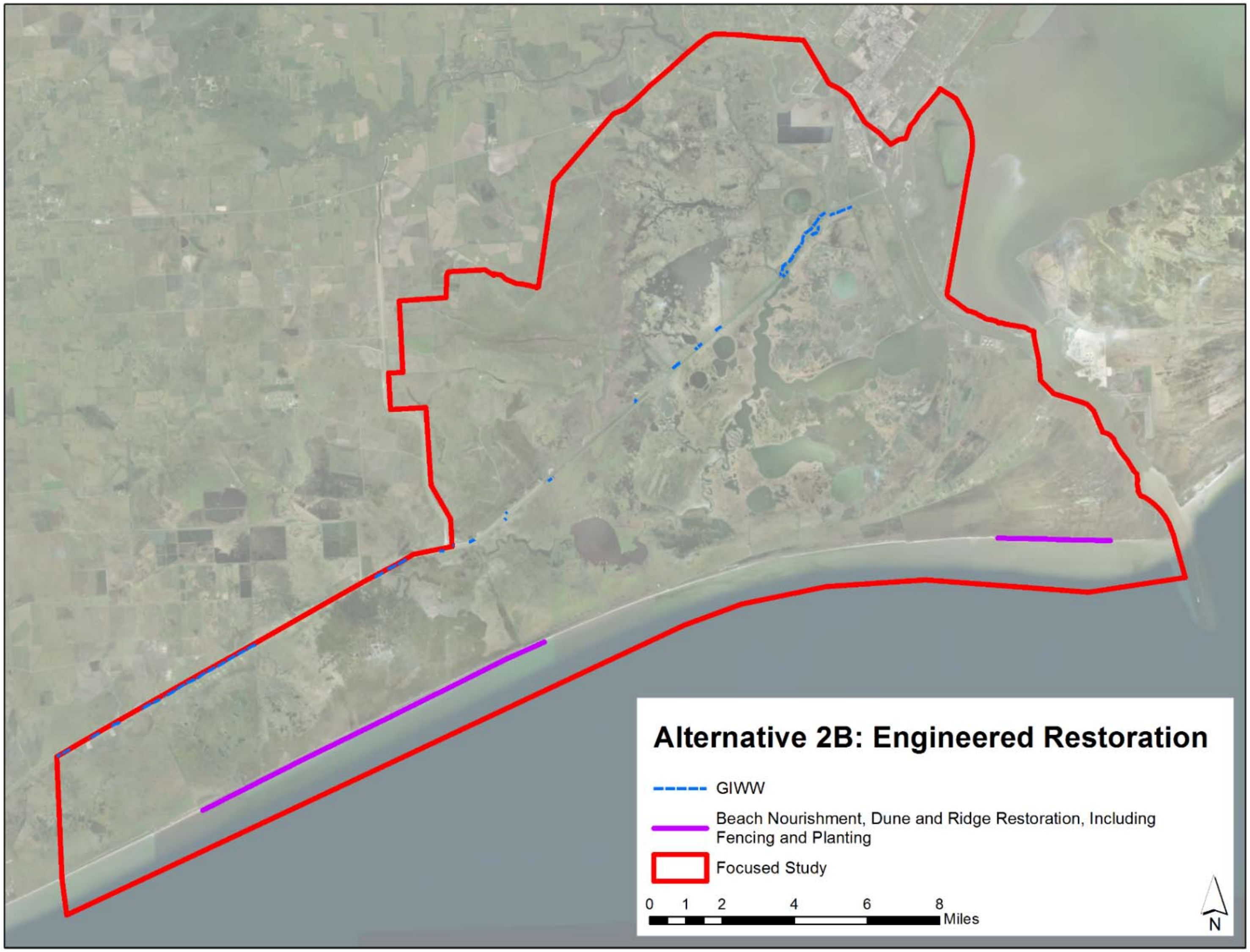


Figure 7: Alternative 2B (Engineered Restoration) including GIWW shoreline armoring and beach and dune nourishment

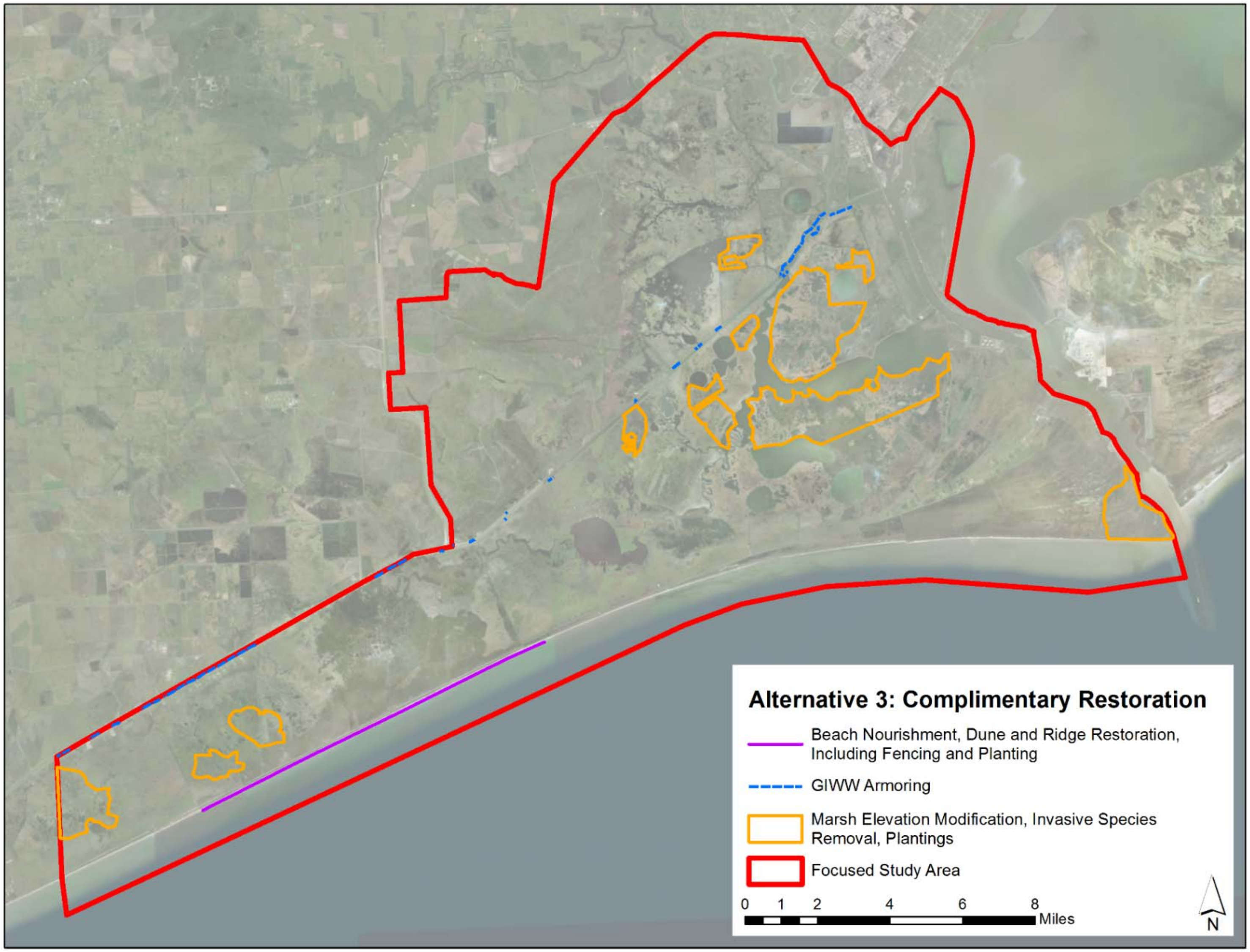


Figure 8: Alternative 3 (Complimentary Restoration) including beach and dune nourishment, GIWW shoreline armoring, and marsh nourishment

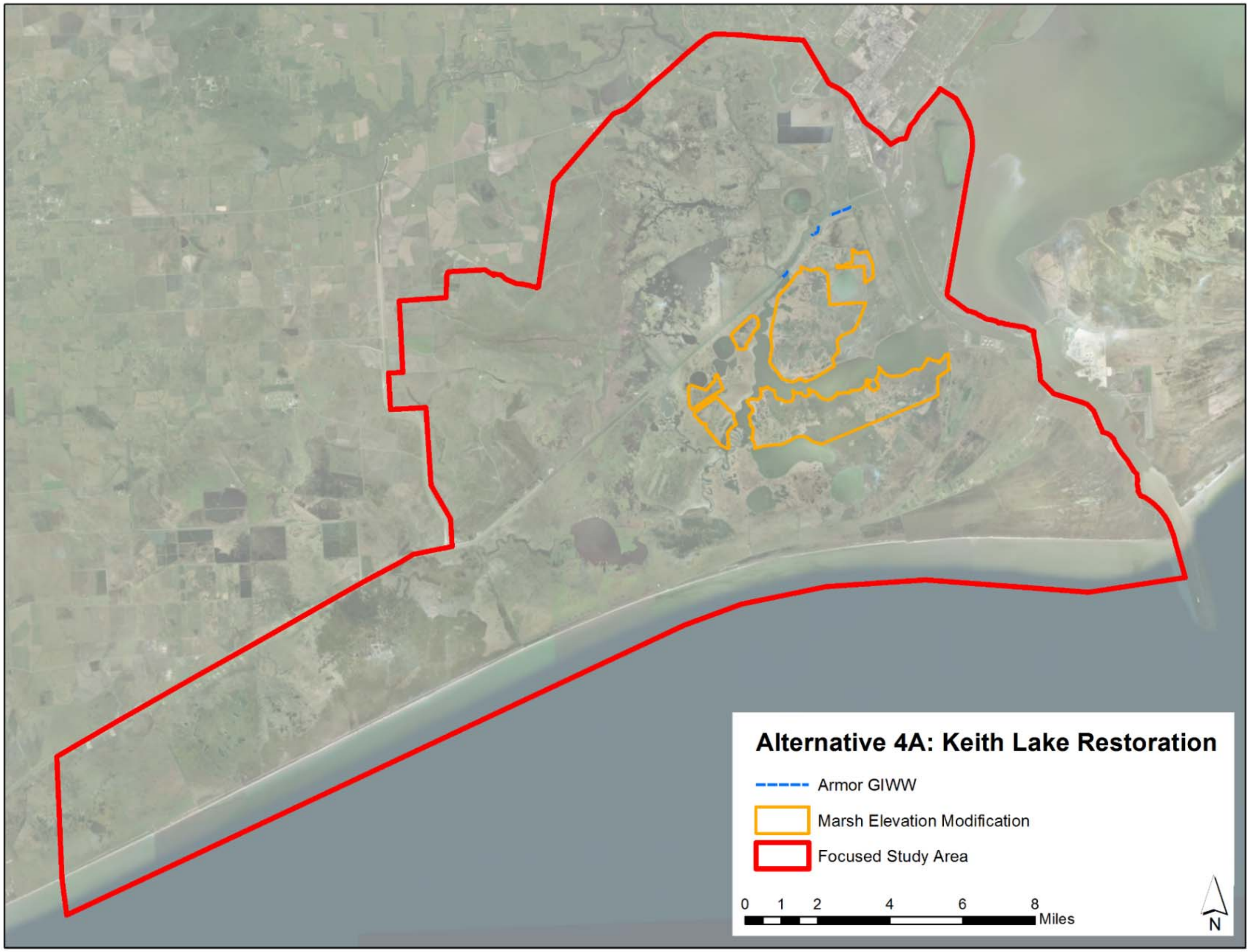


Figure 9: Alternative 4A (Keith Lake Restoration) including GIWW shoreline armoring and marsh nourishment

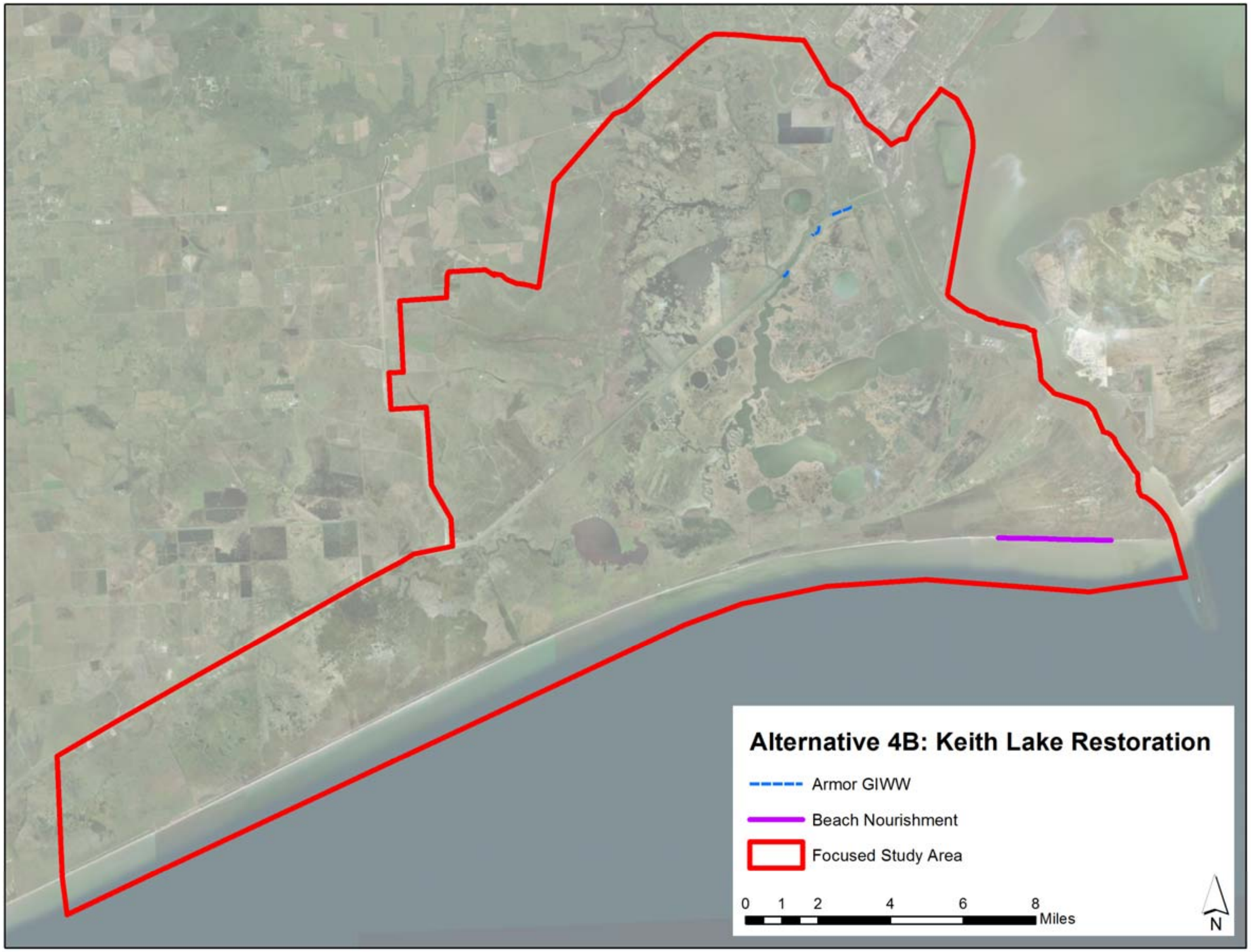


Figure 10: Alternative 4B (Keith Lake Restoration) including GIWW shoreline armoring and beach nourishment

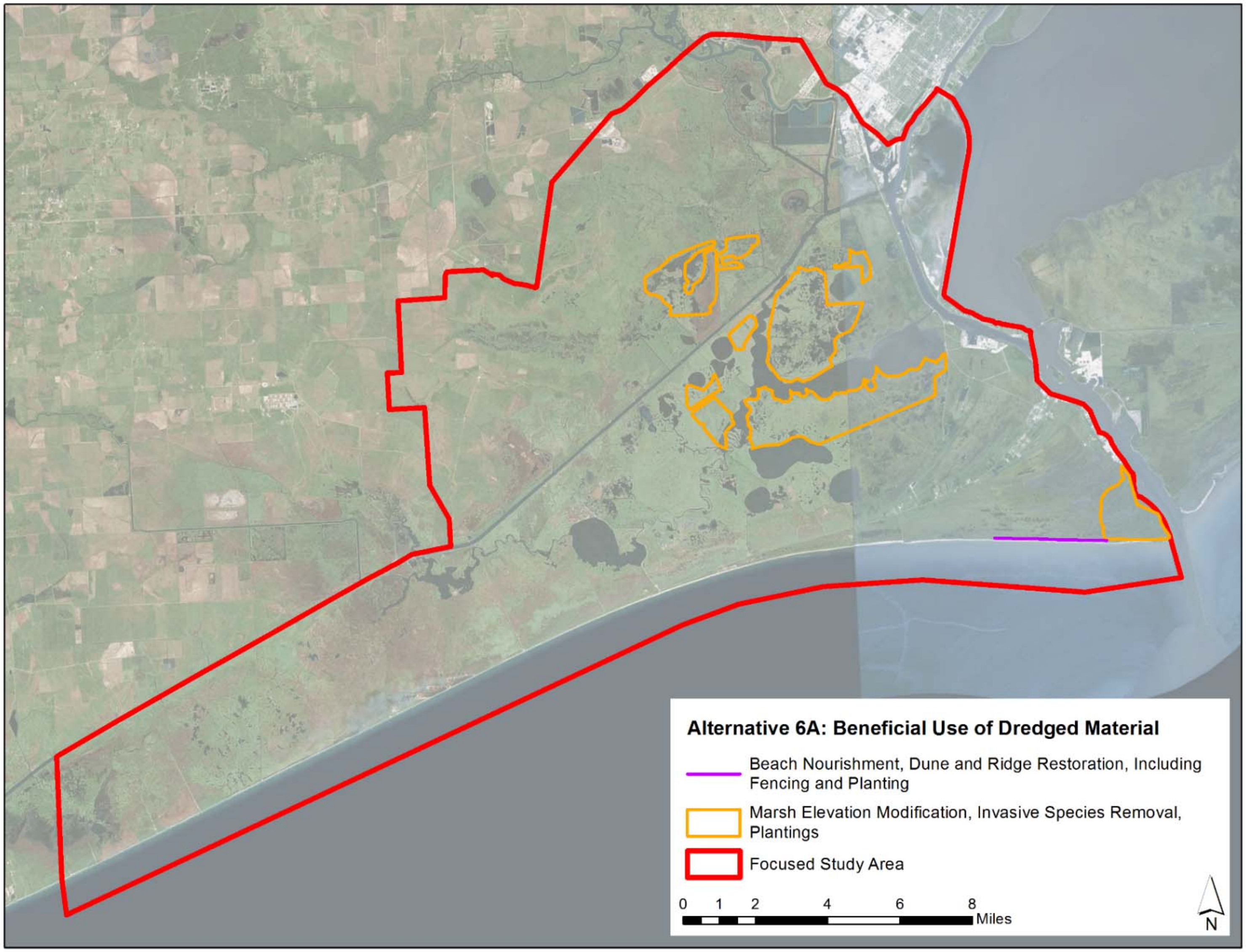


Figure 11: Alternative 6A (Beneficial Use of Dredged Material) including marsh nourishment and beach and dune nourishment

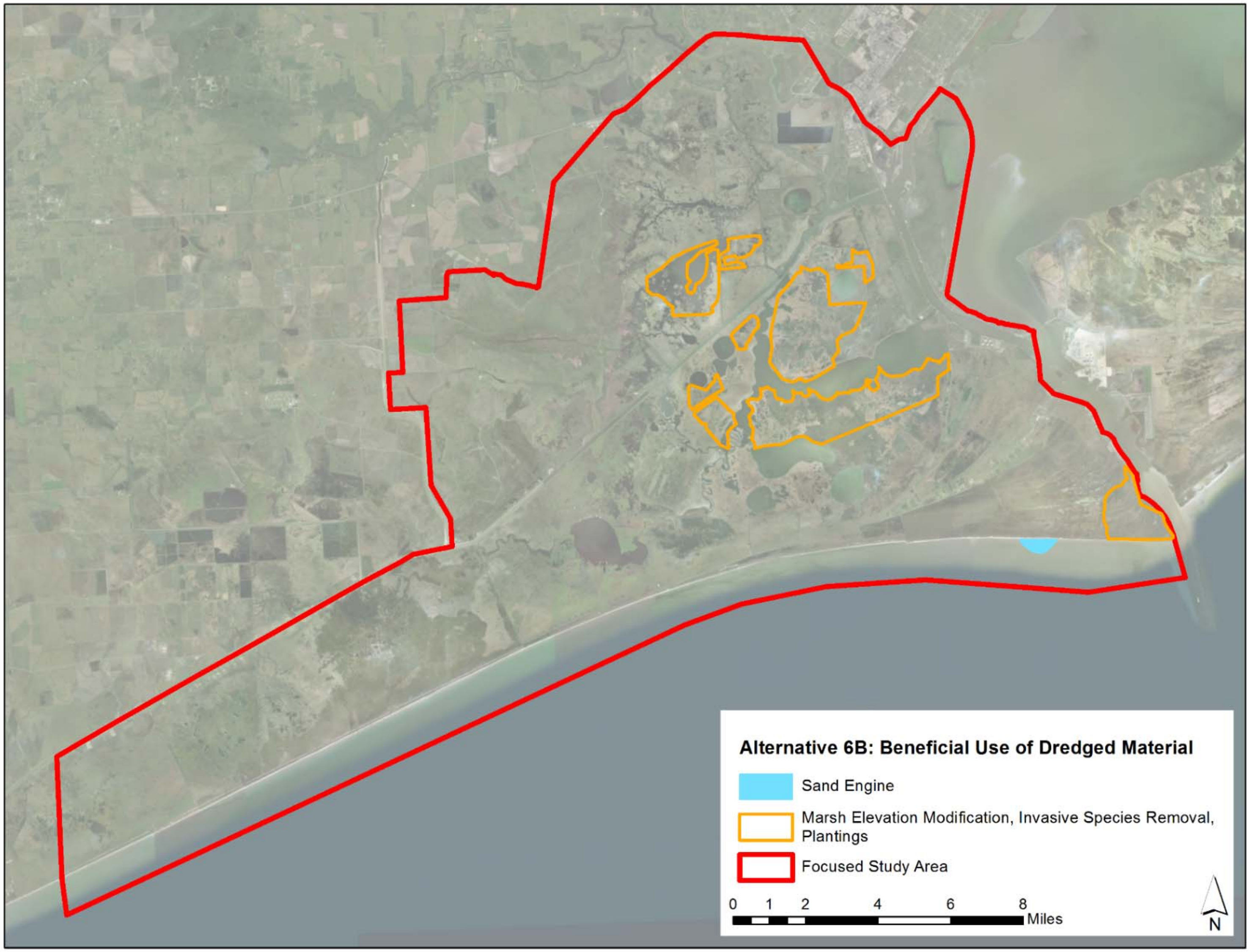


Figure 12: Alternative 6B (Beneficial Use of Dredged Material) including marsh nourishment and a sand engine

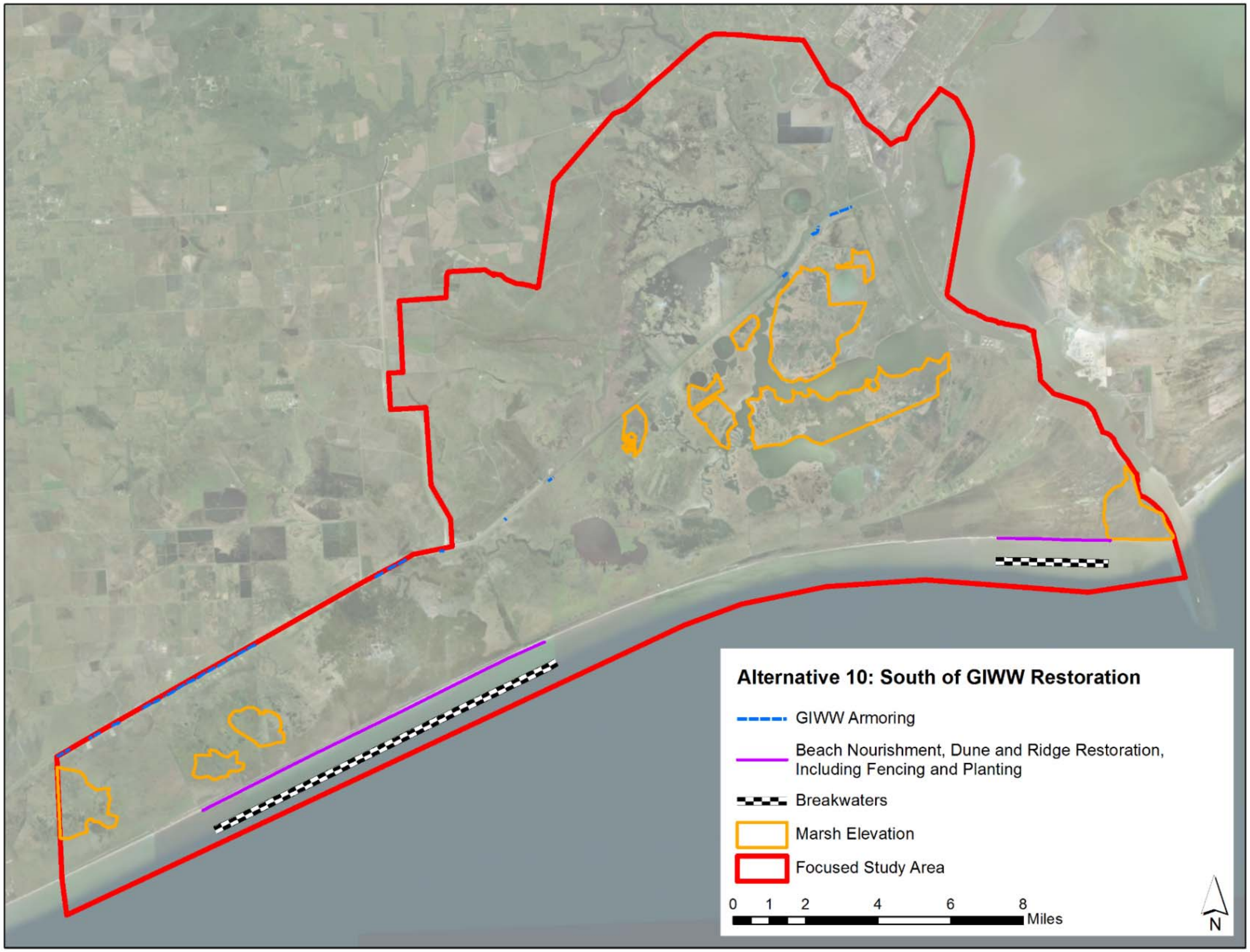


Figure 13: Alternative 10 (South of GIWW Restoration) including GIWW shoreline armoring, beach and dune nourishment, marsh nourishment, and segmented offshore breakwaters

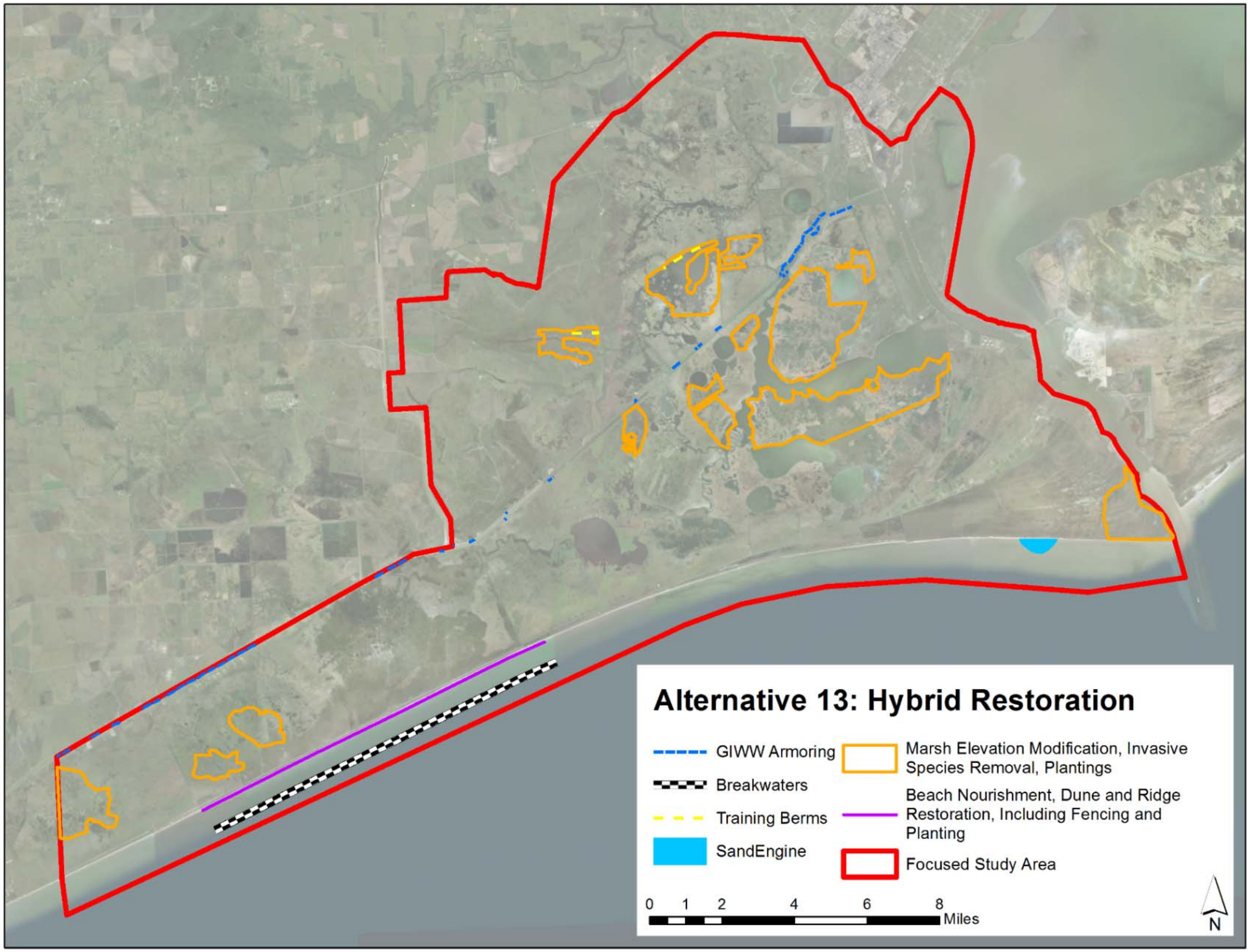


Figure 14: Alternative 13 (Hybrid Restoration) including GIWW shoreline armoring, marsh nourishment, training berms, beach and dune nourishment, segmented offshore breakwaters, and a sand engine

3 Hydraulics and Hydrology

3.1 Tidal Datum and Vertical Datum

Tidal datums are derived from long-term water-level monitoring such that there is a statistical description of the water-surface elevation, e.g., mean sea level, mean higher-high water, etc. The permanent tidal gages operated and maintained by the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) near the study area are shown in figure 15. Table 2 shows the relationship between the various tidal datums and the North American Vertical Datum of 1988 (NAVD88).

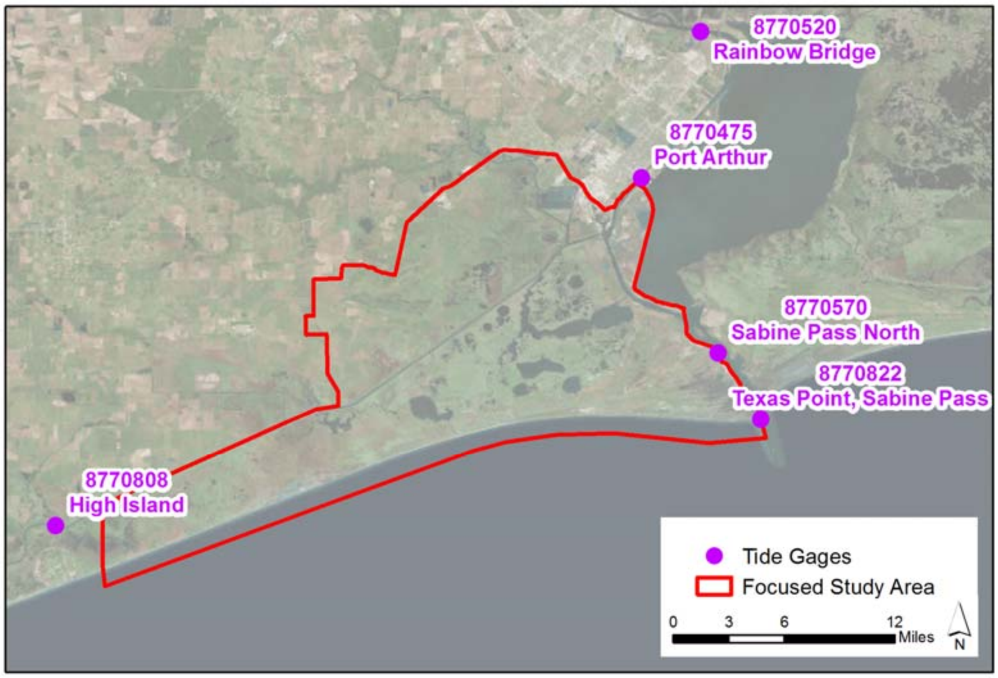


Figure 15: NOAA permanent tide gages near the project area

Table 2: Tidal datum information, and relationship to NAVD88, for gage 8770570, Sabine Pass North, TX

Datum	Value [ft]	Datum	Value [ft]
MHHW	1.61	DTL	0.80
MHW	1.50	MLW	0.41
MTL	0.96	MLLW	0.00
MSL	0.97	NAVD88	0.37

3.2 Hydrology

Drainage in and around the study area is broadly from north to south and west to east. Hydrology is disrupted in the study area; the north to south drainage is interrupted by the GIWW. The USGS hydrologic units (4 digit), streams, and waterbodies are shown in figure 16. Salt Bayou is the primary drainage path through the study area (HUC 1204020103), running west to east south of the GIWW. The drainage channels connect the series of lakes before reaching Keith Lake and Sabine Lake. Though there are channels, significant flow in the marsh areas is shallow sheet-flow. This makes subtle gradients in the landscape important for proper drainage through the wetlands.

A potential measure to help restore hydrologic connectivity in the system are inverted siphons. These are culverts that would run under the GIWW and restore freshwater input to the marshes south of the GIWW. These were originally included in the alternative formulation as an ER measure in this project. However, they are now considered part of the no-action condition given the intention of other agencies to install the siphons. The locations of the siphons are shown in figure 17.

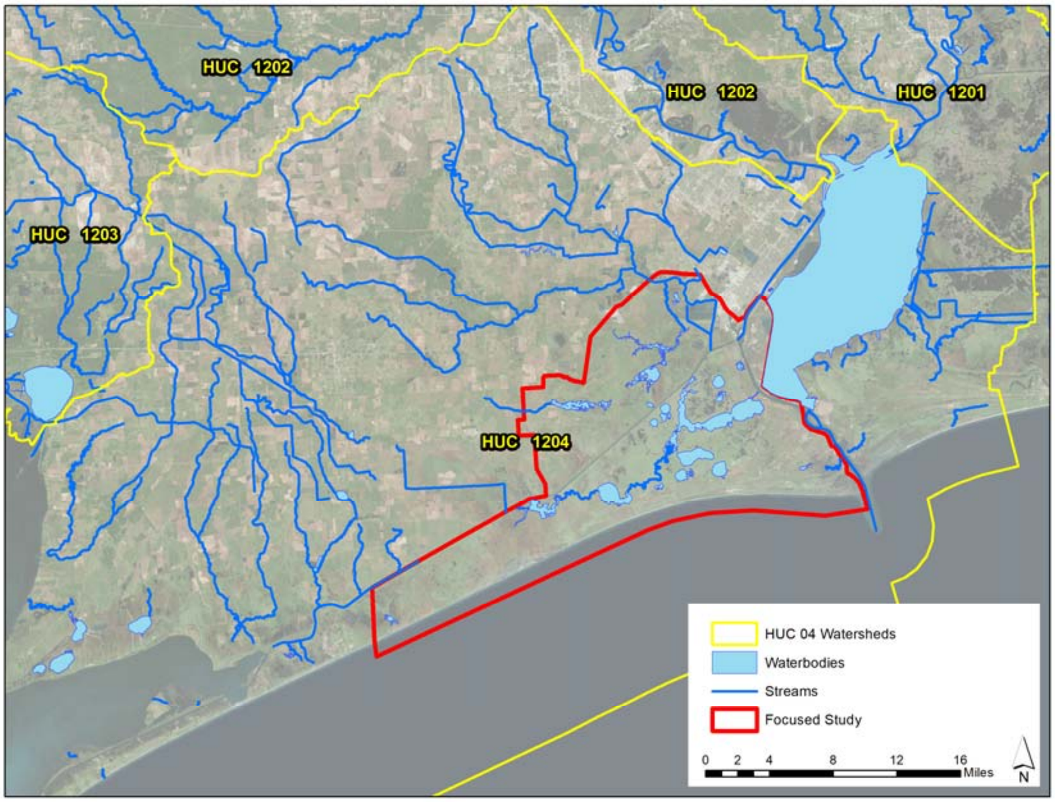


Figure 16: USGS hydrologic units, streams, and waterbodies in and around the study area

3.3 Climate Change

Coastal Jefferson County is highly vulnerable to RSLC (Thieler et al., 2000) which threatens the coast along with the wetlands and habitats further inland. The effects of future RSLC with respect to USACE projects are considered using guidance from ER 1100-2-8162 (USACE, 2013) and ETL 1100-2-1 (USACE, 2014b). Making an assessment of future RSLC is predicated on adequate historical water level data. USACE (2013) recommends a minimum of 40 years such that the record encompasses two tidal epochs. The closest station to the project area with an adequate history is tidal gage 8770570, Sabine Pass North, TX (fig. 15).

The trajectory of future RSLC has been estimated by USACE through three scenarios (USACE, 2013 and 2014b). The sea-level rise scenarios are shown in figure 18 for NOAA tidal gage 8770570 Sabine Pass North, TX (USACE, 2014a). The “low” rate of RSLC in based on an extrapolation of the historical trend.

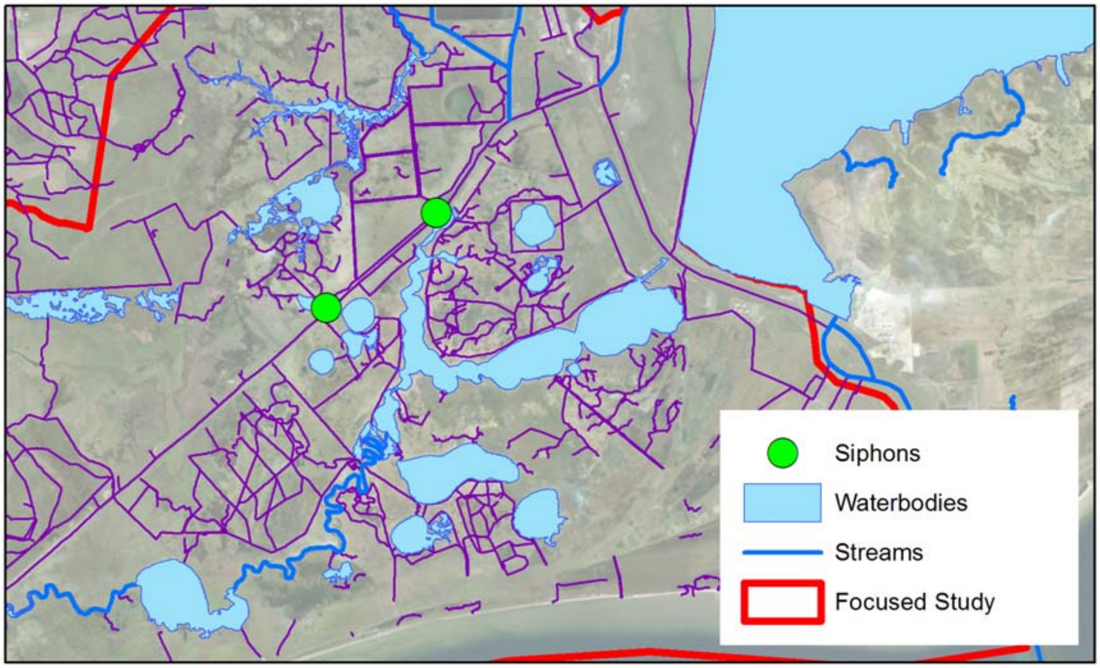


Figure 17: Location of inverted siphons to be installed in Jefferson County and considered as part of the no-action condition in this study

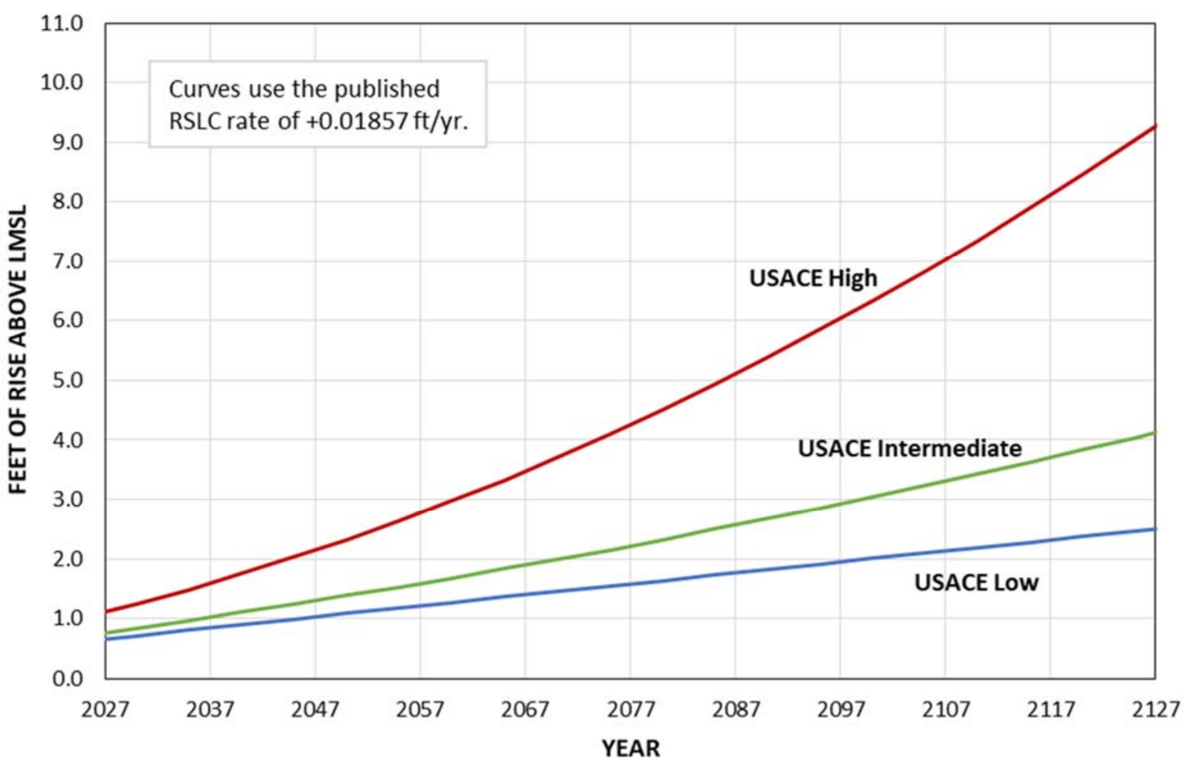


Figure 18: RSLC scenarios at NOAA gage 8770570, Sabine Pass North, TX (USACE, 2014a).

The “intermediate” and “high” rates of RSLC represent a future acceleration in sea-level change. The “intermediate” and “high” trajectories are based on modified National Resource Council (NRC, 1987) curves I and III respectively and adjusted for local vertical land movement. Each curve in figure 18 represents the projected trends in water-level above local mean sea-level (LMSL). For the purpose of our analysis, RSLC is assumed to raise LMSL, though leave the tidal amplitude unaffected. A year and scenario nomenclature will used in referring to LMSL conditions as a function of year and scenario taking the format YYYY-C (where C is the curve, L for low, I for intermediate, and H for high). For example, 2077-I would represent the year 2077 on the intermediate curve and 2050-L would represent the low curve in year 2050. Since a particular water-level condition exists along the various curves, multiple scenarios may be noted.

Plan formulation and feature design was done based on the USACE “intermediate” RSLC curve. The “high” and “low” scenarios were considered in terms of plan sensitivity, essentially a “what-if” exercise regarding different RSLC conditions. The sensitivity of the individual measures is discussed in the feature design section while resiliency and adaptability are discussed more broadly in a standalone section at the end of this appendix.

In terms of the consequences of RSLC in the project area, figure 19 shows the widespread inundation expected throughout Jefferson County at mean higher-high water (MHHW) from +2 feet of RSLC relative to 2010 water levels (2081-I) (NOAA/OCM, 2017c). Figure 20 shows the impact on the landscape in terms of land cover from the added RSLC inundation (NOAA/OCM, 2017b, 2017c). In this case, the water-levels are relative to 2010 and MHHW since that is the baseline for the NOAA data from which the inundation and land cover changes are derived.

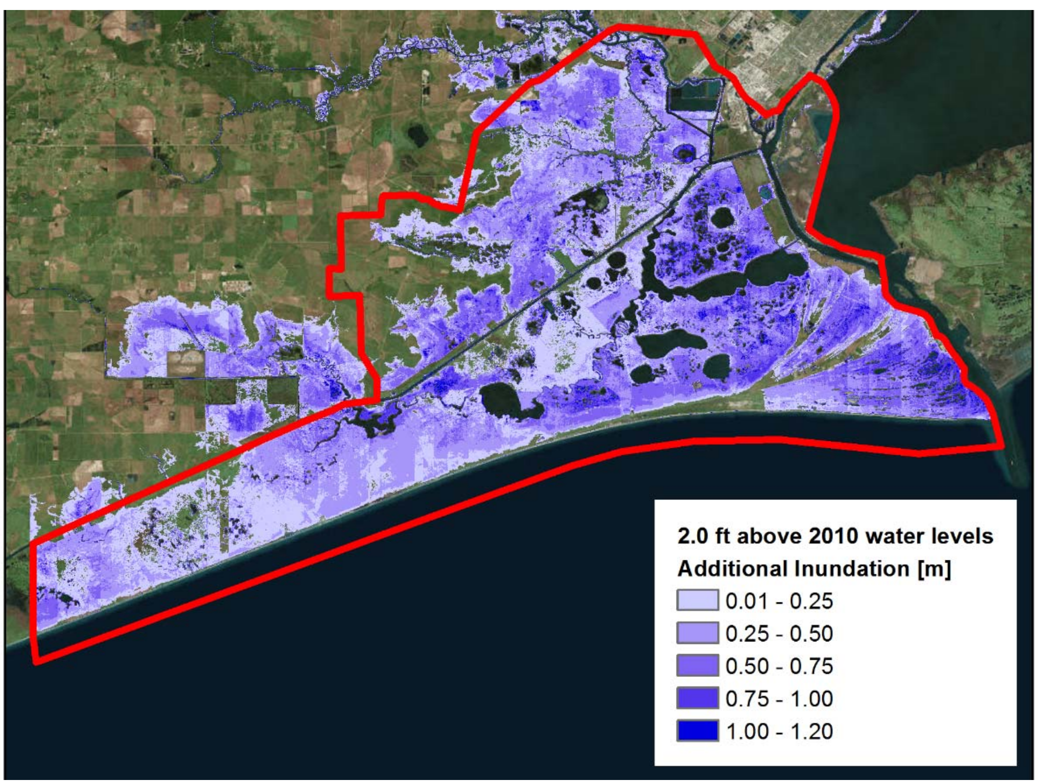


Figure 19: Overview of added inundation at MHHW from 2 ft. of RSLC in Jefferson County, TX (NOAA, 2016c).

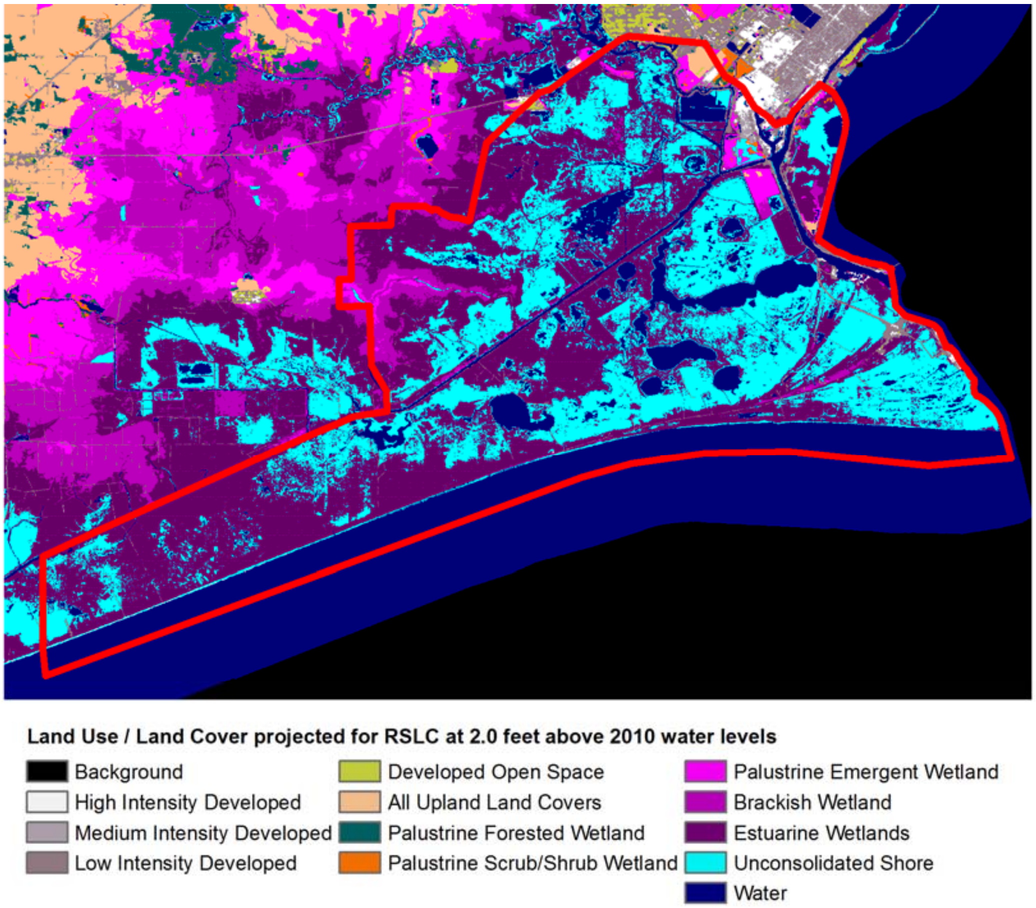


Figure 20: Land Use / Land Cover types projected for RSLC at 2.0 feet above 2010 water levels (2081-I)

By way of other climate-related vulnerabilities and risks, the project area was qualitatively evaluated in conjunction with ECB 2016-25 (USACE, 2016c). The Climate Hydrology Assessment Tool (CHAT) was applied near the study area. The focused study area resides in 4-digit HUC 1204 (Galveston Bay-San Jacinto). The nearest gage in the same 4-digit HUC is approximately 40 miles away and in the vicinity of Baytown, TX, an industrialized area near the Houston Ship Channel. That said, regression on USGS gage 08041700 (Pine Island Bayou nr Sour Lake, TX), which is in the 4-digit HUC 1202 and still over 20 miles from the study area, shows a poor fit. Overall, projections associated with HUC 1204 show generally constant flow values through the year 2100. Applying the nonstationarity tool (Friedman et al., 2018) to the period of record at USGS gage 08041700, no nonstationarities were identified.

Climate change is also thought to have an impact of the severity and frequency of coastal storm events. There is still considerable uncertainty regarding the climate-induced trajectory of storm climate such that the effects are omitted for the purposes of this study. In addition to the storm climatology changes, there are potential changes to precipitation during rainfall events. There is even more uncertainty regarding the climate-change-related changes to precipitation. The analysis discussed above with the CHAT and nonstationarity detection tool indicate minimal hydrologic changes in the historical record. However, this does not preclude future change. As with any other risk or uncertainty, more and better information can be incorporated in PED.

3.4 Coastal Processes

3.4.1 Tides

The tides in the project area are diurnal with a great diurnal range of approximately 1.6 feet as indicated at NOAA station 8770570. The Texas coast has a weak astronomical tidal signal and water levels often deviate from the predicted level, based solely on tides, from high fluvial discharges or wind-driven currents.

The tides at gage 8770570 are considered indicative of tides throughout the study area for the purposes of analysis and planning. This is likely not strictly true given tidal attenuation at progressively further points from Sabine Pass. This assumption can be revisited, if needed, during PED to better refine ecologically important elevations in the marsh nourishment cells.

3.4.2 Currents, Circulation, and Salinity

Sabine Lake is connected to the Gulf of Mexico by Sabine Pass, a jettied inlet for the deep-draft SNWW. Freshwater is provided to the system from the north primarily from the Sabine and Neches Rivers. Tidal action works through the study area via the Keith Lake and Salt Bayou systems. Apart from fluvial input to Sabine Lake, freshwater enters the study area from the north through the Salt Bayou system, though is interrupted by the GIWW. The area south of the GIWW has minimal freshwater input beyond local precipitation runoff. At current, the GIWW acts as a boundary between fresh/intermediate marsh to the north and saline marsh to the south.

3.4.3 Storm History

Tropical storms and hurricanes are major events that impact the landscape. The cyclonic weather pattern creates a combination of elevated water levels and larger-than-typical waves. These events lead to shoreline erosion, overwash, and expansive inundation. The landscape impacts are widespread and impact the shoreface, nearshore, beach, and marsh; there are also impacts on man-made infrastructure such as industrial facilities, flood protection facilities, and navigation channels.

Though tropical events can be devastating to the landscape and infrastructure, they are irregular and infrequent. Table 3 shows the history of coastal storms in and around the project area and figure 21 shows the storm tracks of select storms. Historical storm information was collected from sources such as NOAA/NWS (2017a and 2017b) and Roth (2010).

3.4.4 Extremal Water-Surface Elevations and Storm Effects

Extremal water-surface elevations published by NOAA for station number 8770570 (Sabine Pass North, TX) are shown in figure 22. In terms of storm modeling, surge events and associated extremal water-surface elevations were not modeled specifically for this study. However, the ongoing Coastal Texas Protection and Restoration Feasibility Study, another project at the Galveston District, undertook surge modeling whose values are presented herein.

The water-surface elevations are based on the modeling output from a 660 storm suite that covered a parameter space spanning reasonable combinations of central pressure, radius to maximum winds, forward speed, angle of storm track relative to the coastline, and the storm track itself. Storm surge was modeled using ADCIRC simulations for the individual storms in the suite. The associated stage frequency relationships were developed using the Joint Probability Method-Optimal Sampling (JPM-OS). Full details regarding this storm modeling and the computation of extremal water-surface elevations can be reviewed in the Coastal Texas Protection and Restoration Study Draft Feasibility Report (USACE, 2018).

The water-surface elevations simulated through Jefferson County are shown in figures 23-25. Figure 23 shows surge levels as a function of return frequency based on water-levels at existing conditions. Figures 24 and 25 show surge levels based on modeling with water-levels elevated above existing to simulate relative sea-level change (RSLC) for 2035-I and 2085-I respectively. Linear superposition is, generally, a reasonable method of incorporating RSLC, but the modeling shown in the figures overtly incorporates the water-level difference and reflects any non-linearity. Since this modeling was not conducted specifically for this study and leveraged from a separate study, the years do not correspond to the beginning or end of the period of analysis though they are close. Figure 26 summarizes the stage-frequency relationships in the study area in an averaged sense at the nearshore near McFaddin NWR, the nearshore near Texas Point, and near Keith Lake.

Table 3: Historical storms near the project site

			Conditions at Landfall			
Date	Type	Name	Latitude	Longitude	Max Wind Speed [kts]	Min. Central Pressure [mb]
August 1879	Hurricane	No Name	29.6	-94.4	90	964
June 1886	Tropical Storm	No Name	29.6	-94.2	85	-
October 1886	Hurricane	No Name	29.8	-93.5	105	-
October 1895	Tropical Storm	No Name	29.3	-94.8	35	-
September 1897	Hurricane	No Name	29.7	-93.8	75	-
September 1898	Tropical Storm	No Name	29.4	-94.7	50	-
August 1940	Hurricane	No Name	29.7	-94.1	85	972
September 1940	Tropical Storm	No Name	29.8	-93.4	40	-
September 1941	Tropical Storm	No Name	29.6	-94.0	30	1006
August 1942	Hurricane	No Name	29.5	-94.6	65	-
July 1943	Hurricane	No Name	29.5	-94.6	90	967
September 1946	Tropical Storm	No Name	29.7	-93.8	25	-
July 1954	Tropical Storm	Barbara	29.7	-92.8	50	999
June 1957	Hurricane	Audrey	29.8	-93.7	110	946
August 1957	Tropical Storm	Bertha	29.7	-93.9	55	998
July 1959	Hurricane	Debra	29.1	-95.2	75	980
September 1963	Tropical Storm	Cindy	29.8	-94.4	65	997
September 1970	Tropical Storm	Felice	29.4	-94.1	60	997
September 1971	Hurricane	Edith	29.5	-93.1	85	978
August 1978	Tropical Storm	Debra	29.6	-93.6	50	1000
July 1979	Tropical Storm	Claudette	29.6	-93.9	45	1000
September 1980	Tropical Storm	Danielle	29.4	-94.9	40	1004
September 1982	Tropical Storm	Chris	29.8	-93.8	55	994
June 1986	Hurricane	Bonnie	29.6	-94.2	75	990
June 1989	Tropical Storm	Allison	28.7	-95.7	40	1002
July 1989	Tropical Storm	Chantal	29.6	-94.2	75	990
October 1989	Hurricane	Jerry	29.2	-95.0	75	983
August 2003	Tropical Storm	Grace	29.4	-95.1	35	1007
September 2004	Hurricane	Ivan	29.8	-93.6	30	1004
September 2005	Hurricane	Rita	29.7	-93.7	100	937
September 2007	Hurricane	Humberto	29.6	-94.3	80	985
August 2008	Tropical Storm	Edouard	29.6	-94.2	55	996
September 2008	Hurricane	Ike	29.3	-94.7	95	950

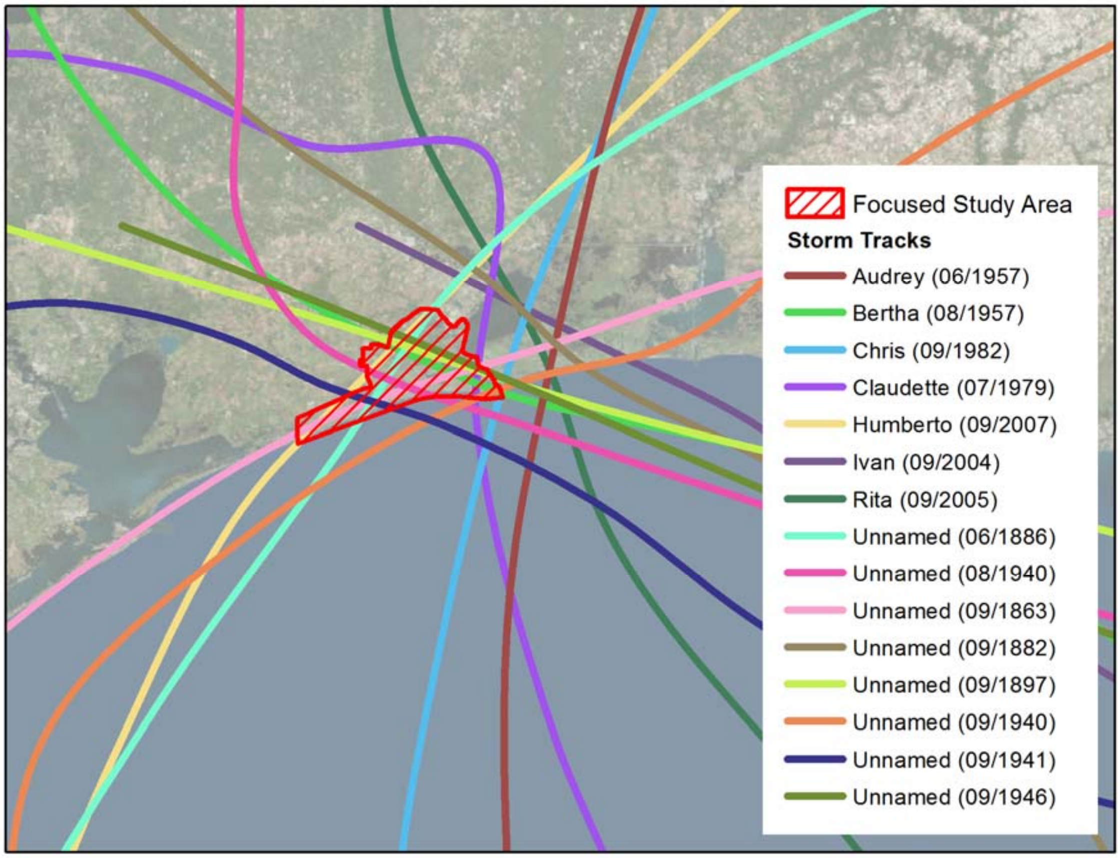


Figure 21: Select storm tracks in and around the study area

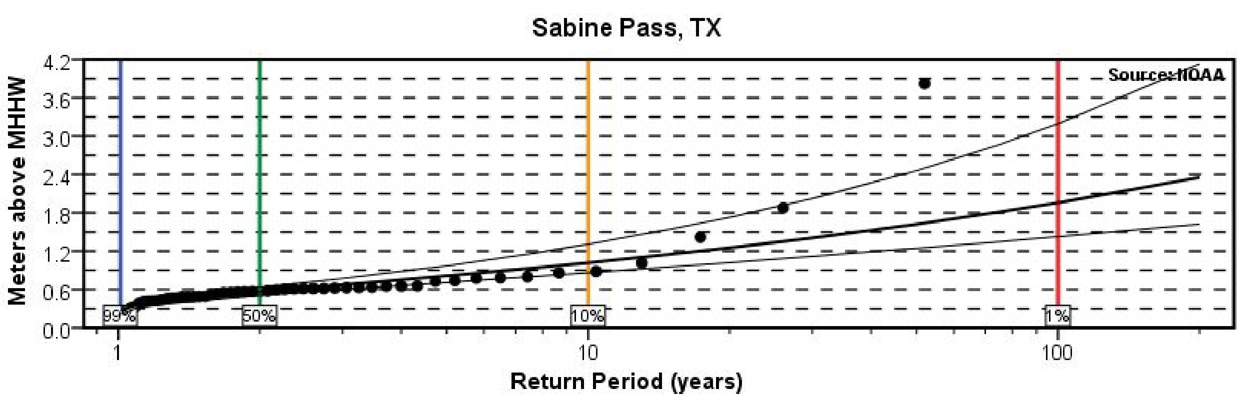
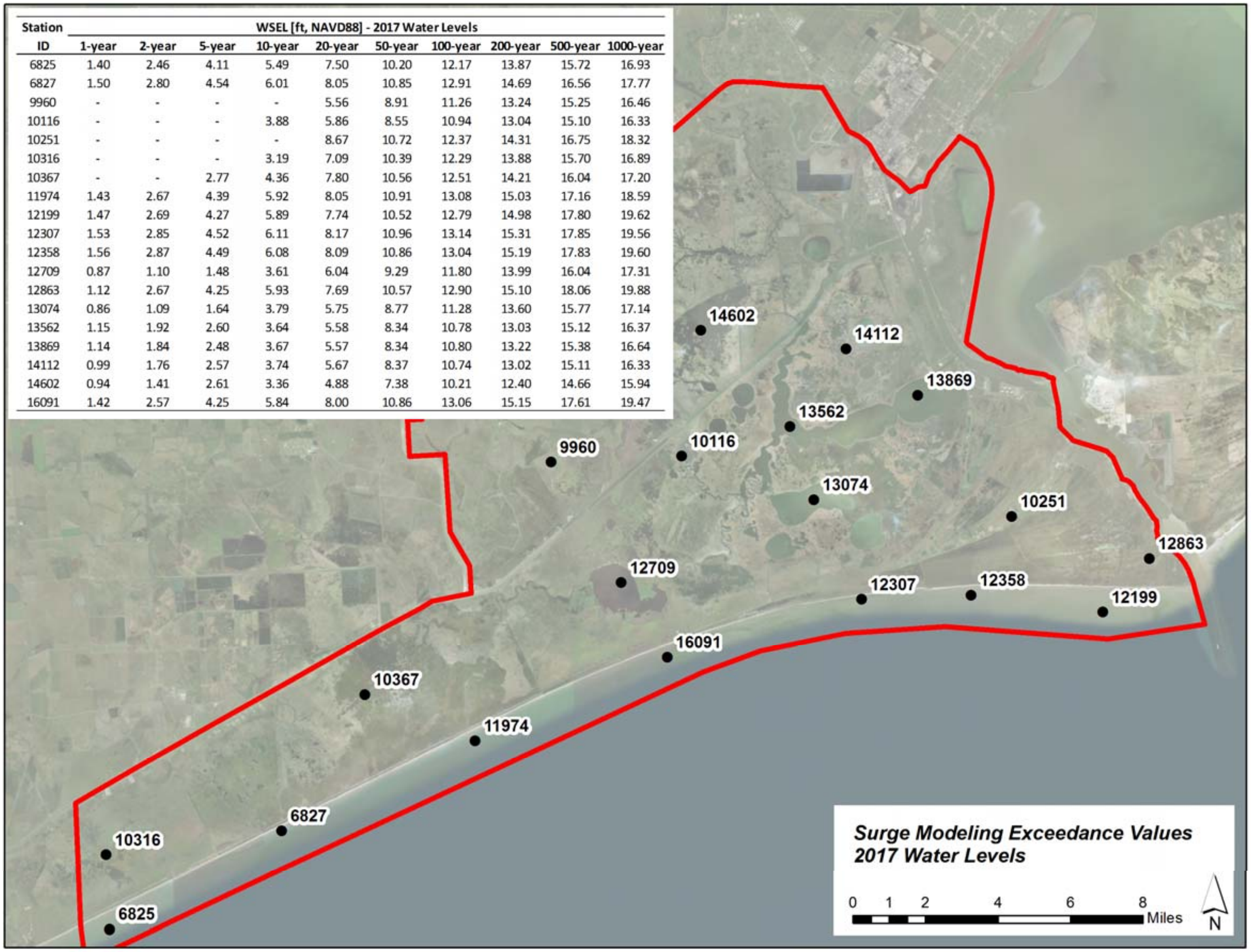
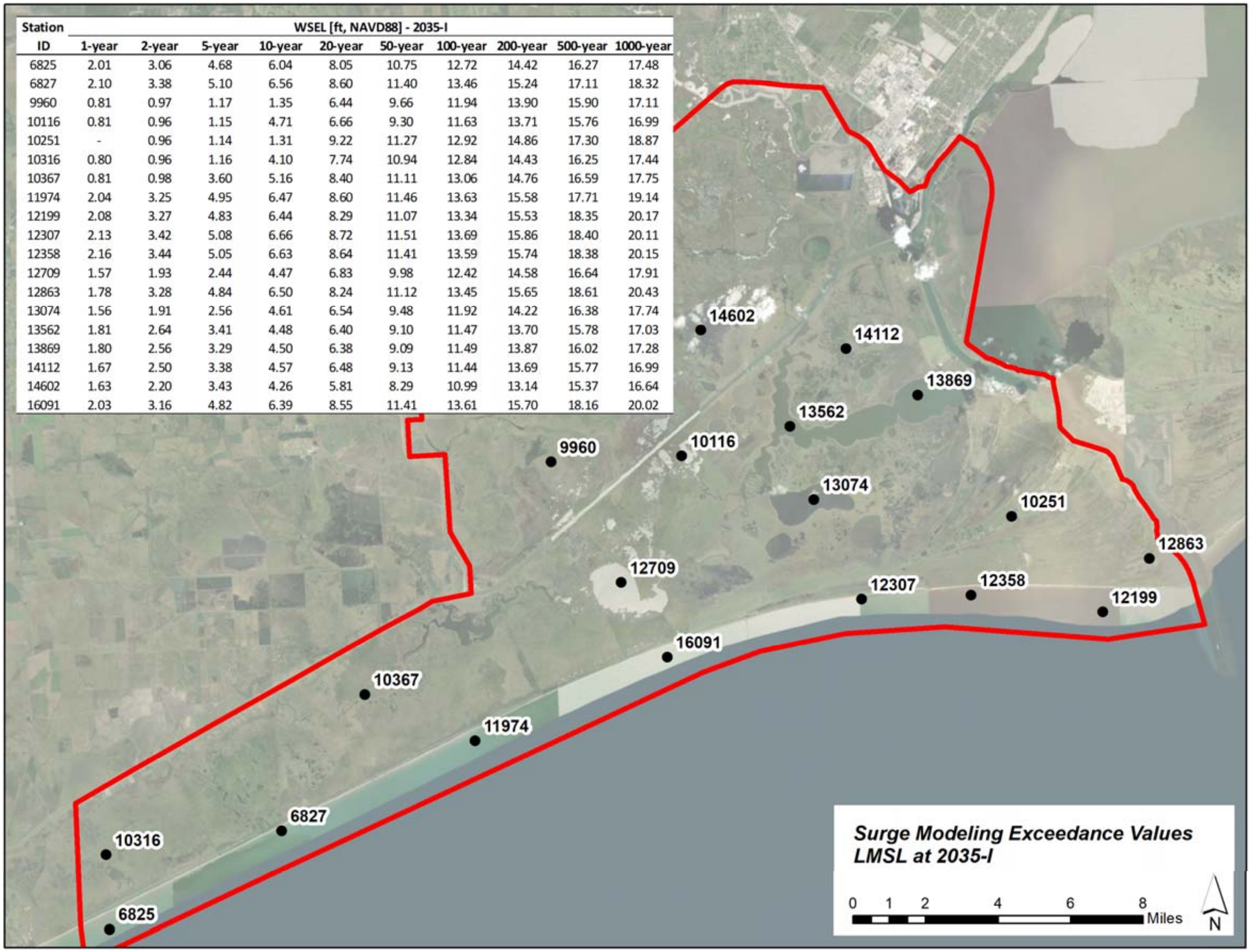


Figure 22: Extremal water-surface elevations for NOAA station 8770570



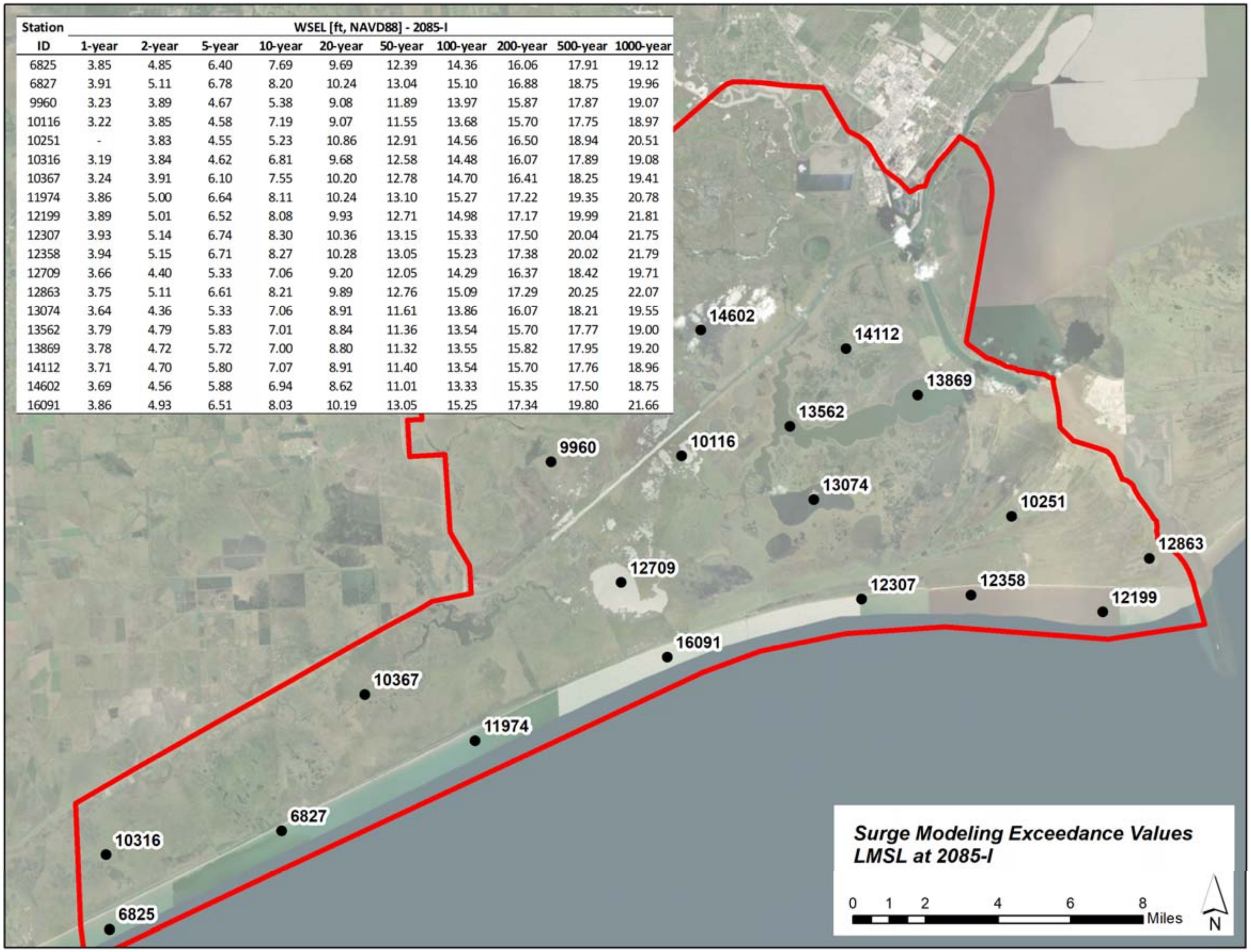
Station	WSEL [ft, NAVD88] - 2017 Water Levels									
ID	1-year	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1000-year
6825	1.40	2.46	4.11	5.49	7.50	10.20	12.17	13.87	15.72	16.93
6827	1.50	2.80	4.54	6.01	8.05	10.85	12.91	14.69	16.56	17.77
9960	-	-	-	-	5.56	8.91	11.26	13.24	15.25	16.46
10116	-	-	-	3.88	5.86	8.55	10.94	13.04	15.10	16.33
10251	-	-	-	-	8.67	10.72	12.37	14.31	16.75	18.32
10316	-	-	-	3.19	7.09	10.39	12.29	13.88	15.70	16.89
10367	-	-	2.77	4.36	7.80	10.56	12.51	14.21	16.04	17.20
11974	1.43	2.67	4.39	5.92	8.05	10.91	13.08	15.03	17.16	18.59
12199	1.47	2.69	4.27	5.89	7.74	10.52	12.79	14.98	17.80	19.62
12307	1.53	2.85	4.52	6.11	8.17	10.96	13.14	15.31	17.85	19.56
12358	1.56	2.87	4.49	6.08	8.09	10.86	13.04	15.19	17.83	19.60
12709	0.87	1.10	1.48	3.61	6.04	9.29	11.80	13.99	16.04	17.31
12863	1.12	2.67	4.25	5.93	7.69	10.57	12.90	15.10	18.06	19.88
13074	0.86	1.09	1.64	3.79	5.75	8.77	11.28	13.60	15.77	17.14
13562	1.15	1.92	2.60	3.64	5.58	8.34	10.78	13.03	15.12	16.37
13869	1.14	1.84	2.48	3.67	5.57	8.34	10.80	13.22	15.38	16.64
14112	0.99	1.76	2.57	3.74	5.67	8.37	10.74	13.02	15.11	16.33
14602	0.94	1.41	2.61	3.36	4.88	7.38	10.21	12.40	14.66	15.94
16091	1.42	2.57	4.25	5.84	8.00	10.86	13.06	15.15	17.61	19.47

Figure 23: Modeled surge water-surface elevations as a function of return period for 2017 water levels



Station	WSEL [ft, NAVD88] - 2035-I									
ID	1-year	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1000-year
6825	2.01	3.06	4.68	6.04	8.05	10.75	12.72	14.42	16.27	17.48
6827	2.10	3.38	5.10	6.56	8.60	11.40	13.46	15.24	17.11	18.32
9960	0.81	0.97	1.17	1.35	6.44	9.66	11.94	13.90	15.90	17.11
10116	0.81	0.96	1.15	4.71	6.66	9.30	11.63	13.71	15.76	16.99
10251	-	0.96	1.14	1.31	9.22	11.27	12.92	14.86	17.30	18.87
10316	0.80	0.96	1.16	4.10	7.74	10.94	12.84	14.43	16.25	17.44
10367	0.81	0.98	3.60	5.16	8.40	11.11	13.06	14.76	16.59	17.75
11974	2.04	3.25	4.95	6.47	8.60	11.46	13.63	15.58	17.71	19.14
12199	2.08	3.27	4.83	6.44	8.29	11.07	13.34	15.53	18.35	20.17
12307	2.13	3.42	5.08	6.66	8.72	11.51	13.69	15.86	18.40	20.11
12358	2.16	3.44	5.05	6.63	8.64	11.41	13.59	15.74	18.38	20.15
12709	1.57	1.93	2.44	4.47	6.83	9.98	12.42	14.58	16.64	17.91
12863	1.78	3.28	4.84	6.50	8.24	11.12	13.45	15.65	18.61	20.43
13074	1.56	1.91	2.56	4.61	6.54	9.48	11.92	14.22	16.38	17.74
13562	1.81	2.64	3.41	4.48	6.40	9.10	11.47	13.70	15.78	17.03
13869	1.80	2.56	3.29	4.50	6.38	9.09	11.49	13.87	16.02	17.28
14112	1.67	2.50	3.38	4.57	6.48	9.13	11.44	13.69	15.77	16.99
14602	1.63	2.20	3.43	4.26	5.81	8.29	10.99	13.14	15.37	16.64
16091	2.03	3.16	4.82	6.39	8.55	11.41	13.61	15.70	18.16	20.02

Figure 24: Modeled surge water-surface elevations as a function of return period for water levels at 2035-I



Station	WSEL [ft, NAVD88] - 2085-I									
ID	1-year	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1000-year
6825	3.85	4.85	6.40	7.69	9.69	12.39	14.36	16.06	17.91	19.12
6827	3.91	5.11	6.78	8.20	10.24	13.04	15.10	16.88	18.75	19.96
9960	3.23	3.89	4.67	5.38	9.08	11.89	13.97	15.87	17.87	19.07
10116	3.22	3.85	4.58	7.19	9.07	11.55	13.68	15.70	17.75	18.97
10251	-	3.83	4.55	5.23	10.86	12.91	14.56	16.50	18.94	20.51
10316	3.19	3.84	4.62	6.81	9.68	12.58	14.48	16.07	17.89	19.08
10367	3.24	3.91	6.10	7.55	10.20	12.78	14.70	16.41	18.25	19.41
11974	3.86	5.00	6.64	8.11	10.24	13.10	15.27	17.22	19.35	20.78
12199	3.89	5.01	6.52	8.08	9.93	12.71	14.98	17.17	19.99	21.81
12307	3.93	5.14	6.74	8.30	10.36	13.15	15.33	17.50	20.04	21.75
12358	3.94	5.15	6.71	8.27	10.28	13.05	15.23	17.38	20.02	21.79
12709	3.66	4.40	5.33	7.06	9.20	12.05	14.29	16.37	18.42	19.71
12863	3.75	5.11	6.61	8.21	9.89	12.76	15.09	17.29	20.25	22.07
13074	3.64	4.36	5.33	7.06	8.91	11.61	13.86	16.07	18.21	19.55
13562	3.79	4.79	5.83	7.01	8.84	11.36	13.54	15.70	17.77	19.00
13869	3.78	4.72	5.72	7.00	8.80	11.32	13.55	15.82	17.95	19.20
14112	3.71	4.70	5.80	7.07	8.91	11.40	13.54	15.70	17.76	18.96
14602	3.69	4.56	5.88	6.94	8.62	11.01	13.33	15.35	17.50	18.75
16091	3.86	4.93	6.51	8.03	10.19	13.05	15.25	17.34	19.80	21.66

Figure 25: Modeled surge water-surface elevations as a function of return period for water levels at 2085-I

Aside from the above discussed modeling, Stockdon et al. (2012) and Doran et al. (2016) considered vulnerability to hurricane-induced erosion. They used the probability of dune overwash and dune inundation as a surrogate for erosion vulnerability with higher water-surface elevations corresponding to coastal land loss through high rates of sediment transport in the inland direction. This was developed by comparing water-surface elevations simulated from SLOSH (Sea, Lake, and Overland Surges from Hurricanes) and SWAN (Simulating Waves Nearshore) to dune crest elevations. This analysis for Jefferson County is shown in figure 29 for a category 1 hurricane (Stockdon et al., 2016). A high probability of inundation persists throughout Jefferson County.

The landscape is a coupled morphologic system wherein the marsh itself affects coastal storms and in turn the coastal storms affect the marsh. Coastal storms represent a category of environmental forcing, but one that has a profound effect of the landscape and infrastructure. The coastal marsh is thought to be beneficial toward storm surge attenuation and wave energy dissipation (Leonardi et al., 2018); a boon for regional resiliency. Coastal storms, though, impact marshes through incision, erosion, deposition, and deformation. The particular impacts imparted by a storm event are largely a function of the particular properties of the storm and the subject marsh (Leonardi et al., 2018).

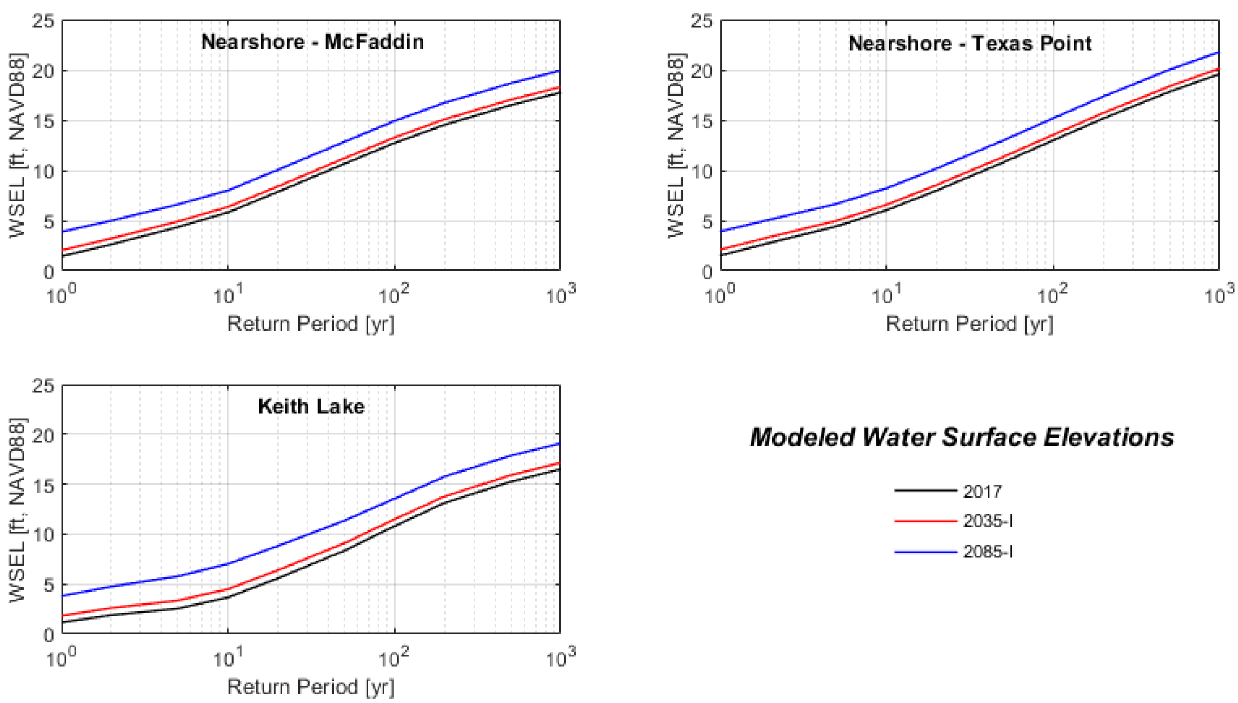


Figure 26: Modeled stage-frequency curves at locations through the study area: Nearshore-McFaddin (averaged from stations 6825, 6827, and 11974), Nearshore-Texas Point (averaged from stations 12358, 12199, and 12307), and Keith Lake (averaged from stations 13562 and 13869)

Figure 27: Probability of coastal inundation from category 1 hurricane landfall (Doran et al., 2016)

3.4.5 Wave Climate

There are two general sources for wave characteristics available for the project area: (1) Wave Information Study (WIS) hindcasts compiled by the USACE ERDC-CHL (USACE/ERDC, 2017b) and (2) direct measurements obtained and reported as a part of the National Data Buoy Center (NDBC) network (NOAA/NWS, 2017c). There are several WIS stations near the project site: 73077, 73079, 73080, 73082, 73083, 73085, 73086, and 73088. Since WIS is predicated on wave hindcast estimates, the spatial density is much larger than the physical buoys. The closest NDBC buoy is 42035. The locations of both are shown in figure 28.

King (2007) presented a comparison between the NDBC measurements and WIS station hindcasts; Pacific International Engineering (PIE) (2003) conducted a similar comparison with similar results. An evaluation of the differences indicates relatively good agreement between the two data sources. This is particularly true of wave height where error is minimal, especially during calmer months. However, wave height is slightly overpredicted by WIS during winter storm events. Wave direction typically has the most error, particularly with larger waves. Broadly, the two data sources compare better with smaller waves than with larger waves.

Extremal wave heights at several of the nearby WIS stations are shown in table 4. Those for the 50-100 year recurrence are often extrapolated. The distribution between wave period and wave height for station 73085 is shown in table 5 and the associated wave rose is shown in figure 29. Waves are predominately small, of short period, and from the south-southeast.

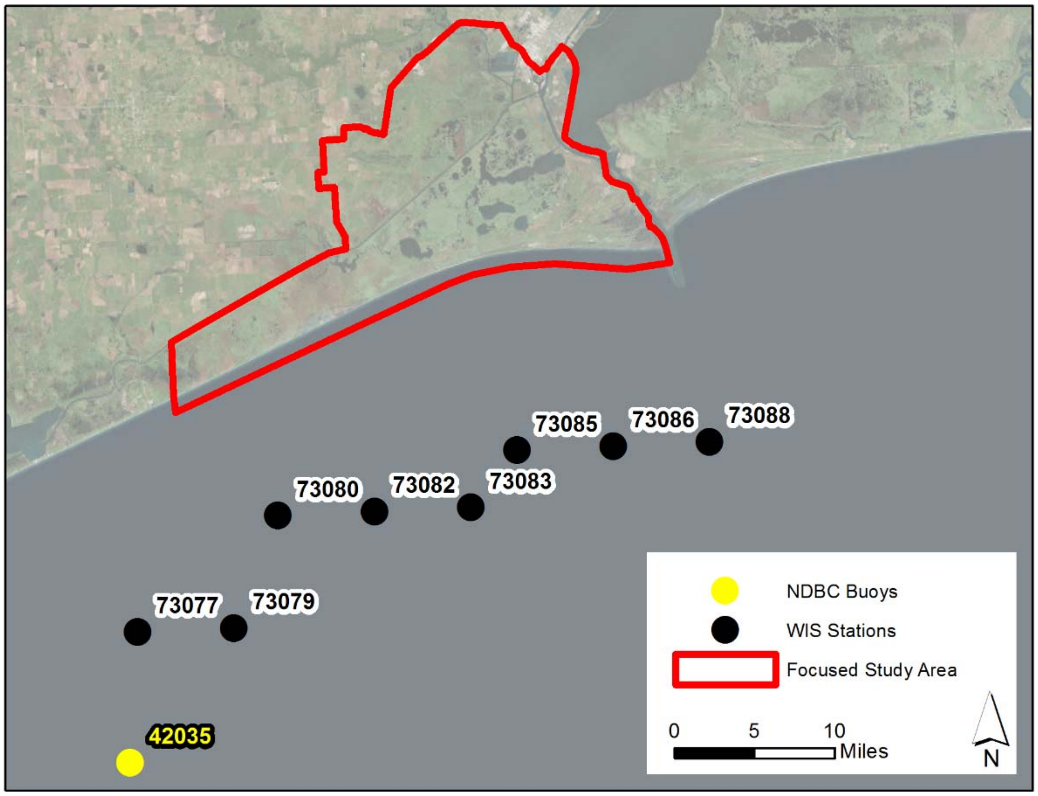


Figure 28: Locations of NDBC Buoys and WIS stations near the study area

Table 4: Extremal wave heights at nearby WIS Stations

WIS Station	Depth [m]	Peak Significant Wave Height [m]				
		5-year	10-year	20-year	50-year	100-year
73079	7	2.42	2.63	2.83	3.11	3.32
73080	5	1.84	1.95	2.07	2.22	2.33
73082	5	1.84	1.91	1.99	2.09	2.17
73083	6	2.16	2.30	2.45	2.64	2.79
73085	5	1.86	1.95	2.05	2.17	2.26
73086	5	1.84	1.90	1.97	2.05	2.11
73088	6	2.17	2.31	2.45	2.63	2.76

Table 5: Distribution by percent of occurrence of wave height and period at WIS Station 73085

Wave Height [m]	Wave Period [sec] < 2.0	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-11.9	12.0+
< 0.10		1.17	0.63	0.50	0.50	0.50	0.33	0.12	0.13	0.17	0.12	0.03
0.10 - 0.49		9.99	19.90	10.70	7.76	4.66	1.92	0.56	0.22	0.09	0.04	0.13
0.50-0.99		0.69	18.23	9.30	3.33	2.25	1.60	0.85	0.22	0.07	0.02	0.09
1.00-1.50			0.11	1.15	0.50	0.53	0.31	0.20	0.07	0.02	0.01	0.03
1.50-1.99				0.09	0.04	0.01	0.01	0.02	0.03		0.01	0.01
2.00-2.49												
2.50-2.99												
3.00-3.49												
3.50-3.99												
4.00+												

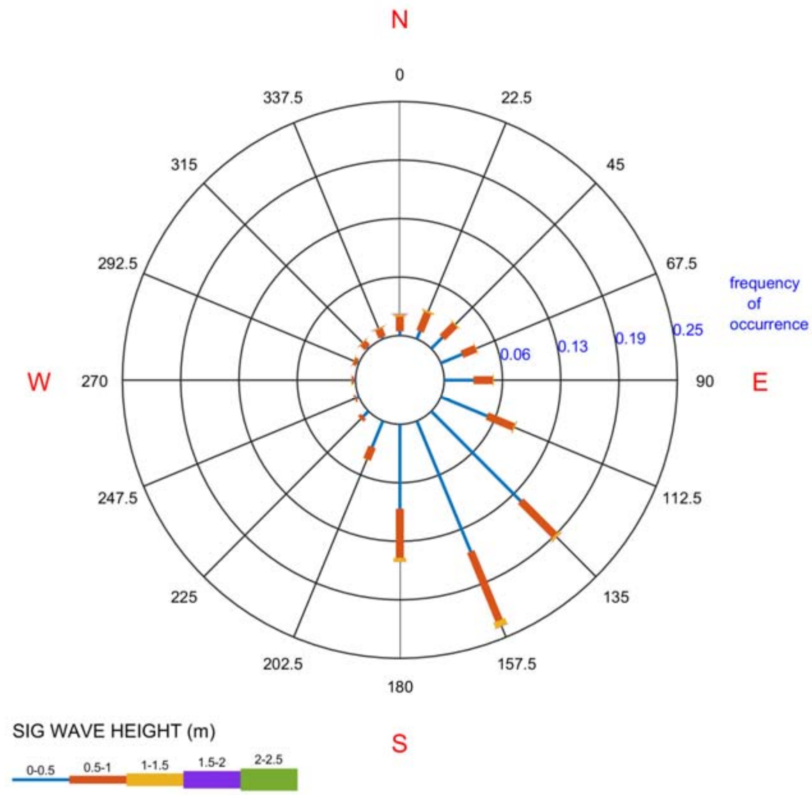


Figure 29: Wave rose for WIS station 73085 for period 1980-2014

3.5 Sediment Budget

Sediment is delivered to Sabine Lake from two major fluvial sources, the Sabine River and Neches River. Sabine Lake is a relatively efficient sediment trap and detains much of the sand before it can reach the shoreline. Some of this sediment is deposited in the SNWW and subsequently removed by maintenance dredging. Figure 30 shows the navigation channels in the area which include the SNWW and the GIWW; table 6 shows the dredging volumes indicated by the SNWW channel improvement feasibility study (USACE, 2011). The GIWW is dredged infrequently through the study area; the vast majority of sediment removed is from the SNWW. Dredged material from the jetty channel and the reaches further offshore is placed in offshore dredged material disposal sites (ODMDS) to the west side of the channel. Material dredged from the Pass Channel and inland is placed in upland confined placement areas throughout the area, removing the sediment from the system.

As for sediment transport along the coast, figure 31 shows the sediment budget cells delineated by Morang (2006) with the associated fluxes. Longshore transport through the area is generally east to west, however it is interrupted near the project site from the SNWW jetties. This leaves the littoral system through the project area relatively sediment starved and facilitates the shoreline erosion issues. Texas Point NWR is severely eroding but for a small filet adjacent to the west of the SNWW jetties.

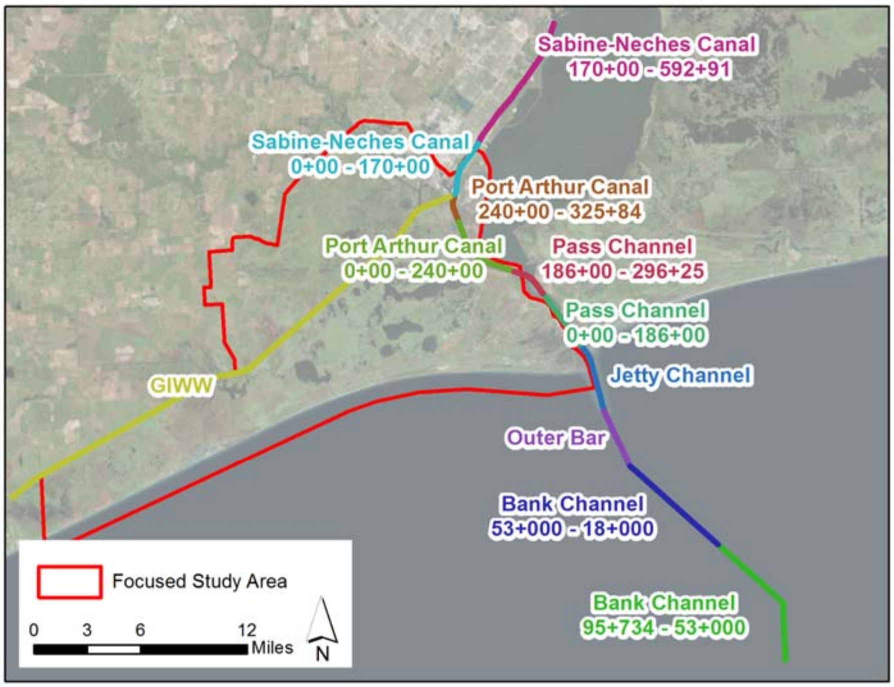


Figure 30: Navigation channels in and around the study area

Table 6: Dredging cycles and average annual removal rate for navigation channels in the area (USACE, 2011)

Channel	Stationing	Cycle [yr]	Volume per Cycle [CY]	Annual Volume [CY/yr]
Sabine-Neches Canal	170+00 - 592+91	4	2,469,800	617,450
	0+00 - 170+00	2	1,219,400	609,700
Port Arthur Canal	240+00 - 325+84	2	2,320,350	1,160,175
	0+00 - 240+00	3	1,890,000	630,000
Sabine Pass Channel	186+00 - 296+25	3	1,051,800	350,600
	0+00- 186+00	3	860,100	286,700
Sabine Pass Jetty Channel	-214+88 - 0+00	5	1,138,500	227,700
Sabine Outer Bar	18+000 - 0+000	1	1,993,700	1,993,700
Sabine Bank Channel	53+000 - 18+000	4	1,722,400	430,600
	95+734 - 53+000	4	2,512,800	628,200
GIWW Port Arthur to High Island			Minimal Dredging	

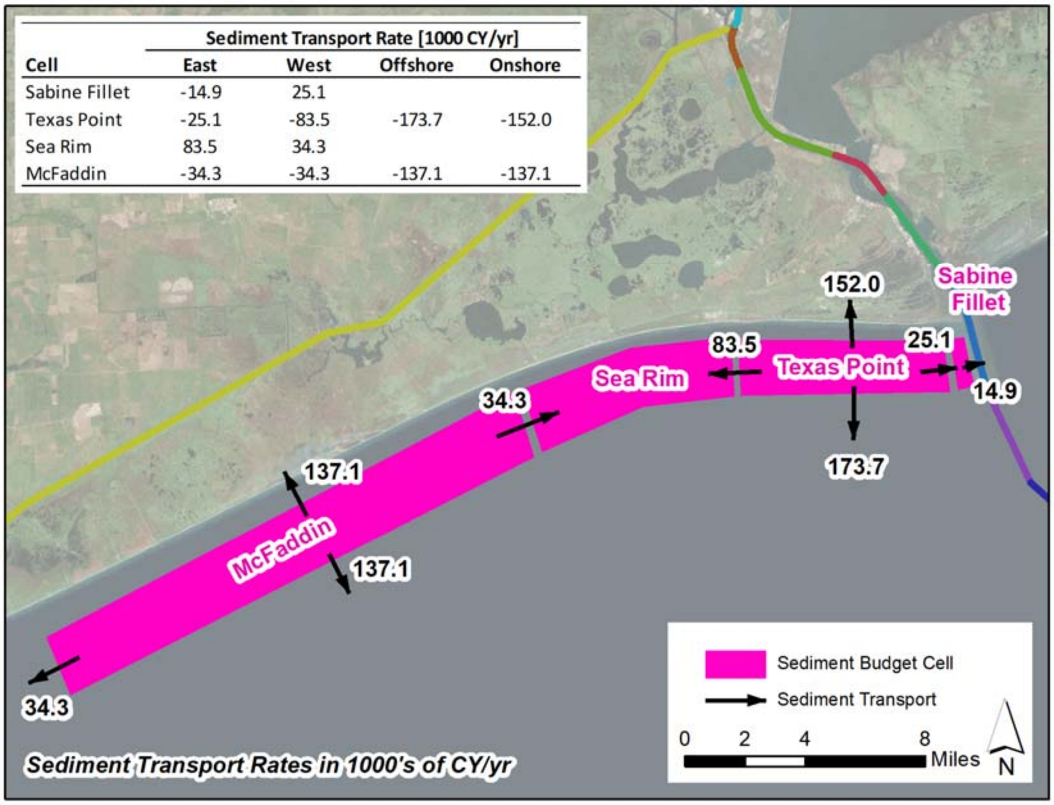


Figure 31: Sediment budget cells in and around the study area (Morang, 2006)

3.6 Shoreline Change

Jefferson County has a long history of coastal erosion (Paine et al., 2014). The long-term and more recent shoreline change rates along the Jefferson County coast are shown in figures 32 and 33 respectively. The spatiotemporally-averaged long-term erosion rate between the 1930's and 2012 throughout Jefferson County is 3.34 m/yr which corresponds to an areal loss rate of approximately 43 ac/yr. Shoreline erosion, and the accompanying land loss, have been more intense when the temporal average is restricted to a more recent period, 2000-2012, where it was 5.18 m/yr and approximately 67 ac/yr respectively (Paine et al., 2014). If left unmitigated this trend shows no sign of abating.

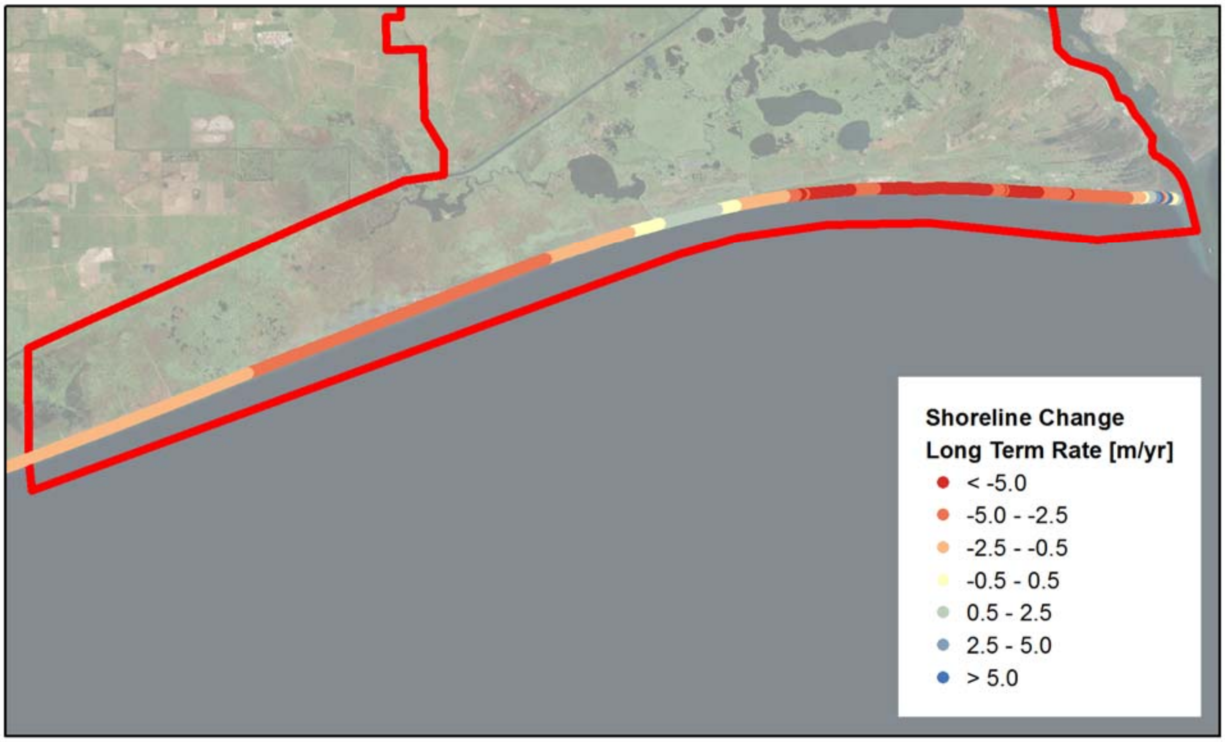


Figure 32: Long-term shoreline change rate through Jefferson County, TX (Paine et al., 2014)

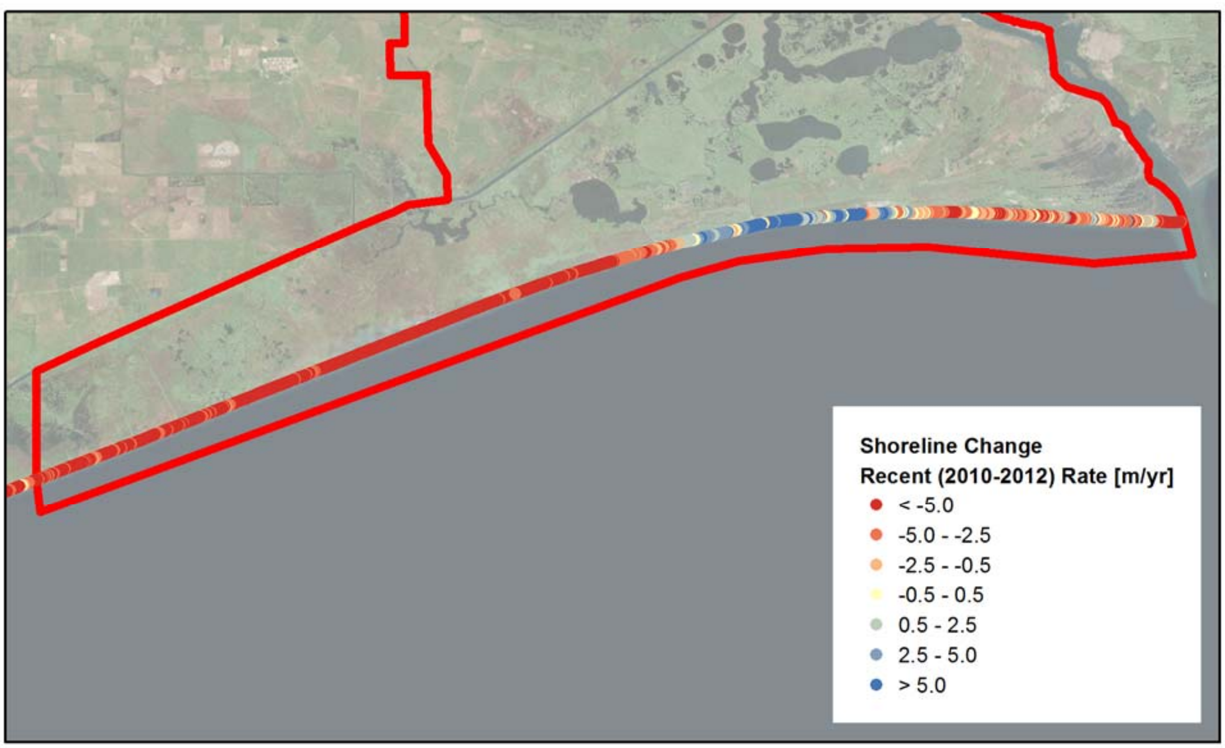


Figure 33: Recent shoreline change in Jefferson County, TX (Paine et al., 2014)

4 Surveying, Mapping, and Other Geospatial Data

No new surveys were conducted to evaluate the focused array of alternatives; existing datasets were used in coordination with resource agencies and land managers to determine key elevations. Site specific survey data will be collected as needed during PED.

The following is an overview of the geospatial and physical data available in and around the study area:

- Aerials from the National Agriculture Imagery Program (NAIP) and Texas Orthoimagery Program are available from the Texas Natural Resources Information System (TNRIS) (TNRIS, 2017).
- LiDAR datasets including: the national coastal mapping program (NCMP) data from 2009 and 2016, 2006 data collected by Texas Water Development Board (TWDB), 2017 data collected by TNRIS.
- NOAA National Ocean Service (NOS) survey data in the nearshore and Sabine Lake areas. These surveys are generally quite old, e.g., 1950s era, however there is often no more current survey (NOAA/NOS, 2017).
- The NOAA Office of Coastal Management (OCM) Coastal Change Analysis Program (C-CAP) has an inventory of land cover types throughout the coastal zone in the US (NOAA/OCM, 2017a).
- The NOAA OCM Marsh Migration viewer and associated data provides the projected change in land cover types under various SLR scenarios (NOAA/OCM, 2017bc, 2017c).
- Bureau of Economic Geology (BEG) shoreline change data (Paine et al., 2014).
- The TxSed database is a compilation of sediment data collected throughout the Texas Coastal zone maintained by the Texas General Land Office (GLO) (GLO, 2017).
- NOAA/CO-OPS water-level stations and associated datums (NOAA/CO-OPS, 2017).
- USACE WIS stations and associated data (USACE/ERDC, 2017b).
- NOAA/NWS NDBC Buoys (NOAA/NWS, 2017c).

Additional data will be utilized during PED as it becomes necessary and available.

5 GEOTECHNICAL

5.1 Geology

The Natural Resource Conservation Service (NRCS) major land resource area (MLRA) data shows the principle surficial geology classes in the focused study area to be gulf coast marsh and gulf coast saline prairie (NRCS, 2017). The area is generally Pleistocene headland overlain by Holocene deposits (Park and Edge, 2011). The Beaumont Formation, a spatially expansive late-Pleistocene fine-grained formation, spans much of the study area. These sediments are principally fluvial from the Mississippi River and delta system.

Beaumont Clay is the predominant Pleistocene formation whose eroded surface forms the upper limit of stiff to very stiff clay material. It is red, yellow, and brown calcareous stiff clay that weathers into black or gray soil at the surface. Lenses of fine-grained, poorly graded sand and silt and a few calcareous nodules are sometimes encountered in this formation.

The clay fraction is composed of montmorillonite, kaolinite, illite, and finely ground quartz, in that order of prevalence. The high percentage of montmorillonite accounts for the high shrink-swell potential of the material. Previous dessication of the clays results in significant overconsolidation to great depths, with preconsolidation pressure approaching 6,000 psf.

The study area can broadly be described as a chenier plain. This is particularly evident in the eastern portion of the study area where there are series of chenier ridges. These cheniers developed as a series of prograding mudflats that are intermittently reworked and stacked into ridges. The subaerial beach through the study area is generally narrow and becomes progressively finer from west to east (Park and Edge, 2011).

5.2 Geotechnical Analysis and Assumptions

Geotechnical analysis has not been conducted for this study, nor have any soil borings or testing been completed. Data gathering of existing information has been done to provide assumptions for the possible types of material to be dredged from the Sabine Neches Waterway. In areas for construction of stone breakwaters, existing soils information has not been located as of yet. If no data exists, soils investigations should be completed during PED to ascertain the soil stratums in these areas.
Grain size information in and around the area was available from the TxSed database (GLO, 2017). This database is an amalgamation of sediment data collected in the Texas Coastal zone maintained by the Texas GLO. Though maintained by the GLO, the data comes from many sources including Texas Parks and Wildlife Department (TPWD), GLO, USACE, among others. The available data is shown in figure 34.

The sediments are generally fine-grained throughout the study area. This is true even in the beach/nearshore which are relatively fine though there can be pockets of more sandy material. The beach/nearshore becomes progressively less fine to the western portion of the study area. The material in the SNWW and the upland confined placement areas, potential sediment sources, consist of primarily fine material.

Marsh nourishment volumes were determined using broad assumptions that will be discussed in a subsequent section.

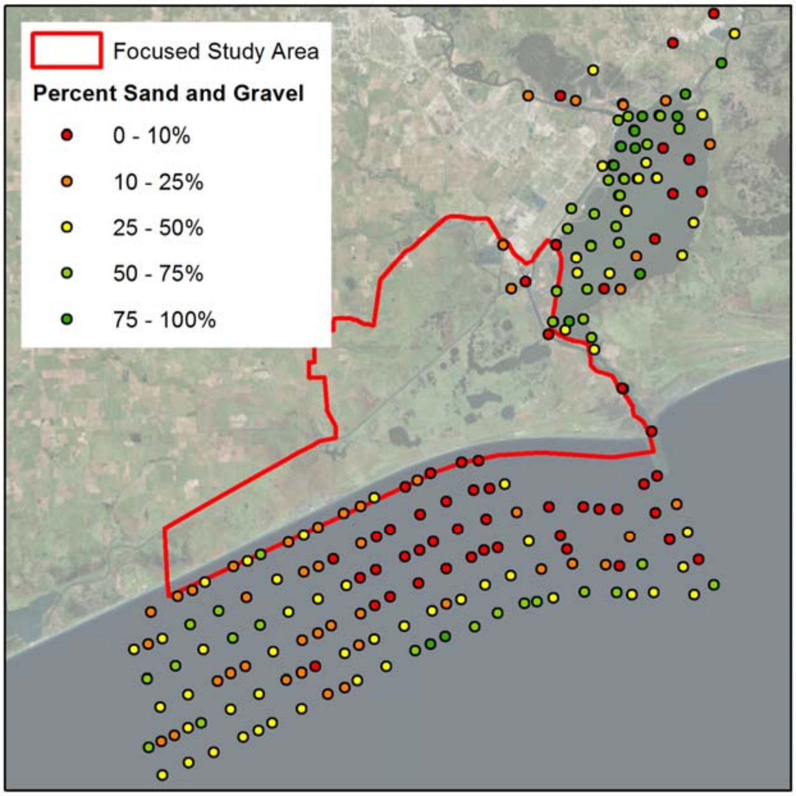


Figure 34: Grain size information available from the TxSed database (GLO, 2017)

5.2.1 Analyses

A generalized cross section for the stone breakwaters has been used for cost estimating purposes of this study. During PED, the stone breakwaters will be designed to verify the assumed cross section in this study. Geotechnical analyses should include stability, bearing capacity and settlement in determining the appropriate dimensions for the breakwater.

6 ER Feature Design

Herein we discuss the assumptions and design considerations associated with each of the ER features in the various alternatives. The measures generally fall into three categories: GIWW shoreline armoring, marsh restoration/nourishment, and gulf shoreline stabilization/protection.

6.1 GIWW Shoreline Armoring

Armoring the shoreline along the GIWW was considered as a means of reducing marsh erosion associated with adjacent shipwake. This type of measure has been successful in reducing shoreline erosion in open bays and waterways. An example of the measure in-place is shown in figure 35 and a typical section in figure 36.

The design was based on breakwaters constructed in the area by Ducks Unlimited (e.g., fig. 35) and concepts developed for the Sabine to Galveston Feasibility Study (USACE, 2016e). The assumptions and design considerations associated with GIWW shoreline armoring are:

- shoreline protection would be provided in areas meeting two criteria: (1) there is not existing armoring in the area and (2) the immediately adjacent land is not an upland confined placement area for the GIWW;
- breakwaters would be placed sufficiently offset from the boundaries of the GIWW navigation channel for safe navigation;
- breakwaters would be placed approximately at the -3 feet contour up to a crest elevation of +3 feet;
- breakwaters would be raised as need throughout the period of analysis to account for RSLC and remain effective;
- maintenance volumes are assumed as 15% of the initial volume at year 15 and 10% of the initial volume at year 25 (USACE, 2016d);
- the base of the armoring should be on filter cloth ballasted to secure placement and prevent displacement of the outboard edges;
- openings would be required only at major channel entrances or at access points required for fisheries access or circulation (to be determined in PED);
- living shoreline concepts will be explored if part of the selected plan;
- placement of armoring on the natural bottom outside the dredged GIWW channel provides benefits for ship-wake-induced shoreline erosion and can help reduce shoaling;
- shallow natural bottom between the top-of-cut of GIWW and the channel-side toe of the armoring would reduce or prevent damage from barge or boat traffic and reduce the chance for armoring undermining from channel-side erosion;
- permeability of the armoring would be low enough to prohibit the passage of oils and high enough to allow sufficient flow-through for interior drainage and tidal flow exchange with the adjacent bays and tidal ponds;
- locating the armoring alongside the channel would facilitate construction and maintenance;
- one disadvantage of a armoring in the vicinity of the channel is that is a danger that an empty barge tow could be blown off course by strong onshore winds, damaging the armoring or empty barges;

- it is not practical or necessary to construct the armoring to an elevation above water levels associated with tropical events; in the event of hurricane tides, the armoring would be inundated at an early stage in the approaching storm tides and would not suffer severe damage as a result of being completely covered.

Figure 35: Constructed breakwater along the GIWW in Jefferson County, TX (Ducks Unlimited, 2013)

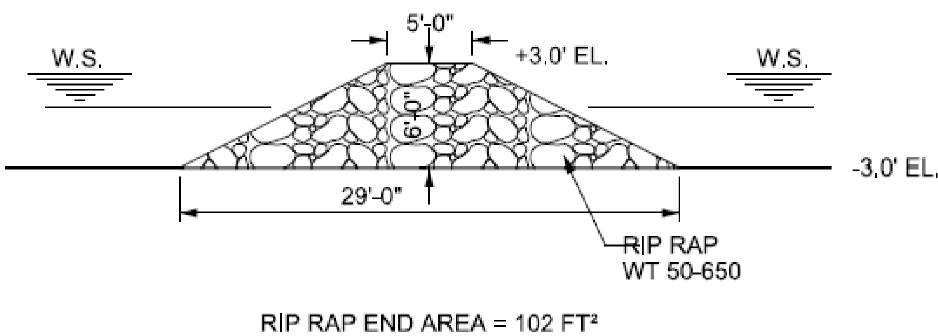


Figure 36: Typical section for GIWW armoring

The quantity was calculated using the trapezoidal area of the assumed breakwater section with a density of 118.5 lbs/cu.ft. The quantities for the various alternatives containing breakwaters along the GIWW are shown in table 7.

The shoreline erosion rate in the absence of breakwaters is estimated to be 4 ft./yr. The benefit to the study area is a preservation of marsh adjacent to the navigation channel.

Table 7: Breakwater quantities (rounded) for GIWW armoring for each alternative

Alternative	Length [ft]	Volume [ft^3]	Weight [tons]	Year 15 Maintenance Weight [tons]	Year 25 Maintenance Weight [tons]
Alternative 2A	56,455	5,758,410	341,200	51,200	34,100
Alternative 2B	56,455	5,758,410	341,200	51,200	34,100
Alternative 3	56,455	5,758,410	341,200	51,200	34,100
Alternative 4A	6,592	672,384	39,800	6,000	4,000
Alternative 4B	6,592	672,384	39,800	6,000	4,000
Alternative 10	38,237	3,900,174	231,100	34,700	23,100
Alternative 13	56,455	5,758,410	341,200	51,200	34,100

6.2 Marsh Restoration / Nourishment

Marsh restoration and nourishment is a component in most of the alternatives. This measure includes making modifications to the marsh elevation through thick layer placement.

The assumptions and design considerations associated with marsh nourishment are:

- nourishment cells are assumed to be degraded such that 50% of the cell is at the ecological target elevation and will be raised to 65% of the cell at that elevation (fig. 37);
- based on agency input, the 15% of the marsh cell to be elevated exists at approximately 0 ft. NAVD88 and will be raised to 1.6 ft. NAVD88 (fig. 38);
- to account for RSLC, the original marsh nourishment areas would be raised an additional 1.0 feet at year 30 (this additional lift was included during plan comparison, but subsequently removed from the recommended plan);
- final elevations will be determined during PED with resource agency input, available data, and additional surveys as needed;
- quantity calculations assume 20% settlement, a bulking factor of 1.2, and a loss factor of 1.5;
- the sediment source is assumed to be from SNWW BUDM or SNWW PAs for marsh creation areas toward the east of the project area and offshore sources for areas to the west (a full description of sediment sources is in a subsequent section);
- marsh placement will include the removal of invasive species;
- containment levees will be constructed with in-situ material and the extent of the requirement will be evaluated on the selected plan;
- training berms, associated with certain alternatives within marsh nourishment cells, are not overtly considered since they would be a very small part of the overall cost.

The marsh nourishment quantities were calculated using the aforementioned areal, elevation, and engineering assumptions. The marsh nourishment volumes calculated for each alternative as a function of sediment source for both initial and continuing construction are shown in table 8.

The additional volume for marsh nourishment at year 30 was allocated to account for RSLC assuming the intermediate scenario. The volume and/or timing of additional marsh nourishment could be different in actuality under different water-level conditions. The assumed additional volume was calculated conservatively with passive inundation of the marsh from RSLC, however there would be a degree of marsh accretion that can be revaluated in PED.

Absent the inclusion of marsh nourishment in the study area, the expectation is further marsh erosion and conversion to open water. Figure 20 is an approximation of landscape change in the case of FWOP based on the NOAA marsh migration viewer (NOAA/OCM, 2017a).

6.3 Gulf Shoreline Protection / Stabilization

There are several restoration features proposed for the purposes of protecting and stabilizing the gulf shoreline. The extents of the gulf shoreline protection and stabilization measures were based on available shoreline change data (Paine et al., 2014). The shoreline change information and locations of the shoreline measures near McFaddin and Texas Point are shown in figure 39. Without action along the Gulf coast, the future condition consists of continued erosion, though perhaps with an acceleration over historic levels due to RSLC. The balance of this section outlines the various measures considered.

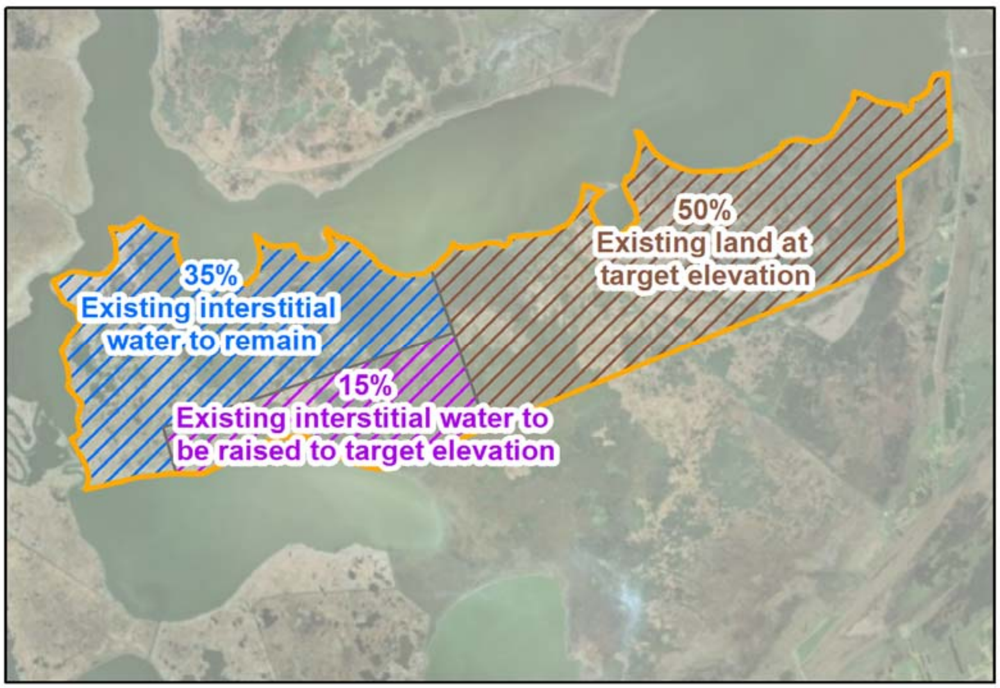


Figure 37: Cartoon showing the fractional treatment of the marsh nourishment cells: 50% consists of emergent marsh, 35% consists of interstitial water that will remain, and 15% consists of interstitial water to be raised to be emergent marsh. This is not meant to be indicative of the actual spatial distribution of a marsh cell, but meant to show the assumed fractional areal distribution.

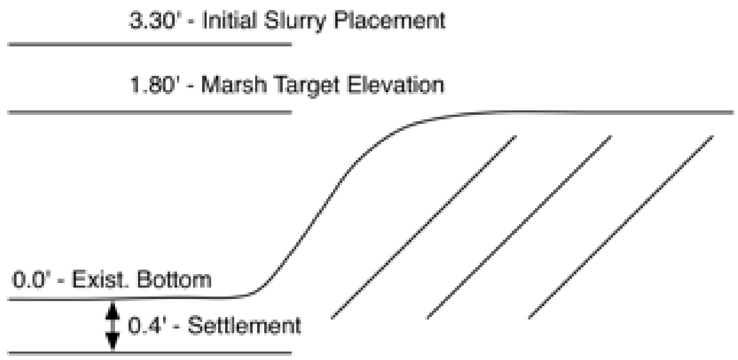


Figure 38: Cartoon showing key elevations used for the computation of marsh nourishment quantities

Table 8: Summary of marsh nourishment quantities for each alternative as a function of source area for both initial and continuing construction

	Sediment Quantity [yd^3]			
Alternative	**SNWW Borrow Init. Const.**	**Offshore Borrow Init. Const.**	**SNWW Borrow Cont. Const.**	**Offshore Borrow Cont. Const.**
Alternative 1A	10,009,120	1,969,880	5,459,520	1,074,480
Alternative 1B	10,009,120	1,969,880	5,459,520	1,074,480
Alternative 2A	10,009,120	1,969,880	5,459,520	1,074,480
Alternative 2B				
Alternative 3	8,358,680	1,969,880	4,559,280	1,074,480
Alternative 4A	6,708,240		3,659,040	
Alternative 4B				
Alternative 6A	9,263,760		5,052,960	
Alternative 6B	9,263,760		5,052,960	
Alternative 10	8,039,240	1,969,880	4,385,040	1,074,480
Alternative 13	10,009,120	1,969,880	5,459,520	1,074,480

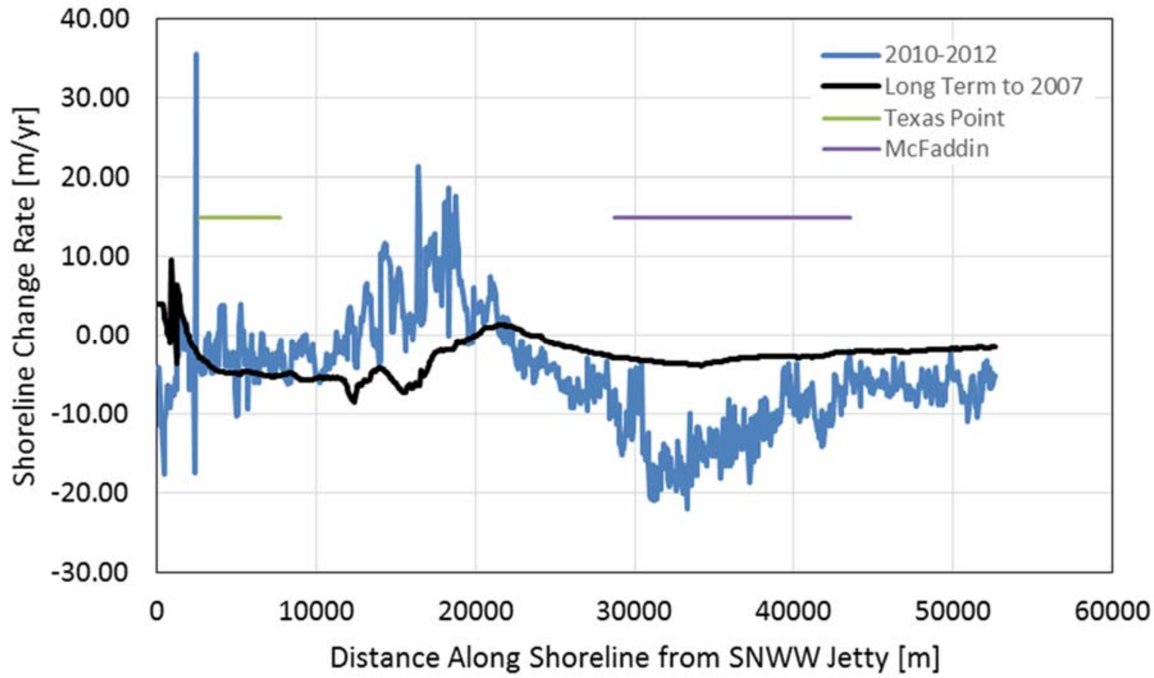


Figure 39: Shoreline change data and locations of gulf shoreline measures

6.3.1 Beach and Dune Nourishment

Beach and dune nourishment is proposed as a means of protecting the shoreline and interior marsh, and providing habitat. The measure would construct dune and extend the subaerial beach.

The assumptions and design considerations associated with beach and dune nourishment were based on work done by PIE (2005) and are:

- RSLC is accounted for using a linearized intermediate rate over the 50 year period of analysis (8.90 mm/yr);
- the depth of closure was obtained using the USACE/ERDC database (Brutsche et al., 2016; USACE/ERDC, 2017a) (8.7 feet (2.64 m) at McFaddin, 9.4 feet (2.87 m) at Texas Point);
- shoreline retreat was estimated based on an arithmetic mean of long term shoreline change rates within the alongshore extent of the measure (7.9 ft./yr (2.41 m/yr) at McFaddin, 15.7 ft./yr (4.80 m/yr) at Texas Point);
- the Bruun Rule (Bruun, 1962) is applied to account for the SLR effects on shoreline position;
- the initial added beach width is 164 feet (50m);
- the beach-fill sediment is assumed compatible;
- the renourishment interval is assumed 10 years.;
- the source material is assumed to be offshore for beach nourishment in and around McFaddin and assumed to be SNWW DMPAs and the SNWW for Texas Point;
- the sediment source is assumed the same for beach and dune nourishment;
- the dune crest elevation is taken as 9.0 feet (NAVD88);

- the dune crest width is take as 6 feet (1.83m);
- the constructed landward and seaward dune slopes are 3:1;
- dune vegetation (bitter panicum (*Panicum amarum*), sea oats (*Uniola paniculata*), and/or marshhay cordgrass (*Spartina patens*) would be planted on 3-foot centers to stabilize the dune system;
- sand fencing would be added as needed to reduce/control erosion of the dune system;
- the assumed overfill ratio is 1.25 for both beach and dune;
- the material will be loosely placed, not compacted;
- the specific locations of degraded dune and beach throughout the county could be refined during final feasibility and PED based on forthcoming data from the 2016 JALBTCX dataset.

The beach nourishment and dune restoration volumes were calculated independently. The beach nourishment quantities were developed using available data and volume relationships (USACE, 2008). The volume needed to extend the subaerial beach is related to whether the nourished beach will have an intersecting or non-intersecting profile. This is determined by the following relationship:

$$W\left(\frac{A_N}{D_C}\right)^{3/2} + \left(\frac{A_N}{A_F}\right)^{3/2} \qquad (1)$$

where A_N and A_F are parameters related to the native and fill grain sizes respectively, D_C is the depth of closure, and W is the added beach width from the nourishment. For the relationship, a value less than unity indicates an intersecting profile and greater than unity indicates a non-intersecting profile. The volume associated with adding additional equilibrium width for a non-intersecting profile is:

$$V = WB + \frac{3}{5}\left(\frac{D_C}{A_F}\right)^{5/2}\left(A_N\left[1 + W\left(\left(\frac{A_F}{D_C}\right)^{3/2}\right)\right]^{5/3} - A_F\right) \qquad (2)$$

and for intersecting profiles:

$$V = WB + \frac{\frac{3}{5}W^{5/3}A_N A_F}{\left(A_F^{3/2} - A_N^{3/2}\right)^{2/3}} \qquad (3)$$

where B is the beach berm elevation. The volume to replenish the existing sediment deficit in the profile was not explicitly considered here, rather additional advance maintenance width was added to the estimates. The total volume estimated was multiplied by the assumed overfill ratio and the longshore length of the measure to get a total volume for initial construction.

For renourishment, the volume was estimated based on expected volumetric change rate given by:

$$\frac{dV}{dt} = (D_C + B)E_R + W_C(S - S_0) \qquad (4)$$

where E_R is the shoreline change rate, W_C is the distance offshore to depth of closure, S is the projected RSLC rate, and S_0 is the historical RSLC rate (Dean and Dalrymple, 2004). This relationship reflects volume lost from background erosion and additional expected volume lost by RSLC. This volumetric loss rate is multiplied by the renourishment period, assumed overfill ratio and the length of the measure to get a periodic nourishment volume.

The estimated quantity for beach fill at Texas Point is 1.56 MCY for initial construction and 4.26 MCY for renourishment at 10 year intervals. The USFWS is undertaking beach nourishment at McFaddin NWR and initial construction at that location is not included in the alternatives. The estimated renourishment volume at that location is 3.97 MCY. The approximate profile for beach nourishment is shown in figure 40. The intermediate RSLC curve was used to compare the plans, though the realization of the low or high RSLC scenario would change the expected quantities for the same feature performance. To establish that sensitivity, all factors were held constant but for the linearized RSLC rate. It is assumed that the initial placement would be the largely similar, but that variable quantities would be required for the periodic renourishment. For McFaddin NWR the low and high RSLC curves would require an estimated 60% and 240% of that for the intermediate curve. The volumes would be approximately 65% and 325% at the Texas Point site.

The volume required for dune restoration/creation was developed based on a geometric treatment of a trapezoidal section. All dunes had a similar section with a crest at 9.0 feet NAVD88, a 6 feet wide crest, and 3H:1V side slopes on both the seaward and landward sides (PIE, 2005). An assumed overfill ratio of 1.25 was applied for dune construction. A renourishment volume equal to 0.50 the initial construction volume is allocated for every 20 years. Though dunes can certainly be self-sustaining, this conservative step was taken to account for volume required to reconstruct dunes after storm events, or raise dunes in response to RSLC. The initial construction volume estimated at Texas Point is approximately 225,000 CY. As with the beach fill, initial construction in and around McFaddin is taken to occur as part of the no-action condition. The renourishment volume at that location was estimated as 381,000 CY. To account for RSLC, the dune crest elevation would be increased during the renourishment events to keep pace with the increase in local MSL.

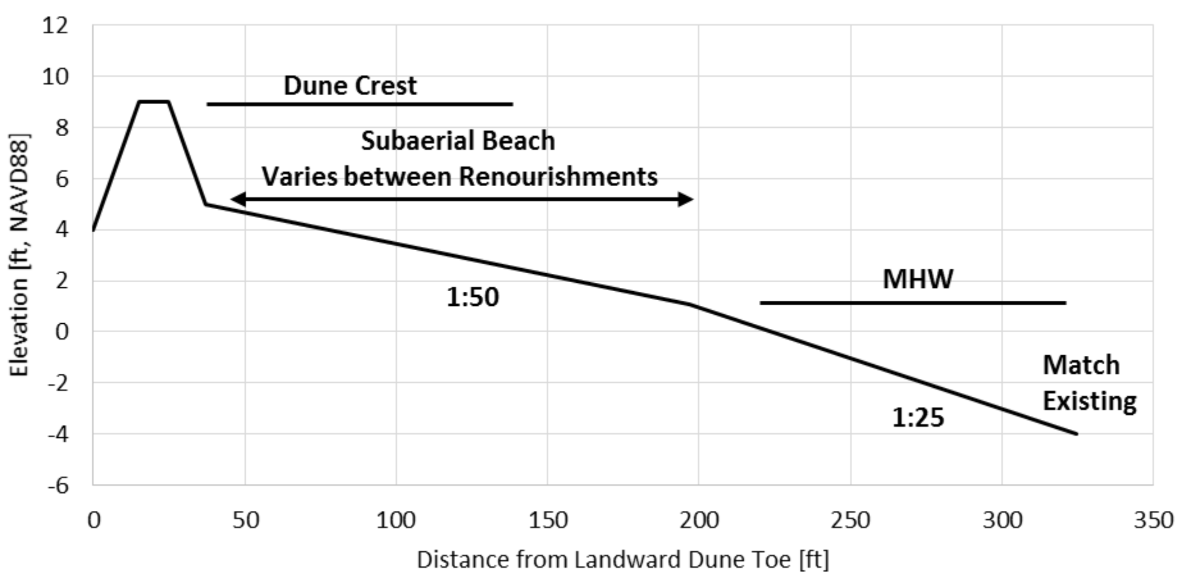


Figure 40: Approximate beach nourishment profile

6.3.2 Nearshore Breakwaters

Nearshore breakwaters were evaluated as a means of wave energy dissipation and increased sediment detention. The design considerations associated with the nearshore breakwaters are largely based on analysis done by PIE (2005) and are:

- the nearshore breakwaters are emergent and segmented;
- the individual breakwaters throughout the extent of the measure have a length of 150 feet with a gap of 300 feet;
- the breakwaters will be placed at -5 feet MLLW with a crest elevation up to +5 feet MLLW;
- there will be a 1 foot blanket stone base;
- riprap will be barged in to site and placed from the barge;
- an access channel would need to be excavated for barge-based construction;
- breakwaters would be raised as need throughout the period of analysis to account for RSLC and remain effective;
- maintenance volumes are assumed as 15% of the initial volume at year 15 and 10% of the initial volume at year 25 (USACE, 2016e);
- the breakwaters would extend the effectiveness of the associated beach fill from 10 years to 20 years.

The quantity was calculated similarly to the breakwater measure along the GIWW – using the trapezoidal area of the assumed breakwater section with a density of 118.5 lbs/cu.ft. The quantities for the various alternatives containing breakwaters along the gulf shoreline are shown in table 9. A typical section for this measure is shown in figure 41. Figure 42 shows an aerial of offshore segmented breakwaters in place at Grand Isle, LA. These breakwaters would need to be elevated over time in response to RSLC based on the actual observed rate.

Table 9: Breakwater quantities for the gulf shoreline at the two locations

Location	Shoreline Length [ft]	Stone Volume [CY]	Blanket Stone Volume [CY]	Year 15 Maintenance Volume [CY]	Year 25 Maintenance Weight [CY]
McFaddin	55,413	205,200	49,800	30,800	20,500
Texas Point	16,404	60,800	14,700	9,100	6,100

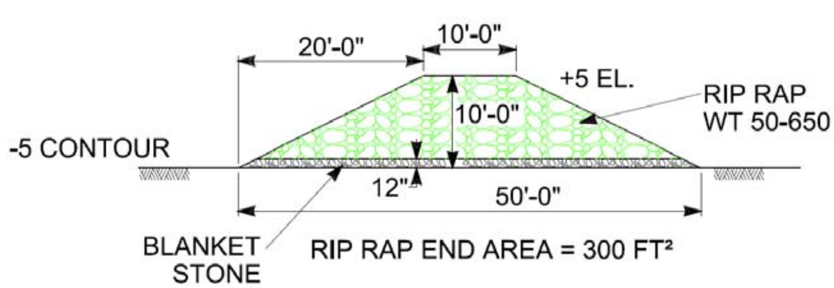


Figure 41: Typical section for segmented nearshore breakwaters

Figure 42: Breakwaters at Grand Isle, LA (Google Earth)

6.3.3 Sand Engine

The sand engine is a beach nourishment strategy currently employed in The Netherlands (fig. 43). The concept is that sediment is placed on the beach as a mega-nourishment rather than as periodic renourishment. This is a method of indirect beach nourishment to be aided by natural advection and diffusion processes. Material would be pumped to the swash zone with minimal shaping, and reworked by nature over time.

The volume was calculated according to the expected volumetric loss over the period of analysis as estimated by equation 4. For the case of McFaddin NWR where the initial construction of a beach nourishment project is assumed as part of the no-action condition, the sand engine volume is placed at year 10. That volume, intended to nourish that portion of the beach through the rest of the period of analysis is 14.6 MCY. For Texas Point, where the material would be placed at initial construction, the estimated volume is 19.6 MCY.

This type of mega-nourishment has been studied by several authors (e.g., Stive et al., 2013; de Schipper et al., 2016). This would be a unique measure in Texas and the U.S. at large. The functionality of this type of nourishment would be further explored in final feasibility design and in PED to ensure maximum shoreline protection and ecological benefit.

Figure 43: Sand engine in The Netherlands as imaged: (A) in July 2011 and (B) in July 2017

6.3.4 Nearshore Berm

A nearshore berm is a shoreline protection strategy that places material in the littoral system rather than attached to the coast as in traditional beach nourishment. The berm is submerged offshore within the active profile. The function of a nearshore berm is to provide indirect beach nourishment as sediment is worked inland. The berm has the added benefit of acting as a submerged offshore breakwater and dissipating incoming wave energy.

This strategy has been actively pursued at South Padre Island in conjunction with maintenance dredging. While the specific transport and fate of the placed sediment has not been fully documented, there has been a reduction in shoreline erosion in the area. Since the ultimate goal is to stymie shoreline retreat, this strategy has shown to be effective.

The assumptions and design considerations associated with the nearshore berm measures are:

- placed approximately at the -15 feet contour up to an elevation of approximately -10 feet (MLLW);
- the berm will have a top width of 100 feet with assumed side slopes of 50H:1V;
- the material would be placed in the nearshore in the approximate template.

The quantity was calculated as a trapezoidal area multiplied by the longshore extent. The quantities for the two locations at the gulf shoreline are shown in table 10. Renourishment is assumed to take place every 10 years with 80% of the initial volume replenished. The location of the material placement would be moved inland as appropriate with RSLC depending on shoreline position.

Table 10: Nearshore berm volume estimates

Location	Shoreline Length [ft]	Volume [CY]
McFaddin	55,413	2,746,000
Texas Point	16,404	812,900

6.4 Sediment Sources

The marsh nourishment and gulf shoreline measures require sediment borrow sites. Potential sediment sources were identified through the study area and include:

- offshore sources such as nearshore shoreface sediments, paleo channels, and the Sabine and Heald Banks (fig. 44);
- mining of upland confined placement areas used for the SNWW (fig. 45);
- BUDM in association with maintenance material from the SNWW (fig. 46);
- mining within the GIWW navigation channel (there are minimal BUDM opportunities);
- new work material association with the planned expansion of the SNWW (currently in PED);
- mining within the SNWW navigation channel;
- dredging of the SNWW offshore dredge material disposal sites (ODMDS).

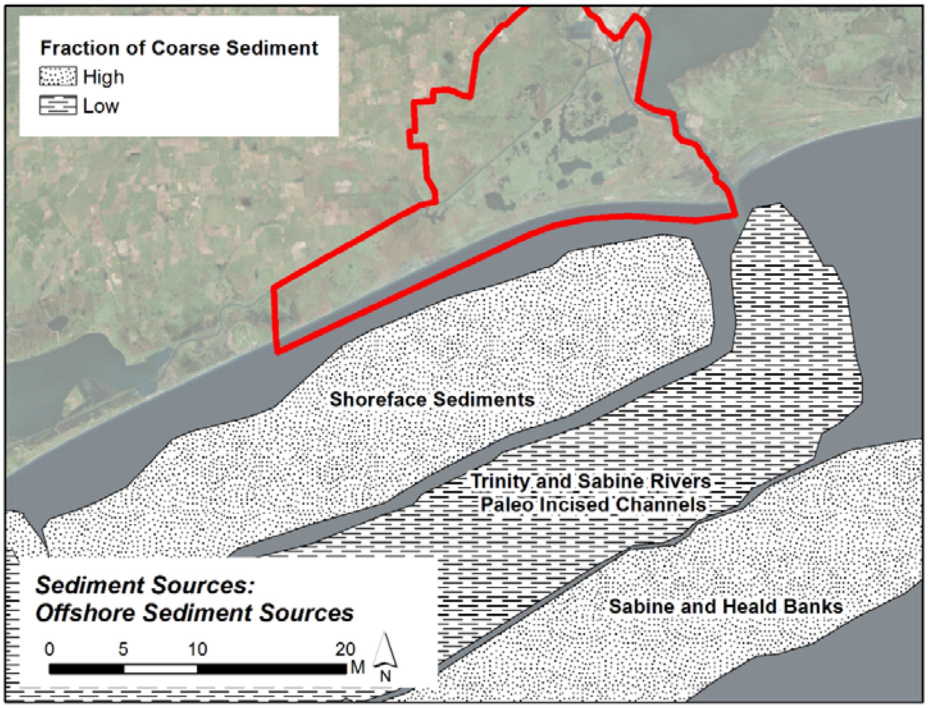


Figure 44: Offshore sediment sources available for ER measures (after Moya et al., 2016)

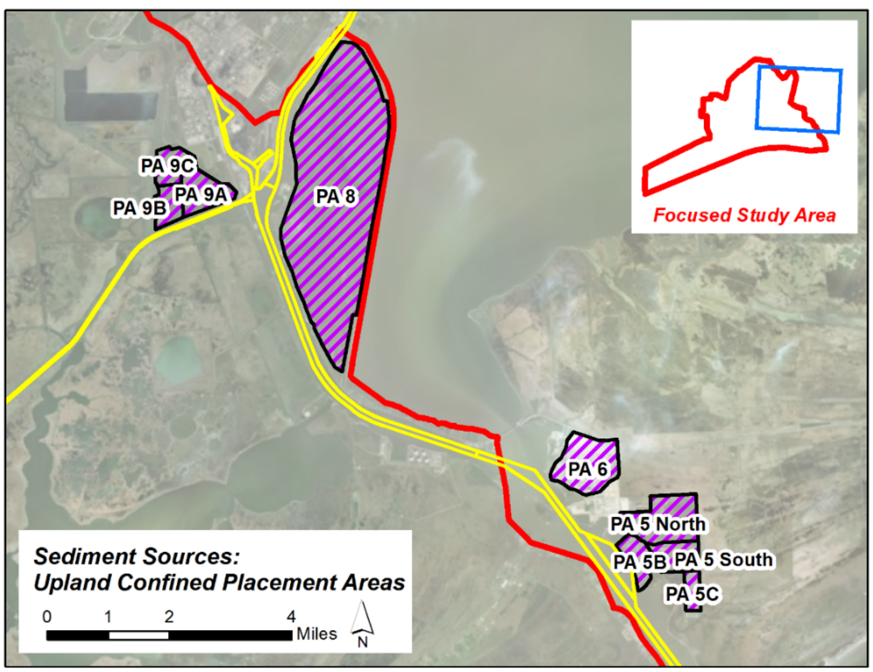
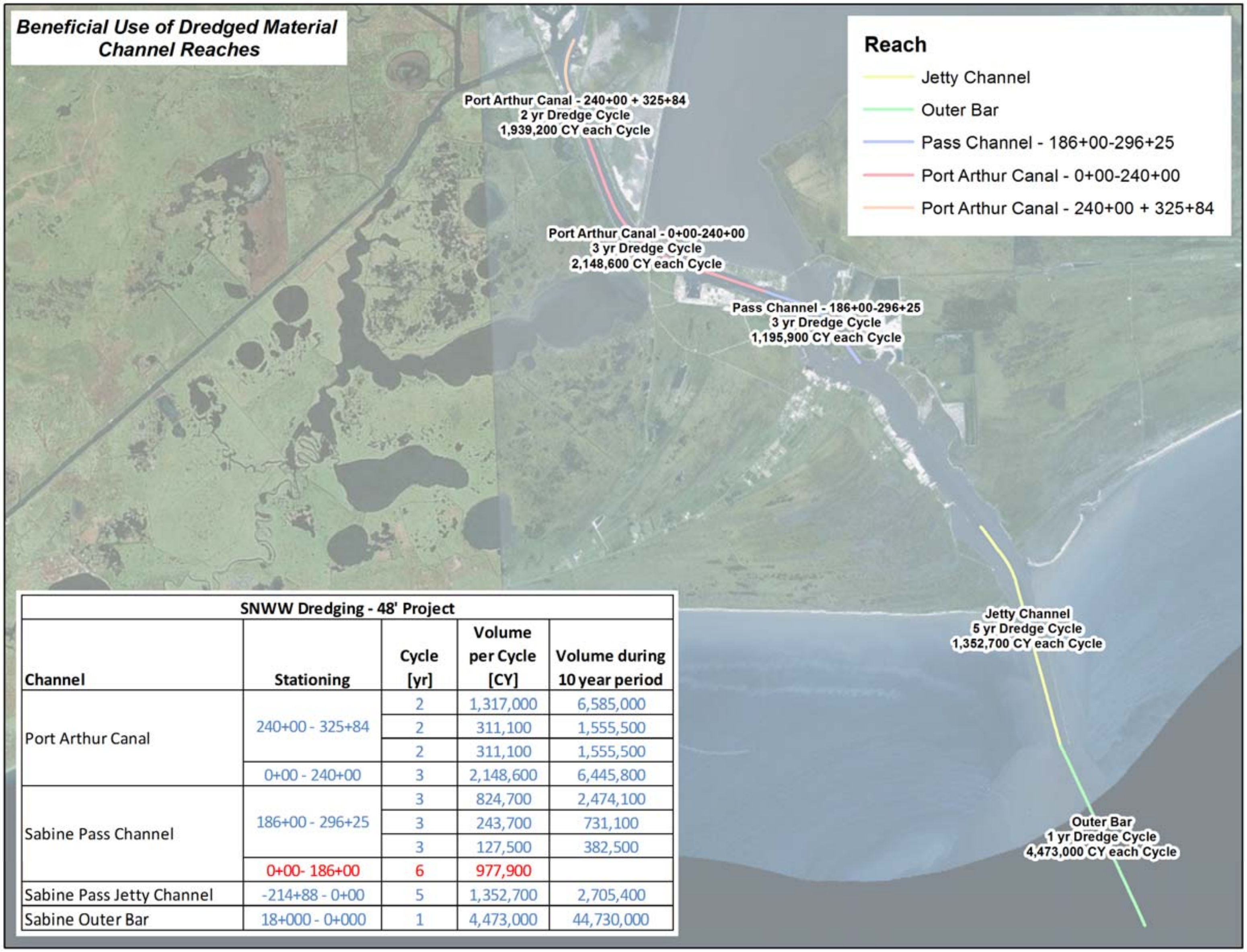


Figure 45: Upland confined placement areas along the SNWW that could be mined as sediment sources for ER measures



SNWW Dredging - 48' Project				
Channel	Stationing	Cycle [yr]	Volume per Cycle [CY]	Volume during 10 year period
Port Arthur Canal	240+00 - 325+84	2	1,317,000	6,585,000
		2	311,100	1,555,500
		2	311,100	1,555,500
	0+00 - 240+00	3	2,148,600	6,445,800
Sabine Pass Channel	186+00 - 296+25	3	824,700	2,474,100
		3	243,700	731,100
		3	127,500	382,500
	0+00- 186+00	6	977,900	
Sabine Pass Jetty Channel	-214+88 - 0+00	5	1,352,700	2,705,400
Sabine Outer Bar	18+000 - 0+000	1	4,473,000	44,730,000

Figure 46: Channel reaches considered BUDM sediment sources for ER measures

Figure 47 shows how sediment sources were assumed as a function of measure location. The primary sediment sources identified for the measures are: the Sabine and Heald Banks (fig. 44), mining of SNWW PAs (fig. 45), and SNWW BUDM (fig. 46).

The sediment source identification for the western portion of the study area was primarily constrained by finding suitable sand for the gulf shoreline measures along McFaddin. The Sabine and Heald Banks were identified as the primary sediment source for that purpose; this area has abundant sand suitable for beach nourishment. Nearshore shoreface sediment is another possible source for beach nourishment, though it could not be assumed as the sole source considering the volume required for the measures. This is the source of material being used for the initial construction at McFaddin being pursued by USFWS. These are migrating sand waves on the shoreface that are of coarse enough material to be suitable for beach placement. The removal of sediment in these areas would need to be modeled such that any effects to the nearshore hydrodynamics are minimized.

The sediment for marsh nourishment in the western study area would come from offshore in conjunction with the beach nourishment. The material would likely be fine-grained overburden that would otherwise need to be sidecast. Instead, this material would be used for the marsh nourishment measures.

For the measures to the eastern portion of the study area, depending on the measure the source would be SNWW upland confined PAs or SNWW BUDM. Alternatives with the ‘bu’ suffix use SNWW BUDM as the sediment source while those without it use SNWW PAs. The exception to this stipulation is Alternatives 6A and 6B which were conceived using a BUDM strategy from the outset. This difference is reflected in the cost estimates for the various measures – for BUDM the dredging and placement cost is the incremental cost between this project plan and the federal placement plan.

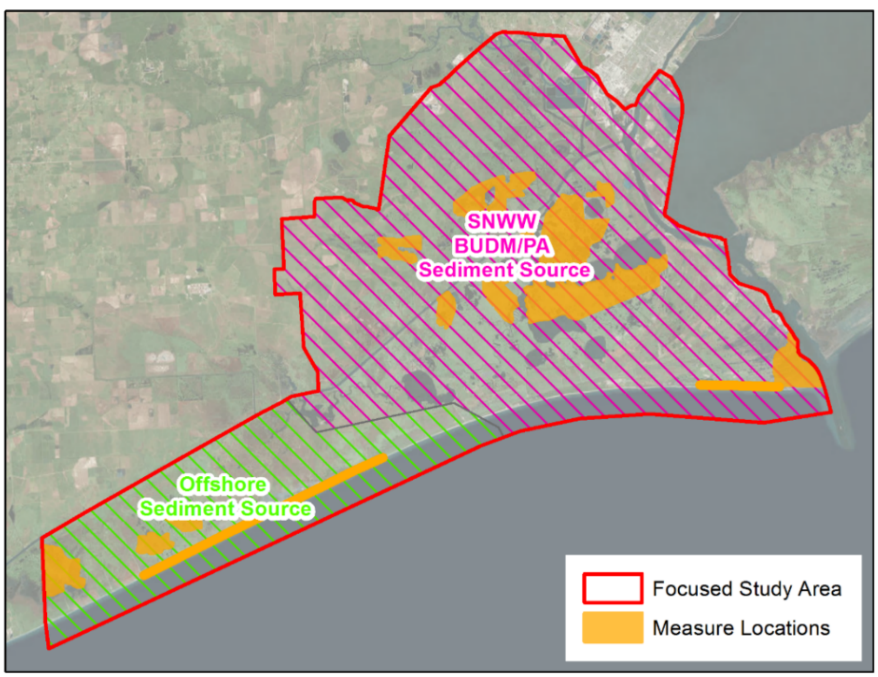


Figure 47: Sediment sources assumed as a function of measure location for the purposes of cost estimation

The SNWW is dredged sufficiently frequently and in sufficient volume as to provide enough sediment for the ER measures. The table within figure 46 shows the dredge cycle and associated volumes expected from the channel (USACE, 2011). The reaches to be used for the ER measures include the outer bar, jetty channel, pass channel, and the Port Arthur Canal. The Sabine Pass Channel segment between 0+00 and 186+00 is omitted from this plan since that material is designated for BU sites in association with the SNWW expansion (USACE, 2011).

The SNWW material is generally fine which makes it suitable for both marsh nourishment and gulf shoreline measures at Texas Point. According to historic dredging records, the sediment sources from these PAs consists of 51 percent silt, 31 percent clay, and 18 percent fine sand. The shoreline at Texas Point is a fine-grained system naturally; adding more fine-grained material would act to reduce the current shoreline retreat. If the coarser fraction of the SNWW material is desired, a baffle box or similar sediment sorter could be used in conjunction with the project to utilize coarser material at the gulf shoreline and finer material in the marsh nourishment cells.

Table 11 shows the assumed sediment sources for each feature in each alternative for the purposes of generating cost. As a part refinement of the selected plan, the specific reaches of the SNWW will be paired with the specific marsh nourishment cells and shoreline measures. Furthermore, approximate pipeline corridors and construction staging areas will be identified as part of refinement.

Table 11: Sediment sources by alternative assumed for the purpose of determining cost estimation during plan comparison

Alt.	Feature	Sed. Source	Alt.	Feature	Sed. Source
1A	Marsh Nourishment - East	SNWW UC PAs	1Abu	Marsh Nourishment - East	SNWW BUDM
	Marsh Nourishment - West	Offshore		Marsh Nourishment - West	Offshore
	Nearshore Berm - Texas Point	SNWW UC PAs		Nearshore Berm - Texas Point	SNWW BUDM
	Nearshore Berm - McFaddin	Offshore		Nearshore Berm - McFaddin	Offshore
1B	Marsh Nourishment - East	SNWW UC PAs	1Bbu	Marsh Nourishment - East	SNWW BUDM
	Marsh Nourishment - West	Offshore		Marsh Nourishment - West	Offshore
	Sand Engine - Texas Point	SNWW UC PAs		Sand Engine - Texas Point	SNWW BUDM
	Sand Engine - McFaddin	Offshore		Sand Engine - McFaddin	Offshore
2A	Marsh Nourishment - East	SNWW UC PAs	2Abu	Marsh Nourishment - East	SNWW BUDM
	Marsh Nourishment - West	Offshore		Marsh Nourishment - West	Offshore
	Beach Nourishment - Texas Poin	SNWW UC PAs		Beach Nourishment - Texas Poin	SNWW BUDM
	Beach Nourishment - McFaddin	Offshore		Beach Nourishment - McFaddin	Offshore
2B	Beach Nourishment - Texas Poin	SNWW UC PAs	2Bbu	Beach Nourishment - Texas Poin	SNWW BUDM
	Beach Nourishment - McFaddin	Offshore		Beach Nourishment - McFaddin	Offshore
3	Marsh Nourishment - East	SNWW UC PAs	3bu	Marsh Nourishment - East	SNWW BUDM
	Marsh Nourishment - West	Offshore		Marsh Nourishment - West	Offshore
	Beach Nourishment - McFaddin	Offshore		Beach Nourishment - McFaddin	Offshore
4A	Marsh Nourishment - East	SNWW UC PAs	4Abu	Marsh Nourishment - East	SNWW BUDM
4B	Beach Nourishment - Texas Poin	SNWW UC PAs	4Bbu	Beach Nourishment - Texas Poin	SNWW BUDM
6A	Marsh Nourishment - East	SNWW BUDM	No parallel alternative - 6A and 6B utilize BUDM		
	Beach Nourishment - Texas Poin	SNWW BUDM			
6B	Marsh Nourishment - East	SNWW BUDM			
	Sand Engine - Texas Point	SNWW BUDM			
10	Marsh Nourishment - East	SNWW UC PAs	10bu	Marsh Nourishment - East	SNWW BUDM
	Marsh Nourishment - West	Offshore		Marsh Nourishment - West	Offshore
	Beach Nourishment - Texas Poin	SNWW UC PAs		Beach Nourishment - Texas Poin	SNWW BUDM
	Beach Nourishment - McFaddin	Offshore		Beach Nourishment - McFaddin	Offshore
13	Marsh Nourishment - East	SNWW UC PAs	13bu	Marsh Nourishment - East	SNWW BUDM
	Marsh Nourishment - West	Offshore		Marsh Nourishment - West	Offshore
	Sand Engine - Texas Point	SNWW BUDM		Sand Engine - Texas Point	SNWW BUDM
	Beach Nourishment - McFaddin	Offshore		Beach Nourishment - McFaddin	Offshore

6.5 Changes to the Recommended Plan Following ADM

6.5.1 Removal of Continuing Construction from the Recommended Plan

Guidance from the vertical team (VT) around the time of the ADM indicated that future nourishment should be omitted from the recommended plan while policy considerations are pursued. As such, the continuing construction assumed at year 30 during plan evaluation is not included in the recommended plan.

6.5.2 Removal of Private Lands from the Recommended Plan

The NFS informed the USACE following the ADM that they had no intention of acquiring private lands for the purposes of marsh restoration in this study. The computation of costs and benefits were revaluated to confirm plan selection with the exclusion of continuing construction and private lands previously dedicated for marsh restoration from all of the alternatives in the focused array. The areas removed from the selected plan are shown in figure 48.

6.6 Feasibility Design of the Recommended Plan

Following the Agency Decision Milestone (ADM), additional detail was added to the recommended plan, Alternative 4Abu. The additional detail consisted of: (1) identification of specific sediment sources for each marsh cell in conjunction with the best estimate of future maintenance dredging, (2) identification of marsh cell containment requirements based on elevation data, (3) identification of likely pipeline routes between the SNWW and marsh cells, and (4) a projection of marsh accretion under the various RSLC conditions using the Marsh Equilibrium Model (MEM) (Morris et al., 2002). Additionally, there were modifications to the breakwaters along the GIWW.

Taking first the best estimate of future maintenance dredging, the contract award date and associated volume were projected based on consultation with the SNWW operations manager (table 12) (Kinman, 2018). This is a revision to the values obtained from the SNWW feasibility report (USACE, 2011). Two of the marsh cells were subdivided to accommodate the available material from the projected maintenance dredging (fig. 48). Conceptual pipeline routes were identified as an assumption for cost estimation. Attachment 1 contains engineering drawings showing the breakout of contracts in terms of sediment source form the SNWW and marsh cell to be nourished (the marsh cells are also shown in figure 49).

Secondly, the need for containment along the perimeter of the marsh cells was considered using the 2017 Jefferson County LiDAR dataset. Containment will be required along the entirety of the marsh cell perimeter since the boundaries do not connect with higher ground. This dataset was also used to seek a refinement in the initial elevation within the marsh cell, however the LiDAR data was not suitable for such a task. The open water areas created flat spots in the dataset which skewed the elevation statistics such that they could not be adopted to refine the existing marsh elevation. Therefore, the original assumptions were retained.

Lastly, the future nourishment used in plan evaluation was assumed based on progressive inundation from RSLC. This sort of passive inundation is not strictly true given there will be a degree of marsh accretion that occurs in conjunction with RSLC. The marsh equilibrium model (MEM) is intended to estimate the trajectory of coastal marshes under relative sea-level change (RSLC) conditions (Morris et al., 2002). It was used to consider the sensitivity of the marsh accretion in the project area to the various RSLC scenarios. The principle output from the MEM is the elevation of the marsh surface relative to mean sea level (MSL). This project seeks to nourish existing marsh areas by raising the marsh surface elevation to an ecologically productive level. Here, we use the MEM to forecast changes to the marsh elevation under various RSLC scenarios for the 100 years following construction.

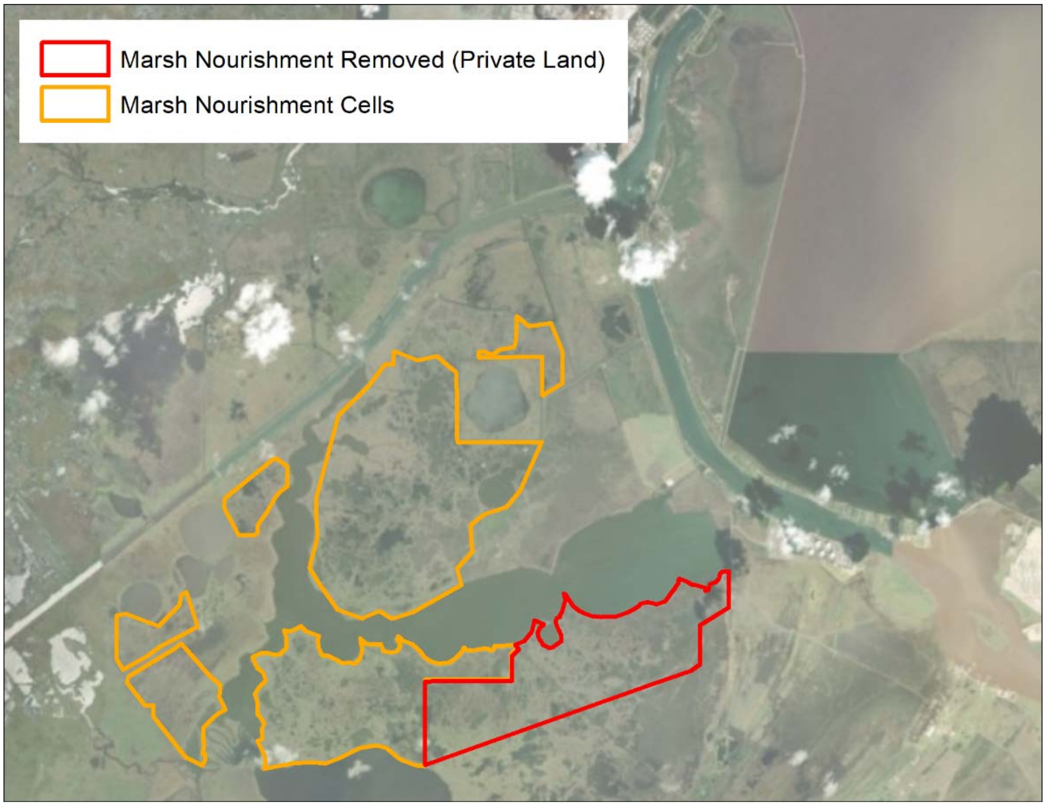


Figure 48: Private land removed from the selected plan following ADM

Table 12: Projected maintenance dredging contracts, associated volumes, and marsh cell construction

O&M Contract Award	Location	Volume [MCY]	Marsh Cell	Volume for Marsh Construction [CY]
FY19	PA Canal (FULL) + Taylors Bayou	1.7	Prior to JCER construction	
FY20	Pass Channel	1.5		
FY20	PA Junction + Taylors Bayou	1.5		
FY22	PA Junction + Taylors Bayou	1.5	1	165,040
			2A	1,334,960
FY23	Pass Channel	0.7	6A	700,000
FY24	PA Junction + Taylors Bayou	1.5	2B	690,750
			3	186,340
			4	196,990
			5	425,920
FY25	PA Canal (FULL)	1.7	Too Much Material to Finish Marsh	
FY26	Pass Channel	0.7	Too Little Material to Finish Marsh	
FY27	PA Canal + Taylors Bayou	1.5	2C	588,370
			6B	774,700

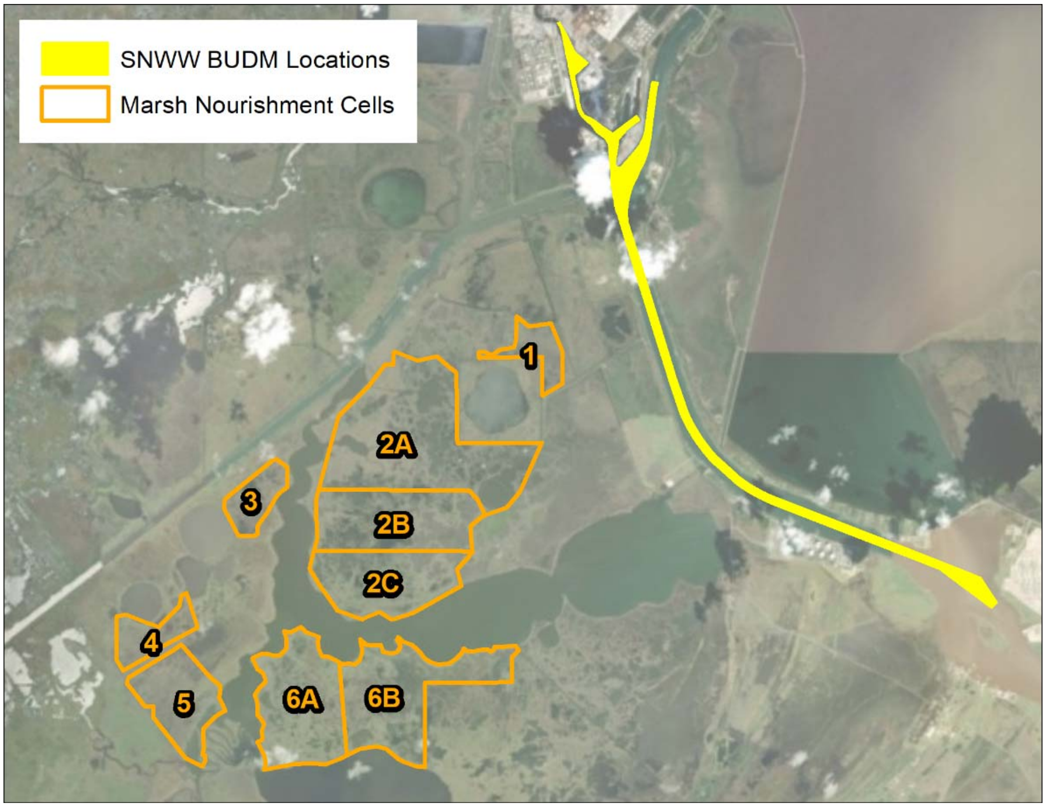


Figure 49: SNWW BUDM Locations and subdivided marsh cells

The inputs used for the MEM are shown in table 13. The only variable modified is the future RSLC conditions; all other inputs are held constant in the scenarios. Figure 50 shows the results from the MEM for the three RSLC scenarios, and the difference between the marsh platform and MSL over time for those scenarios. This provides some context as to how the marsh nourishment could evolve over time.

As for the breakwaters in the recommended plan, slight changes were made to the cross-section to accommodate future stone placement as a response to RSLC and allow an additional 2 feet raise in the crest elevation without increasing the base width. The revised section is shown in the engineering drawings. Additionally, one of the three segments contained in the selected plan was removed from the feasibility design; more recent aerials indicated that the particular location already had shoreline armoring. The feasibility design and breakdown of construction is shown in attachment 1. The system of breakwaters through Jefferson County, including those currently in place and those to be constructed through this project, is shown in figure 51.

Table 13: MEM inputs for the JCER recommended plan

Parameter	Units	Low RSLC	Int. RSLC	High RSLC
Physical Inputs				
Start Year			2027	
Sea Level Forecast	cm/100yr	56.7	89.0	192.6
Mean High Water	cm, NAVD88		34.4	
Mean Sea Level	cm, NAVD88		18.3	
Lunar Nodal Amp	cm		0	
Initial Rate SLR	cm/yr		0.58	
Suspended Sed. Conc.	mg/L		20	
Marsh Elevation @ t0	cm, NAVD88		54.9	
Biological Inputs				
Max Veg Elev	cm, NAVD88		90	
Min Veg Elev	cm, NAVD88		-22	
Max peak biomass	g/m^2		1200	
OM decay rate	1/yr		-0.8	
Root and Rhizome Shoot Ratio	g/g		3	
BG turnover rate	1/yr		3	
Refractory Fraction	g/g		0.02	
Max(95%) root depth	cm		10	
Trapping Coefficient and Settling Velocity				
ks	1/cm-yr		3.22E-02	
q	$g/yr\text{-}cm^2$		1.50E-03	

6.6.1 Additional Data and Analysis Required in PED

This feasibility study, including alternatives evaluation and feasibility design, was completed using available data. As such, there will be additional data and analysis requirements during PED which include:

- collection of survey data. The existing elevation in the marsh cells for this study was assumed based on discussions with local resource agencies.
- refinement of the marsh cell boundaries based on anticipated availability of O&M dredge material and refined existing marsh cell elevations based on surveys. This will ensure the marsh boundaries match the availability of material such that the entirety of O&M material is used for marsh nourishment.

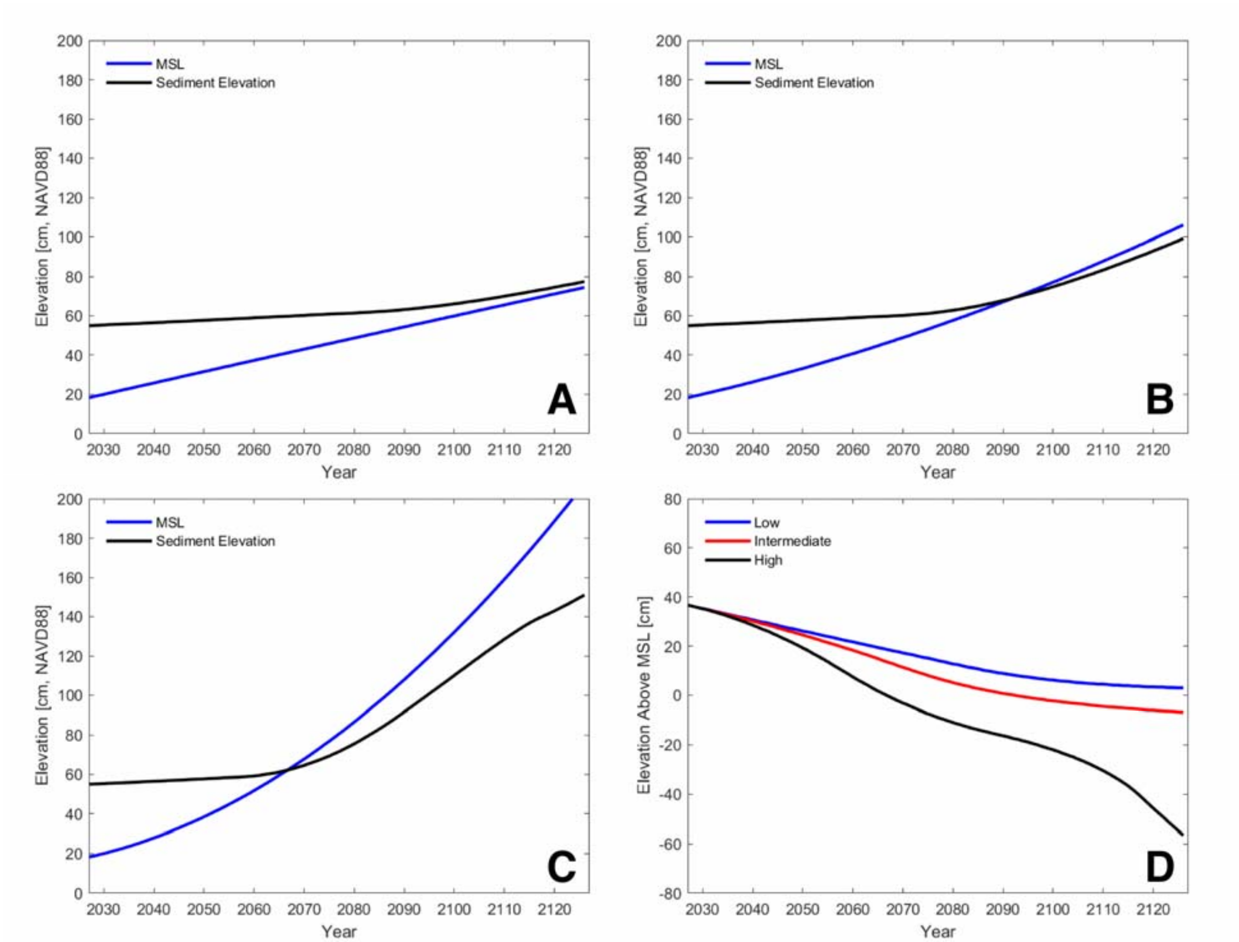


Figure 50: MEM outputs as a function of time for: (A) the low RSLC scenario, (B) the intermediate RSLC scenario, (C) the high RSLC scenario, and (D) the marsh platform elevation above MSL for each scenario

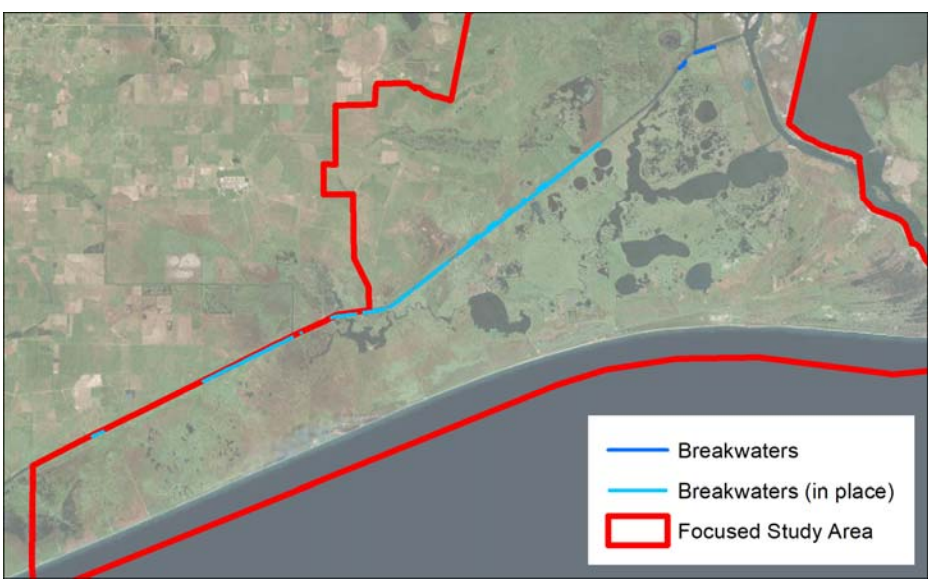


Figure 51: System of breakwaters (in place and part of recommended plan)

7 Operation, Maintenance, Repair, Replacement, and Rehabilitation (OMRR&R) and Continuing Construction

During plan comparison there were future construction actions that were considered OMRR&R and some that were consider continuing construction. Future work associated with hardened structures, i.e., breakwaters in the alternatives, was considered OMRR&R while the addition of sediment to constructed measures, e.g., beach and marsh nourishment, was considered continuing construction. The assumptions and quantities for OMRR&R and continuing construction were identified for each measure in the feature design section.

As noted in the feature design section, the continuing construction associated with the marsh nourishment in the selected plan has been removed from the final recommended plan.

8 COST ESTIMATES

8.1 References

ASTM E 2516-11 – Standard Classification for Cost Estimate Classification System
ER 1110-2-1302 – Civil Works Cost Engineering, 30 Jun 2016
EP 1110-1-8 – Construction Equipment Ownership and Operating Expense Schedule, Nov 2016
EM 1110-2-1304 – Civil Works Construction Cost Index System (CWCCIS), 30 Sept 2017
RSMeans Labor Rates for the Construction Industry, 2018

8.2 Classification and Scope

For this study, a Class 3 cost estimate per ER 1110-2-1302 utilizing Microcomputer Aided Cost Engineering System (MCACES) software tools was developed for Alternative 4ABU to October 2018 price levels. The MCACES cost estimate can be found in Attachment 3. The MCACES software tools, such as the latest MII Unit Cost Book Library and the Region VI Equipment Library per EP 1110-1-8, were used when applicable. Hourly labor rates were adjusted based on recent historical data and the latest RSMeans book to reflect rates expected in the study area. This estimate is supported by site specific developed crews and vendor material quotes as necessary. All dredging costs were calculated using the Cost Engineering Dredge Estimating Program (CEDEP).

This estimate was categorized into different contracts aligning the expected O&M dredge cycle from the SNWW with marsh cells chosen economically by pumping distance. These contracts were further organized in accordance to the Civil Works Work Breakdown Structure (CW-WBS) per Appendix B of ER 1110-2-1302. All costs were inputted into a Total Project Cost Summary (TPCS) spreadsheet. The TPCS can be found in Attachment 2. Costs for each contract were escalated to Constant Price Levels with use of the Civil Works Construction Cost Index System (CWCCIS) indices per EM 1110-2-1304. The baseline estimate provides all pertinent elements for a complete and operational project.

A formal Cost & Schedule Risk Analysis (CSRA) Crystal Ball was performed with the cooperation of the PDT and the Civil Works Cost Engineering and Agency Technical Review Mandatory Center of Expertise Cost Engineering Directory of Expertise (Cost MCX) of the Walla Walla District in November 2018. The CSRA report can be found in Attachment 4. The risks were quantified and a cost risk model was used to develop project contingencies at 80% confidence level. The calculated contingency of 17% was inputted into the aforementioned TPCS. The 50-year Operation and Maintenance (O&M) estimate was prepared with an effective pricing date of October 2018.

ACCOUNT CODE 01 – LANDS AND DAMAGES: Cost for this account code was provided by SWG, Real Estate Division.

ACCOUNT CODE 06 – FISH AND WILDLIFE FACILITIES: Quantities and design features were provided by SWG, Engineering Branch. The costs include all labor, equipment, and material required to dredge and pump SNWW maintenance dredge material into selected marsh sites. The estimated Operation & Maintenance cost to dispose of this dredge material in upland disposal areas was subtracted from the total cost to represent the incremental costs to pump material to the marsh cells. Costs to create containment dikes and shaping of pumped material using a marsh buggy and excavator was included. This account code also includes required marsh plantings for approximately half of included marsh areas. The final cost estimate assumes the prime contractor will perform all required dredging, while a sub-contractor will build the marsh cells.

ACCOUNT CODE 10 – BREAKWATERS AND SEAWALLS: For the first construction contract, the final cost estimate includes rip-rap armoring along specified reaches outside of the GIWW. The costs includes labor, equipment, and material to procure and install blanket stone, rip-rap, and geotextile. The final cost estimate assumes a sub-contractor under the prime contractor will perform all work related to the GIWW armoring.

ACCOUNT CODE 30 – PLANNING, ENGINEERING, AND DESIGN: Costs in this account code were developed using the guidelines provided in the TPCS, with concurrence from the Project Manager and Cost Engineer for each individual contract.

ACCOUNT CODE 31 – SUPERVISION AND ADMINISTRATION: Costs in this account code were developed using the guidelines provided in the TPCS with the assistance of SWG, Construction Branch in Engineering & Construction Division, as well as the Project Manager and Cost Engineer.

9 RISK AND UNCERTAINTY

There is a degree of risk and uncertainty associated with the development and evaluation of the focused array of alternatives and selection of a recommended plan. These include, though are not necessarily limited to the following:

1. No site-specific survey data was collected for alternatives evaluation, nor is there any intention to do so before PED. Key elevations for measure design was based on available data and in conjunction with resource agencies and land managers.
2. No site-specific borings were taken; the analysis was based on available data from sources such as TxSed (GLO, 2017) and work done for the SNWW (USACE, 2011).
3. RSLC estimates carry uncertainty. The actual rate may be higher or lower than considered.
4. The sediment source for borrow material has been narrowed to BUDM from several reaches of the SNWW. Material is assumed to be available when necessary for construction. That said, the quantity is thought to be sufficient; the uncertainty resides in the timing.
5. It was assumed that pipeline access would be available for each feature.

10 Resiliency and Adaptability

Since this project resides in the coastal zone, it is susceptible to RSLC and the commensurate effects on project performance. The sensitivity of individual measures to RSLC were discussed in the feature design section. Here the discussion is on resiliency and adaptability of the project more broadly.

The resiliency and climate preparedness of a particular project can be discussed by asking a few questions:

1. What is the envelope of possible future conditions?
2. Would the selected plan change given different future conditions than those assumed?
3. Is the selected plan sufficiently adaptable to accommodate the domain of reasonable future conditions?

Starting with the first question, the envelope of possible future conditions is reasonably bound by the USACE 'low' RSLC curve and the USACE 'high' RSLC curve. The curves are shown in figure 18. A good way to think about these curves is in terms of timing in reaching particular thresholds. To note the disparity in the range of outcomes, 2043 could see 0.50 feet, 1.20 feet, or somewhere in between. The intermediate RSLC curve was used for project formulation.

Next, we take the latter two questions posed at the outset together. For most measures adaptability is attainable in the features since it largely amounts to placing more sediment in a particular area. Most the alternatives include a degree of marsh nourishment which includes raising the elevation of the marsh platform by placing sediment. If a more aggressive RSLC regime were realized than assumed, action would be required earlier and with potentially more sediment. Conversely, if a less extreme RSLC scenario were realized, renourishment would be required later with less sediment. Either way, the alternatives would have scaled similarly since the additional (or lesser) sediment demands would be similar. In this way, we conclude that plan selection would be no different under a more aggressive or less aggressive RSLC condition given that the benefits would be the same, and that the costs would scale reasonably amongst the alternatives.

In terms of adaptability, to expand briefly on the above discussion, the initial construction of a marsh cell does not preclude the addition of sediment in the future, regardless of the timing or quantity. BUDM from the SNWW is the intended sediment source for this project which will have sufficient quantities for continued nourishment of these marsh cells, likely even under the high RSLC scenario. The envelope of possible outcomes underscores the importance of adaptive management and monitoring early after construction.

As noted, the future nourishment of the marsh cells has been excluded from the recommended plan. This however does not preclude additional nourishment in the area by future USACE authorizations or by the non-federal sponsor. In terms of regional resiliency more broadly, this project would act as a natural buffer for the hurricane flood protection system (HFPS) around Port Arthur (fig. 52). Improvements to this HFPS are currently in PED.

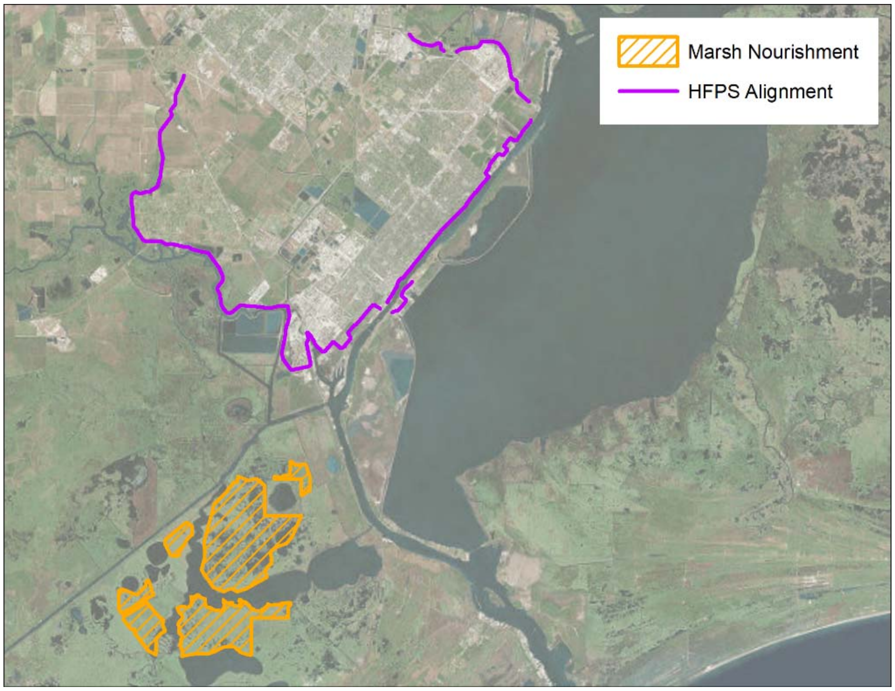


Figure 52: Marsh nourishment cell locations relative to the Port Arthur HFPS

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Acronyms Used in References:

GLO	Texas General Land Office
NOAA	National Oceanic and Atmospheric Administration
NOAA/CO-OPS	NOAA Center for Operational Oceanographic Products and Services
NOAA/NOS	NOAA National Ocean Service
NOAA/NWS	NOAA National Weather Service
NOAA/OCM	NOAA Office for Coastal Management
NRC	National Resource Council
NRCS	Natural Resource Conservation Service
PIE	Pacific International Engineering
TNRIS	Texas Natural Resources Information System
USACE	US Army Corps of Engineers
USACE/ERDC	USACE Engineer Research and Development Center

ATTACHMENT 1
ENGINEERING DRAWINGS

JEFFERSON COUNTY, TEXAS

ECOSYSTEM RESTORATION

FEASIBILITY STUDY

Center of Excellence

Coastal Navigation and Environmental Restoration

Office of the District Engineer
U. S. Army Engineer District, Galveston
Corps of Engineers
Galveston, Texas
February 2019

This project was designed by the Galveston District of the U.S. Army Corps of Engineers. The initials or signatures and registration designations of individuals appear on these project documents within the scope of their employment as required by ER 1110-1-8152.

ROBERT C. THOMAS, P.E.
CHIEF, ENGINEERING AND CONSTRUCTION DIVISION

SOLICITATION NO.: W9126G18B0031
SWG FILE NO.: HSC 401-569

CADD GALVESTON DISTRICT

TOTAL ARMY QUALITY

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U.S. Army Corps of Engineers
Galveston District

Rev.	Description	Date	By

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.,
COLONEL, U.S. ARMY, COMMANDING

Drawn by: B.C.
Designed by:
Checked by:
Submitted by:
DAVID B. BOOTHBY, P.E.
Chief, General Engineering Section
Date: FEB 2019
Rev.
Scale: AS SHOWN
Approval Recommended:
JOSEPH L. KING, R.A.
Chief, Engineering Branch
Approved by:
ROBERT C. THOMAS, P.E.
Chief, Engineering and Construction Division

JEFFERSON COUNTY
ECOSYSTEM RESTORATION
FEASIBILITY STUDY

LAYOUT PLAN

Drawing No.:
C-101

SWG FILE NO. ####

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Galveston District

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Checked by:
Submitted by:
DAVID B. BOOTHBY, P.E.
Chief, Geotech/Structure Section
Approved by:
ROBERT C. THOMAS, P.E.
Chief, Engineering and Construction Division

Date: FEB 2019
Scale: AS SHOWN
Approval Recommended:
JOSEPH L. KING, R.A.
Chief, Engineering Branch

Rev.

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.,
COLONEL, U.S. ARMY, COMMANDING

JEFFERSON COUNTY
ECOSYSTEM RESTORATION
FEASIBILITY STUDY

BREAKWATER PLAN

Drawing No.:
C-102

SWG FILE NO. ####

File: Rev 2_SNWW-JCER_STUDY-CIVIL-PLANS_TxSc83.dgn
Model Name: 02-C-102-BREAKWATER PLAN
By: m3ecebbc Date: 2/6/2019 Time: 8:57:41 AM

LEGEND

- MARSH NOURISHMENT CELLS
- SNWW BUDM LOCATIONS
- PIPELINE ROUTE

CONTRACT 1 NOTES

1. BUDM FROM O&M DREDGING OF THE PORT ARTHUR CANAL AND TAYLOR'S BAYOU IN FY 22.

PLAN

0 2,500 5,000 7,500
SCALE IN FEET

U.S. Army Corps of Engineers
Galveston District

Rev.	Description	Date	By

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.,
COLONEL, U.S. ARMY, COMMANDING

Drawn by:
Designed by:
Checked by:
Submitted by:
Date: FEB 2019
Rev.
Scale: AS SHOWN
Approval Recommended:
JOSEPH L. KING, R.A.
Chief, Engineering Branch
Approved by:
ROBERT C. THOMAS, P.E.
Chief, Engineering and Construction Division

JEFFERSON COUNTY
ECOSYSTEM RESTORATION
FEASIBILITY STUDY

CONTRACT 1 PLAN

Drawing No.:
C-103

SWG FILE NO. ####

File: Rev 2_SNWW-JCER_STUDY-CIVIL-PLANS_TxSc83.dgn
Model Name: 03-C-103 CONTRACT 1
By: m3ecebbc Date: 2/6/2019 Time: 9:03:02 AM

File: Rev 2_SNWW-JCER_STUDY-CIVIL-PLANS_TxSc83.dgn
Model Name: 04 C-104 CONTRACT 2
By: m3ecebbc Date: 2/6/2019 Time: 9:04:14 AM

U.S. Army Corps of Engineers
Galveston District

Rev.	Description	Date	By

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.,
COLONEL, U.S. ARMY, COMMANDING

Drawn by: BXC. Date:
Designed by: X FEB 2019
Checked by: X Scale: AS SHOWN
Rev.
Submitted by: Approval Recommended:
JOSEPH L. KING, R.A.
Chief, Engineering Branch
Approved by:
ROBERT C. THOMAS, P.E.
Chief, Engineering and Construction Division

JEFFERSON COUNTY
ECOSYSTEM RESTORATION
FEASIBILITY STUDY

CONTRACT 2 PLAN

Drawing No.:
C-104

SWG FILE NO. ####

CONTRACT 3 NOTES

1. BUDM FROM O&M DREDGING OF THE PORT ARTHUR CANAL AND TAYLOR'S BAYOU IN FY 23.

U.S. Army Corps of Engineers
Galveston District

Rev.	Description	Date	By

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.,
COLONEL, U.S. ARMY, COMMANDING

Drawn by:
Designed by:
Checked by:
Submitted by:
Date: FEB 2019
Rev.
Scale: AS SHOWN
Approval Recommended: JOSEPH L. KING, R.A.
Chief, Engineering Branch
Approved by: ROBERT C. THOMAS, P.E.
Chief, Engineering and Construction Division

JEFFERSON COUNTY
ECOSYSTEM RESTORATION
FEASIBILITY STUDY

CONTRACT 3 PLAN

Drawing No.:
C-105

SWG FILE NO. ####

File: Rev 2_SNWW-JCER_STUDY-CIVIL-PLANS_TxSc83.dgn
Model Name: 05 C-105 CONTRACT 3
By: m3ecebbc Date: 2/6/2019 Time: 9:05:25 AM

CONTRACT 4 NOTES

1. BUDM FROM O&M DREDGING OF THE PORT ARTHUR CANAL AND TAYLOR'S BAYOU IN FY 25.

U.S. Army Corps of Engineers
Galveston District

Rev.	Description	Date	By

Drawn by:	Date: FEB 2019
Designed by:	Rev.
Checked by:	Scale: AS SHOWN
Submitted by:	Approval Recommended: JOSEPH L. KING, R.A. Chief, Engineering Branch
Approved by: ROBERT C. THOMAS, P.E. Chief, Engineering and Construction Division	

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.,
COLONEL, U.S. ARMY, COMMANDING

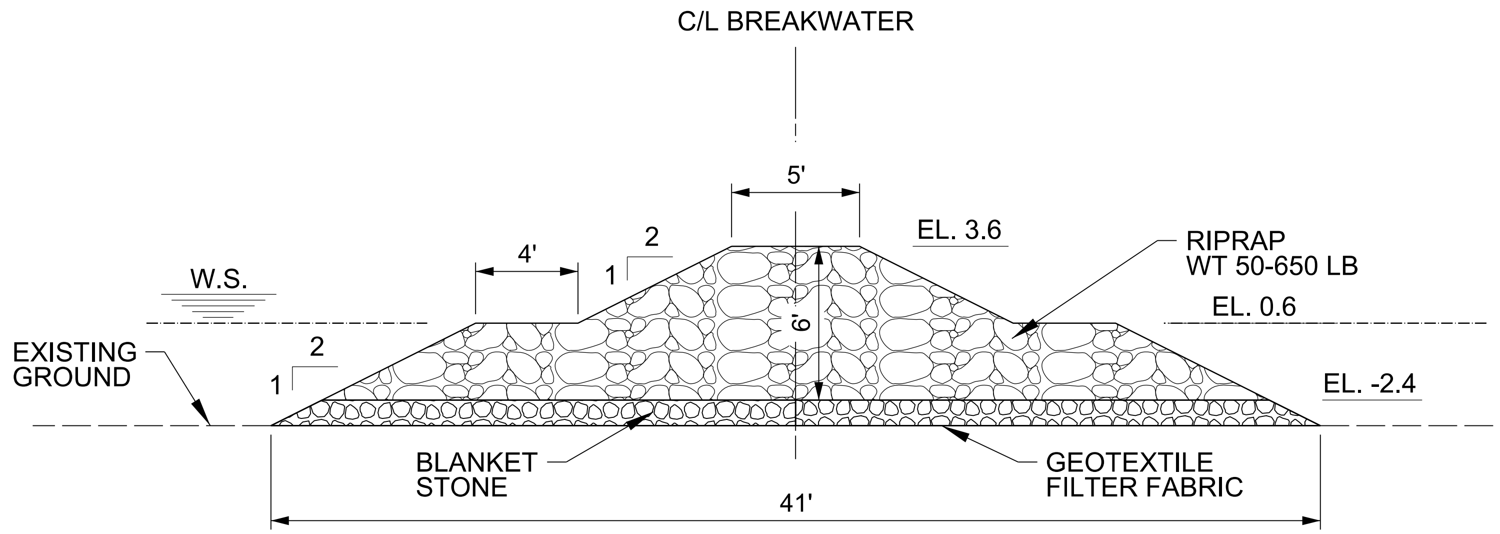
JEFFERSON COUNTY
ECOSYSTEM RESTORATION
FEASIBILITY STUDY

CONTRACT 4 PLAN

Drawing No.:
C-106

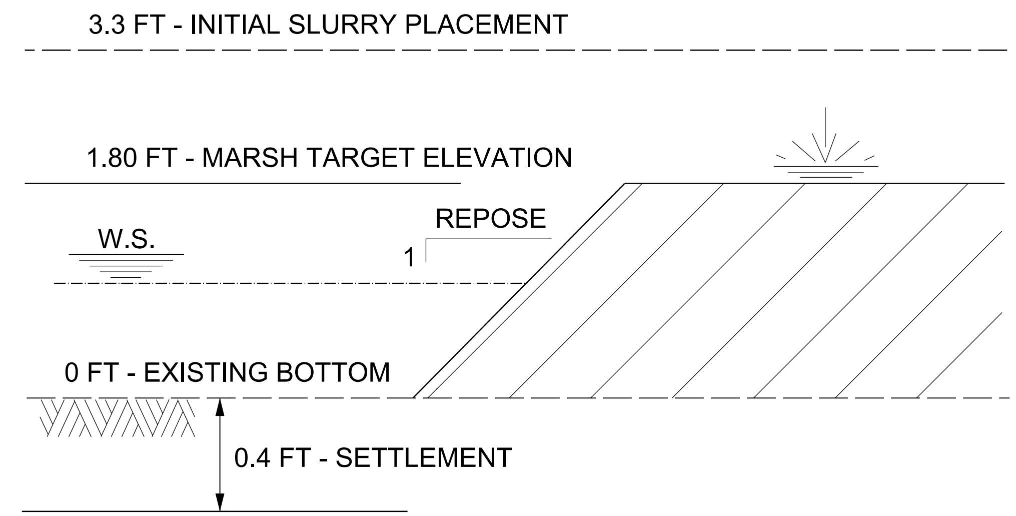
SWG FILE NO. ####

File: Rev 2_SNWW-JCER_STUDY-CIVIL-PLANS_TxSc83.dgn
Model Name: 06 C-106 CONTRACT 4
By: m3ecebbc Date: 2/6/2019 Time: 9:06:41 AM



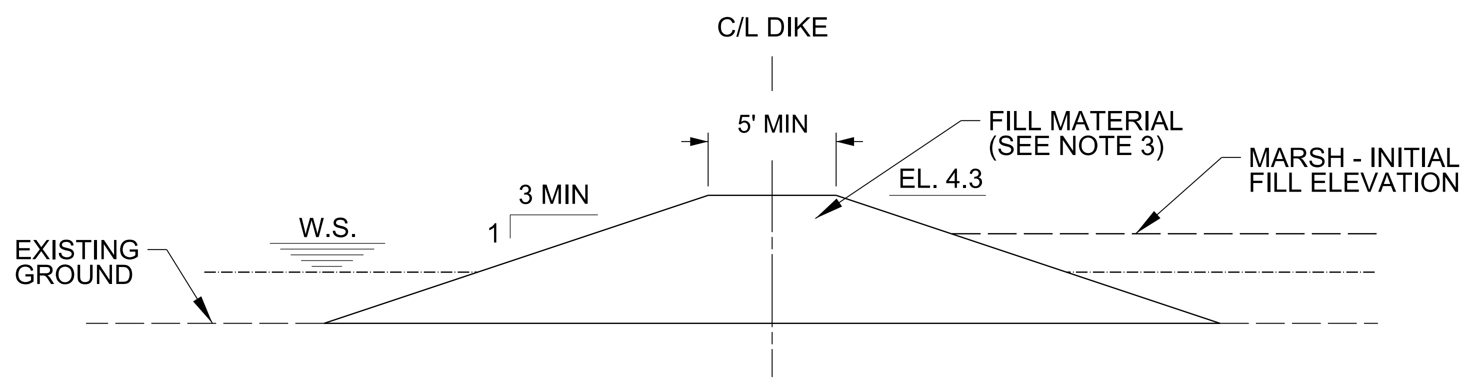
BREAKWATER - TYPICAL SECTION

N.T.S.



MARSH - TYPICAL SECTION

N.T.S.



DIKE - TYPICAL SECTION

N.T.S.

NOTES:

1. BREAKWATER ADAPTABLE TO +5 MLT ELEVATION.
2. DIKE WILL BE USED TO ENCLOSE OPEN AREAS OF MARSH CELLS.
3. FILL MATERIAL FOR DIKE SHALL BE FROM WITHIN MARSH CELL.

U.S. Army Corps of Engineers
Galveston District

Rev.	Description	Date	By

Drawn by: B.C.
Designed by:
Checked by:
Submitted by:
DAVID B. BOOTHBY, P.E.
Chief, Geotech/Structure Section
Approval Recommended:
JOSEPH L. KING, R.A.
Chief, Engineering Branch
Approved by:
ROBERT C. THOMAS, P.E.
Chief, Engineering and Construction Division
Date: FEB 2019
Scale: AS SHOWN
Rev.

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.,
COLONEL, U.S. ARMY, COMMANDING

JEFFERSON COUNTY
ECOSYSTEM RESTORATION
FEASIBILITY STUDY

TYPICAL SECTIONS

Drawing No.:
C-501

SWG FILE NO. ####

File: Rev 2_SNWW-JCER_STUDY-CIVIL-PLANS_TxSc83.dgn
Model Name: 08-C-501-TYPICAL SECTIONS Time: 9:07:55 AM
By: m3ecebbc Date: 2/6/2019

ATTACHMENT 2
TOTAL PROJECT COST SUMMARY (TPCS)

WALLA WALLA COST ENGINEERING MANDATORY CENTER OF EXPERTISE

COST AGENCY TECHNICAL REVIEW

CERTIFICATION STATEMENT

For Project No. 445800

SWG – Jefferson County Ecosystem Restoration Feasibility Study

The Jefferson County Ecosystem Restoration Feasibility Study, as presented by Galveston District, has undergone a successful Cost Agency Technical Review (Cost ATR), performed by the Walla Walla District Cost Engineering Mandatory Center of Expertise (Cost MCX) team. The Cost ATR included study of the project scope, report, cost estimates, schedules, escalation, and risk-based contingencies. This certification signifies the products meet the quality standards as prescribed in ER 1110-2-1150 Engineering and Design for Civil Works Projects and ER 1110-2-1302 Civil Works Cost Engineering.

As of February 14, 2019, the Cost MCX certifies the estimated total project cost:

FY19 Project First Cost: $ 62,252,000
Fully Funded Amount: $ 72,960,000

It remains the responsibility of the District to correctly reflect these cost values within the Final Report and to implement effective project management controls and implementation procedures including risk management through the period of Federal Participation.

®

JACOBS.MICHAEL.PIERRE.1160569537

Digitally signed by JACOBS.MICHAEL.PIERRE.1160569537
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=JACOBS.MICHAEL.PIERRE.1160569537
Date: 2019.02.14 13:13:30 -08'00'

Michael P. Jacobs, PE, CCE
Chief, Cost Engineering MCX
Walla Walla District

**** TOTAL PROJECT COST SUMMARY ****

PROJECT: Jefferson County Ecosystem Restoration Study
PROJECT | 445800
LOCATION: Jefferson County, TX

DISTRICT: Galveston District **PREPARED: 1/7/2019**
POC: CHIEF, COST ENGINEERING, Willie Joe Honza, P.E.

This Estimate reflects the scope and schedule in report; Jefferson County Ecosystem Restoration Study Nov 2018

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)						TOTAL PROJECT COST (FULLY FUNDED)			
						Program Year (Budget EC): 2019; Effective Price Level Date: 1 OCT 18									
WBS NUMBER *A*	Civil Works Feature & Sub-Feature Description *B*	COST ($K) *C*	CNTG ($K) *D*	CNTG (%) *E*	TOTAL ($K) *F*	ESC (%) *G*	COST ($K) *H*	CNTG ($K) *I*	TOTAL ($K) *J*	Spent Thru: 1-Oct-18 ($K)	TOTAL FIRST COST ($K) *K*	INFLATED (%) *L*	COST ($K) *M*	CNTG ($K) *N*	FULL ($K) *O*
06	FISH & WILDLIFE FACILITIES	$35,820	$6,089	17.0%	$41,909	0.0%	$35,820	$6,089	$41,909	$0	$41,909	15.5%	$41,386	$7,036	$48,422
10	BREAKWATER & SEAWALLS	$6,233	$1,060	17.0%	$7,293	0.0%	$6,233	$1,060	$7,293	$0	$7,293	10.4%	$6,882	$1,170	$8,052
	CONSTRUCTION ESTIMATE TOTALS:	$42,053	$7,149		$49,202	0.0%	$42,053	$7,149	$49,202	$0	$49,202	14.8%	$48,268	$8,206	$56,474
01	LANDS AND DAMAGES	$2,552	$638	25.0%	$3,190	0.0%	$2,552	$638	$3,190	$0	$3,190	10.3%	$2,815	$704	$3,519
30	PLANNING, ENGINEERING & DESIGN	$5,059	$864	17.1%	$5,924	0.0%	$5,059	$864	$5,924	$0	$5,924	29.7%	$6,562	$1,121	$7,683
31	CONSTRUCTION MANAGEMENT	$3,364	$572	17.0%	$3,936	0.0%	$3,364	$572	$3,936	$0	$3,936	33.4%	$4,487	$763	$5,250
	PROJECT COST TOTALS:	$53,028	$9,223	17.4%	$62,252		$53,028	$9,223	**$62,252**	$0	**$62,252**	17.1%	$62,133	$10,793	$72,926

CHIEF, COST ENGINEERING, Willie Joe Honza, P.E.

MISIR.SHAKHAR.D.1231146772 Digitally signed by MISIR.SHAKHAR.D.1231146772 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=MISIR.SHAKHAR.D.1231146772 Date: 2019.02.19 11:36:40 -06'00'
PROJECT MANAGER, Shakhar Misir

Timothy Nelson
CHIEF, REAL ESTATE, Timothy Nelson

CHIEF, PLANNING, Brian Harper

CHIEF, ENGINEERING, Joe King, R.A., LEED Green Assoc.

CHIEF, OPERATIONS, Joseph Hrametz, P.E.

CHIEF, CONSTRUCTION, Donald W. Carelock, P.E.

CHIEF, CONTRACTING, Jeffrey C. Neill

CHIEF, PM-G, Debby Jones

CHIEF, DPM, Edmond J. Russo Jr., PhD, P.E., D.CE, D.NE

TOTAL PROJECT FIRST COST: $62,252

TOTAL PROJECT COST (FULLY FUNDED): $72,926

**** TOTAL PROJECT COST SUMMARY ****

**** CONTRACT COST SUMMARY ****

PROJECT: Jefferson County Ecosystem Restoration Study
LOCATION: Jefferson County, TX
This Estimate reflects the scope and schedule in report; Jefferson County Ecosystem Restoration Study Nov 2018

DISTRICT: Galveston District PREPARED: 1/7/2019
POC: CHIEF, COST ENGINEERING, Willie Joe Honza, P.E.

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared: Effective Price Level:			7-Jan-19 1-Oct-18	Effective Price Level Date:			2019 1 OCT 18	FULLY FUNDED PROJECT ESTIMATE				
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	INFLATED (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*P*	*L*	*M*	*N*	*O*
	CONTRACT 1 - Marsh Renourishment Cell 1 & 2A and GIWW Armoring													
06	FISH & WILDLIFE FACILITIES	$7,061	$1,200	17.0%	$8,262	0.0%	$7,061	$1,200	$8,262	2024Q1	10.4%	$7,796	$1,325	$9,122
10	BREAKWATER & SEAWALLS	$6,233	$1,060	17.0%	$7,293	0.0%	$6,233	$1,060	$7,293	2024Q1	10.4%	$6,882	$1,170	$8,052
	CONSTRUCTION ESTIMATE TOTALS:	$13,295	$2,260	17.0%	**$15,555**		$13,295	$2,260	$15,555			$14,679	$2,495	$17,174
01	LANDS AND DAMAGES	$1,099	$275	25.0%	$1,373	0.0%	$1,099	$275	$1,373	2022Q4	7.7%	$1,184	$296	$1,479
30	PLANNING, ENGINEERING & DESIGN													
0.5%	Project Management	$66	$11	17.0%	$77	0.0%	$66	$11	$77	2023Q2	18.7%	$78	$13	$92
1.0%	Planning & Environmental Compliance	$133	$23	17.0%	$156	0.0%	$133	$23	$156	2023Q2	18.7%	$158	$27	$185
6.0%	Engineering & Design	$798	$136	17.0%	$934	0.0%	$798	$136	$934	2023Q2	18.7%	$947	$161	$1,108
0.7%	Reviews, ATRs, IEPRs, VE	$86	$15	17.0%	$101	0.0%	$86	$15	$101	2023Q2	18.7%	$102	$17	$119
0.5%	Life Cycle Updates (cost, schedule, risks)	$60	$10	17.0%	$70	0.0%	$60	$10	$70	2023Q2	18.7%	$71	$12	$83
0.0%	Contracting & Reprographics	$4	$1	17.0%	$5	0.0%	$4	$1	$5	2023Q2	18.7%	$5	$1	$6
1.0%	Engineering During Construction	$133	$23	17.0%	$156	0.0%	$133	$23	$156	2024Q1	22.5%	$163	$28	$191
0.2%	Planning During Construction	$27	$5	17.0%	$32	0.0%	$27	$5	$32	2024Q1	22.5%	$33	$6	$39
0.2%	Project Operations	$27	$5	17.0%	$32	0.0%	$27	$5	$32	2023Q2	18.7%	$32	$5	$38
	Real Estate In-House Labor	$28	$7	25.0%	$35	0.0%	$28	$7	$35	2023Q2	18.7%	$33	$8	$41
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$665	$113	17.0%	$778	0.0%	$665	$113	$778	2024Q1	22.5%	$814	$138	$953
0.5%	Project Operation:	$66	$11	17.0%	$77	0.0%	$66	$11	$77	2024Q1	22.5%	$81	$14	$95
2.5%	Project Management	$332	$56	17.0%	$388	0.0%	$332	$56	$388	2024Q1	22.5%	$407	$69	$476
	CONTRACT COST TOTALS:	$16,818	$2,949		**$19,767**		$16,818	$2,949	$19,767			$18,786	$3,291	**$22,077**

**** TOTAL PROJECT COST SUMMARY ****

**** CONTRACT COST SUMMARY ****

PROJECT: Jefferson County Ecosystem Restoration Study
LOCATION: Jefferson County, TX
This Estimate reflects the scope and schedule in report; Jefferson County Ecosystem Restoration Study Nov 2018

DISTRICT: Galveston District
POC: CHIEF, COST ENGINEERING, Willie Joe Honza, P.E.
PREPARED: 1/7/2019

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared: 7-Jan-19 Effective Price Level: 1-Oct-18				Effective Price Level Date: 2019 1 OCT 18				FULLY FUNDED PROJECT ESTIMATE				
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	INFLATED (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*P*	*L*	*M*	*N*	*O*
	CONTRACT 2 - Marsh Renourishment Cell 6A													
06	FISH & WILDLIFE FACILITIES	$5,908	$1,004	17.0%	$6,912	0.0%	$5,908	$1,004	$6,912	2024Q3	11.5%	$6,588	$1,120	$7,708
	CONSTRUCTION ESTIMATE TOTALS:	$5,908	$1,004	17.0%	**$6,912**		$5,908	$1,004	$6,912			$6,588	$1,120	$7,708
01	LANDS AND DAMAGES	$664	$166	25.0%	$830	0.0%	$664	$166	$830	2023Q4	9.9%	$730	$182	$912
30	PLANNING, ENGINEERING & DESIGN													
0.5%	Project Management	$30	$5	17.0%	$35	0.0%	$30	$5	$35	2024Q2	23.7%	$37	$6	$43
1.0%	Planning & Environmental Compliance	$59	$10	17.0%	$69	0.0%	$59	$10	$69	2024Q2	23.7%	$73	$12	$85
6.0%	Engineering & Design	$354	$60	17.0%	$414	0.0%	$354	$60	$414	2024Q2	23.7%	$438	$74	$512
0.7%	Reviews, ATRs, IEPRs, VE	$38	$6	17.0%	$44	0.0%	$38	$6	$44	2024Q2	23.7%	$47	$8	$55
0.5%	Life Cycle Updates (cost, schedule, risks)	$27	$5	17.0%	$32	0.0%	$27	$5	$32	2024Q2	23.7%	$33	$6	$39
0.0%	Contracting & Reprographics	$2	$0	17.0%	$2	0.0%	$2	$0	$2	2024Q2	23.7%	$2	$0	$3
1.0%	Engineering During Construction	$59	$10	17.0%	$69	0.0%	$59	$10	$69	2024Q3	25.0%	$74	$13	$86
0.2%	Planning During Construction	$12	$2	17.0%	$14	0.0%	$12	$2	$14	2024Q3	25.0%	$15	$3	$18
0.2%	Project Operations	$12	$2	17.0%	$14	0.0%	$12	$2	$14	2024Q2	23.7%	$15	$3	$17
	Real Estate In-House Labor	$13	$3	25.0%	$16	0.0%	$13	$3	$16	2024Q2	23.7%	$16	$4	$20
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$295	$50	17.0%	$345	0.0%	$295	$50	$345	2024Q3	25.0%	$369	$63	$432
0.5%	Project Operation:	$30	$5	17.0%	$35	0.0%	$30	$5	$35	2024Q3	25.0%	$38	$6	$44
2.5%	Project Management	$148	$25	17.0%	$173	0.0%	$148	$25	$173	2024Q3	25.0%	$185	$31	$217
	CONTRACT COST TOTALS:	$7,650	$1,355		**$9,005**		$7,650	$1,355	$9,005			$8,660	$1,532	**$10,191**

**** TOTAL PROJECT COST SUMMARY ****

**** CONTRACT COST SUMMARY ****

PROJECT: Jefferson County Ecosystem Restoration Study
LOCATION: Jefferson County, TX
This Estimate reflects the scope and schedule in report; Jefferson County Ecosystem Restoration Study Nov 2018

DISTRICT: Galveston District
POC: CHIEF, COST ENGINEERING, Willie Joe Honza, P.E.
PREPARED: 1/7/2019

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared: 7-Jan-19								FULLY FUNDED PROJECT ESTIMATE				
		Effective Price Level: 1-Oct-18				Effective Price Level Date: 2019 1 OCT 18								
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	INFLATED (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*P*	*L*	*M*	*N*	*O*
	CONTRACT 3 - Marsh Renourishment Cell 2B, 3, 4, & 5													
06	FISH & WILDLIFE FACILITIES	$10,572	$1,797	17.0%	$12,369	0.0%	$10,572	$1,797	$12,369	2025Q4	14.3%	$12,086	$2,055	$14,140
	CONSTRUCTION ESTIMATE TOTALS:	$10,572	$1,797	17.0%	**$12,369**		$10,572	$1,797	$12,369			$12,086	$2,055	$14,140
01	LANDS AND DAMAGES	$532	$133	25.0%	$665	0.0%	$532	$133	$665	2024Q4	12.1%	$596	$149	$745
30	PLANNING, ENGINEERING & DESIGN													
0.5%	Project Management	$53	$9	17.0%	$62	0.0%	$53	$9	$62	2025Q2	29.0%	$68	$12	$80
1.0%	Planning & Environmental Compliance	$106	$18	17.0%	$124	0.0%	$106	$18	$124	2025Q2	29.0%	$137	$23	$160
6.0%	Engineering & Design	$634	$108	17.0%	$742	0.0%	$634	$108	$742	2025Q2	29.0%	$818	$139	$957
0.7%	Reviews, ATRs, IEPRs, VE	$69	$12	17.0%	$81	0.0%	$69	$12	$81	2025Q2	29.0%	$89	$15	$104
0.5%	Life Cycle Updates (cost, schedule, risks)	$48	$8	17.0%	$56	0.0%	$48	$8	$56	2025Q2	29.0%	$62	$11	$72
0.0%	Contracting & Reprographics	$3	$1	17.0%	$4	0.0%	$3	$1	$4	2025Q2	29.0%	$4	$1	$5
1.0%	Engineering During Construction	$106	$18	17.0%	$124	0.0%	$106	$18	$124	2025Q4	31.8%	$140	$24	$163
0.2%	Planning During Construction	$21	$4	17.0%	$25	0.0%	$21	$4	$25	2025Q4	31.8%	$28	$5	$32
0.2%	Project Operations	$21	$4	17.0%	$25	0.0%	$21	$4	$25	2025Q2	29.0%	$27	$5	$32
	Real Estate In-House Labor	$9	$2	25.0%	$12	0.0%	$9	$2	$12	2025Q2	29.0%	$12	$3	$15
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$529	$90	17.0%	$619	0.0%	$529	$90	$619	2025Q4	31.8%	$697	$119	$816
0.5%	Project Operation:	$53	$9	17.0%	$62	0.0%	$53	$9	$62	2025Q4	31.8%	$70	$12	$82
2.5%	Project Management	$264	$45	17.0%	$309	0.0%	$264	$45	$309	2025Q4	31.8%	$348	$59	$407
	CONTRACT COST TOTALS:	$13,020	$2,257		**$15,277**		$13,020	$2,257	$15,277			$15,182	$2,630	**$17,811**

****** TOTAL PROJECT COST SUMMARY ******

****** CONTRACT COST SUMMARY ******

PROJECT: Jefferson County Ecosystem Restoration Study
LOCATION: Jefferson County, TX
This Estimate reflects the scope and schedule in report; Jefferson County Ecosystem Restoration Study Nov 2018

DISTRICT: Galveston District PREPARED: 1/7/2019
POC: CHIEF, COST ENGINEERING, Willie Joe Honza, P.E.

Civil Works Work Breakdown Structure		**ESTIMATED COST**				**PROJECT FIRST COST (Constant Dollar Basis)**				**TOTAL PROJECT COST (FULLY FUNDED)**				
		Estimate Prepared:			**7-Jan-19**				2019					
		Effective Price Level:			1-Oct-18	Effective Price Level Date:			1 OCT 18	FULLY FUNDED PROJECT ESTIMATE				
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	INFLATED (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*P*	*L*	*M*	*N*	*O*
	CONTRACT 4 - Marsh Renourishment Cell 2C & 6B													
06	FISH & WILDLIFE FACILITIES	$10,074	$1,713	17.0%	$11,787	0.0%	$10,074	$1,713	$11,787	2028Q3	20.7%	$12,161	$2,067	$14,229
	CONSTRUCTION ESTIMATE TOTALS:	$10,074	$1,713	17.0%	**$11,787**		$10,074	$1,713	$11,787			$12,161	$2,067	$14,229
01	LANDS AND DAMAGES	$257	$64	25.0%	$321	0.0%	$257	$64	$321	2027Q4	18.9%	$306	$76	$382
30	PLANNING, ENGINEERING & DESIGN													
0.5%	Project Management	$50	$9	17.0%	$59	0.0%	$50	$9	$59	2028Q2	46.8%	$73	$12	$86
1.0%	Planning & Environmental Compliance	$101	$17	17.0%	$118	0.0%	$101	$17	$118	2028Q2	46.8%	$148	$25	$173
6.0%	Engineering & Design	$604	$103	17.0%	$707	0.0%	$604	$103	$707	2028Q2	46.8%	$887	$151	$1,038
0.7%	Reviews, ATRs, IEPRs, VE	$65	$11	17.0%	$76	0.0%	$65	$11	$76	2028Q2	46.8%	$95	$16	$112
0.5%	Life Cycle Updates (cost, schedule, risks)	$45	$8	17.0%	$53	0.0%	$45	$8	$53	2028Q2	46.8%	$66	$11	$77
0.0%	Contracting & Reprographics	$3	$1	17.0%	$4	0.0%	$3	$1	$4	2028Q2	46.8%	$4	$1	$5
1.0%	Engineering During Construction	$101	$17	17.0%	$118	0.0%	$101	$17	$118	2028Q3	48.5%	$150	$25	$175
0.2%	Planning During Construction	$20	$3	17.0%	$23	0.0%	$20	$3	$23	2028Q3	48.5%	$30	$5	$35
0.2%	Project Operations	$20	$3	17.0%	$23	0.0%	$20	$3	$23	2028Q2	46.8%	$29	$5	$34
	Real Estate In-House Labor	$4	$1	25.0%	$5	0.0%	$4	$1	$5	2028Q2	46.8%	$5	$1	$7
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$504	$86	17.0%	$590	0.0%	$504	$86	$590	2028Q3	48.5%	$748	$127	$875
0.5%	Project Operation:	$50	$9	17.0%	$59	0.0%	$50	$9	$59	2028Q3	48.5%	$74	$13	$87
2.5%	Project Management	$252	$43	17.0%	$295	0.0%	$252	$43	$295	2028Q3	48.5%	$374	$64	$438
	CONTRACT COST TOTALS:	$12,150	$2,086		**$14,236**		$12,150	$2,086	$14,236			$15,152	$2,601	**$17,753**

****** TOTAL PROJECT COST SUMMARY ******

****** CONTRACT COST SUMMARY ******

PROJECT: Jefferson County Ecosystem Restoration Study | DISTRICT: Galveston District | PREPARED: 1/7/2019
LOCATION: Jefferson County, TX | POC: CHIEF, COST ENGINEERING, Willie Joe Honza, P.E.
This Estimate reflects the scope and schedule in report; Jefferson County Ecosystem Restoration Study Nov 2018

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared: Effective Price Level:			7-Jan-19 1-Oct-18	Effective Price Level Date:			2019 1 OCT 18	FULLY FUNDED PROJECT ESTIMATE				
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	INFLATED (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*P*	*L*	*M*	*N*	*O*
	CONTRACT 5 - Adaptive Management & Monitoring													
06	FISH & WILDLIFE FACILITIES	$2,204	$375	17.0%	$2,579	0.0%	$2,204	$375	$2,579	2030Q2	25.0%	$2,754	$468	$3,223
	CONSTRUCTION ESTIMATE TOTALS:	$2,204	$375	17.0%	**$2,579**		$2,204	$375	$2,579			$2,754	$468	$3,223
01	LANDS AND DAMAGES													
30	PLANNING, ENGINEERING & DESIGN													
0.5%	Project Management	$50	$9	17.0%	$59	0.0%	$50	$9	$59	2024Q4	26.4%	$63	$11	$74
1.0%	Planning & Environmental Compliance	$101	$17	17.0%	$118	0.0%	$101	$17	$118	2024Q4	26.4%	$128	$22	$149
6.0%	Engineering & Design	$604	$103	17.0%	$707	0.0%	$604	$103	$707	2024Q4	26.4%	$763	$130	$893
0.7%	Reviews, ATRs, IEPRs, VE	$65	$11	17.0%	$76	0.0%	$65	$11	$76	2024Q4	26.4%	$82	$14	$96
0.5%	Life Cycle Updates (cost, schedule, risks)	$45	$8	17.0%	$53	0.0%	$45	$8	$53	2024Q4	26.4%	$57	$10	$67
0.0%	Contracting & Reprographics	$3	$1	17.0%	$4	0.0%	$3	$1	$4	2024Q4	26.4%	$4	$1	$4
1.0%	Engineering During Construction	$101	$17	17.0%	$118	0.0%	$101	$17	$118	2030Q2	60.5%	$162	$28	$190
0.2%	Planning During Construction	$20	$3	17.0%	$23	0.0%	$20	$3	$23	2030Q2	60.5%	$32	$5	$38
0.2%	Project Operations	$20	$3	17.0%	$23	0.0%	$20	$3	$23	2024Q4	26.4%	$25	$4	$30
	Real Estate In-House Labor	$0	$0	25.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$110	$19	17.0%	$129	0.0%	$110	$19	$129	2030Q2	60.5%	$177	$30	$207
0.5%	Project Operation:	$11	$2	17.0%	$13	0.0%	$11	$2	$13	2030Q2	60.5%	$18	$3	$21
2.5%	Project Management	$55	$9	17.0%	$64	0.0%	$55	$9	$64	2030Q2	60.5%	$88	$15	$103
	CONTRACT COST TOTALS:	$3,389	$576		**$3,965**		$3,389	$576	$3,965			$4,353	$740	**$5,093**

ATTACHMENT 3
MCACES COST ESTIMATE

Total Project Costs (Does Not Include Contingency, 01, 30, or 31 Account Code)

JCER - October 2018 Price Level - Certified 14Feb2019

Estimated by Adam Tallman
Designed by Galveston District Engineering
Prepared by Adam Tallman
Preparation Date 10/25/2018
Effective Date of Pricing 10/25/2018
Estimated Construction Time Days

Description	Quantity	UOM	ProjectCost
Project Cost Summary Report			**42,053,042**
01 Contract 1 - Marsh Renourishment Cell 1 & 2A and GIWW Armoring	**1.00**	**LS**	**13,294,837**
012 Federal Costs	**1.00**	**LS**	**13,294,837**
01206 Fish and Wildlife Facilities	**1.00**	**LS**	**7,061,403**
01210 Breakwaters and Seawalls	**1.00**	**EA**	**6,233,434**
02 Contract 2 - Marsh Renourishment Cell 6A	**1.00**	**LS**	**5,907,524**
022 Federal Costs	**1.00**	**LS**	**5,907,524**
02206 Fish and Wildlife Facilities	**1.00**	**LS**	**5,907,524**
03 Contract 3 - Marsh Renourishment Cell 2B, 3, 4, & 5	**1.00**	**LS**	**10,572,098**
032 Federal Costs	**1.00**	**LS**	**10,572,098**
03206 Fish and Wildlife Facilities	**1.00**	**LS**	**10,572,098**
04 Contract 4 - Marsh Renourishment Cell 2C & 6B	**1.00**	**EA**	**10,074,383**
042 Federal Costs	**1.00**	**EA**	**10,074,383**
04206 Fish and Wildlife Facilities	**1.00**	**LS**	**10,074,383**
05 Contract 5 - Adaptive Management & Monitoring	**1.00**	**LS**	**2,204,200**
052 Federal Costs	**1.00**	**LS**	**2,204,200**
05206 Fish and Wildlife Facilities	**1.00**	**LS**	**2,204,200**

ATTACHMENT 4
COST SCHEDULE RISK ANALYSIS (CSRA)

US Army Corps of
Engineers®

Jefferson County Ecosystem Restoration Study

Project Cost and Schedule Risk Analysis Report

Prepared for:

U.S. Army Corps of Engineers,

Galveston District

Prepared by:

Walla Walla District, U.S. Army Corps of Engineers

February 28, 2019

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EXECUTIVE SUMMARY

The US Army Corps of Engineers (USACE), Galveston District, presents this cost and schedule risk analysis (CSRA) report regarding the risk findings and recommended contingencies for the Jefferson County Ecosystem Restoration Study. In compliance with Engineer Regulation (ER) 1110-2-1302 CIVIL WORKS COST ENGINEERING, dated September 15, 2008, a *Monte-Carlo* based risk analysis was conducted by the Project Development Team (PDT) on remaining costs. The purpose of this risk analysis study is to present the cost and schedule risks considered, those determined and respective project contingencies at a recommended 80% confidence level of successful execution to project completion.

Restoring approximately 180 acres of riverine and riparian habitat along the north and south banks of the Lower Yuba River downstream of Englebright Dam and upstream from Marysville, CA. Approximately 689,000 cy of gravel and cobble will be excavated from within the bank full channel to create 1.) Riverine habitat in the form of side channels, backwaters, and bank scallops and 2.) Lower bar and bank elevations so that the groundwater table is reachable by riparian vegetation at low flows. Approximately 200,000 plantings of live cuttings will be performed through the project area to enhance physical stability, provide woody and riparian habitat, and to provide shade. Construction is assumed to be completed in 4 seasons/years.

Specific to Jefferson County Ecosystem Restoration, the current project base cost estimate, pre-contingency, approximates $66.8M. This CSRA is expressed in FY 2019 dollars. Since the Real Estate office provided a separate 25% contingency for its real estate requirements, the Cost MCX performed study on the estimated construction costs of $366.8M. Based on the results of the analysis, the Cost Engineering Mandatory Center of Expertise for Civil Works (MCX located in Walla Walla District) recommends a contingency value of $11.4M or approximately 17% of base project cost at an 80% confidence level of successful execution. This contingency includes a separate $252K for Real Estate.

Cost estimates fluctuate over time. During this period of study, minor cost fluctuations can and have occurred. For this reason, contingency reporting is based in cost and per cent values. Should cost vary to a slight degree with similar scope and risks, contingency per cent values will be reported, cost values rounded.

Table 1 Construction Contingency Results

Contingency on Base Estimate	80% Confidence Project Cost	
Base Construction Estimate	$66,763,000	
Baseline Estimate Cost Contingency Amount ->	$11,430,430	17%
Baseline Estimate Construction Cost (80% Confidence) ->	$78,193,430	

KEY FINDINGS/OBSERVATIONS RECOMMENDATIONS

The PDT worked through the Project Book, completing it in FY19. That period of time allowed improved project scope definition, investigations, design and cost information, and resulted in reduced risks in certain project areas.

Weather and potential impacts from hurricanes appear to be driving both the Schedule and Cost Risk.

Cost Risks: From the CSRA, the key or greater Cost Risk items of include:

- <u>CO2 – Weather</u> – This Risk is driven mostly by the frequency that weather events have been occurring and the effects they are having on the restoration area.

Schedule Risks: The high value of schedule risk indicates a significant uncertainty of key risk items, time duration growth that can translate into added costs. Over time, risks increase on those out-year contracts where there is greater potential for change in new scope requirements, uncertain market conditions, and unexpected high inflation. The greatest risk is:

- <u>EX1 - Funding</u> – Given current administration prioritieis, environmental projects funding may be less certain.

Recommendations

The PDT must include the recommended cost and schedule contingencies and incorporate risk monitoring and mitigation on those identified risks. Further iterative study and update of the risk analysis throughout the project life-cycle is important in support of the remaining project work within an approved budget and appropriation.

MAIN REPORT

1.0 PURPOSE

Within the authority of the US Army Corps of Engineers (USACE), Galevston District, this report presents the efforts and results of the cost and schedule risk analysis for Jefferson County Ecosystem Restoration. The report includes risk methodology, discussions, findings and recommendations regarding the identified risks and the necessary contingencies to confidently administer the project, presenting a cost and schedule contingency value with an 80% confidence level of successful execution.

2.0 BACKGROUND

Restoring approximately 180 acres of riverine and riparian habitat along the north and south banks of the Lower Yuba River downstream of Englebright Dam and upstream from Marysville, CA. Approximately 689,000 CY of gravel and cobble will be excavated from within the bank full channel to create 1.) Riverine habitat in the form of side channels, backwaters, and bank scallops and 2.) Lower bar and bank elevations so that the groundwater table is reachable by riparian vegetation at low flows. Approximately 200,000 plantings of live cuttings will be performed through the project area to enhance physical stability, provide woody and riparian habitat, and to provide shade. Construction is assumed to be completed in 4 seasons/years.

3.0 REPORT SCOPE

The scope of the risk analysis report is to identify cost and schedule risks with a resulting recommendation for contingencies at the 80 percent confidence level using the risk analysis processes, as mandated by U.S. Army Corps of Engineers (USACE) Engineer Regulation (ER) 1110-2-1150, Engineering and Design for Civil Works, ER 1110-2-1302, Civil Works Cost Engineering, and Engineer Technical Letter 1110-2-573, Construction Cost Estimating Guide for Civil Works. The report presents the contingency results for cost risks for construction features. The CSRA excludes Real Estate costs and does not include consideration for life cycle costs.

3.1 Project Scope

The formal process included extensive involvement of the PDT for risk identification and the development of the risk register. The analysis process evaluated the Micro Computer Aided Cost Estimating System (MCACES) cost estimate, project schedule, and funding profiles using Crystal Ball software to conduct a *Monte Carlo* simulation and statistical sensitivity analysis, per the guidance in Engineer Technical Letter (ETL) CONSTRUCTION COST ESTIMATING GUIDE FOR CIVIL WORKS, dated September 30, 2008.

The project technical scope, estimates and schedules were developed and presented by the Galveston District. Consequently, these documents serve as the basis for the risk analysis.

The scope of this study addresses the identification of concerns, needs, opportunities and potential solutions that are viable from an economic, environmental, and engineering viewpoint.

3.2 USACE Risk Analysis Process

The risk analysis process for this study follows the USACE Headquarters requirements as well as the guidance provided by the Cost Engineering MCX. The risk analysis process reflected within this report uses probabilistic cost and schedule risk analysis methods within the framework of the Crystal Ball software. Furthermore, the scope of the report includes the identification and communication of important steps, logic, key assumptions, limitations, and decisions to help ensure that risk analysis results can be appropriately interpreted.

Risk analysis results are also intended to provide project leadership with contingency information for scheduling, budgeting, and project control purposes, as well as to provide tools to support decision making and risk management as the project progresses through planning and implementation. To fully recognize its benefits, cost and schedule risk analysis should be considered as an ongoing process conducted concurrent to, and iteratively with, other important project processes such as scope and execution plan development, resource planning, procurement planning, cost estimating, budgeting and scheduling.

In addition to broadly defined risk analysis standards and recommended practices, this risk analysis was performed to meet the requirements and recommendations of the following documents and sources:

- Cost and Schedule Risk Analysis Process guidance prepared by the USACE Cost Engineering MCX.
- Engineer Regulation (ER) 1110-2-1302 CIVIL WORKS COST ENGINEERING, dated September 15, 2008.
- Engineer Technical Letter (ETL) CONSTRUCTION COST ESTIMATING GUIDE FOR CIVIL WORKS, dated September 30, 2008.

4.0 METHODOLOGY / PROCESS

The Cost Engineering MCX performed the Cost and Schedule Risk Analysis, relying on local Galveston District staff to provide expertise and information gathering. The Galveston PDT conducted initial risk identification via on-site CSRA meeting with the Walla Walla Cost Engineering MCX facilitator on 07 November 2018. The initial risk identification meeting also included qualitative analysis to produce a risk register that served as the draft framework for the risk analysis.

Table 2 Attendee List 07 Nov 2018

Participant	Org./Role
Shakhar Misir	SWJ/PM
Michael Scuderi	NWS/Biologist
Adam Tallman	SWG/ Cost Engineering
Paul Hamilton	SWG/EC-HG
Cris Michalsky	SWG/ECE-S
Nichole Schlund	SWG/RES
Nancy Parrish	SWF/PEC-TN
Norman Lewis	SWF/PEC
Natalie Garrett	SWF/PEC
Malinda Fisher	SWF/PEC
Derek Nelson	NWW/Cost Engineer

The draft CSRA model was completed November 2018. However, subsequent sanity checks and technical review of the base cost estimate required revisions, necessitating a rerun of the original model. Results were furthered on December 6, 2018, ready for ATR. ATR comments resulted in revisions to the estimate.

The risk analysis process for this study is intended to determine the probability of various cost outcomes and quantify the required contingency needed in the cost estimate to achieve the desired level of cost confidence. Per regulation and guidance, the P80 confidence level (80% confidence level) is the normal and accepted cost confidence level. District Management has the prerogative to select different confidence levels, pending approval from Headquarters, USACE.

In simple terms, contingency is an amount added to an estimate to allow for items, conditions or events for which the occurrence or impact is uncertain and that experience suggests will likely result in additional costs being incurred or additional time being required. The amount of contingency included in project control plans depends, at least in part, on the project leadership's willingness to accept risk of project overruns. The less risk that project leadership is willing to accept the more contingency should be applied in the project control plans. The risk of overrun is expressed, in a probabilistic context, using confidence levels.

The Cost MCX guidance for cost and schedule risk analysis generally focuses on the 80-percent level of confidence (P80) for cost contingency calculation. It should be noted that use of P80 as a decision criteria is a risk averse approach (whereas the use of P50 would be a risk neutral approach, and use of levels less than 50 percent would be risk seeking). Thus, a P80 confidence level results in greater contingency as compared to a P50 confidence level. The selection of contingency at a particular confidence level is ultimately the decision and responsibility of the project's District and/or Division management.

The risk analysis process uses *Monte Carlo* techniques to determine probabilities and contingency. The *Monte Carlo* techniques are facilitated computationally by a commercially available risk analysis software package (Crystal Ball) that is an add-in to Microsoft Excel. Cost estimates are packaged into an Excel format and used directly for cost risk analysis purposes. The level of detail recreated in the Excel-format schedule is sufficient for risk analysis purposes that reflect the established risk register, but generally less than that of the native format.

The primary steps, in functional terms, of the risk analysis process are described in the following subsections. Risk analysis results are provided in Section 6.

4.1 Identify and Assess Risk Factors

Identifying the risk factors via the PDT is considered a qualitative process that results in establishing a risk register that serves as the document for the quantitative study using the Crystal Ball risk software. Risk factors are events and conditions that may influence or drive uncertainty in project performance. They may be inherent characteristics or conditions of the project or external influences, events, or conditions such as weather or economic conditions. Risk factors may have either favorable or unfavorable impacts on project cost and schedule.

A formal PDT meeting was held with the Galveston District office for the purposes of identifying and assessing risk factors. The meeting (conducted November 7) included capable and qualified representatives from multiple project team disciplines and functions, including project management, cost engineering, design, environmental compliance, and real estate.

The initial formal meetings focused primarily on risk factor identification using brainstorming techniques, but also included some facilitated discussions based on risk factors common to projects of similar scope and geographic location. Additionally, numerous conference calls and informal meetings were conducted throughout the risk analysis process on an as-needed basis to further facilitate risk factor identification, market analysis, and risk assessment.

4.2 Quantify Risk Factor Impacts

The quantitative impacts (putting it to numbers of cost and time) of risk factors on project plans were analyzed using a combination of professional judgment, empirical data and analytical techniques. Risk factor impacts were quantified using probability distributions (density functions) because risk factors are entered into the Crystal Ball software in the form of probability density functions.

Similar to the identification and assessment process, risk factor quantification involved multiple project team disciplines and functions. However, the quantification process relied more extensively on collaboration between cost engineering and risk analysis team members with lesser inputs from other functions and disciplines. This process used an iterative approach to estimate the following elements of each risk factor:

- Maximum possible value for the risk factor
- Minimum possible value for the risk factor
- Most likely value (the statistical mode), if applicable
- Nature of the probability density function used to approximate risk factor uncertainty
- Mathematical correlations between risk factors
- Affected cost estimate and schedule elements

The resulting product from the PDT discussions is captured within a risk register as presented in section 6 for both cost and schedule risk concerns. Note that the risk register records the PDT's risk concerns, discussions related to those concerns, and potential impacts to the current cost and schedule estimates. The concerns and discussions support the team's decisions related to event likelihood, impact, and the resulting risk levels for each risk event.

4.3 Analyze Cost Estimate and Schedule Contingency

Contingency is analyzed using the Crystal Ball software, an add-in to the Microsoft Excel format of the cost estimate and schedule. *Monte Carlo* simulations are performed by applying the risk factors (quantified as probability density functions) to the appropriate estimated cost and schedule elements identified by the PDT. Contingencies are calculated by applying only the moderate and high level risks identified for each option (i.e., low-level risks are typically not considered, but remain within the risk register to serve historical purposes as well as support follow-on risk studies as the project and risks evolve).

For the cost estimate, the contingency is calculated as the difference between the P80 cost forecast and the baseline cost estimate. Each option-specific contingency is then allocated on a civil works feature level based on the dollar-weighted relative risk of each feature as quantified by *Monte Carlo* simulation. Standard deviation is used as the feature-specific measure of risk for contingency allocation purposes. This approach results in a relatively larger portion of all the project feature cost contingency being allocated to features with relatively higher estimated cost uncertainty.

5.0 PROJECT ASSUMPTIONS

The following data sources and assumptions were used in quantifying the costs associated with the project.

a. The Galveston District provided MII MCACES (Micro-Computer Aided Cost Estimating Software) files electronically. The final MII report file was transmitted and downloaded on November 15, 2018 was the basis for the final cost and schedule risk analyses.

b. The cost comparisons and risk analyses performed and reflected within this report are based on design scope and estimates that are at the preconstruction engineering and design (PED) level, most approximating a 35% design stage.

c. Schedules are analyzed for impact to the project cost in terms of delayed funding, uncaptured escalation (variance from OMB factors and the local market) and unavoidable fixed contract costs and/or languishing federal administration costs incurred throughout delay.

d. The Cost Engineering MCX guidance generally focuses on the eighty-percent level of confidence (P80) for cost contingency calculation. For this risk analysis, the eighty-percent level of confidence (P80) was used. It should be noted that the use of P80 as a decision criteria is a moderately risk averse approach, generally resulting in higher cost contingencies. However, the P80 level of confidence also assumes a small degree of risk that the recommended contingencies may be inadequate to capture actual project costs.

e. Only high and moderate risk level impacts, as identified in the risk register, were considered for the purposes of calculating cost contingency. Low level risk impacts should be maintained in project management documentation, and reviewed at each project milestone to determine if they should be placed on the risk “watch list”.

6.0 RESULTS

The cost and schedule risk analysis results are provided in the following sections. In addition to contingency calculation results, sensitivity analyses are presented to provide decision makers with an understanding of variability and the key contributors to the cause of this variability.

6.1 Risk Register

A risk register is a tool commonly used in project planning and risk analysis. The actual risk register is provided in Appendix A. The complete risk register includes low level risks, as well as additional information regarding the nature and impacts of each risk.

It is important to note that a risk register can be an effective tool for managing identified risks throughout the project life cycle. As such, it is generally recommended that risk registers be updated as the designs, cost estimates, and schedule are further refined, especially on large projects with extended schedules. Recommended uses of the risk register going forward include:

- Documenting risk mitigation strategies being pursued in response to the identified risks and their assessment in terms of probability and impact.
- Providing project sponsors, stakeholders, and leadership/management with a documented framework from which risk status can be reported in the context of project controls.
- Communicating risk management issues.
- Providing a mechanism for eliciting feedback and project control input.
- Identifying risk transfer, elimination, or mitigation actions required for implementation of risk management plans.

6.2 Cost Contingency and Sensitivity Analysis

The result of risk or uncertainty analysis is quantification of the cumulative impact of all analyzed risks or uncertainties as compared to probability of occurrence. These results, as applied to the analysis herein, depict the overall project cost at intervals of confidence (probability).

Table 3 provides the construction cost contingencies calculated for the P80 confidence level and rounded to the nearest thousand. The construction cost contingencies for the P5, P50 and P90 confidence levels are also provided for illustrative purposes only. Cost contingency for the Construction risks (including schedule impacts converted to dollars) was quantified as approximately $9.5 Million at the P80 confidence level (17% of the baseline construction cost estimate). Figure 1 graphically shows the cost confidence level contingencies.

Table 3 Construction Cost Comparison Summary (Uncertainty Analysis)

Base Case Estimate (Excluding 01)	$55,660,000	
Confidence Level	Contingency Value	Contingency
0%	-1,669,800	-3%
10%	2,783,000	5%
20%	3,896,200	7%
30%	5,009,400	9%
40%	6,122,600	11%
50%	6,679,200	12%

60%	7,235,800	13%
70%	8,349,000	15%
80%	9,462,200	17%
90%	11,132,000	20%
100%	18,924,400	34%

Figure 1 Cost Contingency Graph

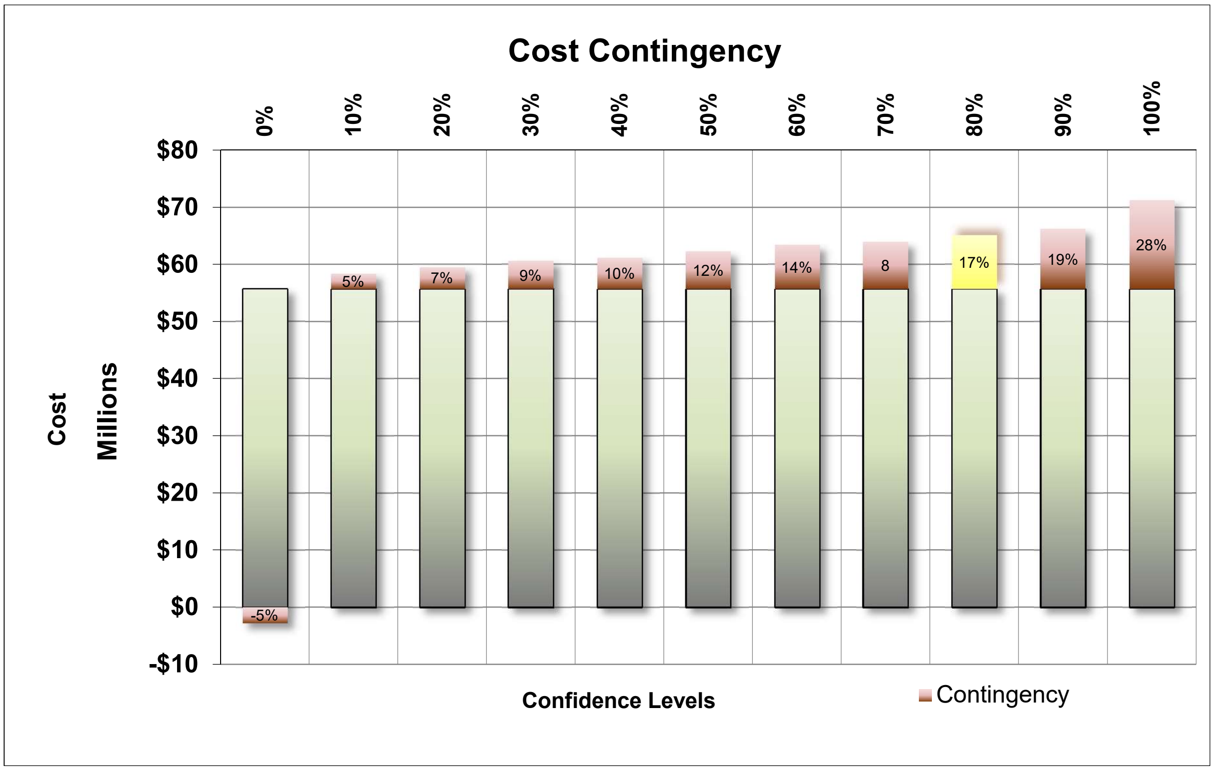


Table 4 is the Construction Cost Contingency Summary, showing the Base Construction amount used, which is the USACE estimate, the Contingency Amount and Percentage, and the Baseline Estimate Construction Cost at the 80% Confidence Level.

Table 4 Construction Cost Contingency Summary

Contingency on Base Estimate	80% Confidence Project Cost	
Base Construction Estimate	$66,763,000	

Baseline Estimate Cost Contingency Amount ->	$11,430,430	17%
Baseline Estimate Construction Cost (80% Confidence) ->	$78,193,430	

6.2.1 Sensitivity Analysis

Sensitivity analysis generally ranks the relative impact of each risk/opportunity as a percentage of total cost uncertainty. The Crystal Ball software uses a statistical measure (contribution to variance) that approximates the impact of each risk/opportunity contributing to variability of cost outcomes during *Monte Carlo* simulation.

Key cost drivers identified in the sensitivity analysis can be used to support development of a risk management plan that will facilitate control of risk factors and their potential impacts throughout the project lifecycle. Together with the risk register, sensitivity analysis results can also be used to support development of strategies to eliminate, mitigate, accept or transfer key risks.

6.2.2 Sensitivity Analysis Results

The risks/opportunities considered as key or primary cost drivers and the respective value variance are ranked in order of importance in contribution to variance bar charts. Opportunities that have a potential to reduce project cost and are shown with a negative sign; risks are shown with a positive sign to reflect the potential to increase project cost. A longer bar in the sensitivity analysis chart represents a greater potential impact to project cost.

Figure 2 presents a sensitivity analysis for cost growth risk from the high level cost risks identified in the risk register. Likewise, Figure 3 presents a sensitivity analysis for schedule growth risk from the high level schedule risks identified in the risk register.

Figure 2 Cost Sensitivity Analysis

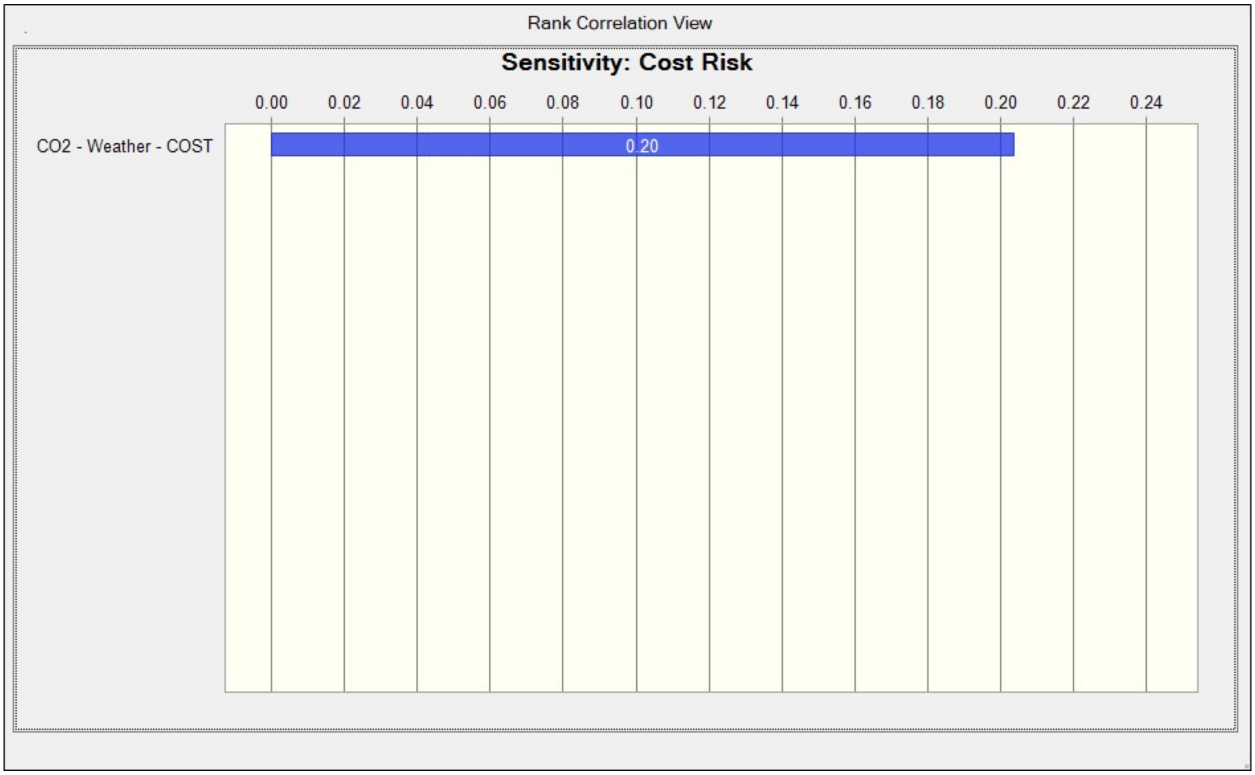
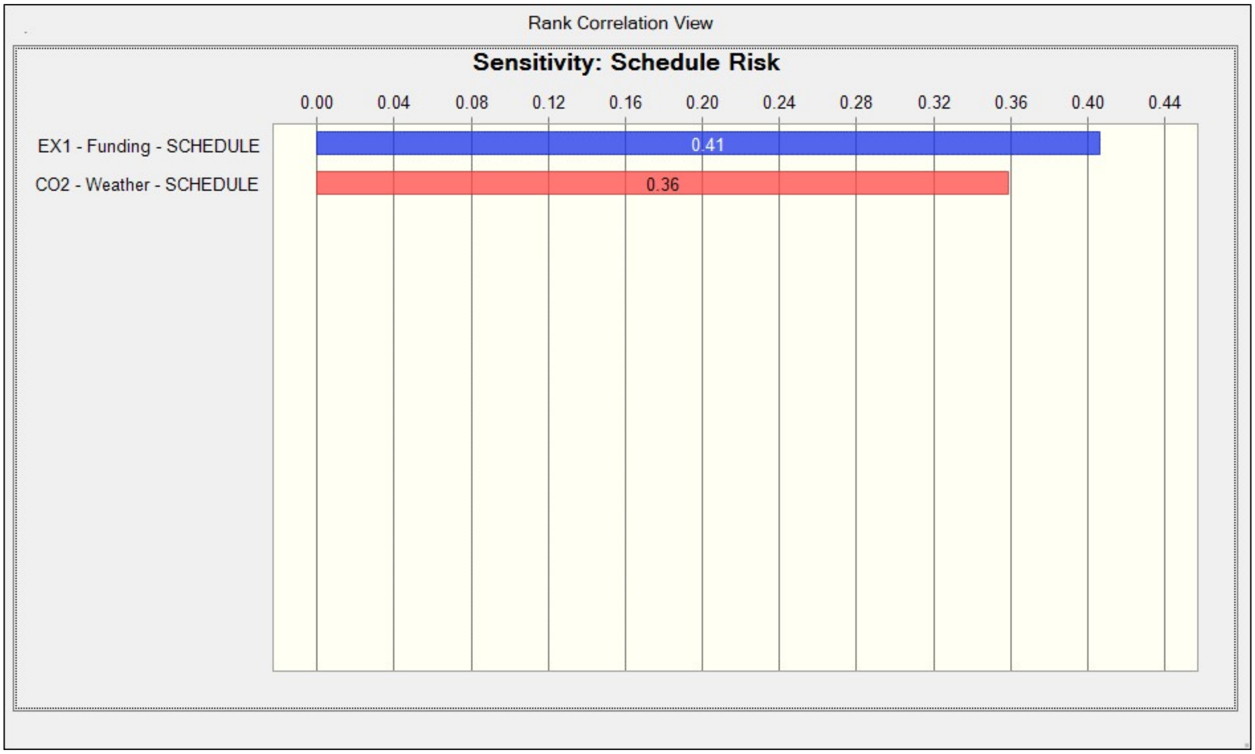


Figure 3 Schedule Sensitivity Analysis



6.3 Schedule and Contingency Risk Analysis

The result of risk or uncertainty analysis is quantification of the cumulative impact of all analyzed risks or uncertainties as compared to probability of occurrence. These results, as applied to the analysis herein, depict the overall project duration at intervals of confidence (probability).

Table 3 provides the schedule duration contingencies calculated for the P80 confidence level. The schedule duration contingencies for the P50 and P90 confidence levels are also provided for illustrative purposes.

Schedule duration contingency was quantified as 19 months based on the P80 level of confidence. These contingencies were used to calculate the projected residual fixed cost impact of project delays that are included in the Table 1 presentation of total cost contingency. The schedule contingencies were calculated by applying the high level schedule risks identified in the risk register for each option to the durations of critical path and near critical path tasks.

The schedule was not resource loaded and contained open-ended tasks and non-zero lags (gaps in the logic between tasks) that limit the overall utility of the schedule risk analysis. These issues should be considered as limitations in the utility of the schedule contingency data presented. Schedule contingency impacts presented in this analysis are based solely on projected residual fixed costs. Figure 4 graphically shows the schedule confidence level contingencies.

Table 5 Construction Schedule Comparison Summary (Uncertainty Analysis)

Base Case Schedule	72.1 Months	
Confidence Level	Contingency Value	Contingency
0%	1 Months	1%
10%	5 Months	7%
20%	7 Months	10%
30%	9 Months	12%
40%	11 Months	15%
50%	12 Months	17%
60%	14 Months	19%
70%	16 Months	22%
80%	19 Months	26%
90%	23 Months	32%
100%	47 Months	65%

Figure 4 Schedule Contingency Graph

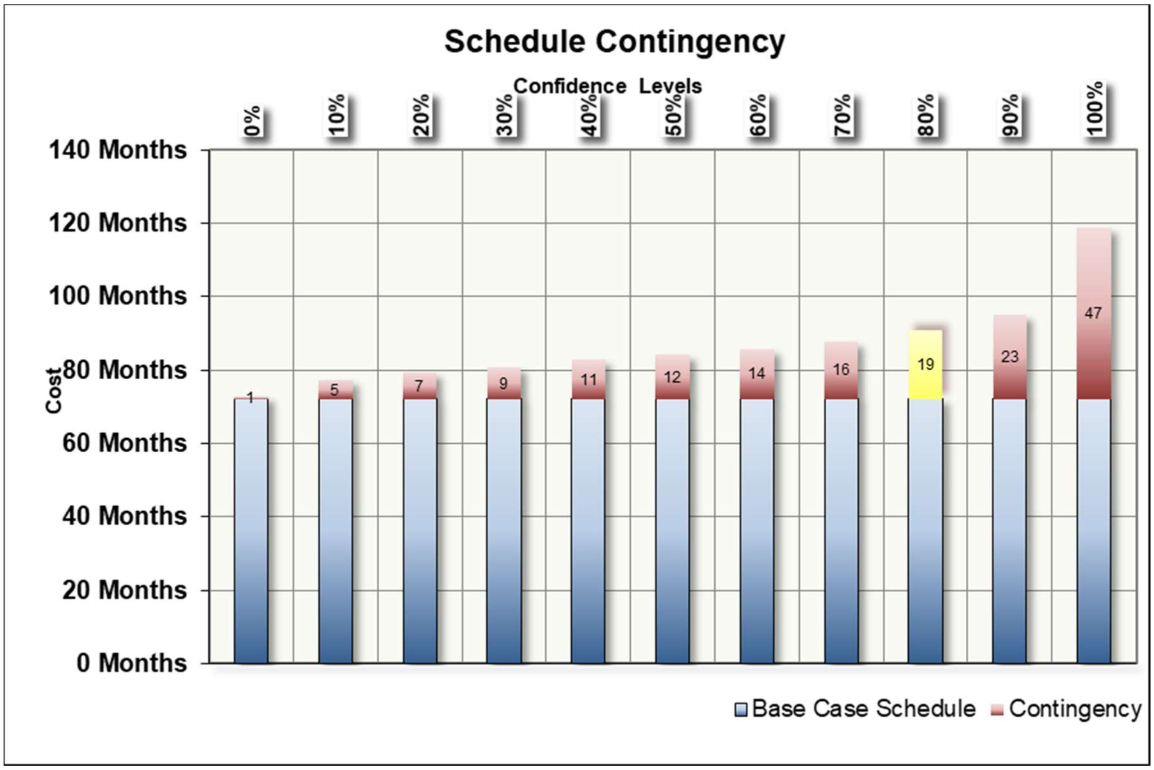


Table 4 is the Schedule Duration Contingency Summary, showing the Project Base Schedule Duration used, which is from the Project Book, the Schedule Duration Contingency and Percentage, and the Project Schedule Duration at the 80% Confidence Level.

Table 6 Schedule Duration Contingency Summary

Contingency on Schedule	80% Confidence Project Schedule	
Project Base Schedule Duration ->	72.1	26%
Schedule Contingency Duration ->	19 Months	
Project Schedule Duration (80% Confidence) ->	91.1 Months	

7.0 MAJOR FINDINGS/OBSERVATIONS/RECOMMENDATIONS

This section provides a summary of significant risk analysis results that are identified in the preceding sections of the report. Risk analysis results are intended to provide project leadership with contingency information for scheduling, budgeting, and project control purposes, as well as to provide tools to support decision making and risk management as projects progress through planning and implementation. Because of the potential for use of risk analysis results for such diverse purposes, this section also reiterates and highlights important steps, logic, key assumptions, limitations, and decisions to help ensure that the risk analysis results are appropriately interpreted.

7.1 Major Findings/Observations

Project cost and schedule comparison summaries are provided in Table 2 and Table 4 respectively. Additional major findings and observations of the risk analysis are listed below.

Cost Risks: From the CSRA, the key or greater Cost Risk items of include:

- CO2 – Weather – This Risk is driven mostly by the frequency that weather events have been occurring and the effects they are having on the restoration area.

Schedule Risks: The high value of schedule risk indicates a significant uncertainty of key risk items, time duration growth that can translate into added costs. Over time, risks increase on those out-year contracts where there is greater potential for change in new scope requirements, uncertain market conditions, and unexpected high inflation. The greatest risk is:

- EX1 - Funding – Given current administration prioritieis, environmental projects funding may be less certain.

7.2 Recommendations

Risk Management is an all-encompassing, iterative, and life-cycle process of project management. The Project Management Institute's (PMI) *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, *4th edition*, states that "project risk management includes the processes concerned with conducting risk management planning, identification, analysis, responses, and monitoring and control on a project." Risk identification and analysis are processes within the knowledge area of risk management. Its outputs pertinent to this effort include the risk register, risk quantification (risk analysis model), contingency report, and the sensitivity analysis.

The intended use of these outputs is implementation by the project leadership with respect to risk responses (such as mitigation) and risk monitoring and control. In short, the effectiveness of the project risk management effort requires that the proactive management of risks not conclude with the study completed in this report.

The Cost and Schedule Risk Analysis (CSRA) produced by the PDT identifies issues that require the development of subsequent risk response and mitigation plans. This section provides a list of recommendations for continued management of the risks identified and analyzed in this study. Note that this list is not all inclusive and should not substitute a formal risk management and response plan.

The CSRA study serves as a “road map” towards project improvements and reduced risks over time. Timely coordination and risk resolution between the Sponsor, Railroad, and USACE is needed in areas of ROW, mobile home relocations, site access and staging, and funding needs and updates as applicable. The PDT must include the recommended cost and schedule contingencies and incorporate risk monitoring and mitigation on those identified risks. Further iterative study and update of the risk analysis throughout the project life-cycle is important in support of remaining within an approved budget and appropriation.

Risk Management: Project leadership should use of the outputs created during the risk analysis effort as tools in future risk management processes. The risk register should be updated at each major project milestone. The results of the sensitivity analysis may also be used for response planning strategy and development. These tools should be used in conjunction with regular risk review meetings.

Risk Analysis Updates: Project leadership should review risk items identified in the original risk register and add others, as required, throughout the project life-cycle. Risks should be reviewed for status and reevaluation (using qualitative measure, at a minimum) and placed on risk management watch lists if any risk’s likelihood or impact significantly increases. Project leadership should also be mindful of the potential for secondary (new risks created specifically by the response to an original risk) and residual risks (risks that remain and have unintended impact following response).

Appendix A Risk Register

				Project Cost			Project Schedule		
CREF	Risk/Opportunity Event	Risk Event Description	PDT Discussions on Impact and Likelihood	Likelihood ©	Impact ©	Risk Level ©	Likelihood (S)	Impact (S)	Risk Level (S)
Organizational and Project Management Risks (PM)									
PM1	Environmental Restoration Scope	Marsh Creation	Cost share with Fish and Wildlife are included may result in opportunity to reduce scope. USFW likely to prioritize beach nourishment over marsh development resulting in a significant cost savings and scope reduction as they may decide to not perform marsh development. OPPORTUNITY As an environmental restoration project there is flexibility in the scope and scope can be adjusted to fit available budget.	Possible	Significant	Medium	Very Likely	Negligible	Low
PM2	Project Staffing	Galveston district increasing capacity of workforce	District is currently growing workforce to meet upcoming demand. Project staffing is unlikely to have any impact to the project.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
Contract Acquisition Risks (CA)									
CA1	Multiple Contract Invitation for Bid	Contract award based on dredge cycle	Multiple contract awards based on material available at each dredge cycle. Schedule duration could be impacted by the variation material volume per dredged cycle.	Unlikely	Negligible	Low	Likely	Marginal	Medium
CA2	8A Small Business	8A Small Business	SBA or 8A likely for the GIWW Armoring. Due to size of piping is unlikely on dredging. Impact will be marginal.	Likely	Marginal	Medium	Very Likely	Negligible	Low
Technical Design Risks (TR)									
TR1	Planting	Placing seeding/plantings in high erosion areas	Planting and subsequent replanting is included in the adaptive management plan.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
Lands and Damages (LD)									
LD1	Acquisition	State Land, private land, USFW land	The majority of the land is state-owned or private. The USFWS only owns a small portion (~8%) and is the only federal land owner. The private land is unlikely to impact schedule or cost. This land is scheduled to be utilized late in the project and any impact from private land can be mitigated prior to construction.	Unlikely	Negligible	Low	Likely	Negligible	Low
LD2	Site Footprints	Site footprint flexibility	If contentious land is encountered the footprints for each nourishment area can be adjusted. Unlikely to impact schedule or cost.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
Regulatory Environmental Risks (RG)									
RG1	Biological Monitoring	All construction activities include full time biological monitoring	Recognize that potential exists for whooping crane to impact schedule. Impacts would be in terms of minutes to a couple of hours while birds are within a 1,000 foot radius of work site. No seasonal restrictions.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
RG2	Cultural Resource Monitoring	Cultural resource Monitoring has been pushed to PED.	Cultural Resources could require additional time during ped but impacts would be minimal. If cultural sites are identified they would become exclusion zones and materials would be placed elsewhere.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
Construction Risks (CO)									
CO1	Equipment	Specialty equipment	Specialty equipment (marsh buggy's) are identified and costed in the cost estimate. Baseline estimate includes a 30" dredge. A smaller dredge is not likely to be able to complete this work on the western reaches and not likely to be used. The impact to cost of using a smaller dredge for the eastern marshes is marginal. A 24" Dredge was priced out and could impact the cost $24M dollars although it is unlikely this smaller dredge would be technically feasible given the distant the material needs to be transported.	Possible	Significant	Medium	Possible	Marginal	Low
CO2	Weather	Weather impacts	Construction impacts due to a weather event are unlikely to occur impact to schedule could be moderate. <5% chance to occur.	Possible	Moderate	Medium	Possible	Moderate	Medium
CO3	Simple Construction	Simple Heavy equipment common to the gulf region	Minimal other construction risks.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
Estimate and Schedule Risks (ES)									
ES1	Level of Estimate	CDEP	Estimate utilizes CDEP	Unlikely	Negligible	Low	Unlikely	Negligible	Low
ES2	Quantity Calculations			Unlikely	Negligible	Low	Unlikely	Negligible	Low
ES3	Major Assumptions	Mob/demob	Mob & demob is broken out per cdep.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
ES4				Unlikely	Negligible	Low	Unlikely	Negligible	Low
ES5				Unlikely	Negligible	Low	Unlikely	Negligible	Low

				Project Cost			Project Schedule		
CREF	Risk/Opportunity Event	Risk Event Description	PDT Discussions on Impact and Likelihood	Likelihood ©	Impact ©	Risk Level ©	Likelihood (S)	Impact (S)	Risk Level (S)
External Risks (EX)									
EX1	Funding	Sponsor Funding is available Federal Funding	Given current administrations priorities, environmental projects funding may be less certain. Schedule risk is unlikely and impacts moderate. Dredging is a reoccurring O&M function. Multiple other projects in the region could take construction priority over marsh nourishment	Likely	Marginal	Medium	Possible	Moderate	Medium
EX2	Sponsor Support	Navigation sponsor	Navigation sponsor is very supportive for utilizing the dredge spoils for environmental restoration.	Unlikely	Negligible	Low	Unlikely	Negligible	Low
EX3	Competing Projects / Limited Bidder Competition	Large Coastal Texas Project	Relatively simple construction should expand the pool capable contractors. Limited Bidder competition could result in higher construction costs. If Coastal Texas Project has ER aspects could compete for Bidders and funding. Based on recent historical experience PDT is confident that capable bidders will be sufficient that bidder competition is not a high concern.	Possible	Moderate	Medium	Unlikely	Negligible	Low