Appendix F
Engineering Appendix

Matagorda Ship Channel, Port Lavaca, Texas

Feasibility Report and Environmental Impact Statement,
Review of Completed Projects,
Calhoun and Matagorda Counties

July 2019

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1.0 GENERAL INFORMATION

1.1 PURPOSE

This Engineering Appendix documents the engineering analysis and evaluations for the Matagorda Ship Channel Improvement Project (MSCIP) Feasibility Study for the development of the Tentatively Selected Plan (TSP) to improve the channel to accommodate larger vessels. It also provides the baseline cost estimate for construction. This study will reduce transportation costs and increase operational efficiencies of maritime commerce movement through the Port. The majority of deep-draft ships using the MSC have drafts in excess of the operating depth of the channel. If channel dimensions are expanded, cargo vessels could reduce or eliminate light loading measures and begin utilizing the Port and adjacent facilities more often. The engineering studies included previous study information provided in 2009 and 2014 by United Research Services (URS Corporation) to develop the design for project features. This reference information included the Ship Simulation/Navigation Study, HarborSym Modeling, Hydrodynamic Modeling investigations by the Corps of Engineers' Engineer Research & Development Center (ERDC); preliminary geotechnical investigations including sampling/analysis and preparation of a preliminary DMMP by Geotechnical Section and conditional channel surveys. Additionally an updated Ship Simulation/Navigation Study was done by ERDC. Preliminary alternative designs and screening level cost estimates were developed in sufficient detail to substantiate the recommended plan and baseline cost estimate.

1.2 SCOPE

This project was authorized by Congress under the Rivers and Harbors Act of 1958 and the Flood Control Act of 1970. The Engineering Appendix was conducted after a Cost Sharing Agreement for the feasibility study was signed in August 2016. The Engineering Appendix follows the requirements of the ER 1110-2-1150, Appendix C. Input from the non-Federal Sponsor, the Calhoun Port Authority (CPA) was also taken into consideration. This feasibility study was executed under the SMART (Specific, Measurable, Attainable, Risk Informed, Timely) Planning Process. The analysis and data, including the formulation of alternatives, the selection process of the recommended alternative, and the costs and benefits of the TSP were documented in the Engineering Appendix. The technical sections discuss the development of the preliminary designs for the Civil Works Navigation features comprising the plans evaluated in the final array of alternatives. They detail the engineering information that was collected, design references and guidance used, computer programs used, the design criteria assumed, design parameters, assumptions made, and methods of analyses. Narratives of the engineering analyses was broken out by discipline covering hydrology and hydraulics, surveying and mapping, geotechnical engineering, structural engineering, and civil design.

1.3 PROJECT LOCATION

The Matagorda Ship Channel (MSC) study area is shown in Figure 1-1. The existing MSC is located 125 miles southwest of Galveston, Texas and 80 miles northeast of Corpus Christi, Texas. The northern portion of the main channel is located in Calhoun County and the southern portion including the jetty and entrance channel is located in Matagorda County. The MSC extends approximately 26 miles from the entrance channel to the Point Comfort north and south turning basins. The numbers above the boxes designate the existing Placement Areas (PAs) along this route. The Point Comfort north and south turning basins are located at the end of the channel adjacent to PA No. 19.

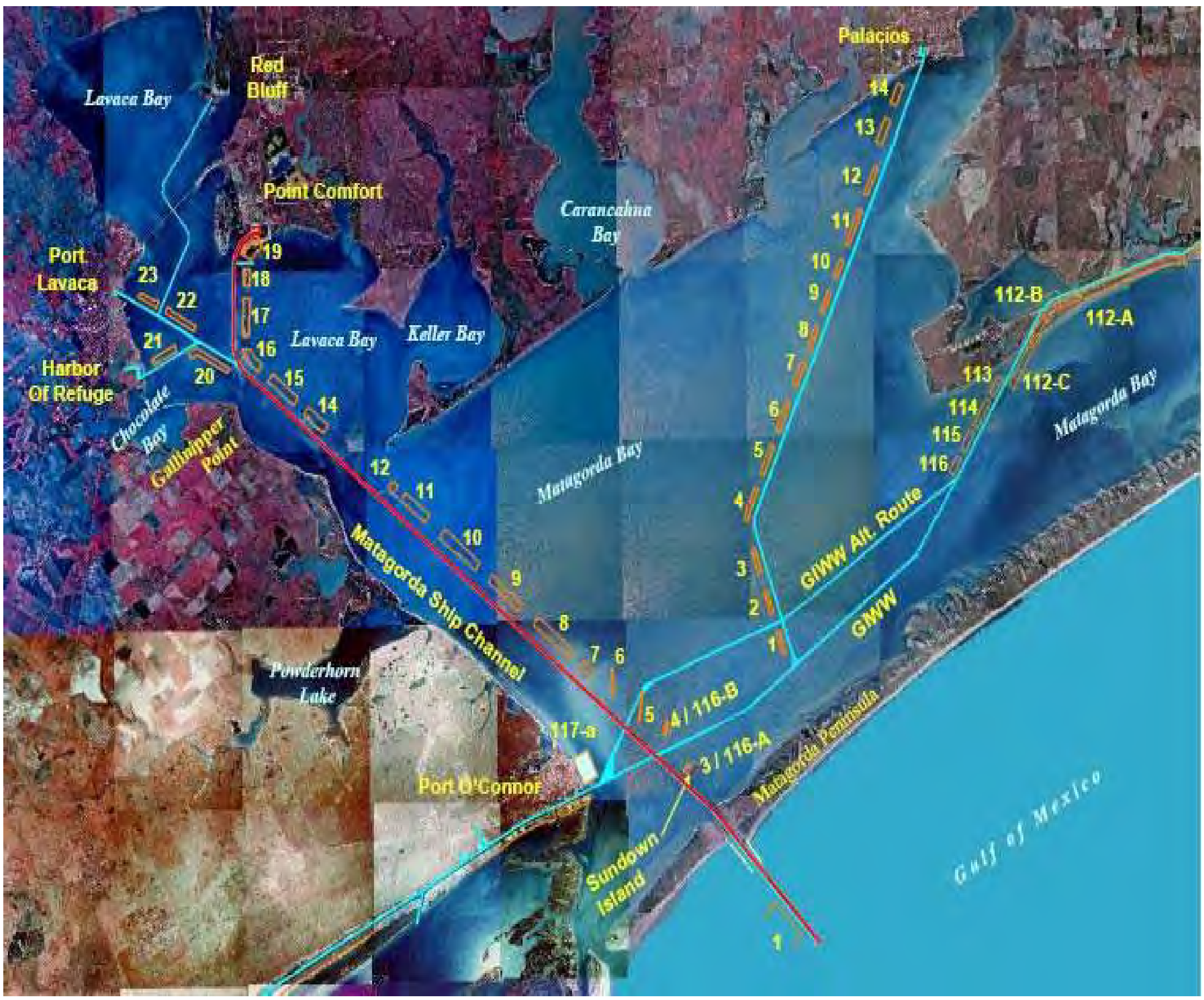


Figure 1-1 – Study Area

1.4 EXISTING CHANNEL DESCRIPTION

The existing MSC consists of the entrance/offshore channel, jetty channel, Matagorda Bay reach, Lavaca Bay reach, Point Comfort turning basin and the Port Comfort north and south basins. The main channel will be referred to as the Matagorda Bay reach, Lavaca Bay reach, Point Comfort turning basin and Point Comfort north and south basins. All depths will be presented in MLLW datum from this point forward unless specifically stated otherwise. The Matagorda Bay reach has an authorized depth of 38 feet, 2 feet of advanced maintenance and 2 feet of overdepth for a width of 200 feet at a distance of 14.20 miles. The Lavaca Bay reach has an authorized depth of 38 feet, 2 feet of advanced maintenance and 2 feet of overdepth for a width of 200 feet at a distance of 7.81 miles. The Point Comfort turning basin has an authorized depth of 38 feet, 2 feet of advanced maintenance and 2 feet of overdepth for a width of 1000 feet at a distance of 1000 feet. The Point Comfort north and south turning basins have authorized depths of 38 feet, 2 feet of advance maintenance and 2 feet of overdepth. The Point Comfort north basin has a varying width from 344.77 feet to 159.43 feet for a distance of 1,279 feet. The Point Comfort south basin has a varying width from 283.78 feet to 185.41 feet for a distance of 1,279 feet. The entrance/offshore channel has an authorized depth of 40 feet, 3 feet of advance maintenance and 2 feet of overdepth for a width of 300 feet at a distance of 2.65 miles. The jetty channel has an authorized depth of 40 feet, 3 feet of advance maintenance and 2 feet of overdepth for a width of 300 feet at a distance of 1.14 miles.

1.5 SUMMARY OF TENTATIVELY SELECTED PLAN

The MSC is shown on the location plan on Drawing No. G-2 and also on Drawing Nos. C-01 thru C-11. The TSP includes the addition of a new 1,200-foot turning basin in the Lavaca Bay reach to accommodate the larger vessels needing to navigate the Port. This plan also includes extending the entrance channel 13,000 feet to account for the increased proposed depth of 49 feet and a 1,600-ft long sediment trap. This improvement will allow larger and deeper draft ships to navigate the channel. The MSC TSP improved reaches are described below.

<u>Entrance/Jetty Channel, Sta -33+000 to Sta 0+000</u>

- 49-ft depth; 3-ft advanced maintenance; 2-ft overdepth; 10H:1V side slope; and 550-ft width

<u>Matagorda Bay Reach (Peninsula), Sta 0+000 to Sta 4+319.91</u>

- 47-ft depth; 2-ft advanced maintenance; 2-ft overdepth; 5H:1V side slope; and 550-ft width

<u>Matagorda Bay Reach, Sta 4+319.91 to Sta 12+600</u>

- 47-ft depth; 2-ft advanced maintenance; 2-ft overdepth; 3H:1V side slope; and 550-ft width

Matagorda Bay Reach, Sta 12+600 to Sta 75+000

- 47-ft depth; 2-ft advanced maintenance; 2-ft overdepth; 3H:1V side slope; and 300-ft width

Lavaca Bay Reach, Sta 75+000 to Sta 116+223

- 47-ft depth; 2-ft advanced maintenance; 2-ft overdepth; 3H:1V side slope; and 300-ft width

Proposed 1,200-ft Turning Basin, Sta 111+450.24 to Sta 116+223

- 47-ft depth; 2-ft advanced maintenance; 2 ft overdepth; 3H:1V side slope; and a width ranging between 300-feet and 1,200-feet

Point Comfort Turning Basin, Sta 116+223 to Sta 117+223

- 47-ft depth; 2-ft advanced maintenance; 2 ft overdepth; 3H:1V side slope; and a 1,000-ft width

Point Comfort North and South Basins, Sta 117+223 to 118+502

- 47-ft depth; 2-ft advanced maintenance; 2 ft overdepth; no side slope; varying widths

2.0 HYDROLOGY AND HYDRAULICS

Matagorda Navigation Channel was analyzed for the following conditions: Present (PWOP, Year = 2024), Present With Project (PWP), Future (FWOP, Years 2074 and 2124), and Future Project (FWP).

Present Conditions include:

- waves (significant wave height at channel entrance of 4 to 10 ft),
- currents of great concern that routinely during every tidal cycle exceed 4 knots and also include strong cross-currents upon entering the Bay, (Analysis from 5 different data sources has been completed and detailed in section "Summary of Matagorda Bay Data Sources".) Comparison of current measurements along the same transects in 2005 and 2018 show an 18% increase in currents during that 13-year time period. In the category of dangerous tidal currents, this entrance channel is classified as the most dangerous in the country, by the experts in a workshop held by the Coast Guard.
- tidal range that is small and has little **direct** effect on water levels, but is the main cause of the strong currents,
- bathymetry that is unusually deep in most of the entrance channel, but includes an offshore bar at the entrance, just offshore of the jetties, which restricts ships' ability to enter,
- scour (>140ft in places) between the jetties that appears not to be jeopardizing the jetties, as long as the significant land buffer remains

Future Conditions:

- continuing shrinkage of Pass Cavallo will cause current speeds in Matagorda Entrance Channel to continue to increase, as long as Pass Cavallo shrinks (since the tidal discharge must remain constant: $Q = V A$),
- sea-level rise is expected to be about 2ft using the Intermediate Curve,
- waves and tides will remain essentially unchanged,
- scour in the entrance channel will continue to worsen as long as Pass Cavallo is small, resulting in most of the flow passing through Matagorda Entrance Channel

Future Project:

- The deepened and widened channel will have little effect on tides and waves.
- Whether the deepening/widening will affect the bathymetry depends on how much dredging will be required. At first, only post-Harvey surveys were available. They showed little necessary dredging in the entrance channel and in the transition segment. Pre-Harvey surveys were subsequently obtained and analyzed. They still show little necessary dredging in the entrance channel. However, Harvey apparently induced widespread deposition in the Bay, once the river sediments reached the large open Bay. Post-Harvey showed 30mcy of dredging would be needed for the new work project. Pre-Harvey shows only 21mcy of needed dredging. This was used to update the economic analysis and is part of the reason that the B/C ratio increased from 1.3 to 2.1. (However, the factor that had the largest effect on the B/C change was reduction of in-Bay channel width from 350ft to 300ft, as justified in the ship simulations).

Present With Project is expected to be essentially the same as Future With Project, but with a lower water level (before sea-level rise).

Conclusions:

- Planned **widening** is adequate, except for the transition segment (between offshore channel width of 600ft and Bay channel width of 350ft) between Matagorda Peninsula and Bird Island. Recommendation is to shift the entire transition segment to the west of Bird Island. (This change was made in the final plan.)
- Recommendations for dealing with the **strong currents** include improving Aids to Navigation by broadcasting real-time current-meter readings to the ships/pilots. (This was implemented during August to December 2018.) Another possible option that would significantly reduce strong currents and also reduce maintenance dredging in the Bay would be relocation of Bird Island. The presence of Bird Island reduces the cross-sectional area of flow, thus increasing velocities. Significant amounts of sediment are being eroded from the island and make their way back into the channel. Relocation of the island is not part of this project.
- Project **authorized depth** will be insufficient to accommodate the deepest draft of the largest ships. If the pilots intend to operate under all wave conditions, then **allowable draft** will be authorized channel depth minus 10 ft. This 10 ft. offset value can be reduced by the difference between the 4 ft significant wave height and the pilots' highest operational wave height. Recommended Authorized Draft = Channel's New Authorized Depth - Safety Clearance - Squat - Wave Motion = 47ft - 1ft - 2ft - 2ft (in Bay) = 42ft. In the entrance channel, the design depth is 2ft greater, and the waves are 2ft greater, so those two changes cancel each other out, and the authorized draft in the entrance remains 42ft.
- Turning basin diameter should be 1200ft for the design ship category. (This number is a crude design recommendation. Since that computation, the turning basin and the approach to the basin were redesigned during ship simulations.)
- Estimation of environmental impacts has been made from the numerical model of currents and salinity.

2.1 EXISTING CONDITIONS

2.1.1 General Description

Existing channel statistics are shown below in Table 2.1. Stationing and past placement areas are shown in Figure 2.1.

Table 2.1 - Existing MSC Channel Sections and Dimensions

Channel Section	Authorized Depth[1] (ft)	Width (ft)	Length
Outer Bar and Jetty Channel	40	300	3.2 mi
Channel to Point Comfort	38	200 – 300	20.9 mi
Approach Channel to Turning Basin	38	200 – 300	1.1 mi
Point Comfort Channel to Turning Basin	38	1,000	1,000 ft
Point Comfort Turning Basin Extension (North & South)	38	300	1,279 ft
Channel to Port Lavaca[2]	13	125	4.1 mi
Lynn Bayou Turning Basin[2]	13	300	532 ft
Channel to Harbor of Refuge[2]	13	125	1.9 mi
North – South Basin[2]	13	300	1,682 ft
East – West Basin[2]	13	250	1,750 ft
Channel to Red Bluff[2]	7	100	20.2 mi

[1]Authorized depth referenced as MLLW

[2]These channels are not currently maintained to the authorized depth based on budgeting priorities and do not support deep-draft navigation access to the port

Existing hydraulic conditions at this site present several unique challenges:

- Dangerous currents between the jetties (>4 knots at the peak of every tidal cycle)
- Strong cross-channel currents between Matagorda Peninsula and Bird Island
- Currents between the jetties continue to scour the bed, in places more than 140ft deep.
- Waves routinely exceeding 10ft high in the winter at the entrance
- An offshore bar, which is unsurveyed, limiting the draft of ships entering the channel

- No wave measurements between the jetties or offshore (only Sep-Dec 2005 in the Bay) Subsequent to the draft report, a wave gage was deployed between the jetties, but has not yet been recovered.
- Current-meter datasets that disagree with each other

2.2 WAVES

Wave measurements at the entrance channel do not appear in public or Corps of Engineers databases. The two closest Wave Information Studies (WIS) hindcast stations (points at which wind data are used to estimate the resulting waves) are: #73050 in 25 m depth at Lat 28.25 Long -96.25, 13 miles to the south, and #73051 in 19 m depth at Lat 28.35 and Long -96.15, 12 miles to the southeast. The latest year processed into the database is 2014.

#73051 southeast of the jetties shows the largest waves coming from the SSW (bearing 202.5 ± 11.25 degrees) with Hmo = 1.2 m, largest Hmo = 2.1 m, and Tp = 4.6 s.

#73050 south of the jetties shows the largest waves coming from two angular bands, directly from the south with Hmo = 1.3 m, largest Hmo = 2.3 m, and Tp = 4.5 s and also from the SSW with Hmo = 1.3 m, largest Hmo = 2.5 m, and Tp = 4.8 s. An earlier study (Kraus et al., 2006 using pre-1989 data) also used this station and reported an Hmo = 1.1 m and Tp = 6.1, but more curiously showed the dominant wave direction coming from the southeast.

The Coast of Texas project is using the ADCIRC numerical model to produce shoaled waves along the entire Texas coast. Wind data from the entire Gulf of Mexico were shoaled into shallow water. The results for the Matagorda Entrance Channel are: Hmo ~ Hs = 1.5m = 4.9ft at the channel entrance.

Averaging the three WIS Hmo values above produces Hmo = 1.2m = 3.94ft with Tp = 5s.

Shoaling these waves from the deepwater WIS sites to the end of the jetties shows that the wave heights do not change, since they are still in deepwater. The depth at the end of the jetties is ~ 60ft. According to (SPM 1984, Eq. 2-8a): $Lo = 1.56\ T^2 = 1.56\ (4.8)^2 = 36$ m, producing d/L = 60ft (0.3048m/ft) / 36 m = 0.51. According to the table on SPM's page 2-9, whenever $d/L > 0.5$, then the wave is still in deepwater.

CONCLUSION from Hindcast Model: Wave height Hmo = 1.2m = 3.94ft and Tp = 5s, both offshore and at the jetties' end.

CONCLUSION from Pilots (Captain David Adrian, 12/28/2017 email): "I would say our significant wave height is much larger than 4'. The ebb (outbound) currents are also a contributing factor in sea height. While it may only be 6' wave height out in the gulf, a strong ebb will increase the height of those waves to 8 or 9' in the jetties and the entrance channel, sometimes even out 2 miles past the entrance buoy. I would say, in the winter, our predominant wave height is 5' while the significant wave height can be 10'."

2.2.1 Waves at Placement Areas in the Bay

(adapted from URS, 2014b, Section 4.5.13 "Shoreline Erosion Protection")

The waves in the Bay will be used for two purposes: estimating bayshore erosion and designing levee protection at placement areas. The URS (2014b, Section 4.5.13) study used the standard

ACES program for taking winds and computing resulting wind-waves at five sites that were proposed in 2006 as placement areas, shown in the Figure below. Results are shown in the following two tables from the URS report (their Tables 4.15 and 4.16). Wave heights are generally 3-4 feet with 3-5 second periods.

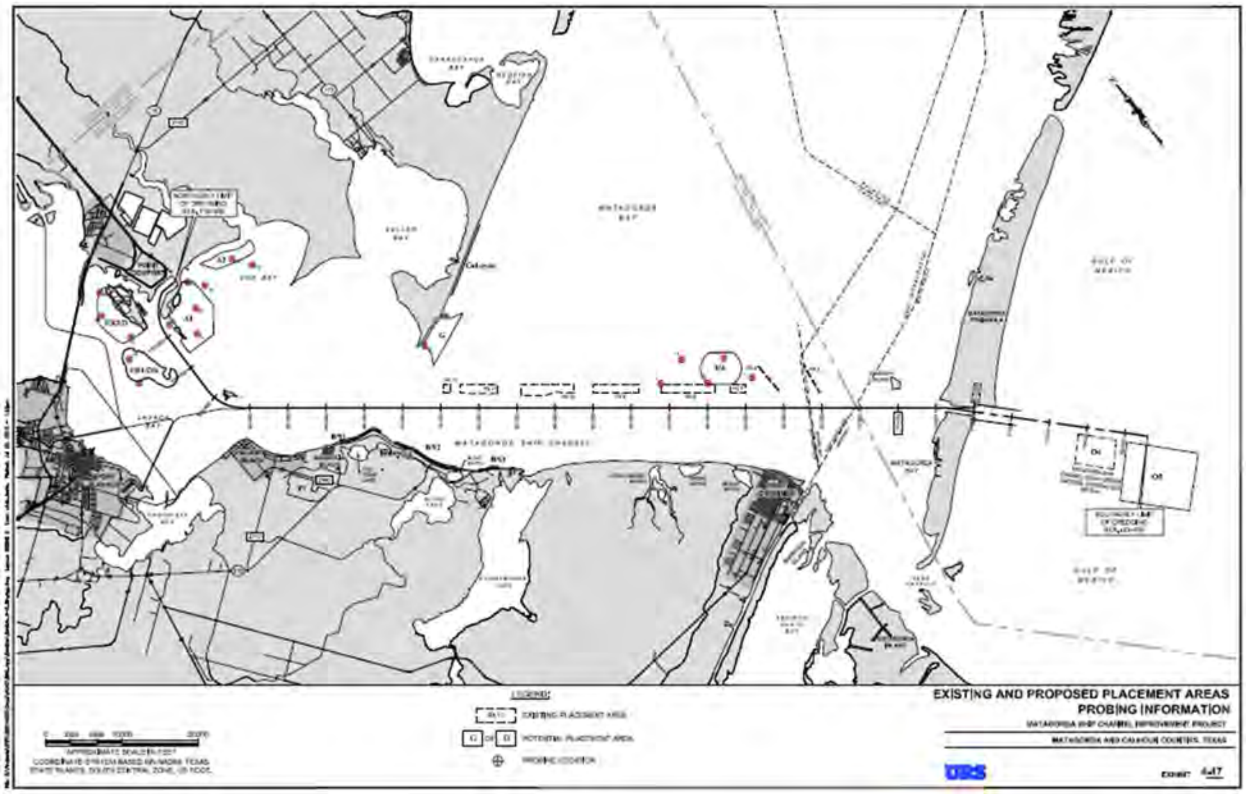


Figure 2.1 - Placement areas considered in the Port's consultant's 2014 reports

Table 2.2

Table 4.15 – Placement Areas with Stabilization Measures	
Site	**Description of Placement Area**
A1	In-Bay Upland
A2	Marsh
ER3/D	In-Bay Upland
G	Marsh and Nearshore Breakwater Levee
H4	Marsh, Seagrass Platform, Bird Island

Table 2.3

Table 4.16 – Maximum Fetch and Estimated Wave Height and Period				
Site	**Shoreline Segment**	**Maximum Fetch Distance (miles)**	**H_{mo} (ft)**	**T_p (s)**
A1	**E**	8	3.4	3.8
	S	8	3.4	3.8
	W	3.5	2.9	3
A2	**E**	1.5	2.3	2.5
	S	4.5	3.1	3.3
	W	0.5	1.4	1.7
ER3/D	**W**	3.2	2.8	3
	S	3.5	2.9	3.1
G	**W**	2.5	2.6	2.8
	S deep	18.9	3.9	4.6
	S shallow	18.9	3.9	4.6
H4	**NW**	14.5	3.8	4.4
	NE	25.8	3.9	4.8
	SE	10.8	3.2	3.5
	SW	14.5	3.8	4.4

2.2.2 Waves at Shorelines in the Bay

(adapted from URS, 2014b, Section 4.5.13 “Shoreline Erosion Protection”)

For use in designing shore protection and levees for placement areas, the standard in Galveston District is to use a 10-year return period wind speed. URS (2014b) computed these waves for the four sites shown in the Figure below.

Waves were computed with the same ACES software used in the Corps, with 10-year return period inputs of water level 2.0ft above MLLW and windspeed of 45 knots. Results are shown below in Moffatt & Nichol's (2006a) Table 2.4 (% Occurrence) and Table 2.5 (Mean Statistics), with results of 3ft waves.

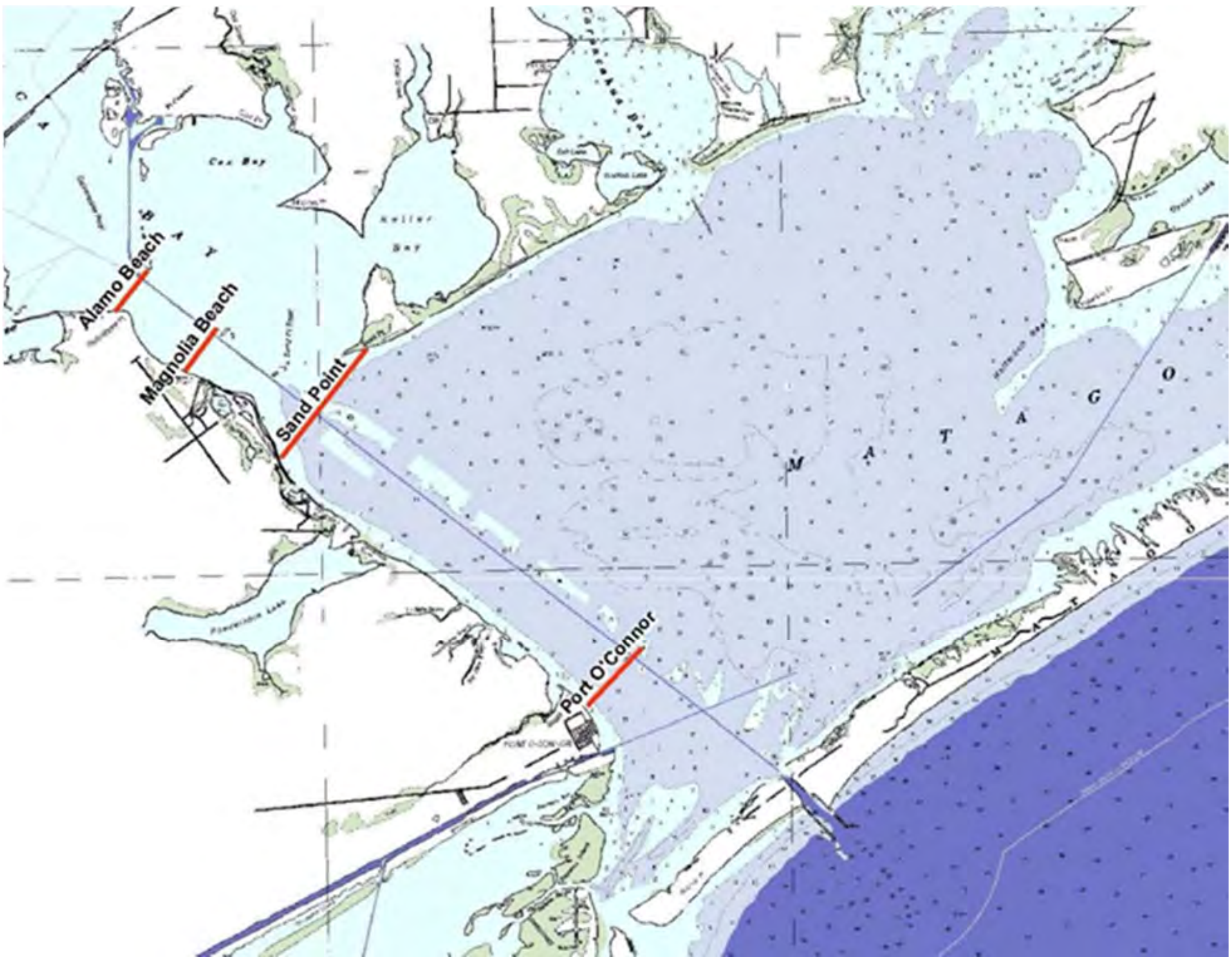


Figure 2.2 - Four in-Bay shore sites where wind waves were estimated

The results for **normal** everyday conditions (20 knot winds) are:

Table 2.4

	Percent Occurrence			
	Port O'Connor	Sand Point	Magnolia Beach	Alamo Beach
Calm, not recorded	42.7	32.8	56.6	63.6
< 0.98	14.8	18.0	9.4	14.5
0.98 – 1.31	16.2	12.5	11.5	0.4
1.31 – 1.64	1.2	5.1	0.0	17.6
1.64 – 1.97	10.6	18.2	7.9	0.1
1.97 – 2.3	10.5	12.2	12.0	2.3
2.3 – 2.62	2.0	0.6	1.6	1.5
2.62 – 2.95	1.9	0.6	0.9	0.0
2.95 – 3.28	0.01	0.0	0.04	0.0
>3.28	0.04	0.0	0.01	0.0

with the resulting mean wave heights and periods:

Table 2.5

Date	Time	Hs (ft)	Tp (s)	Wind Speed, V (knots)	Wind Direction (degrees)
10/24/2005	12 – 6 am	2.9	3.8	29	30
11/17/2005	5 – 10 am	2.9	3.6	28	360

2.2.3 Waves at the Jetties' End (Unlimited Fetch)

In this study waves were computed with the same ACES software for the case in open seas offshore of the jetties. At the bar offshore of the jetties, inputs were the 48ft channel depth at the bar, unlimited fetch, and 3-hour wind duration (the accepted standard for "fully developed winds"). Three cases of windspeeds were run: (1) Table 2.6-20 knots (normal conditions), Table 2.7-45 knots (the same storm conditions that URS ran), and (3) Table 2.8-84.7 mph = 73.6 knots (100-year return period).

Table 2.6 - Wind Waves Offshore from ACES for Normal Conditions

Case: MatagordaNormalWinds20knots

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

Item	Value	Units
El of Observed Wind (Zobs)	25.00	feet
Observed Wind Speed (Uobs)	20.00	knots
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	28.30	deg
Results		
Wind Fetch Length (F)	26.00	MILES
Eq Neutral Wind Speed (Ue)	20.50	knots
Adjusted Wind Speed (Ua)	24.75	knots
Wave Height (Hmo)	2.91	feet
Wave Period (Tp)	3.72	sec

Wind Obs Type	Wind Fetch Options
Overwater	Deep openwater

Wave Growth: Deep

The above result of 3ft wave heights is common along the Texas coast, but the following case of storm winds has been frequently reported by the Matagorda pilots as a "typical winter wave" condition. The computed 11.4ft wave height falls within their winter condition range of 10-12ft. This range also happens to be the pilots' working operational limit for bringing ships into the Bay, which is limited not by the ship's handling, but by the pilots' ability to safely climb the ladder onto the ship.

Table 2.7 - Wind Waves Offshore from ACES for Storm Conditions

Case: MatagordaStormWinds45knots

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

Item	Value	Units
El of Observed Wind (Zobs)	25.00	feet
Observed Wind Speed (Uobs)	45.00	knots
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	28.30	deg
Results		
Wind Fetch Length (F)	26.00	MILES
Eq Neutral Wind Speed (Ue)	46.50	knots
Adjusted Wind Speed (Ua)	71.33	knots
Wave Height (Hmo)	11.36	feet
Wave Period (Tp)	6.94	sec

Wind Obs Type	Wind Fetch Options
Overwater	Deep openwater

Wave Growth: Deep

Ships do not operate under the following hurricane conditions.

Table 2.8 - Wind Waves Offshore from ACES for Hurricane Condition

Case: MatagordaHurricaneWinds74knots

Windspeed Adjustment and Wave Growth

Breaking criteria 0.780

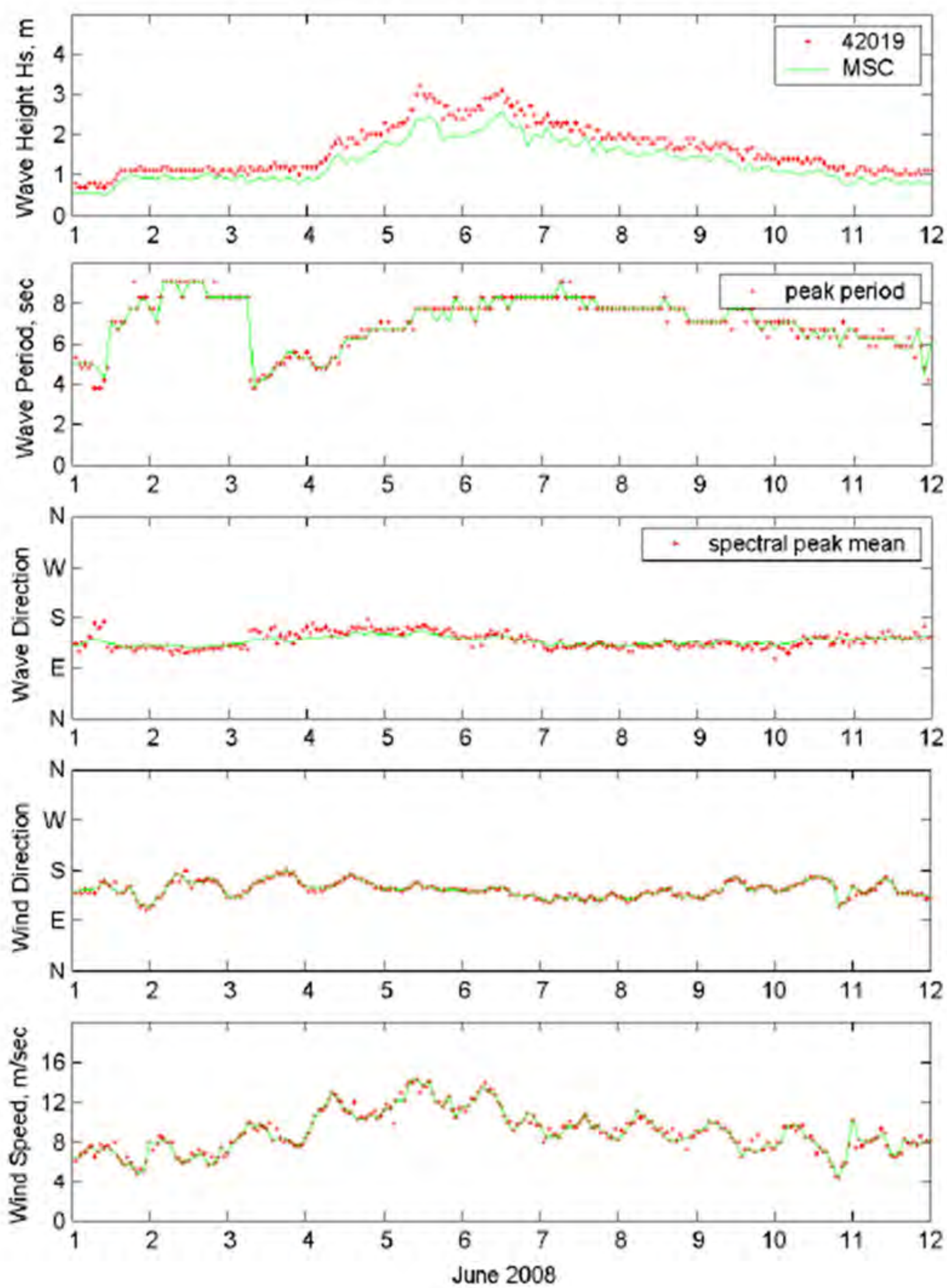
Item	Value	Units
El of Observed Wind (Zobs)	25.00	feet
Observed Wind Speed (Uobs)	73.60	knots
Air Sea Temp. Diff. (dT)	0.00	deg F
Dur of Observed Wind (DurO)	3.00	hours
Dur of Final Wind (DurF)	3.00	hours
Lat. of Observation (LAT)	28.30	deg
Results		
Wind Fetch Length (F)	26.00	MILES
Eq Neutral Wind Speed (Ue)	76.59	knots
Adjusted Wind Speed (Ua)	141.01	knots
Wave Height (Hmo)	24.87	feet
Wave Period (Tp)	9.03	sec

Wind Obs Type	Wind Fetch Options
Overwater	Deep openwater

Wave Growth: Deep

Waves were recorded at an NDBC buoy far offshore in the early 2000's. Two weeks (a typical winter week and a summer week) were modeled with the Coastal Modeling System (CMS). Only the summer condition was plotted in the report (Maynord et al., 2011). Figure 2.3 shows summer results for low windspeed waves of 0.8-0.9m (2.9ft) and higher windspeed waves (2.5m) from a weather front. The red curves are the measured waves at the buoy, and the green curves are shoaled to the jetties with the CMS model. The low windspeed result of 2.9ft waves agrees with the 20 knot wind case result of 2.9ft waves from 20 knot winds computed above with ACES software (Table 2.6).

Figure 2.3 - Wind and waves measured at NDBC Buoy #42019 (red) and shoaled to the jetties by the Coastal Modeling System (green) for 1-12 June 2008 (typical summer conditions with a southeasterly wind), with passage of a weather front June 4+



2.2.4 Ship-Generated Waves and Drawdown

Wise (2006) performed an analysis of ship-generated waves between the jetties for three scenarios (Existing Vessel in Existing Channel, Existing Vessel in Proposed Ship Channel, and Proposed LNG Vessel in Proposed Ship Channel). In Chapter 6 of his memorandum, Wise compared ship-generated waves and wind waves. He concluded that "The relative wave energy from wind waves is estimated to comprise 97% to 99% of the total wave energy. Only approximately 1 to 3% of the total wave energy is from the existing ship traffic."

CONCLUSION: Wave Heights at the Entrance Channel are much greater than ship-generated Drawdown. Thus wave heights (over the offshore bar) will be the limiting factor in depth design, and ship drawdown can be ignored.

2.3 CURRENTS

Analysis of currents from five data sources is underway. Unfortunately, the only overlap in the measurements will be the ongoing measurements at the Bird Island and soon-to-be installed Entrance Channel sites in the Google Earth photo below. Thus there is only one intercomparison possible. Currents were measured only briefly in test mode in November 2017. Permanent installation between the jetties is planned for July 2018, to coincide with cross-channel transect runs with another current meter. Routine broadcasting of the currents to the pilots will occur later in 2018.

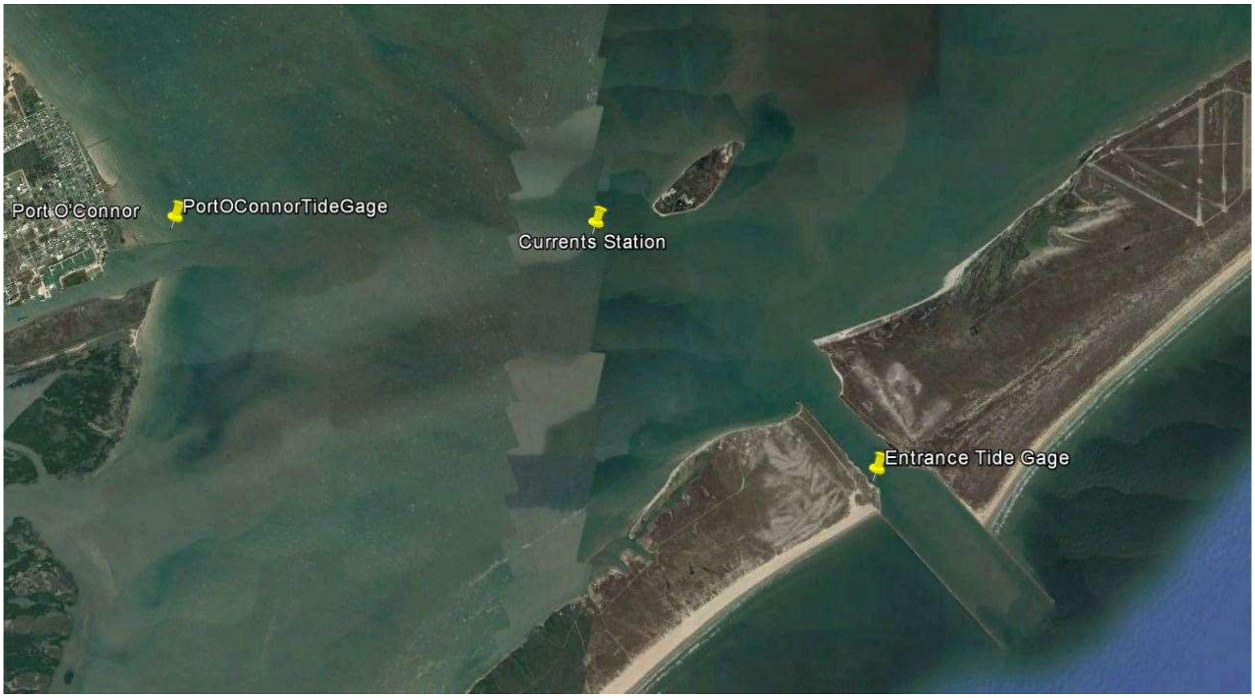


Figure 2.4 - Locations of gages now in place near the Channel:

The entrance channel tide gage (photo in Figure 2.5) now also has a current meter installed in November 2017. The NOAA/TCOON current meter near Bird Island has been in place for several years.

The above status of current comparisons was true in 2018 when the draft report was completed. The cross-channel transects of current measurements completed by the Port's subcontractor in 2005 were repeated by this project in 2018. The actual data were never transmitted to the Port. This project obtained the current data from the 2005 deployment directly from Trap Puckette at Evans-Hamilton, Inc. and placed them in this project's electronic files. Comparison of the 2005 currents and 2018 on the same transects shows an increase in peak currents in the channel of 18%. (See Section "Summary of Matagorda Bay Data Sources of Currents" of this report.)

2.4 TIDES

There are seven relevant tide gages:

1. Rockport, 50 miles to the southwest: this is the only one of the gages surveyed into a land-based datum (NAVD88). All the other gages provide data relative to the Station Datum (station's ground elevation), which is then related to local Mean Sea Level (MSL).

2. Freeport, 70 miles to the northeast
3. Lavaca Tide Gage, at the northern edge of Port Lavaca and directly to the west of the Point Comfort Port
4. Port O'Connor (photo in Figure 2.10)
5. Bird Island
6. Matagorda Entrance Channel (photo in Figure 2.6)
7. Pass Cavallo tide gage temporarily deployed during the 2005 field data collections, which the Port contracted Evans Hamilton, Inc. to perform (Puckette, 2006)

The most important numbers are summarized below. For a more complete listing of all tidal datums, see the H&H RSLC Attachment to this Appendix.

Table 2.9 - Tidal Datums for Relevant Gages

(feet)	**MHW**	**MSL**	**MLW**	**Mean Range (MHW - MLW)**	**Great Range (MHHW - MLLW)**	**Photo**
Rockport*	6.81	6.64	6.46	0.36	0.36	none
Freeport	29.29	28.62	27.91	1.39	1.80	Fig. 2.6
Lavaca	3.95	3.55	3.11	0.90	0.92	Fig. 2.7
Port O'Connor	12.06	11.74	11.34	0.73	0.75	Fig. 2.8
Bird Island	currents only					none
Entrance	26.6	26.15	25.52	1.08	1.09	Fig. 2.5

Pass Cavallo Plots are in Appendix III of Puckette (2006) for Sep-Dec 2005. That temporary station was surveyed into NAVD88 by a registered surveyor, but only **plots** of the tides are shown. Raw data are unavailable.

*: Rockport shows NAVD88 = 5.52ft. Thus MSL = 6.64 - 5.52 = 1.08ft NAVD.

Although the NOAA and TCOON websites list no conversion to NAVD88 at Freeport, such a conversion is mentioned in USACE (June 2016, Table 2-1) as MSL = 5.00ft and NAVD88 = 3.41ft with a data source listed as "USACE Survey, OPUS Control Monuments_Rizzo".

Note that the **Mean Ranges in West Matagorda Bay are all about 1ft** (0.90, 0.73, and 1.08).

Another source claims to have NAVD88 conversions for the Port O'Connor and Lavaca tide gages from the TCOON site, but the current TCOON site lists no such conversion. URS (2014b, Appendix E, Table 3-1) shows the following datums for the two gages at the ports:

Table 2.10

	Port O'Connor 28°26.8' N -96°23.8' W	Port Lavaca 28°38.4' N -96°36.6' W
MHHW	0.79 ft (0.239 m)	0.93 ft (0.283 m)
MHW	0.77 ft (0.233 m)	0.90 ft (0.273 m)
MTL	0.40 ft (0.122 m)	0.48 ft (0.145 m)
MSL	0.42 ft (0.127 m)	0.50 ft (0.15 m)
MLW	0.04 ft (0.011 m)	0.06 ft (0.017 m)
MLLW	0.00 ft (0.00 m)	0.00 ft (0.00 m)
COE MLT	1.21 ft (0.367 m)	-1.17 ft (-0.358 m)
NAVD 88	0.21 ft (0.062 m)	-0.17 ft (-0.053 m)

Figure 2.5 - Freeport tide station (Mean Tide Range = 1.39 ft)

Figure 2.6 - Lavaca Tide Station (Mean Tide Range = 0.90 ft)

Figure 2.7 - Port O’Connor Tide Station (Mean Tide Range = 0.73ft)

Figure 2.8 - Entrance Channel Tide and Current Station (Mean Tide Range = 1.09 ft)

2.5 BATHYMETRY

Two vital measurements are missing. Waves and a survey of the offshore bar, which is the limiting factor for the draft of the ships entering the channel. Without such a survey, design of a safe depth/draft at the entrance cannot be performed. The second missing measurement is wave height.

Recommendation: In PED the offshore bar should be surveyed, and a wave gage installed. With these two measurements, the entrance channel conditions will be known, and an authorized draft can be established.

Update: this project deployed a wave gage in the entrance channel in August 2018. It has not yet been recovered.

2.6 EXPECTED FUTURE WITHOUT-PROJECT CONDITIONS

2.6.1 General Expectations (Summary)

Changes in wave climate and sea-level rise are much easier to predict than changes in currents or bathymetry. Waves should remain unchanged, but the sea level is unknown. The historic rise is the Low Level Curve.

Currents would be expected to increase as long as Pass Cavallo continues to get smaller.

Bathymetric changes are the most difficult parameter to predict. If current trends continue, the entire navigation channel will slowly return to pre-Harvey dimensions. However, as long as Pass Cavallo continues to shrink, velocities in the entrance channel must increase, resulting in increased scouring between the jetties. But Pass Cavallo is unlikely to completely close, due to the large volume of Bay water west of the Pass. If the Pass is to be left at least partially open, then the barrier island should not be allowed to breach.

2.6.2 Waves

Wave heights and periods in deepwater are little affected by changes in currents or water levels (SLR), thus there is no reason to expect significant changes in the wave climate.

2.6.3 Changes in Bathymetry and Inlets' Cross-Sectional Areas

A basic concept in coastal engineering is that inlets must maintain the same tidal prism volume (surface area times tide range). Unfortunately, West Matagorda Bay is complicated by having two or three inlets. (Pass Cavallo inlet has split into two inlets.) In 2006 Pass Cavallo was only a single inlet. A bathymetric survey was performed on 8 transects on 16 May 2006 (Kraus and Batten, 2008, with survey lines shown in their Figure 3). Bathymetric surveys of the critical (minimum) cross-sectional areas were analyzed from 1856 to 2006. Basic principles of tidal inlet physics (the Jarrett equation) were used to compute the tidal prism from these surveys: $A_C = C\,P^n$, in which C and n are empirical coefficients determined from analysis of many inlets. Once the bathymetric surveys are used to determine the critical cross-sectional area A_C, then tidal prism P can be computed. Results are in the Table below. MSC inlet and channel construction occurred in 1963-66. The resulting tidal flows from the new channel's inlet reduced flows through Pass Cavallo and induced collapse of its large ebb-tidal shoal. After that collapse, note that Pass Cavallo's tidal prism stabilized at ~175 million m^3 for spring tide and 110 million m^3 for mean tide.

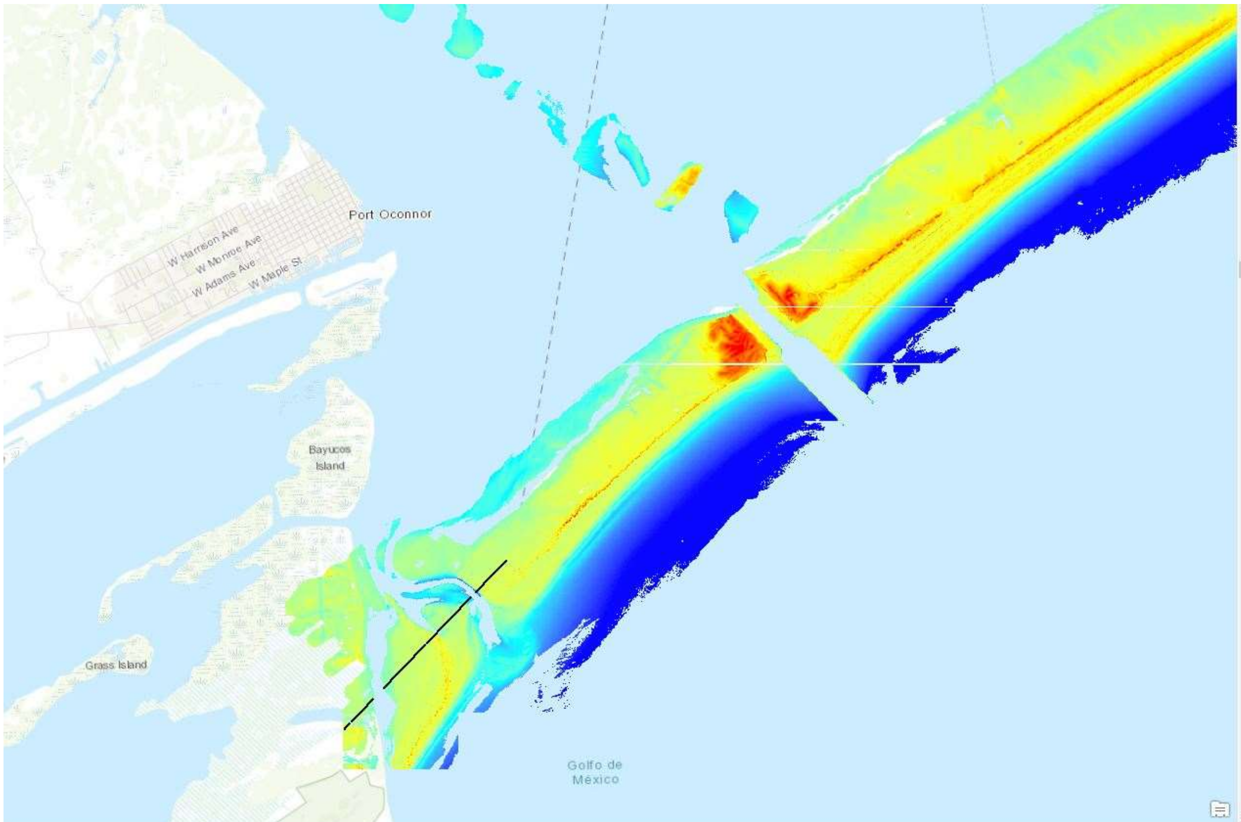
Table 2.11 - Tidal prisms for both channels (Kraus and Batten, 2008)

Table 1: Tidal Prism (millions of cu m)				
	Pass Cavallo		**MSC**	
Year or Action	**Spring Tide**	**Mean Tide**	**Spring Tide**	**Mean Tide**
1856	478.6	351.1	Not open	Not open
1934	399.3	294.5	Not open	Not open
1959	317.1	198.2	Not open	Not open
1965	220.9	161.4	164.2	118.9
1971	163.7	110.4	Not available	Not available
1972	127.4	116.1	189.7	155.7
1975	110.4	96.3	Not available	Not Available
2004	184.1	113.3	478.6	305.8
Alt 3a	164.2	110.4	515.4	359.6
Deepened and Widened Project (Recalculated with Revised 2004 Model Bathymetry)				
2004	175.6	110.4	461.6	290.2
Deepen, widen	175.6	110.4	470.1	294.5
Deepen, widen, remove south bottleneck	172.7	110.4	455.9	286.0
Deepen, widen, remove north and south bottlenecks	167.1	107.6	495.5	303.0
a) See Kraus et al. (2006) for discussion of alternatives. Briefly, Alt 3 refers to removal of both bottlenecks in the MSC entrance.				

Since the total tidal prism must remain constant, these inlets are linked. If one shrinks, then the other must either enlarge its cross-sectional area A or increase its velocity V: $Q = V A$, in order to maintain the same discharge Q.

Kraus and Batten (2008, p. ii) state: "Since the mid-1990s, the width of Pass Cavallo has remained stable, suggesting the sediment load to the inlet from collapse of its ebb shoal has declined." Unfortunately, the situation has changed again since that study. Pass Cavallo has now split into two inlets. A plan view of 2016 Lidar data of the double inlet is shown below (Fig. 2.9), along with a typical cross-section plot (Fig. 2.10).

Figure 2.9 - Pass Cavallo color-coded elevations from 8-16 September 2016 Lidar survey



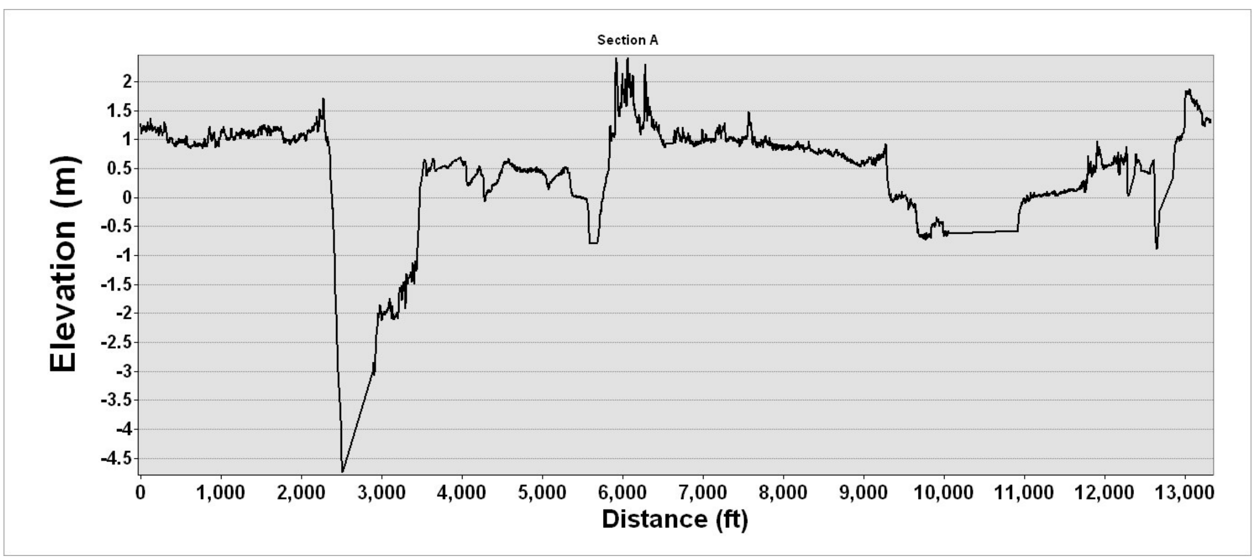


Figure 2.10 - Pass Cavallo side view of two inlets from 8-16 September 2016 Lidar survey

Based on this LIDAR survey, an analysis of changes in cross-sections and currents has been completed. (In Q = V A, if Q remains constant, then changes in A must result in the opposite change in V.) The LIDAR data show that Pass Cavallo is getting smaller. Sinnce Q = V A, velocities must increase somewhere. In fact, comparison of 2005 currents with 2018 currents shows an 18% increase in peak currents.

2.6.4 Changes in Currents

Analysis of cross-sectional areas of the three inlets has been completed. Pass Cavallo has decreased in cross-sectional areas.

2.6.5 Changes in Water Levels (Relative Sea Level Rise or RSLR)

Due to the length and complexity of this subject, this topic is covered as an Attachment to this H&H Appendix. Because of the much larger expected changes in currents and bathymetry, RSLR effectively has no effect on hydraulic design of the new channel. The main effect of RSLR would be to raise water levels, thus **decreasing dredging costs** but **increasing environmental impacts** (raising water levels in marshes, eroding beaches, etc.)

2.7 FUTURE WITH-PROJECT CONDITION

2.7.1 Design Assumptions and Inputs

Construction will occur during 2020-2024, with 2024 then being "Present Condition". Project design life is 50 years, and planning life is 100 years, so futures are years 2074 and 2124.

Design ship is a mid-size Aframax with overall length L_{oa} = 250m, length between perpendiculars L_{bp} = 239m, beam B = 43.8m, and draft T = 14.96m.

Traffic will be one way.

2.7.2 Channel Width

Channel width is designed by taking into account the following factors:

[from EM 1110-2-1613, Section 8-5(a)]

1. Traffic pattern (one-way or two-way),
2. Design ship's beam and length,
3. Channel cross-section shape,
4. Current's speed and direction,
5. Quality and accuracy of aids to navigation, and
6. Variability of the channel and currents.

How these different factors affect a ship's necessary safe channel width is largely empirical and based on two simulator tests (at Brazos Island Harbor and the Sacramento River), one physical model (of Barbers Point Harbor, Hawaii), and one set of field measurements (at the mouth of the Columbia River, where waves and shoals are quite large). The result is "interim" guidance, which has been in place since 2006, which proposes a multiplier of the ship's beam to determine necessary channel width, W = C B, with the coefficient C from the following Table.

Table 2.12 - Channel Width Multipliers for One-Way Traffic (from EM 1110-2-1613)

Table 8-2
One-Way Ship Traffic Channel Width Design Criteria

Channel Cross Section	Design Ship Beam Multipliers for Maximum Current, Knots		
	0.0 to 0.5	0.5 to 1.5	1.5 to 3.0
Constant Cross Section, Best Aids to Navigation			
Shallow	3.0	4.0	5.0
Canal	2.5	3.0	3.5
Trench	2.75	3.25	4.0
Variable Cross Section, Average Aids to Navigation			
Shallow	3.5	4.5	5.5
Canal	3.0	3.5	4.0
Trench	3.5	4.0	5.0

Factors 1, 3, 4, and 5 are taken into account in this multiplier table. The beam (factor 2) is accounted for in the equation for width, W = C B. For the case of the Matagorda Ship Channel, the six factors have been applied as follows:

1. Traffic is **one way**.

2. The **ship** used for hydraulic design was the Gulf Vision, which is an example that falls into the category of mid-size tankers used in this project's economic analysis. That class of tankers has a typical drafted weight of 100,000 tons, overall length L_{oa} of 250 meters (820 ft), and beam B of 43 meters (141 ft). The final design dimensions chosen were 800 ft length and 138 ft width. Using the 138 ft width or beam and Table 4-1 for one-way traffic, channel width should be W = 4 B = 4 x 138 ft = **554 ft** for Best Navigation Aids and currents 1.5 - 3 knots. Although the next two calculations will not be used in this design, for the record W = 414 ft for 0.5 - 1.5 knot currents and 380 ft for 0 - 0.5 knots.

CAVEAT: This navigation channel exceeds allowed design guidelines. (There is no "greater than 3 knots" category in the above table.) Because of a lack of guidance and studies of channels with excessive currents, this designer is unable to provide a professional opinion on the appropriate safe channel width.

However, when guidelines are exceeded, the guidance is to use a combination of ship simulations and pilots' experience. The 2014 ship simulation (WST, 2014) shows that the same channel widths (600ft entrance and 350ft Bay) are safe, except when currents exceed 3.5-4 knots. Unfortunately, the severity of the currents has increased since that study.

CONCLUSION: During the peaks of every tidal cycle, the pilots judge conditions to be unsafe. Furthermore, in the future, these currents will increase in severity and duration, because of the decreasing size of Pass Cavallo. However, the ship simulations and pilots' experience demonstrate that during non-peak conditions, the channel design width (600ft & 350ft) is sufficient.

3. Channel cross-section shape is **Trench**. See Figure 2.11 below. This becomes important when computing Underkeel Clearance.

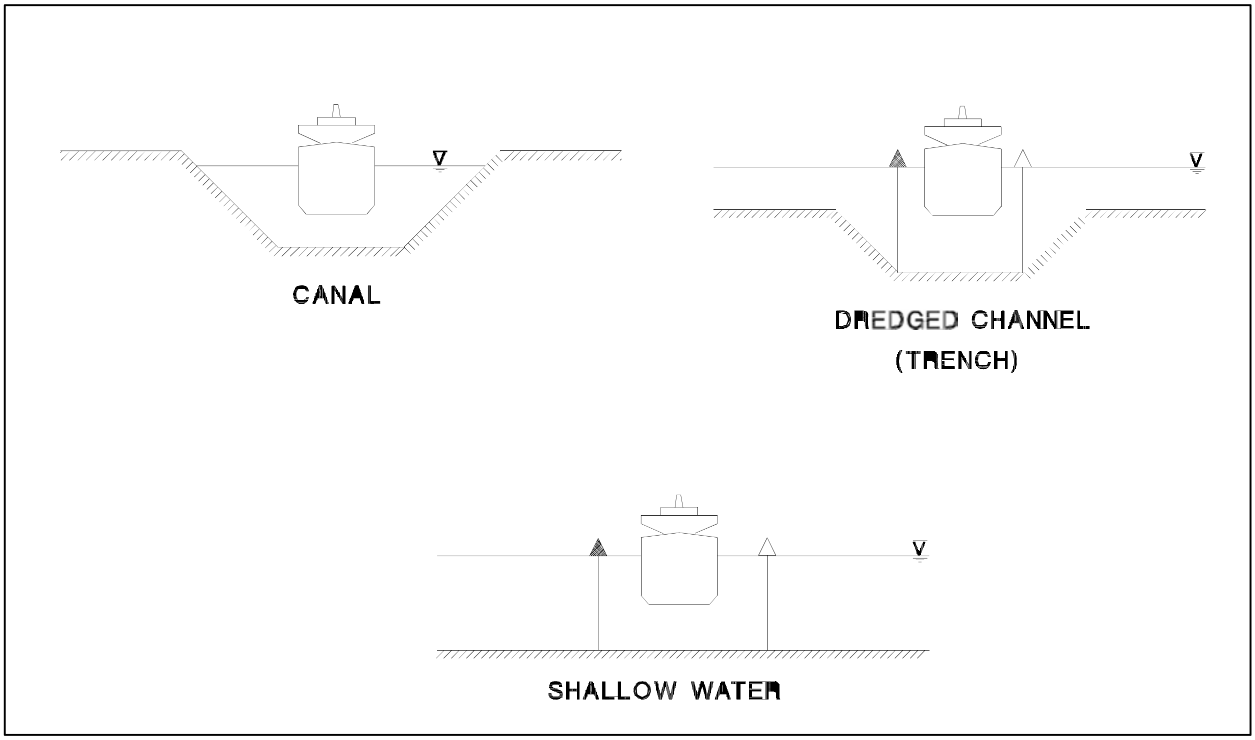


Figure 2.11 - Hydraulic Classifications of Channel Types (EM 1110-2-1613's Figure 8-1): Equations exist for the Canal case and for the no-sides case (shown here as "Shallow Water", but when in deep water it is called "Fairway"). Calculations for the Trench case are made as a simple averaging of the Canal and Fairway results.

4. Current's speed and direction: entrance channel speeds routinely (every tidal cycle) exceeded 4 knots during the 2005 Bird Island deployment (Puckette, 2006), but are now faster. Pilots now deal with this situation by not moving ships during tidal peaks.

5. Aids to Navigation: The current aids are not the best, but a current meter will be installed between the jetties by ERDC in July 2018. There is also a continuously maintained NOAA current meter near Bird Island. **This project plans to broadcast one or both current meter readings to ships,** in order to improve Aids to Navigation. (This was completed between August and December 2018.)

6. Variability of the channel and currents: The only specific guidance on how to deal with this issue is to use ship simulations. Results of the previous simulations (WSI, 2014) when currents were not as strong as they are now, have been used to ground-truth calculations.

Update: ship simulations were performed at ERDC in November 2018. All reaches of the planned new work were redesigned as a result. The most significant change was a reduction of the new channel width in the Bay from 350ft to 300ft.

2.7.2.1 Entrance Channel Width [per EM 1110-2-1613, Section 8-5(b)]

Using the multipliers in Table 2.11, the design ship's beam of 138 ft produces design widths of:

W = 138ft x 4 = 554ft for 1.5kn < v < 3.0kn,

resulting in a channel width slightly smaller than the outer channel proposed width of 600ft. But there is no design guidance for v > 3kn. Using the design width W as a known value and solving for the associated multiplier produces 600ft/138ft = 4.35, which seems low for currents that routinely exceed 4kn.

2.7.2.2 Transition Section Width (Matagorda Peninsula to Bird Island)

This transition section (distance over which the design channel width will taper from 600ft in the entrance to 350ft in the Bay) was initially set to be between the Peninsula and Island. However, the pilots report that this is the most dangerous section, where cross-currents (perpendicular to the along-channel ship path) impact the ships and require skewed thrust and difficulty in maneuvering. Therefore it is inappropriate to place the transition section here. This study is recommending that the transition section be shifted to the northwest (further into the Bay).

2.7.2.3 In-Bay Width

Inside the Bay currents are lower than in either the entrance or transition sections. Using the multipliers in the upper half of Table 4.1 (Best Aids to Navigation), channel width should be:

W = 138ft x 3.25 = 449ft for 0.5 < v < 1.5kn

W = 138ft x 2.75 = 380ft for 0.0 < v < 0.5kn

Both of these widths exceed the proposed design width of 350ft. The reason for this discrepancy is that the original H&H design calculations for this project were based on the results from the ship simulation (WST, 2014) which used a 106ft wide design ship with 800ft length. The design channel width was calculated to be:

W = 108ft x 3.25 = 351ft for 0.5 < v < 1.5kn

Furthermore the 2014 ship simulation also simulated a much larger 966ft long by 152ft wide LNG carrier and found that it could also successfully navigate the 350ft wide channel. However, it should be noted that the pilots maintained the input currents were too low in the simulations, especially the cross-currents (WST, 2014, Table 9-2). The two locations where the pilots tell us the cross-currents are even stronger now than in the 2014 study are just outside the jetties and in the Peninsula-to-Bird-Island transition zone. The 2014 simulation shows that for the currents existing at that time, shipping was safe. A big question remains as to what those currents are now.

2.7.2.4 Turning Basin Width

The turning basin for this project is at Point Comfort, which is well sheltered from both waves and to a lesser extent currents. Thus the low-current applies (Table 2.11). For the design ship length of 800ft, the middle multiplier in Table 2.11 applies, and W_{TB} = 1.5 x 800ft = **1200ft.** During the November 2018 ship simulations, both the turning basin and the approach to it were redesigned. The approach was widened. The basin design itself was changed from the circular turn below to a polygonal shape that more accurately reflects pilots' practice.

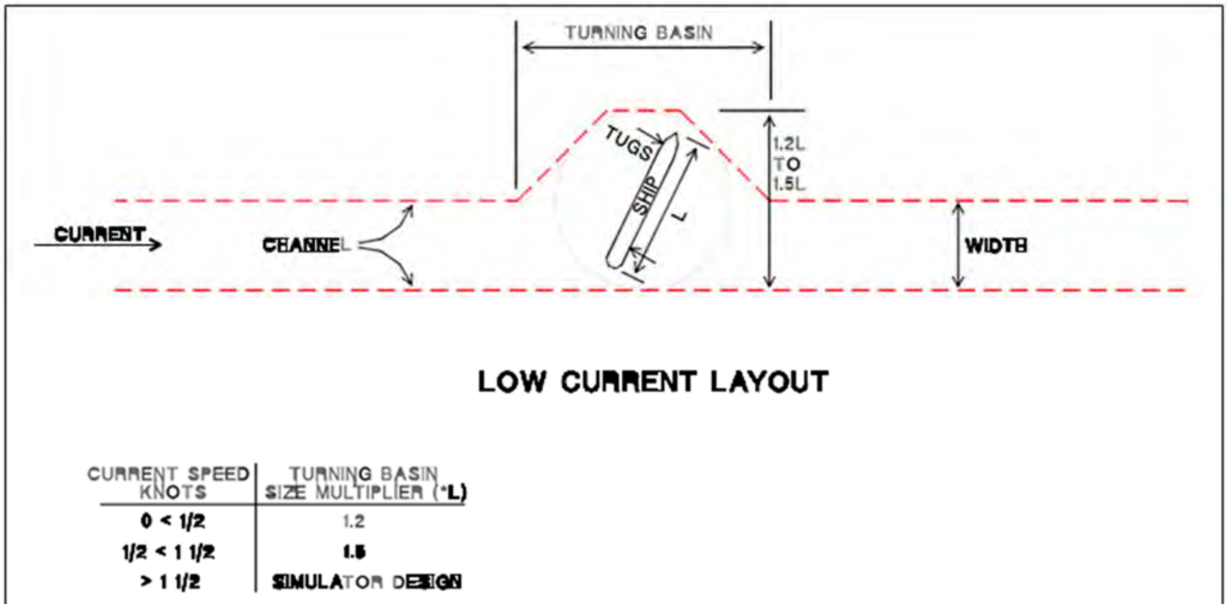


Figure 2.12 - Turning Basin design for low currents (EM 1110-2-1613's Figure 9-1, upper half)

2.7.2.5 Channel Width Calculations by Four Methods

Width calculations have been done using 4 different methods.

(1) Long ago, before the current H&H designer was on this project, the EM Table's method was used to compute a width of 550ft, and 50ft was added for safety (since Matagorda's currents are "off the chart").

(2) Using the official USACE methods, adequacy of the 600ft width was checked in section 2.7.2 of the Engineering Appendix.

(3) In response to comments, an off-the-chart interpolation of Corps guidance was performed:

As shown in section 2.7.2 of the engineering appendix, we are "off the chart" on guidance on channel width design.

Extrapolating an additional column in the guidance tables requires adding 0.75 to the beam multiplier. The result is 138ft x 4.75 = 656 ft

As stated in a footnote in the table, the official guidance calls this EM table's methods "highly conservative".

PIANC's Report Number 121, "Harbour Approach Channels Design Guidelines," which provides alternative formulas for determining channel geometry, may provide a higher level of confidence in the proposed channel design.

(4) Equation 3-4 in the PIANC report was used to compute width,

W = 2WBM + 2{Wi(c)+Wi(d)} + WBR + WBG

W = 2(1.3(138)) + 2{138+0.1(138)} + 0.2(138) + 0.2(138) = 718ft

Of the above 4 methods, the only method shown in this project's draft report was #2.

In-Bay Width:

In addition, the width of the in-bay portion of the channel was determined to be 449 feet for currents ranging from 0.5 to 1.5 knots and 380 feet for currents ranging from 0.0 to 0.5 knots. Both widths exceed the proposed in-bay channel width of 350 feet.

Using PIANC Eq. 3-4, W = 2WBM + 2{Wi(c)+Wi(d)} + WBR + WBG

W = 2(1.3(138)) + 2{138+0.1(138)} + 0.5(138) + 0.5(138) = 800ft

CONCLUSION: Considering the huge variation in official guidance, adequacy of channel width should be addressed by ship simulations. The only offshore channel width simulated in the WTS 2014 was 600ft, which the pilots deemed to be adequate. Two caveats: (1) currents are now stronger than the ones used in that study, and (2) The ships used in that study were smaller than the design ship in this feasibility study. A final decision on channel width will be made in a new ship simulation. Whether to perform a limited ship simulation in this study or wait until PED is under active discussion.

2.8 CHANNEL DEPTH

The various depths for a deep-draft channel design are shown in Figure 2-13. Proceeding upward from the bottom of the channel:

Dredging Tolerance is the for-pay dredging allowed, since depths of cut are imprecise. This value varies from 1-3 feet, but in Galveston District's small tidal range climate with lower wave heights, it is typically **one foot.**

Advance Maintenance Dredging is the planned over-dredging at the **start** of a dredging cycle, so that the average design dredged depth is maintained during the cycle. In Galveston District this is typically **two feet.**

Safety Clearance is somewhat arbitrary, but tends to be larger (two feet) in channels with higher waves and may even be larger in channels with hard bottoms. Matagorda's entrance channel is the opposite: when there are high waves, the channel is not used, and the bottom is soft. Therefore the usual two feet of safety clearance should be **one foot.**

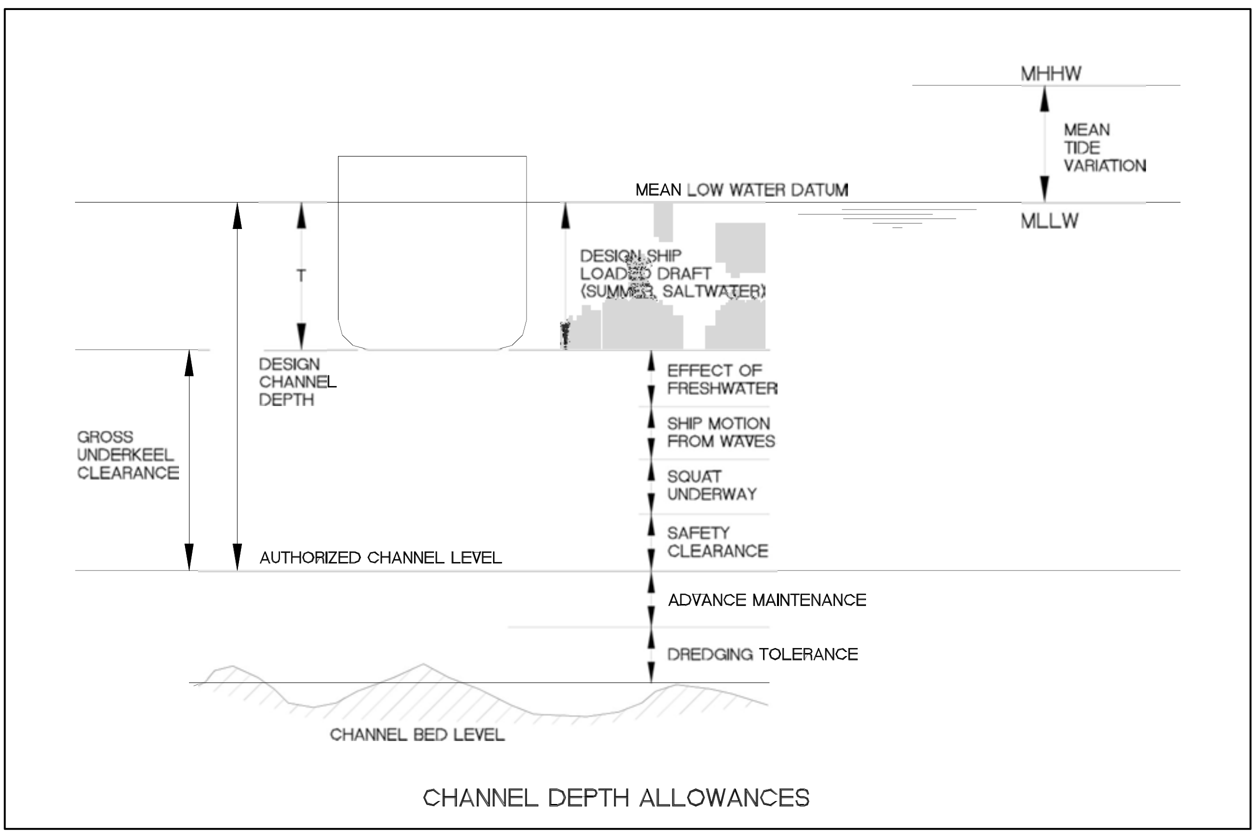


Figure 2.13 - Depth allowances are shown for deep-draft channels (EM 1110-2-1613's Fig. 6-17).
Mean tide variation (MHHW - MLLW) for this site may be calculated as the average of the two nearest coastal gages, but the entrance channel is quite deep. Therefore the governing mean tide

variation should be taken from the Bay gage at Port O'Connor, which shows a mean tide range of 0.73 ft.

2.8.1 Ship Squat

As a ship moves, the increased pressure on the ship's hull causes the ship to lower in the water column. The definitions and Bernoulli's equation are shown in the bottom of Figure 2.14. This effect is more pronounced in channels than in open water (upper half of Figure 2.14).

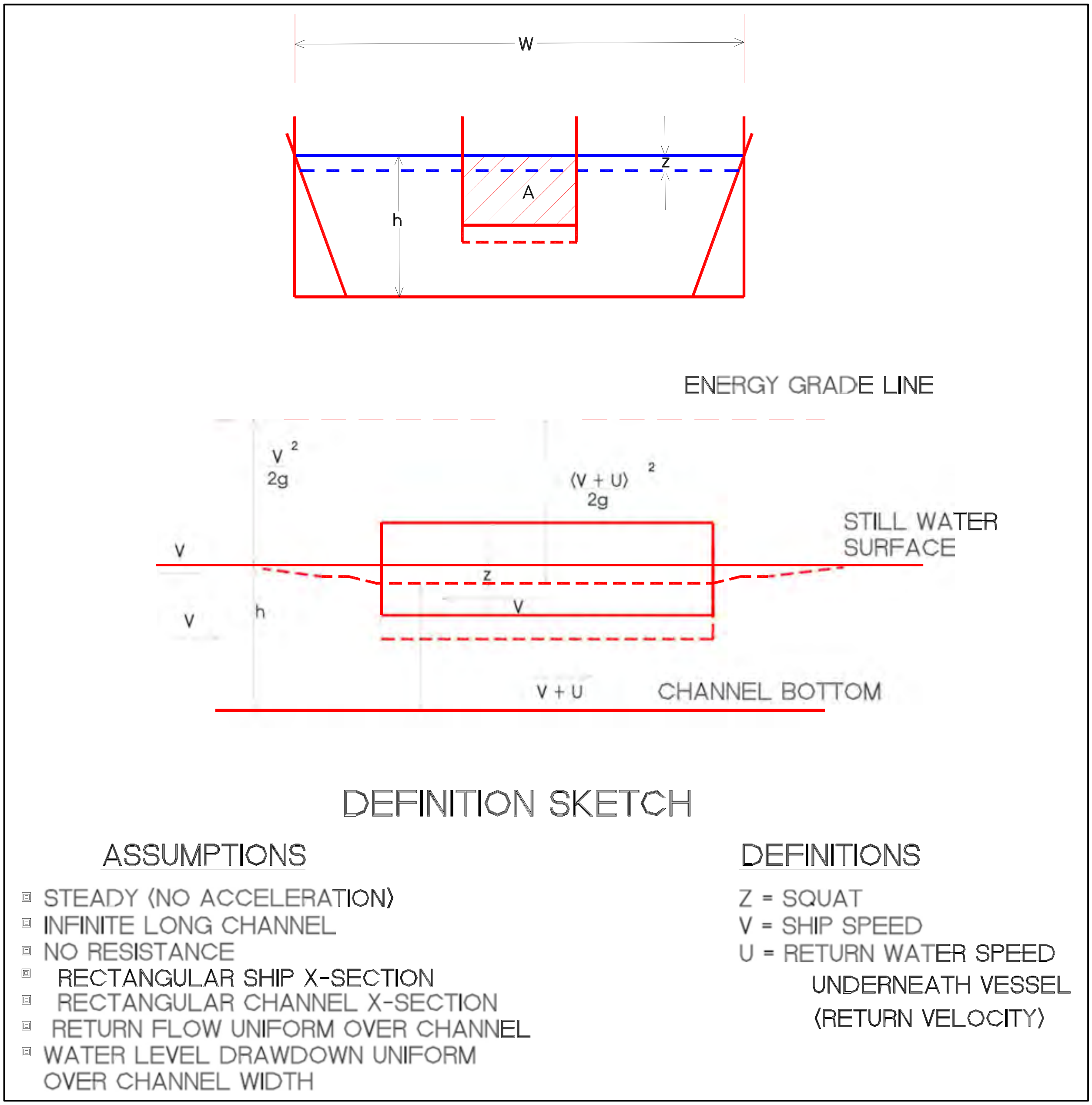


Figure 2.14 - Ship squat definitions (EM 1110-2-1613's Figure 6-2)

Various methods have been used to estimate squat, all of which start with Bernoulli's equation (Figure 2.14) and compute the channel's nondimensional Froude number:

$$F_h = \frac{V}{\sqrt{gh}}$$

where V is the ship's speed, and h is the channel depth.

Simple Squat Method

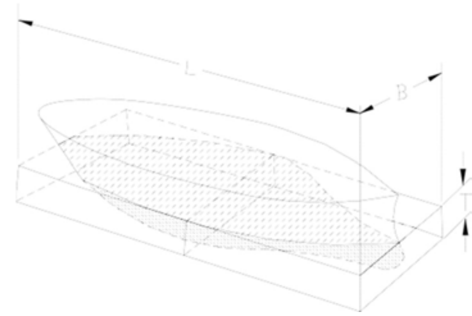
Before proceeding with the more complicated and exact methods now used to compute squat, first consider the basic conceptual method used in the most basic equation for squat. The Froude number has been empirically related through experiments to provide ship squat Z_{max} in the following form with a coefficient of 2.4:

$$\frac{z_{max}}{T} = 2.4 \frac{C_B}{L/B} \frac{F_h^2}{\sqrt{1 - F_h^2}}$$

where T is the ship's molded draft, L its length, B is beam (width), and C_B is a Blocking Coefficient which depends on the particular ship's geometry:

$$C_B = \frac{\nabla}{LBT}$$

where ∇ is the volume displacement of a ship, expressed as the ratio of the ship's displacement compared to that of a rectangular block, as shown below in Figure 4.5:



Block coefficient definition

Block coefficient (C_B) = Ratio of the volume of displacement to the volume of a rectangular block having a length, beam, and draft equal to that of the ship.

$$C_B = \frac{\nabla}{LBT}$$

L = Length between perpendiculars

T = Draft to the designed waterline, or molded ship draft

B = Beam amidships at the designed waterline, or molded beam

∇ = Volume of displacement of molded ship form at draft T

Figure 2.15 - Blocking coefficient (EM 1110-2-1613's Figure 3-3)

A specific ship must be selected in order to determine the blocking. The **ship** used for hydraulic design was the Gulf Vision, which is an example that falls into the category of mid-size tankers used in this project's economic analysis (Aframax Tankers). That class of tankers has a typical drafted weight of 100,000 tons, overall length L_{oa} of 250 meters (141 ft), and beam B of 43 meters (141 ft). The final design dimensions chosen in that economic analysis were 800 ft length and 138 ft width. However, a specific ship must be used in hydraulic design, and the Gulf Vision was selected. As seen in the following Chartering Questionnaire, its dimensions are slightly different with length overall L_{oa} = 249m, length between perpendiculars L_{bp} = 239m = 784ft, beam B = 43.8m = 143.8ft, and draft T = 14.96m = 49.1ft. Minimum salinities in the Bay are typically 20ppt, so water density is 1020 kg/m^3.

Table 2.13 Design Ship Datasheet

Version 4

INTERTANKO'S STANDARD TANKER

CHARTERING QUESTIONNAIRE 88 (Q88) *Created at Q88.com*

1.	VESSEL DESCRIPTION	
1.1	Date updated:	Oct 24, 2017
1.2	Vessel's name (IMO number):	Gulf Vision (9505819)
1.3	Vessel's previous name(s) and date(s) of change:	Not Applicable
1.4	Date delivered / Builder (where built):	Oct 25, 2012 / Samsung Heavy Industries Co., Ltd.
1.5	Flag / Port of Registry:	Bahamas / Nassau
1.6	Call sign / MMSI:	C6ZY2 / 311071700
1.7	Vessel's contact details (satcom/fax/email etc.):	Tel: 870773203793 Fax: 870783011330 Email: gulfvision@gemfleet.com
1.8	Type of vessel (as described in Form A or Form B Q1.11 of the IOPPC):	Oil Tanker
1.9	Type of hull:	Double Hull
Classification		
1.10	Classification society:	Lloyds Register
1.11	Class notation:	+100A1,Double Hull Oil Carrier ESP, CSR, Shipright(ACS(B),BWMP(S),CM,SERS,SCM),+LMC,UMS,SCM,+IWS,LI,SPM4,EP(B,P,Vc),IGS,COW, Green Passport, ETA

1.12	Is the vessel subject to any conditions of class, class extensions, outstanding memorandums or class recommendations? If yes, give details:	No N/A	
1.13	If classification society changed, name of previous and date of change:	Not Applicable , Not Applicable	
1.14	IMO type, if applicable:	N/A	
1.15	Does the vessel have ice class? If yes, state what level:	No , N/A	
1.16	Date / place of last dry-dock:	Aug 27, 2017 / Shanghai, China	
1.17	Date next dry dock due / next annual survey due:	Oct 24, 2022	Oct 24, 2018
1.18	Date of last special survey / next special survey due:	Oct 25, 2017	Oct 24, 2022
1.19	If ship has Condition Assessment Program (CAP), what is the latest overall rating:	No , (N/A)	
1.20	Does the vessel have a statement of compliance issued under the provisions of the Condition Assessment Scheme (CAS): If yes, what is the expiry date?	N/A Not Applicable	
Dimensions			
1.21	Length overall (LOA):	248.97 m	
1.22	Length between perpendiculars (LBP):	239.00 m	
1.23	Extreme breadth (Beam):	43.80 m	
1.24	Moulded depth:	21.00 m	

1.25	Keel to masthead (KTM)/ Keel to masthead (KTM) in collapsed condition, if applicable:			46.65 m	45.24 m
1.26	Bow to center manifold (BCM) / Stern to center manifold (SCM):			125.10 m	123.87 m
1.27	Distance bridge front to center of manifold:				82.65 m
1.28	Parallel body distances:		Lightship	Normal Ballast	Summer Dwt
	Forward to mid-point manifold:		65.80 m	62.00 m	62.00 m
	Aft to mid-point manifold:		25.00 m	55.0 m	76.40 m
	Parallel body length:		90.8 m	117.0 m	138.4 m
1.29	FWA/TPC at summer draft:			302 mm	98.47 MT
1.30	Constant (excluding fresh water):				300 MT
1.31	What is the company guidelines for Under Keel Clearance (UKC) for this vessel?	GEM UKC Policy in line with industry recommendations is: Ocean Passage: 20% of the vessel deepest draft during transit. Fairways, outside port limits: 15% of the vessels deepest draft during transit. Fairways, inside port limits: 10% of the vessels deepest draft during transit. SBM/CBM: 10% of the vessels deepest draft. Alongside: 10% of the vessels deepest draft. GEM UKC Policy for vessels at USA ports is: Fairways, outside port limits: 15% of the vessels deepest draft during transit Fairways inside port limits: 10% of the vessels deepest draft during transit However Not less than 2 feet (0.61 metres) after exemption approved from GEM Office. Alongside: Not less than 2 feet (0.61 metres) at the berth or in close proximity Except vessels entering			

		and transiting San Francisco Bay Area (Richmond, Selby, Rodeo, Martinez and Benicia including Pinhole Shoal) Not less than 3 feet (0.91 metres) UKC. Suez Canal: Vessel may transit at SCA maximum permitted draft as advised by the canal authority.	
1.32	What is the max height of mast above waterline (air draft)	Full Mast	Collapsed Mast
	Lightship:	44.2 m	42.79 m
	Normal ballast:	39.47 m	38.06 m
	At loaded summer deadweight:	31.965 m	30.555 m
Tonnages			
1.33	Net Tonnage:		35576.00
1.34	Gross Tonnage / Reduced Gross Tonnage (if applicable):	61338.00	48927
1.35	Suez Canal Tonnage - Gross (SCGT) / Net (SCNT):	62858.80	57295.70
1.36	Panama Canal Net Tonnage (PCNT):		

Although commercial tables use length overall (L_{oa}), hydraulic analyses use length between perpendiculars (L_{bp}), which the Questionnaire shows to be 239m or 784ft. The loaded volume displacement ∇ for molded depth of 21m and submerged draft T of 14.96m is 118,820 tons, thus the blocking coefficient is:

$$C_B = 118{,}820{,}000 \text{ kg} / (1020 \text{ kg/m}^3)(239\text{m})(43.8\text{m})(14.96\text{m}) = 0.74$$

At the entrance channel depth of 48ft (depth of the offshore bar that is the effective limit on drafts of ships entering the channel), the Froude number is:

$$F_h = V / \text{sqrt}[\ g\ h\ ] = 10 \text{ kn } (1.688 \text{ ft/s-kn}) / \text{sqrt}[\ (32.2 \text{ ft/s}^{2)}\ 48 \text{ ft}\ ] = 0.25$$

This is the Froude number at the channel entrance for a **canal** [Figure 2.11(a)], but our channel is a **trench** [Figure 2.11(b)]. The Froude number for a **trench** is computed as the simple average of that for a **canal** and for a **fairway** [open water, Figure 2.11(c)].

The **fairway** squat is computed from the Coastal Engineering Manual's Equation V-5-6 for cases of $F_h < 0.4$:

$Z = 0.2125\ C_B\ (B / L)\ (T / h)\ V^2 = 0.2125\ (0.74)\ (143.8\text{ft}/239\text{m})\ (14.96\text{m} / 48\text{ ft})\ (10\text{kn})^2 = 2.95$ ft

in which a unit conversion factor of 0.3048 m/ft appears in both the numerator and denominator and cancels itself out.

Complicated Squat Method

The **canal** squat equation (CEM, 2002) is quite complicated:

$$F_L = \frac{V_L}{\sqrt{gh}}$$

$$\simeq \left\{ 8 \cos^3 \left[\frac{\pi}{3} + \frac{1}{3} \cos^{-1} \left(1 - \frac{1}{B_R} \right) \right] \right\}^{\frac{1}{2}} \quad \text{(rectangular canal)} \qquad \text{(V-5-4)}$$

where

F_L = Schijf limiting Froude number

V_L = Schijf limiting ship speed in squat analysis

g = acceleration due to gravity; = 9.80 m/sec^2 (32.2 ft/sec^2)

h = depth of canal (Figure V-5-15)

B_R = channel blockage ratio (Equation V-5-2 and Figure V-5-7)

(4) Maximum ship squat at the Schijf limiting Froude number is given by

$$Z_L = h \left[\frac{F_L^2}{2} \left(F_L^{1/3} - 1 \right) \right] \quad \text{(rectangular canal)} \qquad \text{(V-5-5)}$$

The squat computations for both canal and fairway were computed using the Coastal Engineering Manual's Interactive (2004) software program. Several cases were run using the following inputs: Vessel speed V = 10 knots, Vessel beam B = 143.7ft, Vessel length L = 784ft, and Block coefficient C_B = 0.74. The Vessel draft T, Channel depth h, Channel cross-sectional area A_C, and wave height H were varied between cases. The cross-section in the entrance channel with the minimum cross-section A_C is shown in Figure 2.16.

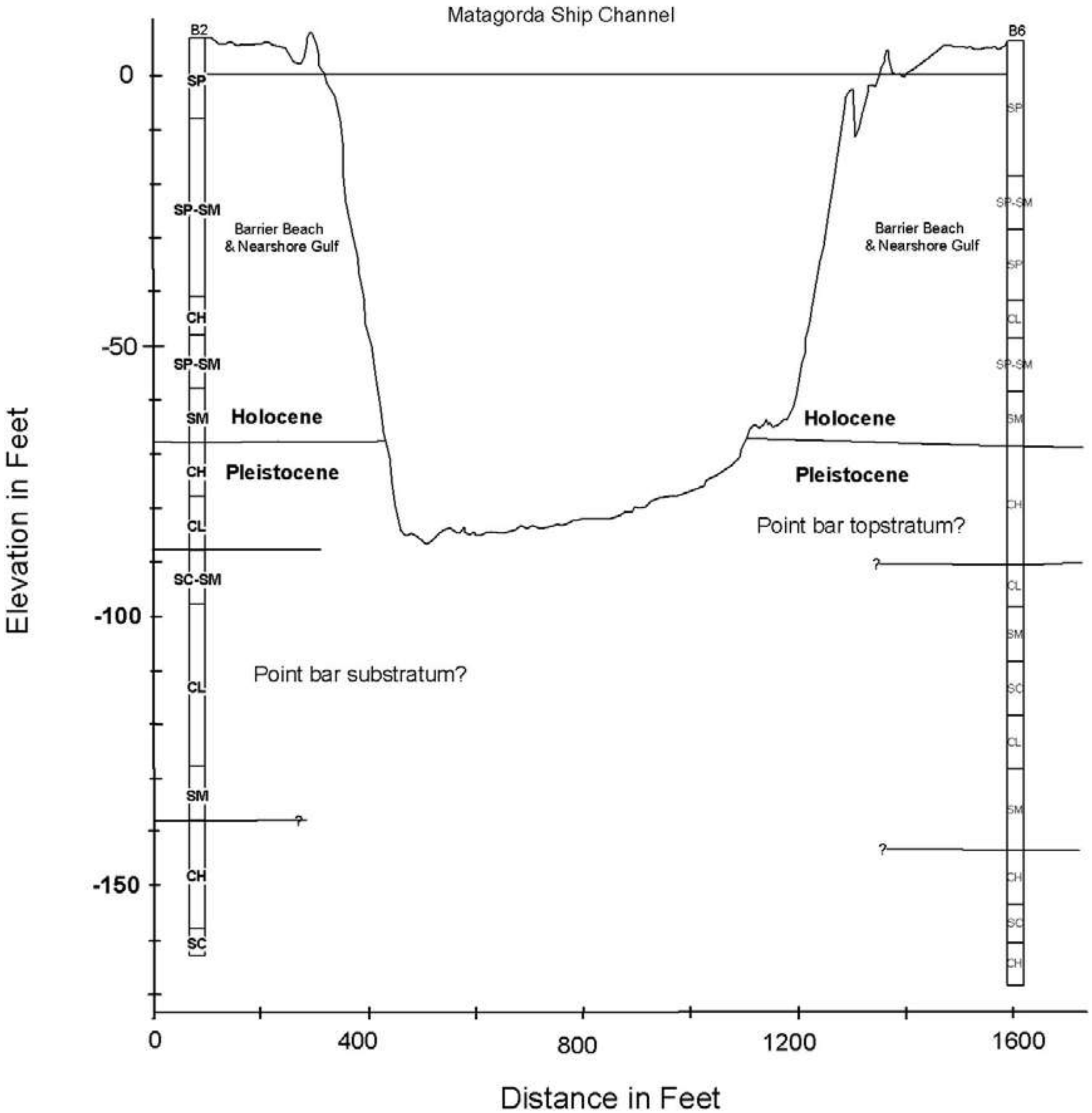


Figure 2.16 - Minimum entrance-channel cross section was at Station 2+150 of **61,620 ft^2** below local Mean Sea Level (from Maynord et al., 2011, Figure 41). View is looking inland, with Boring B2 to the southwest and B6 to the northeast, showing the vertical profile of sediments.

Eight cases were run and are summarized below. The individual calculation sheets are shown in Section **6 Squat Computation Sheets** after the References.

Table 2.14 - Summary of Ship Squat Results in Trench

Case	Location	Draft (ft)	Depth (ft)	Waves (ft)	Squat (ft)
1	Entrance	49	78	0	2.01
2	Entrance	49	78	4	2.01
3	Entrance	49	78	10	2.01
4	Entrance (dredged)	43	49	0	1.95
5	Entrance (dredged)	39	49	4	1.84
6	Entrance (dredged)	33	49	10	1.66
7	Bay	41	47	0	1.75
8	Bay	38	47	3	1.69

A useful check on the validity of this result is to compute a blocking ratio B_R, which may be thought of as the **unblocked** ratio of the channel. $B_R = A_C / A_S$ where A_C is the channel's cross-sectional area and A_S is the vessel's submerged cross-sectional area, $A_S = B\ T$ (upper part of Figure 4.7).

With the 0.25 Froude number, the Coastal Engineering Manual's Figure V-5-7 produces a blocking ratio of $B_R = A_C / A_S = 2.5$ (from the curve in the lower part of Figure 2.17).

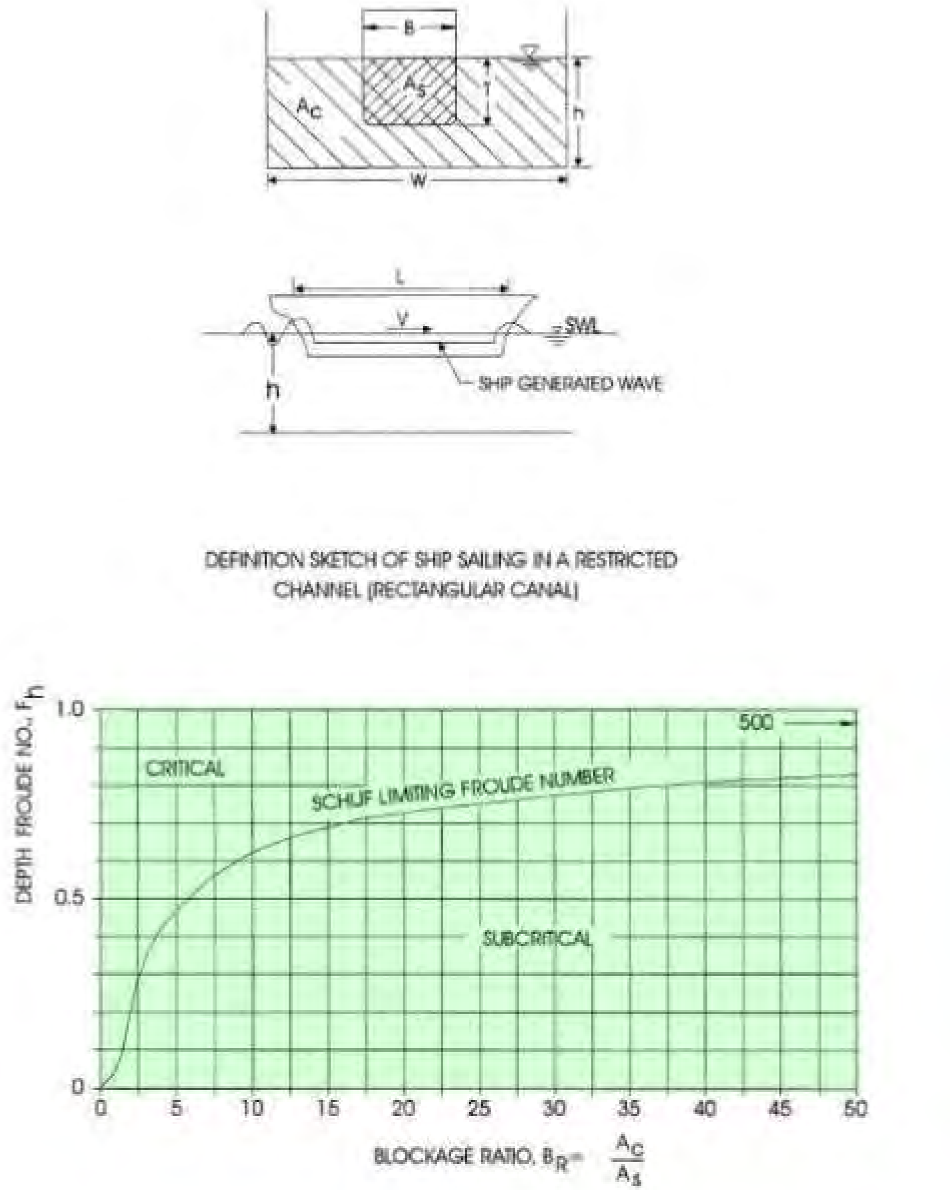


Figure 2.17 - Blockage ratio is illustrated conceptually in the upper part as the amount of blockage that the ship would make, if it were a rectangle. In this project the Froude number was calculated as 0.25, which then produces on the x-axis a B_R of 2.5 (from CEM 2002 Figure V-5-7)

The practical check that can be made on the viability of the channel's design is to examine where this value falls on the curve. Note that in our case the $B_R = 2.5$ is on the lower part of the curve and **not** the upper flatter part of the curve which produces designs of "limiting return" where gains in thrust must increase exponentially in order to produce real increases in vessel speed, because of the increasing difficulty of overcoming the channel's blockage. Therefore **this channel is in the desirable range of increasing thrust producing increasing ship speed.**

2.8.2 Waves

The next consideration for vertical excursion of ships is that caused by waves. Wave height at the entrance (Section 2.2 above) is Hmo = 1.2m = 3.94ft from the hindcast model, but is much higher in winter (10-12ft) at ebb tide, according to the pilots. Waves inside the Bay are much less at close to zero (calm winds) or 3ft during normal storm conditions.

2.8.3 Effect of Freshwater

The effect of freshwater is to reduce buoyancy and thus underkeel clearance (Archimedes' Principle). On the rare occasions when the Bay is flushed with freshwater (e.g., Hurricane Harvey in 2017), ships do not operate until the storm has passed, and even then, cautiously. In design computations, a salinity of 20ppt was used, which is typical of a rain event during which ships still operate.

2.8.4 Authorized Draft CONCLUSION (42 ft)

Figure 2.13 shows 5 depths adding up to the Authorized Channel Level:

Authorized Channel Level = Design Ship Draft + Effect of Freshwater + Waves + Squat + Safety

(Dredging Tolerance and Advanced Maintenance add to these to produce the Channel Bed Level, Fig. 2.13, but do not count toward the Authorized Channel Level.) Inserting the known values,

In the Bay, 47ft = Design Ship Draft + 0ft + 2ft + 2ft + 1ft

Solving for Design Ship Draft = 47 - 0 - 2 - 2 - 1 = 42ft

In the Entrance, 49ft = Design Ship Draft + 0ft + 4ft + 2ft + 1ft

Solving for Design Ship Draft = 49 - 0 - 4 - 2 – 1 = 42ft

The pilots claim that waves are higher in the entrance than 4ft. In fact, they bring in ships with waves as high as 10-12 ft. (Their limiting wave height is an experienced safety limit for climbing the ladder up the side of the ship.)

If the entrance channel were kept dredged to the Authorized Draft of 49ft, then Authorized Draft would be the 42ft calculated above. However, surveys of the offshore bar show that it shoals in a few months after dredging and eventually returns to close to its equilibrium depth of 34ft prior to the next dredging cycle.

Project **authorized depth** will be insufficient to accommodate the deepest draft of the largest ships. If the pilots intend to operate under all wave conditions, then **allowable draft** will be authorized channel depth minus 10 ft. This 10ft offset value can be reduced by the difference between the 4ft significant wave height and the pilots' highest operational wave height.

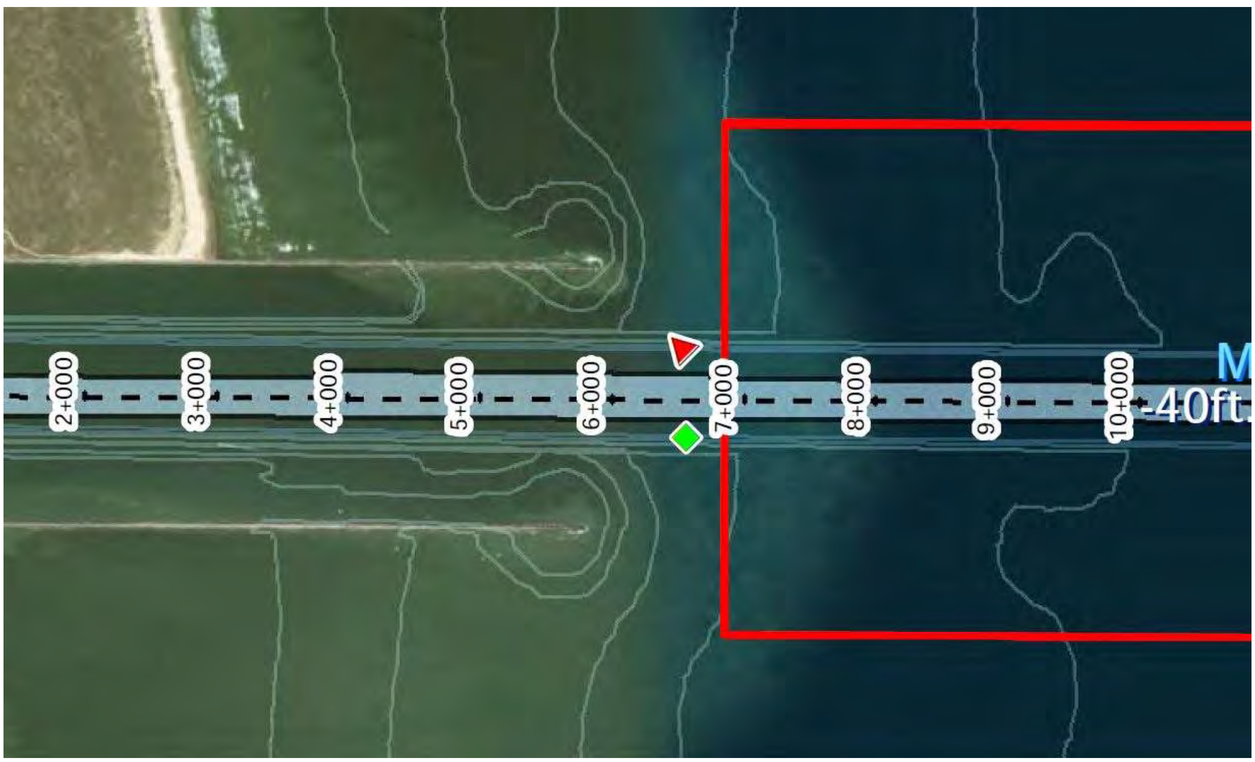
Recommended Authorized Draft = Channel's New Authorized Depth - Safety Clearance - Squat - Wave Motion = 47ft - 1ft - 2ft - 2ft (in Bay) = 42ft.

In the entrance channel, the design depth is 2ft greater, and the waves are 2ft greater, so those two changes cancel each other out, and the authorized draft in the entrance remains 42ft.

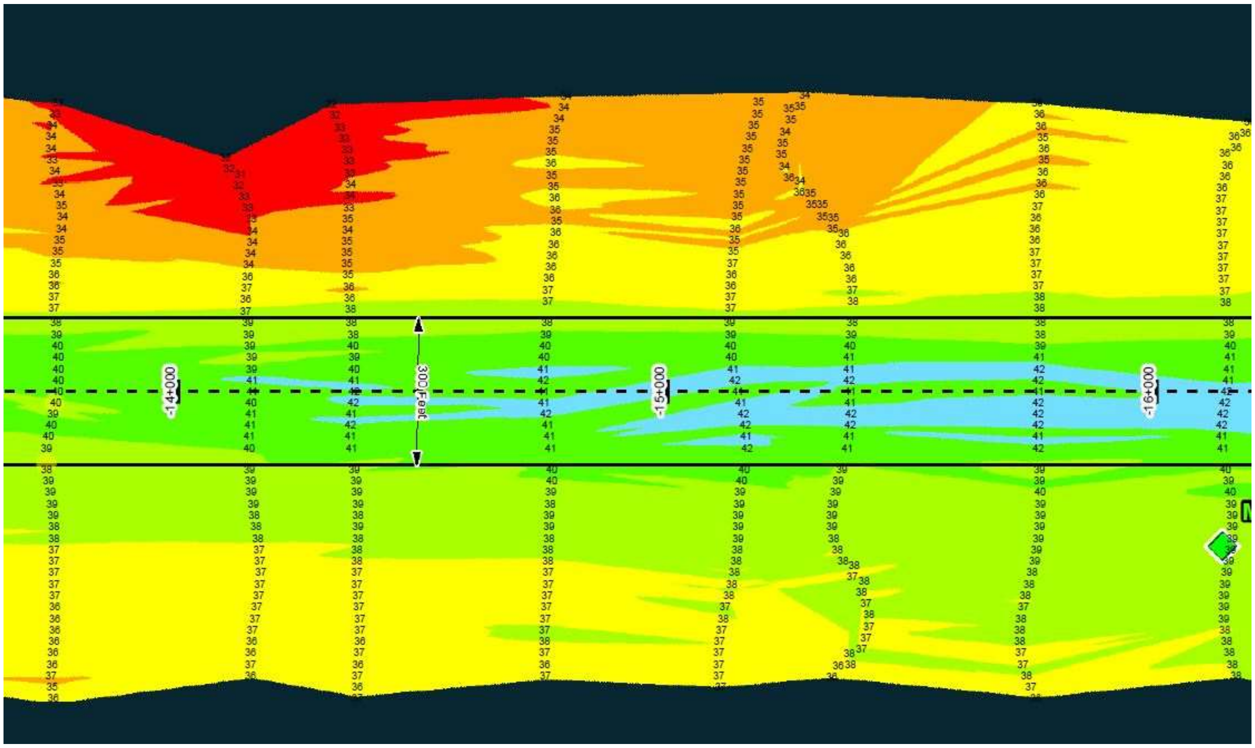
CONCLUSION: Authorized Draft in the entrance would be the designed 49ft immediately after dredging, but will gradually decrease until the next dredging cycle to some depth in the range 34-38ft, UNLESS the offshore bar is overdredged.

2.9 SHOALING ANALYSES AT THE OFFSHORE BAR

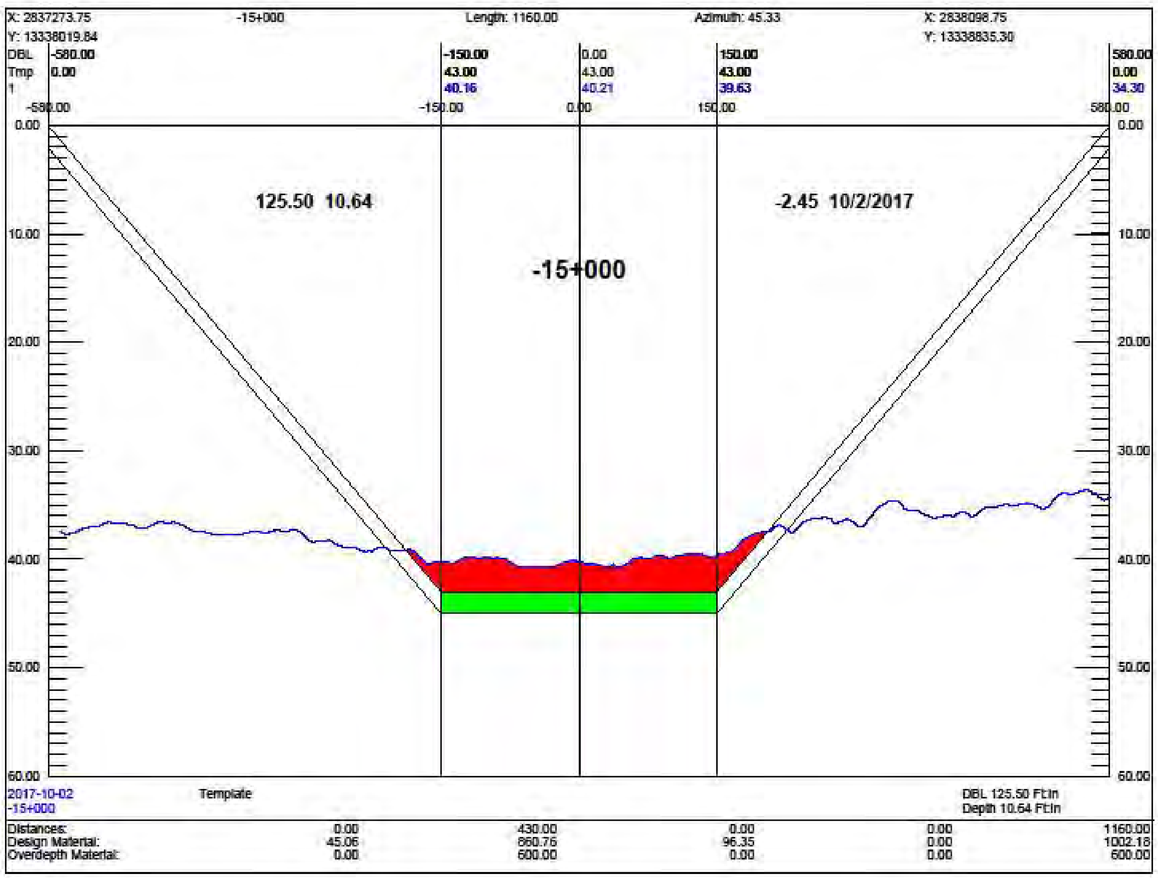
The problem being addressed here is: a **bar offshore** of the jetties (near Station -15). The equilibrium depth at the edges of the authorized channel consistently shows as a depth of 34ft MLLW in several surveys. The authorized channel depth between the jetties and offshore of the jetties is 40ft and is dredged to 45ft (40ft authorized + 2ft squat + 1ft safety + 2ft advanced maintenance). At this critical location where the longshore sediment transport crosses the channel to the southwest, this bar shoaling to 34ft is effectively determining the maximum draft of ships. The turbidity plume above the shallow portion of the offshore shoal is shown below, along with some depth contours that show how the shoal wraps around the channel. Although all these stations are negative, they seem to be shown on the SWG website as positive.



A plan view of the areas bathymetric survey of March 2016 is shown below. Note the depths shallower than the 45ft dredging and the close encroachment of the shoal (red and orange).



The natural (equilibrium) depth of the shoal is 34ft, as shown in the cross-section below, which was from the October 2017 survey after the January 2017 dredging. As seen on the right part of the contour, the equilibrium depth of the shoal is about 34ft. The red section is the material that would be dredged to reach the authorized depth, and the green section is advanced maintenance (both for the existing authorized project).



Four different methods were used to compute shoaling rates in the 300ft wide entrance channel, which is dredged to 45ft. All four methods rely on bathymetric surveys, which are only available during 2011-2017. (Another survey is being conducted as this report is being written.) Two dredgings of the outer channel occurred, in Jan 2017 and Sep-Nov 2012.

Surveys before 2011 were conducted relative to a different datum (MLT) and are not available in the on-line database. All the surveys conducted 2011 and later are relative to Mean Lower Low Water (MLLW). Whenever subaerial surveys (Lidar) are combined with hydrographic surveys, care must be taken to convert datums, since Lidar is relative to NAVD88, and hydrographic are relative to MLLW. These shoaling analyses performed here use only hydrographic surveys, but a separate task analyzing cross-sectional areas and tidal prisms for the two inlets (Pass Cavallo and Matagorda) requires the NAVD88/MLLW datum conversion.

Accuracy of Methods: The first three methods below are fairly reliable, but the last one is referred to as “very crude” (PIANC, 2008, p. 21).

Method #1: Measured Shoaling at the Offshore Bar

Proceeding in chronological order, the shoaled depth at Station -15 was monitored. The change in mid-channel depth divided by the time between surveys produced a shoaling rate.

- In Sep-Nov 2012, the channel was dredged to 45ft. The May 2013 survey shows three feet of accretion to 42 ft. 3ft / (5.5yr/12) = 6.6 ft/yr.
- From March 2015 to July 2015, the bar shoaled from 40 to 37ft. 3ft / (4yr/12) = 9.0 ft/yr.
- From March 2016 to Sept 2016, the bar shoaled from 39 to 38.5ft: 0.5ft / (8yr/12) = 0.75 ft/yr.
- From Sept 2016 to Jan 2017, the bar shoaled from 38.5 to 39.5ft. 1ft / (8yr/12) = 1.5 ft/yr.
- After dredging to 45ft in Jan 2017, the bar shoaled to 41ft in Mar 2017. 4ft / (2yr/12) = 24 ft/yr.
- This decelerated by the May 2017 survey to 39ft. 6ft / (4yr/12) = 18 ft/yr.
- Further deceleration occurred to a depth of 38ft in Sep 2017. 7ft/ (8yr/12) = 10.5 ft/yr.

It is reasonable to expect an exponentially decaying time curve in the shoaling rate after dredging. The numbers above show this, that the initial rate is fast and then decelerates to **6-10 ft/yr.**

Hurricane Harvey occurred in late August 2017. It had three different effects on the channel:

1. In the inner Bay (in smaller embayments and close to the rivers), the heavily laden floodwaters spread out and dropped their sediment load in the Bay. This is what would be expected from the physics, since the flow cross-sectional area vastly increases.
2. In the outer Bay, especially from Bird Island and gulfward, the channels were scoured out to nearly authorized depth, and the sideslopes were vastly reduced in height/size. Likewise, this is the expected result from the physics, since the high water levels are trying to squeeze through the entrance channel.
3. The opposite occurred offshore of the jetties where it appears that mid-channel shoaled to 38ft after the ebb tidal currents spread out and dropped their sediment load. Again, this is what is expected from the physics.

Method #2: Corps Shoaling Analysis Tool (CSAT)

This software uses all bathymetric surveys and all dredging events that have been loaded into the CSAT database to systematically estimate near-future shoaling rates every 10 feet along the channel. However, surveys before and after 2011 cannot be combined into one database and one set of shoaling calculations, because of the datum shift in 2011. The approach and an example are outlined by Dunkin and Mitchell (2015). Application of this method to Matagorda started in mid-April, with a completion in July, in time for the Agency Decision Milestone (ADM) in August.

Method #3: Dredged Pay Volume

In the last two paragraphs on p. 21, PIANC (2008) outlines a simple volumetric method of using the paid or dredged volumes between two stations to determine shoaling at that location. The shoaling rate is

dS/dx = (dredged volume, yd^3) (27 ft^3/yd^3)/ [(station length, ft) (channel width, 300ft) (T_*, yrs)]

where T_* is the time t during which this volume accumulated. Using the August 2016 pay survey, the T_* is 4 years from the 2012 dredging.

dS/dx = (21,697 + 22,384 + 8889 +8889) yd^3 (27 ft^3/yd^3) / [(800ft at Station -15) (300ft width) (4 yr)] = **1.74 ft/yr.** This would seem to be a reasonable estimate of shoaling during normal (non-hurricane) conditions.

Method #4: Volume-of-Cut Method (PIANC, 2008)

This "very crude" method estimates the channel depth at time t = T_*, starting with the initial depth h_o and the equilibrium depth h_e (the water depth surrounding the channel):

(Eq. 3.32) $h_{T*} = h_0 - (h_o - h_e) [1 - \exp\{- V T_* / h_o\}]$ where V is the speed of shoaling.

Solving for V, $V = -h_o / T_* \ln \{ 1 - (h_{T*} - h_o) / (h_e - h_o) \}$

The following results were found for each of the time periods listed:

Existing Project: The change from the Jan 2017 dredging from the initial design depth h_o (45ft = 40 + 2 + 1 + 2) and an equilibrium depth of 34ft:

- March 2017 survey of depth h_{T*} = 41 ft @ 1/6 yr, dS/dx = 11.9 ft/yr
- May 2017 survey of depth of h_{T*} = 39ft @ 1/3 yr, dS/dx = 9.9 ft/yr
- Sept 2017 survey of depth h_{T*} = 38 ft @ 8/12 yr, dS/dx = 5.7 ft/yr

Conclusion: The shoaling rate starts out high but decelerates. The different methods of computing shoaling all produce the same order of magnitude, but shoaling is greatly affected by events (Hurricane Harvey in 2017). Measured shoaling at the offshore bar pre-Harvey varies **between 2 and 10 ft/yr.**

Future Project: The future project's 49ft design depth (in the entrance channel) will be dredged to h_o = 54ft (49 + 2 + 1 + 2). Using the same equilibrium depth h_e = 34ft and the same V found above for the existing project, the shoaling rate with the Sept 2017 survey is 8.5 ft/yr. It is reasonable to expect that a deeper hole will shoal faster than **the existing project's 5.7 ft/yr.** The actual rates with this crude method are not as believable as other methods, but it allows prediction of an expected % increase in shoaling for the new project of 8.5 / 5.7 = 149% (an **approximately 50% increase**).

Possible Solutions to Offshore Shoaling Problem

Several "brainstorming" solutions were considered before eliminating impractical options:

1. Lengthen the jetties (too costly and just extends the problem seaward)
2. A sand trap northeast of the channel bar (See analysis below.)
3. Dredge more frequently (the offshore bar shoals too quickly, just a few months)
4. Dredge the entire entrance channel deeper (unnecessary, since the problem section consistently occurs at one location)
5. Dredge deeper in the channel section near the bar (This is the best option. See analysis below.)

#2: The feasibility of a sand trap was tested in the field at five locations (Weiser, 1962). Five test pits were dug to 30' x 100' x 500' with 3:1 side slopes. Suspended loads, bedloads, and shoaling were measured. The two pits in the Gulf shoaled an ORDER OF MAGNITUDE FASTER than the Bay pits (~300 yd^3/linear ft/yr vs. ~30). Although intertidal sand traps have been used in some locations, a completely submersed trap appears to be too ephemeral.

#5 (**recommended**): It is proposed that the entrance channel "near" the offshore bar be dredged deeper than the 45ft current dredging depth, and in the future, deeper than the 54ft dredging depth. The methods detailed in this paper do not provide enough detail in time or space to specify the length of this extra dredging. However, detailed shoaling rates in both time (a few years) and space (every 10 ft) are the purpose of the CSAT software.

CAVEAT: Currently the entrance channel is dredged and then dumped offshore. This is the classic coastal engineering example of a deficient design: removing sand from the littoral zone. This has already been happening ever since this channel was constructed, as is evident in the cross-shore offset of the shorelines. In order to mitigate this certain starvation of the downdrift beach, it is proposed that the dredged entrance channel sand be placed on the downdrift (southwest) beach (in a nearshore placement berm). Whether this is more practical and cost effective for a cutterhead with pipes or with hopper dredges placing a nearshore berm is a matter for further detailed analysis. But current practice is for hopper dredges.

Dredging Maintenance Plan Change

There is no plan to change the current practice of 3 ft advance maintenance in the entrance and 2 ft advance maintenance in the bay. At the offshore bar, advance maintenance will be 8 ft over a 1600 ft section of channel.

2.10 MATAGORDA SHIP CHANNEL SHOALING ANALYSIS USING CSAT

The Corps Shoaling Analysis Tool (CSAT) was applied to estimate annual shoaling rate along MSC in support of DMMP development. The CSAT computes shoaling rate using channel boundary information from National Channel Framework (NCF), hydrographic survey datasets from e-Hydro (enterprise Hydrosurvey Processing), and historical dredging records. The NCF provides detailed information about the boundaries of the navigation channel and is divided into reaches that are designated at the District level and may represent historical shoal areas, typical dredging areas, hydrographic survey areas, or changes in operational use. The e-Hydro is a GIS desktop application tool that processes and makes USACE hydrographic surveys available online. The e-Hydro database also archives hydrographical surveys, which are regularly collected by the USACE to assess channel conditions. CSAT uses historical dredging records to identify dredging events, and shoaling rate and is computed based on elevation differences for the survey pairs between dredging events. Each survey set comparison is combined to provide an overall channel shoaling between periods of analysis. Further detailed information on CSAT computation methods is available in Lauren et al. (2017).

The color-coded polygons in Figure 1 denote the boundary of MSC reaches where shoaling rate was computed in this study. Hydrographic surveys along these reaches are available in e-Hydro for the time period of 2012~2018.Those surveys datasets were interpolated into uniform 10ft x 10ft grid for shoaling rate estimation. Hydrographic surveys need to be in a consistent vertical datum for the time period of CSAT analysis. SWG has changed reference vertical datum for hydrographic surveys from MLT to MLLW starting in 2016. Therefore, one set of average annual shoaling rates along MSC was calculated for the time period of 2012-2015 when hydrographic surveys were collected w.r.t MLT vertical datum. Table 1 lists date and percentage coverage of each hydrographic survey that was used for the 2012-2015 time period CSAT analysis. Hydrographic surveys along MSC between March 2016 and May 2017, which were referenced w.r.t MLLW, were also used to determine another set of annual shoaling rates. However, CSAT requires at least three hydrographic surveys for meaningful shoaling rate estimation. Unfortunately, more than three hydrographic surveys were only available along the sea bar and jetty channel reaches. Therefore, CSAT was able to resolve shoaling rates along this channel only for the time period of March 2016 to May 2017. CSAT was also not able to resolve shoaling rates along the “Point Comfort North/South Basins Entrance” reach for the time period of 2012-2015 due to the same data-limited condition. Table 2 lists dates and percentage coverage of each hydrographic survey along sea bar and jetty channel reaches that were used for CSAT analysis for the time period of 2016-2017. Hydrographic surveys that were performed after hurricane Harvey, which struck the Texas coast at the end of August 2017, were not used in this analysis, in order to exclude effects of extreme events on average annual shoaling rate.

Figure 1: Matagorda Ship Channel NCF with reaches denoted by different colors

Table 1: Hydrographic Surveys list for 2012-2015 CSAT Analysis

Survey Date	Survey ID	Reach Name	Percentage Coverage
20110928	MS_01_SJC_20110928_CS_40_MLT	Sea Bar and Jetty Channel	99.97
20130501	MS_01_SJC_20130501_CS_40_MLT	Sea Bar and Jetty Channel	99.96
20140323	MS_01_SJC_20140323_CS_40_MLT_COMBINED	Sea Bar and Jetty Channel	97.01
20150204	MS_01_SJC_20150204_CS_40_MLT	Sea Bar and Jetty Channel	100.00
20150327	MS_01_SJC_20150327_CS_A_40_MLT_PARTIAL	Sea Bar and Jetty Channel	97.20
20150327	MS_01_SJC_20150327_CS_B_40_MLT_PARTIAL	Sea Bar and Jetty Channel	2.30
20150720	MS_01_SJC_20150720_EX	Sea Bar and Jetty Channel	99.86
20151113	MS_01_SJC_20151113_CS_38_MLT	Sea Bar and Jetty Channel	99.83
20120519	MS_02_MPL_20120519_CS_38_MLT	Matagorda Penisula to Light 48	99.77
20130307	MS_02_MPL_20130307_CS_38_MLT	Matagorda Penisula to Light 48	22.28
20130410	MS_02_MPL_20130410_CS_38_MLT	Matagorda Penisula to Light 48	29.71
20130905	MS_02_MPL_20130905_CS_38_MLT	Matagorda Penisula to Light 48	99.56
20150407	MS_02_MPL_20150407_CS_38_MLT	Matagorda Penisula to Light 48	37.35
20150722	MS_02_MPL_20150722_CS_36_MLT_COMBINED	Matagorda Penisula to Light 48	99.49
20151105	MS_02_MPL_20151105_CS_36_MLT	Matagorda Penisula to Light 48	99.52
20120519	MS_03_LAC_20120519_CS_38_MLT	Light 48 to Alcoa Channel	100.00
20130205	MS_03_LAC_20130205_CS_38_MLT_PARTIAL	Light 48 to Alcoa Channel	37.62
20130207	MS_03_LAC_20130207_CS_38_MLT_PARTIAL	Light 48 to Alcoa Channel	41.86

20130828	MS_03_LAC_20130828_CS_38_MLT	Light 48 to Alcoa Channel	100.00
20150209	MS_03_LAC_20150209_CS_38_MLT	Light 48 to Alcoa Channel	37.62
20150407	MS_03_LAC_20150407_CS_38_MLT_PARTIAL	Light 48 to Alcoa Channel	9.64
20150408	MS_03_LAC_20150408_CS_38_MLT_PARTIAL	Light 48 to Alcoa Channel	57.13
20150421	MS_03_LAC_20150421_CS_38_MLT_PARTIAL	Light 48 to Alcoa Channel	30.17
20150617	MS_03_LAC_20150617_OT_38_MLT	Light 48 to Alcoa Channel	98.56
20151105	MS_03_LAC_20151105_CS_36_MLT	Light 48 to Alcoa Channel	99.82

Table 1 (Cont'd): Hydrographic Surveys list for 2012-2015 CSAT Analysis

Survey Date	Survey ID	Reach Name	Percentage Coverage
20120519	MS_04_ATB_20120519_CS_38_ML T	Aloca Channel to Point Comfort Turning Basin	100.00
20130829	MS_04_ATB_20130829_CS_38_ML T	Aloca Channel to Point Comfort Turning Basin	100.00
20150209	MS_04_ATB_20150209_CS_38_ML T	Aloca Channel to Point Comfort Turning Basin	100.00
20150422	MS_04_ATB_20150422_CS_36_ML T	Aloca Channel to Point Comfort Turning Basin	100.00
20151104	MS_04_ATB_20151104_CS_36_ML T	Aloca Channel to Point Comfort Turning Basin	98.48
20120519	MS_05_PCT_20120519_CS_38_MLT	Point Comfort Turning Basin	99.61
20130904	MS_05_PCT_20130904_CS_38_MLT	Point Comfort Turning Basin	99.93

20140222	MS_05_PCT_20140222_CS_38_MLT	Point Comfort Turning Basin	91.80
20150422	MS_05_PCT_20150422_CS_38_MLT	Point Comfort Turning Basin	82.52
20151104	MS_05_PCT_20151104_CS_36_MLT	Point Comfort Turning Basin	89.38
20160306	MS_05_PCT_20160306_CS_38_MLT	Point Comfort Turning Basin	98.08
20120331	PH_01_APC_20120331_CS_12_MLT	Approach Channel	97.38
20131031	PH_01_APC_20131031_CS_12_MLT	Approach Channel	97.33
20140319	PH_01_APC_20140319_CS_12_MLT	Approach Channel	97.34
20120331	PH_02_NSB_20120331_CS_12_MLT	North-South Basin	96.47
20131031	PH_02_NSB_20131031_CS_12_MLT	North-South Basin	99.66
20140319	PH_02_NSB_20140319_CS_12_MLT	002 North-South Basin	85.07
20120331	PH_03_EWB_20120331_CS_12_MLT	East-West Basin	97.12
20131031	PH_03_EWB_20131031_CS_12_MLT	East-West Basin	97.12
20140319	PH_03_EWB_20140319_CS_12_MLT	East-West Basin	97.12
20120331	PL_01_PLC_20120331_CS_12_MLT	Port Lavaca Channel	100.00
20140319	PL_01_PLC_20140319_CS_12_MLT	Port Lavaca Channel	100.00
20150304	PL_01_PLC_20150304_CS_12_MLT	Port Lavaca Channel	100.00

Table 2: Hydrographic Survey list for March 2016 and May 2017 CSAT Analysis

Survey Date	Survey ID	Reach Name	Percentage Coverage
20160304	MS_01_SJC_20160304_CS_40_MLLW	Sea Bar and Jetty Channel	99.89834
20160928	MS_01_SJC_20160928_CS_40_MLLW	Sea Bar and Jetty Channel	50.99827
20160929	MS_01_SJC_20160929_CS_40_MLLW	Sea Bar and Jetty Channel	47.83181
20170313	MS_01_SJC_20170313_CS_PH_40_MLLW	Sea Bar and Jetty Channel	99.86001
20170523	MS_01_SJC_20170523_CS_40_PH_MLLW	Sea Bar and Jetty Channel	99.79001

CSAT Shoaling analysis results for 2012-2015 time period:

CSAT-computed average annual shoaling rates (ft/yr) and shoaling volume (cy/yr) along each MSC reach for the 2012-2015 time period are listed in Table 3. The total annual shoaling rate for the entire MSC was 1,961,333 cy/yr for the 2012-2015 time period.

Table 3: Average annual shoaling rate along MSC reaches for 2012-2015 time period

Reach ID	Reach Name	From Station to Station	Average Shoaling Rate (ft/yr)	Average Shoaling Volume (CY/yr)
MS_01_SJC	Sea Bar and Jetty Channel	-20+000 to 0+000	1.23	273,650
MS_02_MPL	Matagorda Peninsula to Light 48	0+000 to 65+150	0.54	270,237
MS_03_LAC	Light 48 to Alcoa Channel	65+150 to 110+000	2.39	846,411
MS_04_ATB	Alcoa Channel to Turning Basin	110+00 to 116+223	5.18	349,167
MS_05_PCT	Point Turning Comfort Basin	116+223 + 117+223	1.22	44,510

PH_01_APC	Approach Channel	0+00 to 102+23	0.72	40,222
PH_02_NSB	North-South Basin	-1+38 to 16+00	1.55	28,004
PH_03_EWB	East-West Basin	0+50 to 17+50	1.28	20,112
PL_01_PLC	Port Lavaca Channel	0+00 to 217+71	0.85	86,426
PL_02_LBT	Lynn Bayou Turning Basin	0+50 to 5+82	0.75	2,597
				Total=1,961,333

Computed average annual shoaling **volume** was highest for the Light 48 to Alcoa Channel reach, with an average annual volume of 846,411 cy/yr, whereas average annual shoaling **rate** was highest for the Alcoa Channel to Turning Basin reach, with an average rate of 5.18 ft/yr. Figures 2 and 3 display average annual shoaling volume (cy/yr) and shoaling rate (ft/yr) among different MSC reaches, respectively. From Figure 2, it is clear that "Light 48 to Alcoa Channel" and "Alcoa Channel to Turning Basin" reaches contributed the major portion of annual MSC shoaling volume. Also, average annual shoaling rates along both of these two reaches are significantly higher in comparison to other reaches, with shoaling rate values exceeding 2 ft/yr. Shoaling rate variability along each reach is discussed in detail in the following paragraphs.

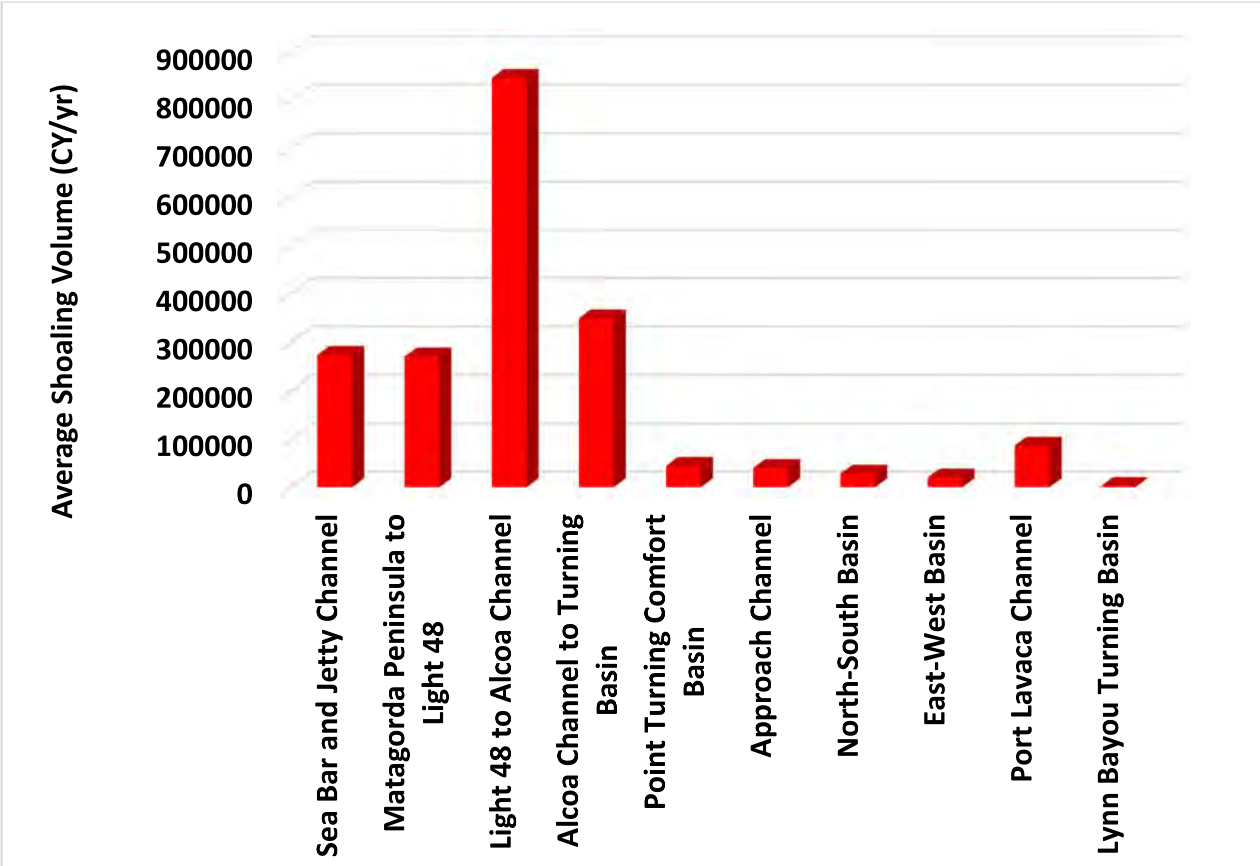


Figure. 2 Average annual shoaling volume (cy/yr) comparisons among different MSC reaches

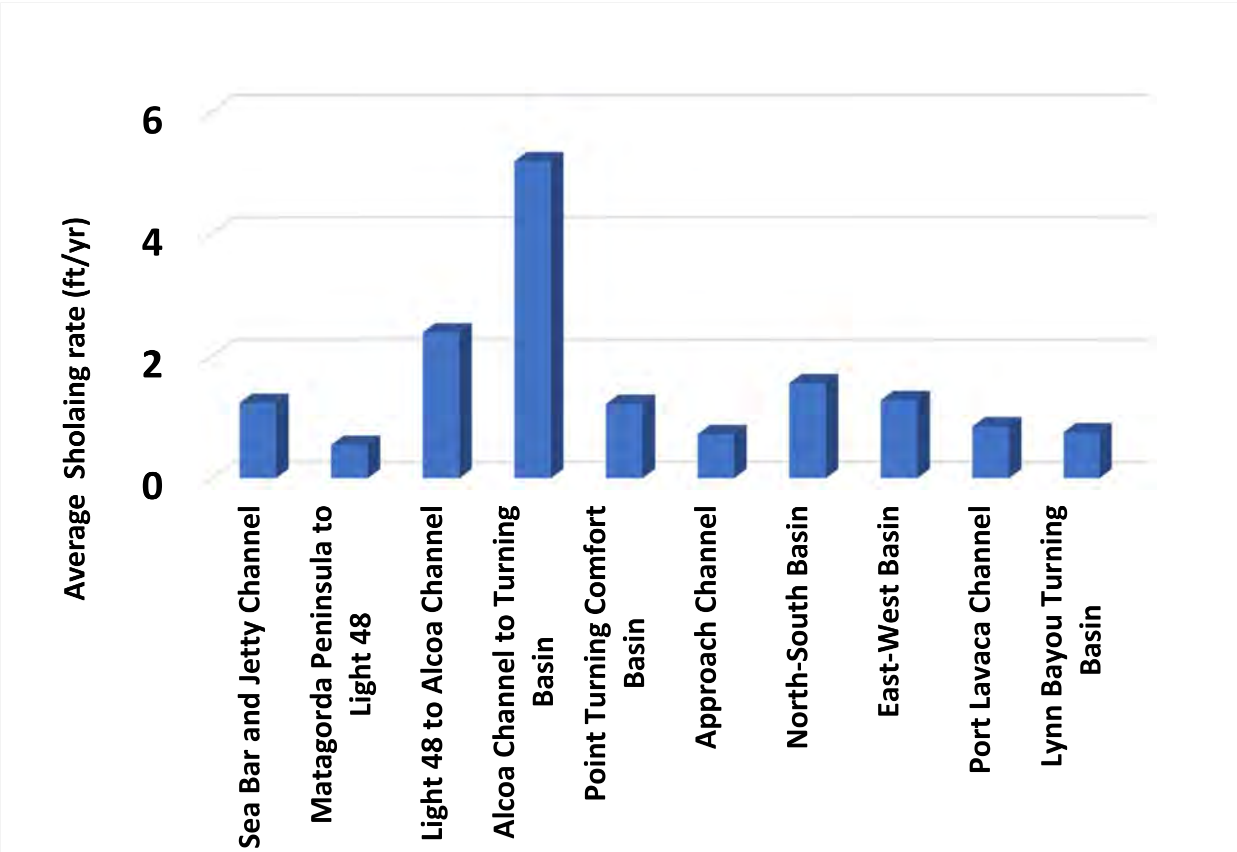


Figure. 3 Average annual shoaling rate (ft/yr) comparisons among different MSC reaches

Sea Bar and Jetty Channel reach, which extends from station -20+000 to station 0+000, has an average annual shoaling rate and shoaling volume of 1.23 ft/yr and 273,650 cy/yr, respectively. There was a significant variability in shoaling rates along this reach, which is clearly visible from the shoaling map shown in Figure 4. Yellow to red colors represent high shoaling rates, whereas blue color denotes large erosion rates. This figure clearly identified the offshore shoaling bar location,from station -12+000 to station -18+000. Shoaling rate in this region was 2.2 ft/yr. Figure 4 also identified pockets of high eroding areas at several locations along this reach (e.g., station -1+000 to -2+000). This shoaling analysis also denoted pockets of high shoaling areas within the south side of the channel in proximity to station -5+000.

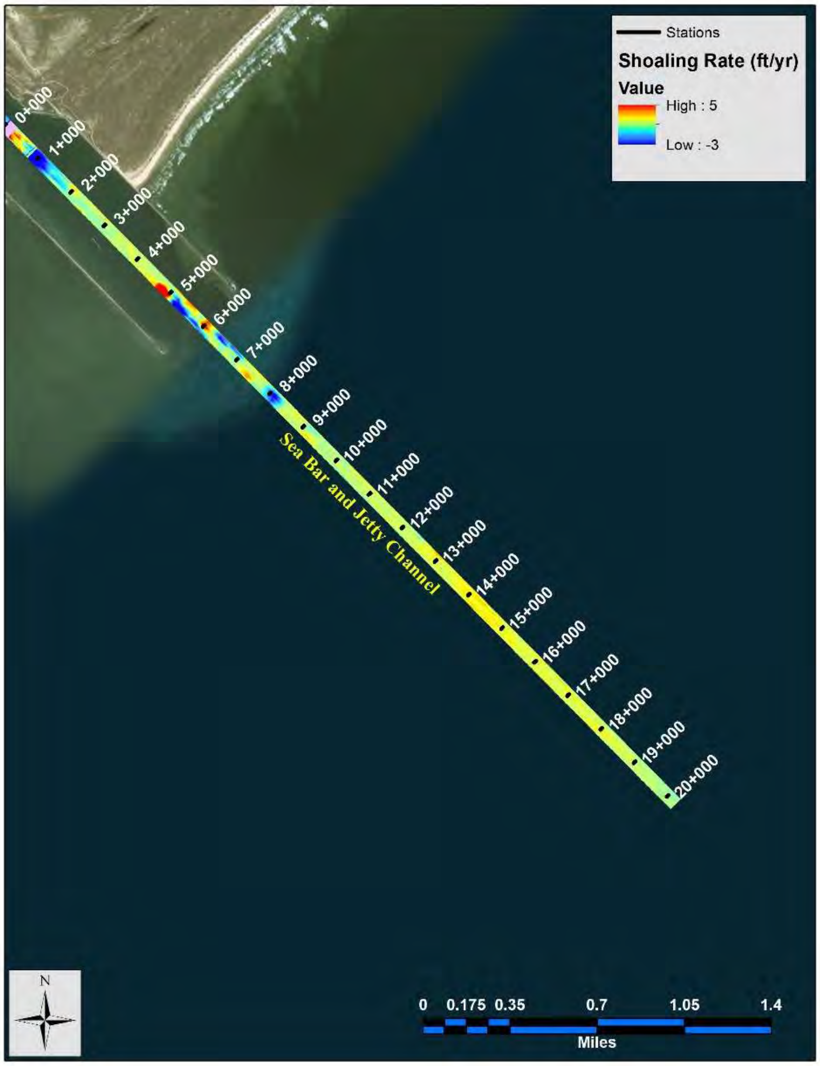


Figure 4: Shoaling Map displaying average annual shoaling rates along Sea Bar and Jetty Channel reach. Note that black lines denote station location along the reach

Matagorda Peninsula to Light 48 Channel reach, which extends from station 0+000 to station 65+150, has an average annual shoaling rate and shoaling volume of 0.54 ft/yr and 270,237 cy/yr, respectively. Although the average annual shoaling rate of the entire reach is low, this channel contains long sections of both eroding and high shoaling areas. This is clearly visible from the shoaling rate map shown in Figure 5. Figure 5 displays shoaling rates along part of Matagorda Peninsula to Light 48, the channel reach from station 0+000 to station 36+000, whereas the shoaling rate for the rest of channel reach is shown in Figure 6. The shoaling rate map for the entire Matagorda Peninsula to Light 48 channel reach is not shown in Figure 5, in order to demonstrate high resolution shoaling variability along the reach. Red color signifies areas of higher shoaling, whereas blue color denotes erosion areas. It is clearly visible from Figure 5 that erosion areas exist between station 0+000 and 15+000 with an approximate average erosion rate of -1.0 ft/ yr. There also exists a pocket of high shoaling areas within the south side of the channel in proximity to station 3+000. Significant shoaling also occurred along the part of Matagorda Peninsula to Light 48 channel reach from station 15+000 to 48+00. (See Figures 5 and 6). The rest of the channel from station 48+00 to 65+150 suffered moderate erosion issues during the 2012-2015 time period, as is evident in Figure 6.

Figure 5. Map showing the shoaling rates for the part of Matagorda Peninsula to Light 48 channel reach (station 0+000 to station 36+000): The red color signifies areas of higher shoaling, while blue color denotes erosion areas. Black lines denote station locations along the reach.

Figure 6. Map showing the shoaling rates for the part of Matagorda Peninsula to Light 48 channel reach (station 36+000 to station 65+000): The red color signifies areas of higher shoaling, while blue color denotes erosion areas. Black lines denote station location along the reach.

Average annual shoaling rate and shoaling volume along Light 48 to Alcoa Channel reach, which extends from station 65+150 to station 110+000, were 2.39 ft/yr and 846,411 CY/yr, respectively. Shoaling maps shown in Figures 7 and 8 display shoaling variability along this channel. Significant shoaling occurred along the entire reach of the channel, as was evident from Figures 7 and 8. Shoaling rate was particularly high along part of the reach from station 96+000 to station 100+00 and also station 105+000 to station 110+000 (Figure 8). High shoaling might occur in this region due to its close proximity to underwater placement areas.

Also, strong current and turbulence might be present along the bending part of the channel (station 96+000 to station 100+00), which might also contribute to high shoaling conditions.

Figure 7. Map showing the shoaling rates for the part of Light 48 to Alcoa Channel reach (station 65+000 to station 98+000): The red color signifies areas of higher shoaling, while blue color denotes erosion areas. Black lines denote station location along the reach.

Figure 8. Map showing the shoaling rates for the part of Light 48 to Alcoa Channel reach (station 65+000 to station 110+000): Approach Channel, North-South Basin, Port Lavaca Channel, Lynn Bayou Turning Basin, Alcoa Channel to Point Comfort Turning Basin, Point Comfort Turning Basin, and Point Comfort North/South Basin Entrance. The red color signifies areas of higher shoaling, while blue color denotes erosion areas. Black lines denote station location along the reach.

Shoaling rate variability along Approach Channel, North-South Basin, Port Lavaca Channel, Lynn Bayou Turning Basin, Alcoa Channel to Point Comfort Turning Basin, Point Comfort Turning Basin and Point Comfort North/South Basin Entrance reaches are shown in Figure 8. Annual average shoaling rate and shoaling volume along these reaches are listed in Table 3. Among these reaches, highest shoaling rates occurred along Alcoa Channel to Point Comfort

Turning basin, with an average annual shoaling rate of 5.18 ft/yr and shoaling volume of 349,167 cy/yr. Significant shoaling also occurred in Point Turning Comfort Basin, North-South Basin, and East-West Basin with an average annual shoaling rate exceeding 1 ft/yr.

CSAT Shoaling Analysis results for the March 2016 - May 2017 Time Period

As discussed earlier, CSAT was not able to resolve shoaling rates along all MSC reaches, except the sea bar and jetty channel reach, due to limited availability of hydrographic surveys for the time period of analysis. Shoaling occurred along Sea Bar and Jetty Channel reach at an average annual rate of 2.69 ft/yr and annual volume of 596,829 cy/yr. Significant shoaling variability along the channel was also evident from the shoaling map shown in Figure 9. The shoaling map also

Figure 9: Shoaling Map displaying average annual shoaling rate along Sea Bar and Jetty Channel reach for time period of March, 2016 to May, 2017. Note. Black lines denote station location along the reach.

identified the offshore shoaling bar location along the same section of the reach (station -12+000 to station -18+000), where high shoaling also occurred during the 2012-2015 time period. Average annual shoaling rates along this region for time period of 2016-2017 exceeded 10 ft/yr, which was significantly higher in comparison to the computed average annual shoaling rate (i.e., 2.2 ft/yr) for the 2012-2015 time period. Shoaling at higher rates might occur for the March 2016 -May 2017 time period due to stabilizing effects of channel after dredging. So it is reasonable to expect exponential decay of shoaling rate over time after dredging. The shoaling map also identifies pockets of high eroding areas at several locations along this reach (e.g., station 0+000 to 1+000). This shoaling analysis also denotes pockets of high shoaling areas within the south side of the channel in proximity to station -5+000.

Conclusion

Average annual shoaling rate for the entire MSC reaches was 1,961,333 cy/yr for the 2012-2015 time period. CSAT identified significant spatial variability in shoaling rates along MSC reaches. Computed average annual shoaling rate along "Alcoa Channel to Turning Basin" reach for time period of 2012-2015 was significantly high with value exceeding 5 ft/yr. Shoaling rate along "Light 48 to Shoaling maps for Alcoa Channel" for time period of 2012-2015 was also high with annual average rate exceeding 2 ft/yr. Both 2012-2015 and March 2016 - May 2017 shoaling maps of Sea Bar and Jetty Channel reach identified existence of an offshore shoaling bar from station -12+000 to station -18+000. Average annual shoaling rate along this region for time period of 2016-2017 exceeded 10 ft/yr, which was significantly higher in comparison to the computed average annual shoaling rate (i.e., 2.2 ft/yr) for the 2012-2015 time period. Shoaling at higher rate might occur from March 2016 - May 2017, due to stabilizing effects of channel after dredging. So it is reasonable to expect exponential decay of shoaling rate over time after dredging. Based on the presence of high shoaling rates in this region, it is suggested that dredging be modified, either performing more frequent dredging or keeping larger advanced dredging maintenance depth in this section, in order to fully utilize the authorized depth along the entire channel reach. CSAT analysis also marked a high shoaling location within the south side of the jetty channel in proximity to station -5+000. High shoaling rate existence in this region warrants further investigation to evaluate jetty performance in maintaining the navigation channel. Detailed sediment transport modeling can be conducted in the PED phase to evaluate jetty performance and understand/quantify processes causing significant shoaling along the identified offshore shoaling bar location.

2.11 SHIP WAKE ANALYSIS IN MATAGORDA BAY

The following ship wake analysis for Matagorda has been completed. Results are below and are the average of 3 methods used, CIRIA, BAW, and Schiereck/PIANC. For the existing channel,

Parameter	CIRIA (2012)	BAW (2010)	Schiereck (1993) /PIANC (1987)	Kriebel and Seelig (2005)	Maximum	Mean	Minimum
Maximum Primary Wave Height at Bank (m)	0.1	0.1	0.2	N/A	0.2	0.1	0.1
Maximum Return	0.1	0.0	0.2	N/A	0.2	0.1	0.0

Velocity at Bank (m/s)							
Maximum Secondary Wave Height at Bank (m)	1.0	1.1	1.0	0.9	1.1	1.0	0.9
Maximum Wavelength of Secondary Wave (m)	28.3	42.3	28.4	N/A	42.3	33.0	28.3
Wave Period of Secondary Wave (s)	4.2	4.3	4.3	N/A	4.3	4.3	4.2

For the proposed wider and deeper channel,

Parameter	**CIRIA (2012)**	**BAW (2010)**	**Schiereck (1993) /PIANC (1987)**	**Kriebel and Seelig (2005)**	**Maximum**	**Mean**	**Minimum**
Maximum Primary Wave Height at Bank (m)	0.3	0.2	0.2	N/A	0.3	0.2	0.2
Maximum Return Velocity at Bank (m/s)	0.1	0.0	0.2	N/A	0.2	0.1	0.0
Maximum Secondary Wave Height at Bank (m)	0.9	1.1	0.9	0.6	1.1	0.9	0.6
Maximum Wavelength of Secondary Wave (m)	28.3	42.3	28.4	N/A	42.3	33.0	28.3
Wave Period of Secondary Wave (s)	4.2	4.3	4.3	N/A	4.3	4.2	4.2

The 3 methods give about the same results.

	Existing	Future Widening/Deepening
H primary =	0.3m	0.8m
V	0.2m/s	0.2m/s
H secondary =	1.0m	0.9m

All wave heights can reach the shore and, unlike the wind waves, are not depth limited. (The depth limitation is 0.78 x 10ft = 7.8ft)

Recommendations:
1. Based on these results alone, a beach erosion analysis is not justified. Even if the higher primary wave mobilizes the sediment, the velocities are so small, that there is no great transport potential.
2. Do one more wake calculation for pre-channel time period (early 60s before cut was dug). Just pick a boat with 10ft draft (barges or recreational) and compare those results to these. Then we'll be able to compare the transport potential before the existing project, during the existing project, and after the future project.

BAW (March 2011) **Principles for the Design of Bank and Bottom Protection for Inland Waterways, Bundesanstalt für Wasserbau (BAW), Kußmaulstraße 17 76187, Karlsruhe, Germany.**

CIRIA (1991) C683 The Rock Manual – The use of rock in hydraulic engineering (2nd edition) CIRIA, Classic House, 174–180 Old Street, London EC1V 9BP, UK.

Kriebel and Seelig (2005), to be provided by Daniel bahrenburg

PIANC (2014) Harbour Approach Channels Guidelines, PIANC Report No. 121 Maritime Navigation Commission, PIANC Secrétariat Général, Boulevard du Roi Albert II 20, B 3, B-1000 Bruxelles, Belgique, http://www.pianc.org**, VAT BE 408-287-945, ISBN 978-2-87223-210-9.**

Schiereck, G.J. (August 1993), "Engineering the interface of soil and water" in **Introduction to Bed Bank Shore Protection,** Delft University of Technology**,** 255pgs.

2.12 SUMMARY OF MATAGORDA BAY DATA SOURCES OF CURRENTS

by Thomas E. White, PhD, PE, D.CE

19 July 2018

(1) Measured Currents

Stationary current meters have been placed at two locations near Bird Island at two different times in the past. A third will be added in the entrance channel. Locations are:

(a) "NOAA BI Current Meter": The NOAA Bird Island station has been deployed long-term and continues to this day. The NOAA station page shows a start date of 14 July 2017. In addition to the standard data products available online (depth-averaged speed and direction), special requests can be made of NOAA for specialized data products. NOAA has proven to be very responsive and quick to fulfill such requests. Our request for detailed data was for the time period 8/4/2017 to 11/15/2017 and produced (a) temperature, (b) 6-minute averaged north currents, (c) 6-minute averaged east currents, and (d) acoustic backscatter strength (which is an uncalibrated or relative measure of the amount of suspended sediment). The data are filed in the project files in a folder named "mg0101".

(b) "NOAA Entrance tide gage": will have a current meter permanently installed in Summer 2018.

(c) "ERDC 2005 Currents" consisted of a short-term deployment of a stationary bottom-mounted ADCP and three transects with a boat-mounted ADCP, shown below.

Figure 7-12: Location of Bottom Mounted ADCP Meter and ADCP Transects from 2005 Field Data Collection

(d) "EH Bi Current Meter": The Evans-Hamilton, Inc., current meter was deployed at the EH BI site shown in the first figure for a limited time, Sep-Dec 2005.

In conclusion, below is a: **Summary of Measured Currents**

From Stationary ADCPs

Measured Quantities	Start Date	End Date	Depth (feet)	Latitude (north)	Longitude (west)	Peak Ebb Speed (cm/s)	Peak Flood Speed (cm/s)
(a) u, v, BS, T	7/11/17	continues	11	28º26.8'	-96º21.4'	102	86
(b) u, v, BS, T, WL	8/18	continues	20+	28º25.6'	-96º19.8'		
(c) u, v, BS, T	?/05	?/05	11	28º26.455'	-96º20.528'		
(d) u, v, BS, S, T, WL	9/05	12/05	11	28º26.455'	-96º20.528'	200	120

Key

u east speed (cm/s)

v	north speed (cm/s)
BS	backscatter signal strength (decibels)
S	salinity (ppt), computed as a function of Conductivity, Temperature, & Depth
T	temperature (degrees Celsius)
WL	water level (cm)

While the stationary current meter was deployed, transects were run with another current meter from a boat at several locations in both Sep and Dec 2005.

The following quantities were measured during the Sep-Dec 2005 time: (a) Waves, (b) Salinity from CTD (Conductivity/Temperature/Depth), (c) Tides, (d) water samples (to measure suspended sediment), and (e) currents. The overall deployment plan was:

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Figure 1.
Matagorda Bay Instrument Locations

The short-term transects were run at the three locations shown in the three figures below (Bird Island/Entrance, Pass Cavallo, and In-Bay [Port Lavaca]). The data from these transects

(Puckette, 2017) are **unpublished, but were obtained by this project** and stored in the project's HH/Field Data folder.

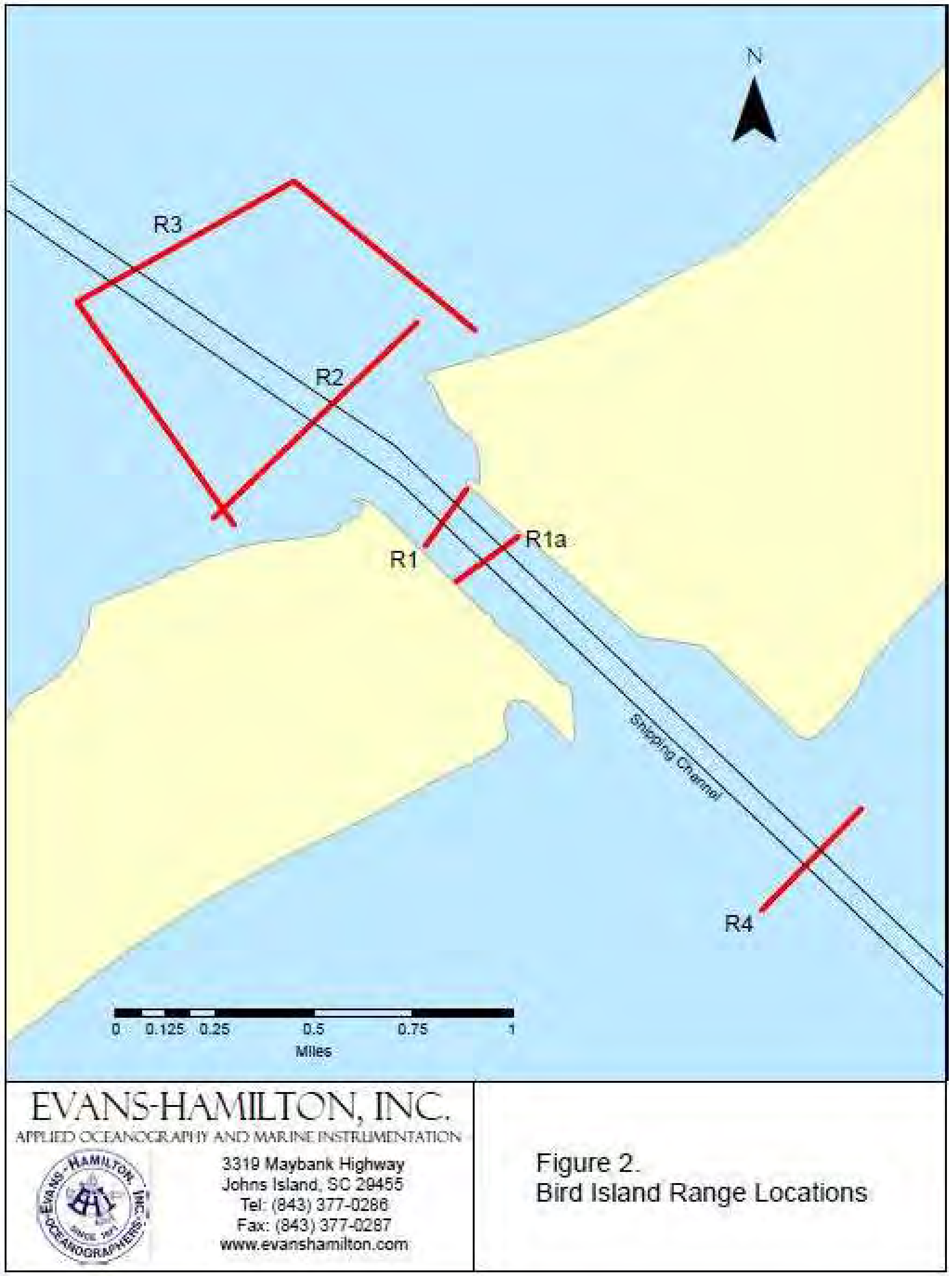
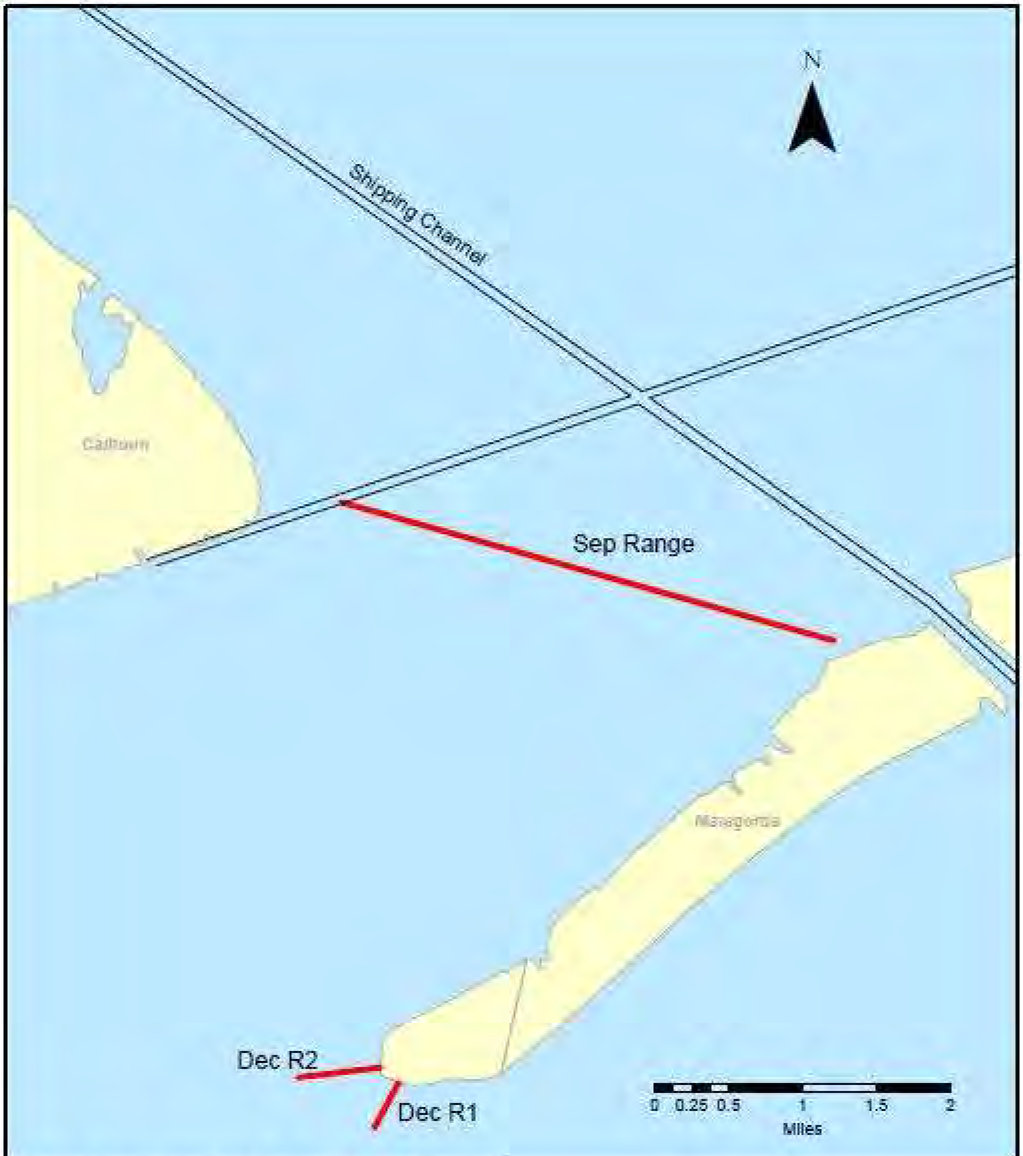


Figure 2.
Bird Island Range Locations



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3319 Maybank Highway
Johns Island, SC 29455
Tel: (843) 377-0286
Fax: (843) 377-0287
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Figure 3.
Pass Cavallo Range Locations

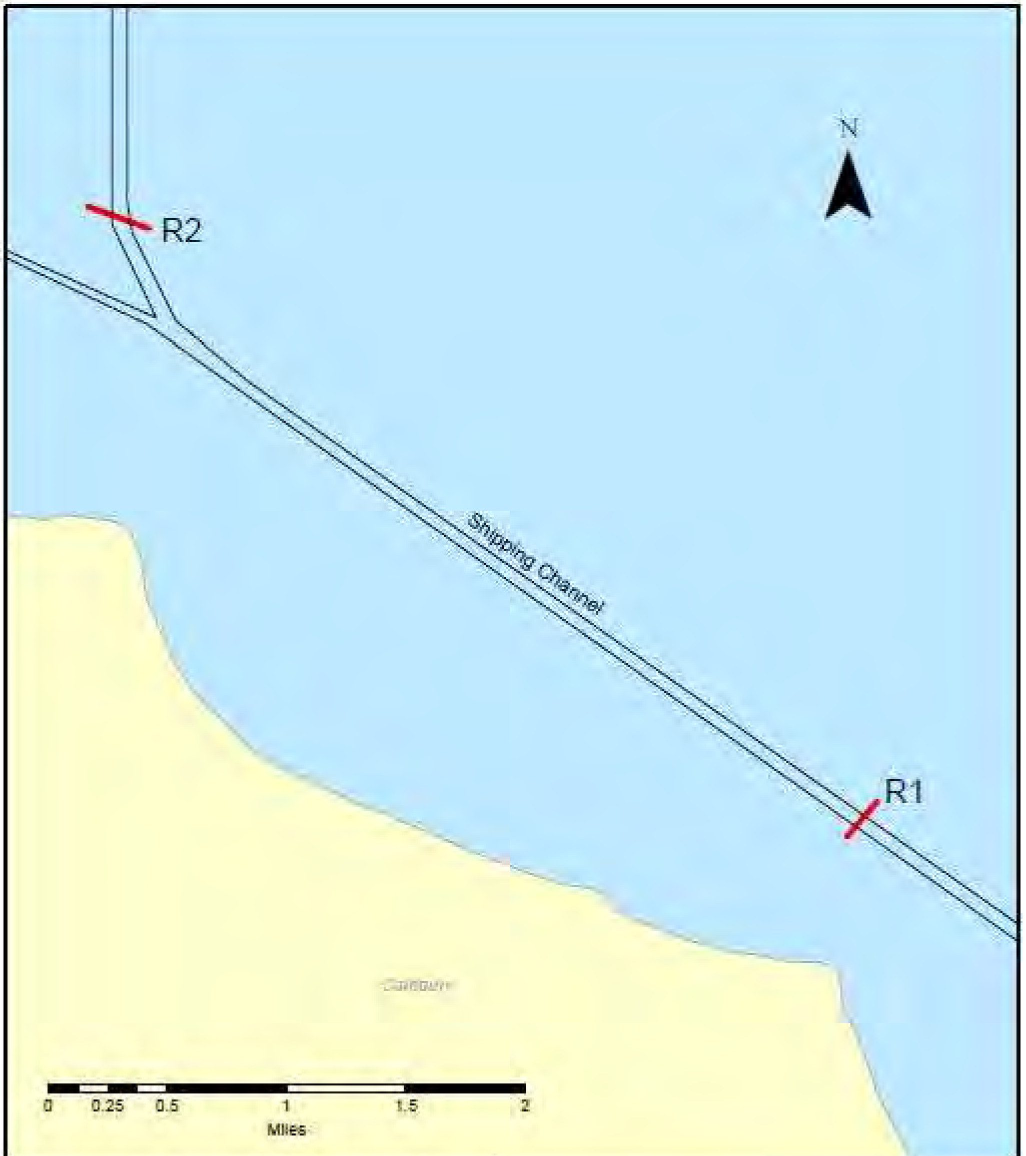

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Figure 4.
Port Lavaca Range Locations

The locations of the CTD casts and Water Samples are shown in the following two figures for the upper and lower parts of the Bay, respectively.

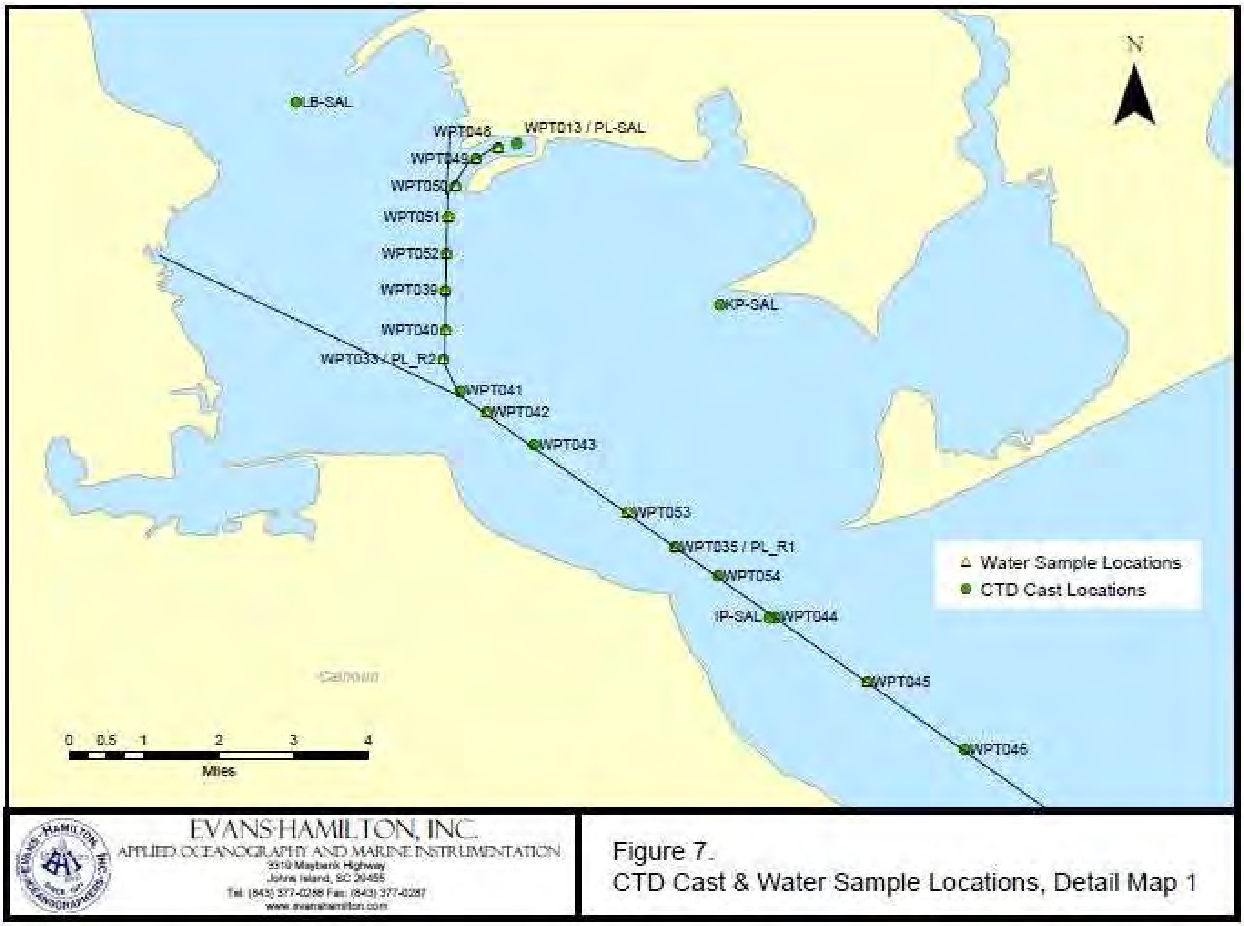

Figure 7.
CTD Cast & Water Sample Locations, Detail Map 1

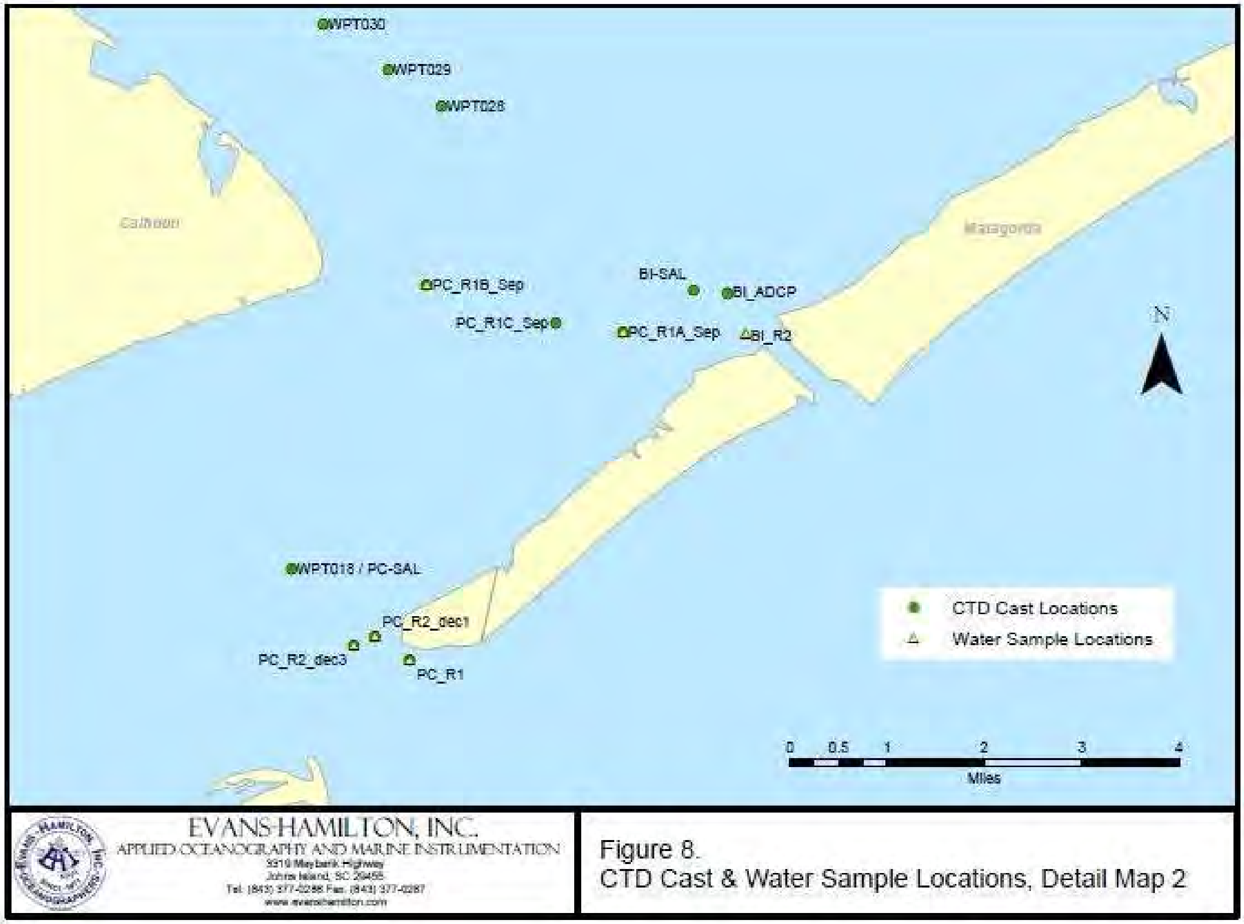

Figure 8.
CTD Cast & Water Sample Locations, Detail Map 2

(2) Currents used as Inputs to Ship Simulations

(a) 2006

A report of a ship simulation was written as:

Moffatt & Nichol, 2006a, “Matagorda Ship Channel Improvement Project, Point Comfort, Texas - Hydrodynamic and Salinity Model - Prepared for Calhoun County Navigation District”, 125pp. + Appendices A-F.

The input currents used in that ship simulation were determined to be **unrealistic by the pilots**. Also ERDC determined that their **2D model was inadequate** for this purpose:

(WTS/MITAGS, April 2014, p. 28-30): “For the specific case of the Matagorda Ship Channel, recent studies by the Corps of Engineers Engineer Research and Development Center (ERDC) have indicated that use of this 2D model is not sufficient based on evaluations of simulations conducted at ERDC by Matagorda pilots[2]. The location where this situation was discovered was

the reach between Sundown Island and the inlet (Buoys 13-14 to 20-21) during ebb tidal conditions.
The outflow from the northern and eastern portions of the bay concentrates between the island and the peninsula and crosses the MSC impacting navigation. The location of the cross flow is identified in **Figure 7-8** by the darker area intersecting with the channel behind the Matagorda Peninsula (upper side of the picture).

[2]Maynord, S.T., et. al., Risks to Navigation at the Matagorda Ship Channel Entrance, Texas, Phase 2: Evaluation of Significant Risk Factors, U.S. Army Engineer Research and Development Center, ERDC TR-11-8, August 2011, p. 132."

Figure 7-8: Aerial Photo Showing Cross-flow in the Navigation Channel from the North

(p. 30): “Consequently, ERDC developed a three-dimensional model that was based on recent data and has been used and tested in the ERDC ship simulator and evaluated by the local licensed pilots. WST has a Cooperative Research and Development Agreement (CRADA) with ERDC and these two organizations worked together to use the three-dimensional model to compute the currents required for the study of optional channel widening proposals.”

(b) 2014

The 2014 WTS/MITAGS ship simulation used updated currents produced by a more recent 3D numerical model (Moffat & Nichol, described in (c) below).

(3) Currents from Numerical Models

(c) Moffatt & Nichol 3D model (2006)

(WTS/MITAGS, p. 30, April 2014): "After much research and discussions with the Directors of the Navigation and the Flood & Storm Protection Division, Coastal and Hydraulics Laboratory (CHL), Engineer Research and Development Center, WST and CHL agreed to an approach for the mathematical modeling of the Matagorda Bay. It was recommended that the most efficient and acceptable approach to computing the currents that would affect navigation in the Matagorda Ship Channel (particularly the entrance and "Bottleneck" reaches) would be to modify and apply the hydrodynamic model, which included modeling the effects of salinity, developed by Moffatt & Nichol for the earlier MSCIP study. This is a three-dimensional model and was validated against field data. However, some adjustments had to be made since the primary purpose of the model's application was to investigate changes in salinity due to proposed changes in the inlet. The modeling of currents by Moffatt & Nichol is described in a separate report called "Hydrodynamic Modeling in Support of Vessel Maneuvering Studies" Technical Report No. 8132RP0001."

Ship simulations typically use peak flow conditions. This M&N 3D model was used to produce peak flows for inputs to the simulation. Color plots of the currents are in WTS/MITAGS (2014), with Peak Flood on p. 37 and Peak Ebb on p. 38.

The M&N 3D model was calibrated with the 2005 Evans-Hamilton measured currents (Puckette, 2006 and 2017). The calibration or "fitting" of the model results to the measured currents are shown in the WTS/MITAG report's **Figure 7-13**, shown below. Of the plots on p. 34, the top plot is u (east speed), middle plot is total speed $(u^2 + v^2)^{0.5}$, and bottom plot is v (north speed). Speeds peak at 2 m/s or 4 knots. (To read values in knots, multiply m/s by 2.)

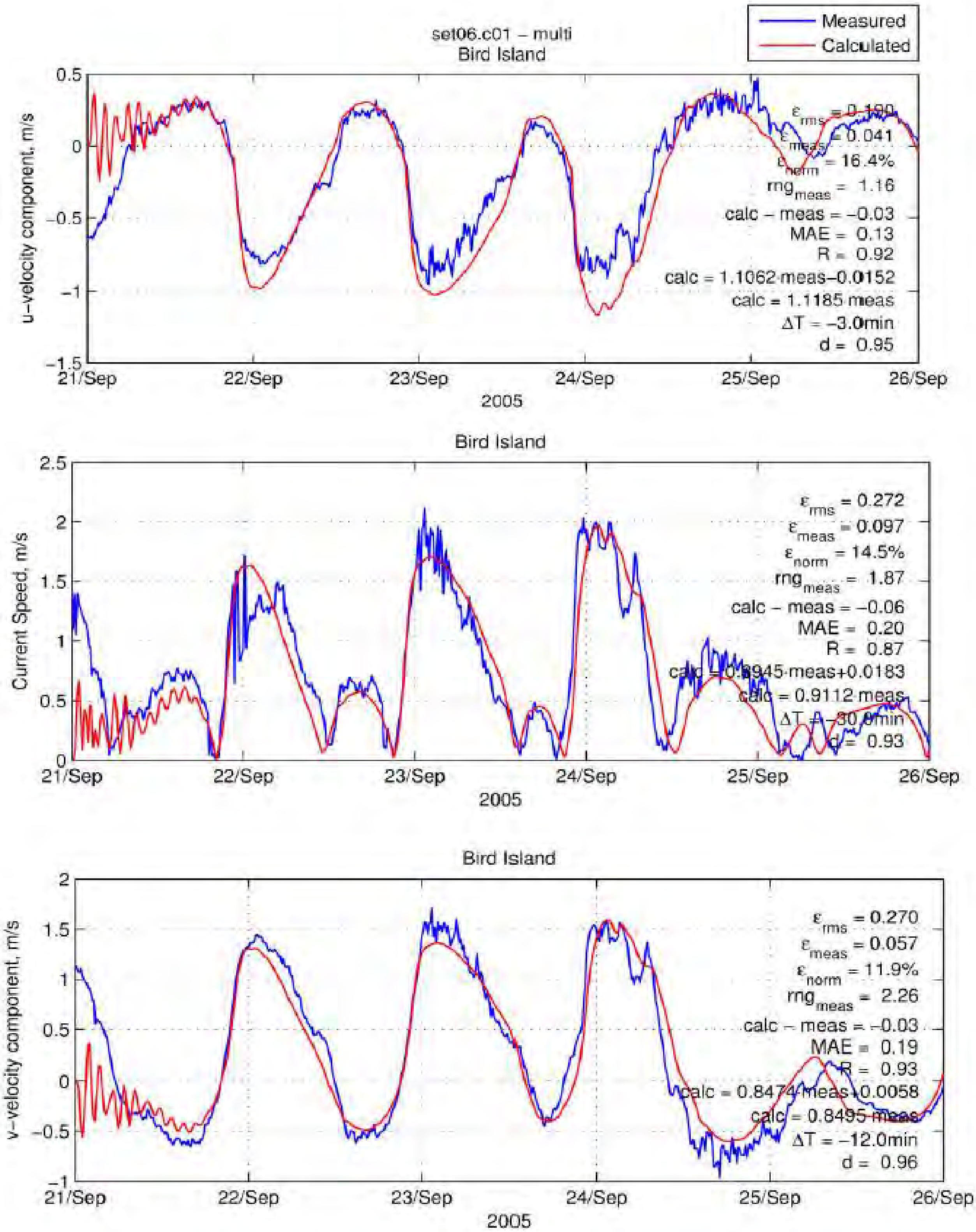

Figure 7-13: Calibration Comparison of Computed Currents to Recorded Currents at Bird Island during the period September 10-30, 2005

Attempts have been made to obtain this report from Moffatt & Nichol and WTS, but have not yet succeeded.

2.13 MATAGORDA SHIP CHANNEL FEASIBILITY LEVEL SHIP SIMULATIONS STUDY REPORT

1. INTRODUCTION

The U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) has completed a Feasibility Level Screening Simulation Program (FLSSP) to assist the USACE Galveston District (CESWG) in evaluating proposals for channel deepening and widening, and turning basin dimensions in the Matagorda Ship Channel (MSC), Texas. The study was performed at CHL's ship/tow simulator on 5-9 November 2018.

2. OVERVIEW

The existing MSC consists of the entrance/offshore channel, jetty channel, Matagorda Bay reach, Lavaca Bay reach, Point Comfort turning basin and the Port Comfort north and south basins (Figure 1). The Matagorda Bay reach has an authorized depth of 38 feet MLLW, for a width of 200 feet at a distance of 14.20 miles. The Lavaca Bay reach has an authorized depth of 38 feet MLLW for a width of 200 feet at a distance of 7.81 miles. The Point Comfort turning basin has an authorized depth of 38 feet MLLW for a width of 1000 feet at a distance of 1000 feet. The Point Comfort north and south turning basins have authorized depths of 38 feet MLLW. The Point Comfort north basin has a varying width from 344.77 feet to 159.43 feet for a distance of 1,279 feet. The Point Comfort south basin has a varying width from 283.78 feet to 185.41 feet for a distance of 1,279 feet. The entrance/offshore channel has an authorized depth of 40 feet MLLW for a width of 300 feet at a distance of 2.65 miles. The jetty channel has an authorized depth of 40 feet MLLW for a width of 300 feet at a distance of 1.14 miles. The draft plan prior to the FLSSP ship simulations was a channel width of 600 feet in the entrance/offshore channel and the jetties with a tapering to 350 feet in the Lavaca Bay reach, and 350 feet at the Matagorda Bay and Lavaca Bay reaches (Figures 2 and 3). The proposed turning basin configuration is illustrated in Figure 3. The proposed depths is 49 feet MLLW.

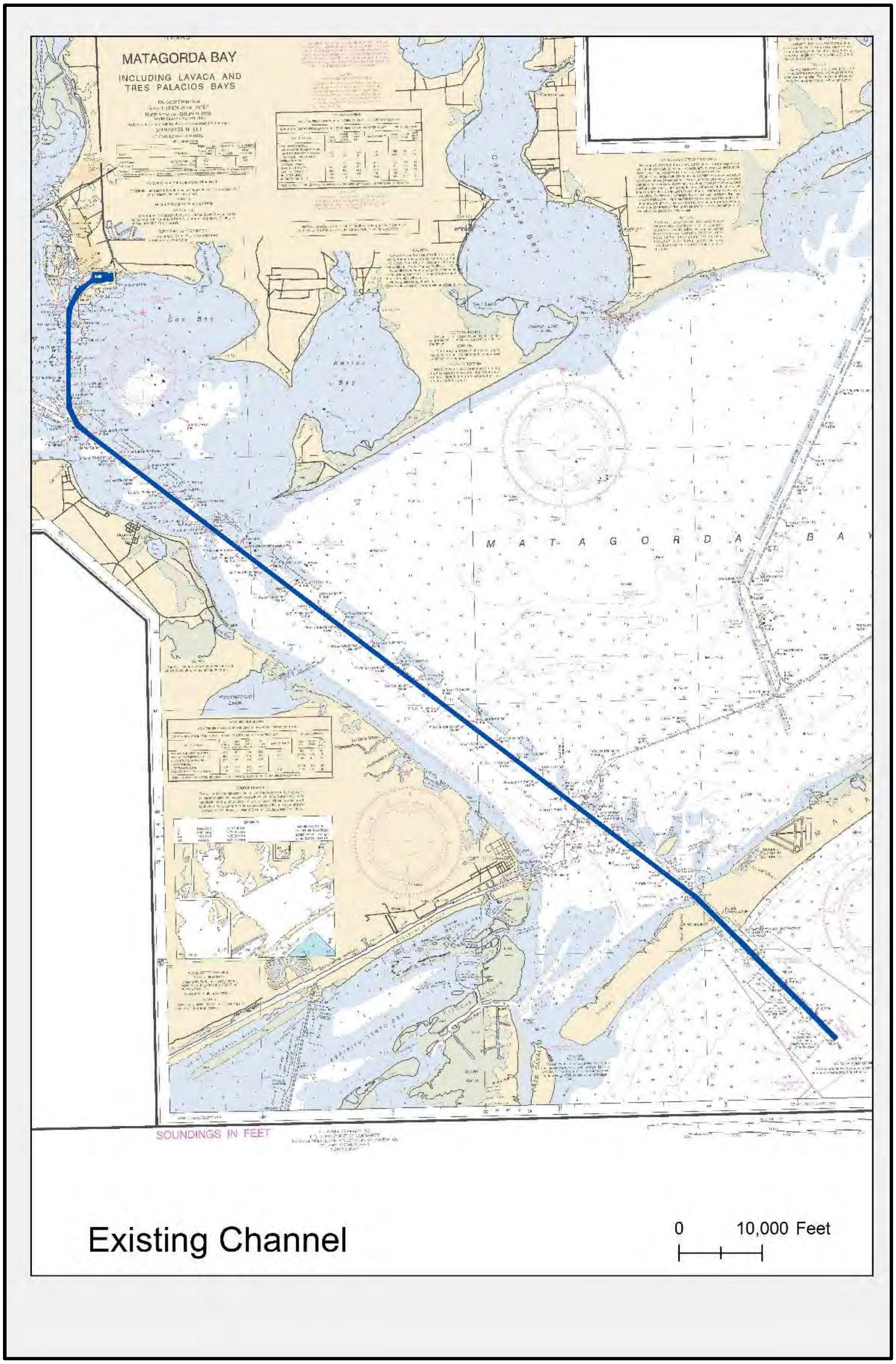

Figure 1. Location Map with Existing Channel Configuration

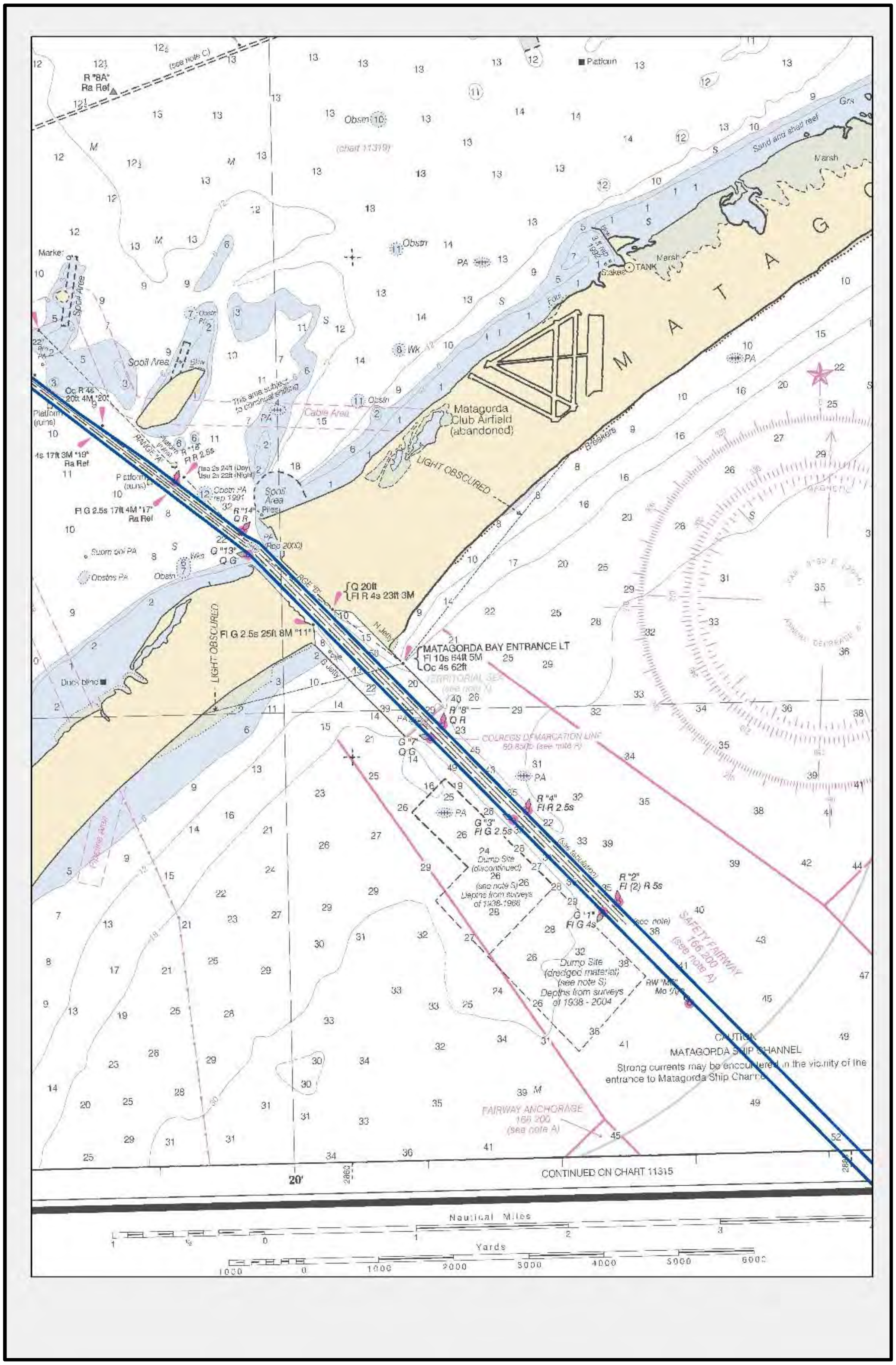

Figure 2. Draft Plan Prior to FLSSP Ship Simulations, Matagorda Entrance Channel and Taper into Lavaca Bay Reach

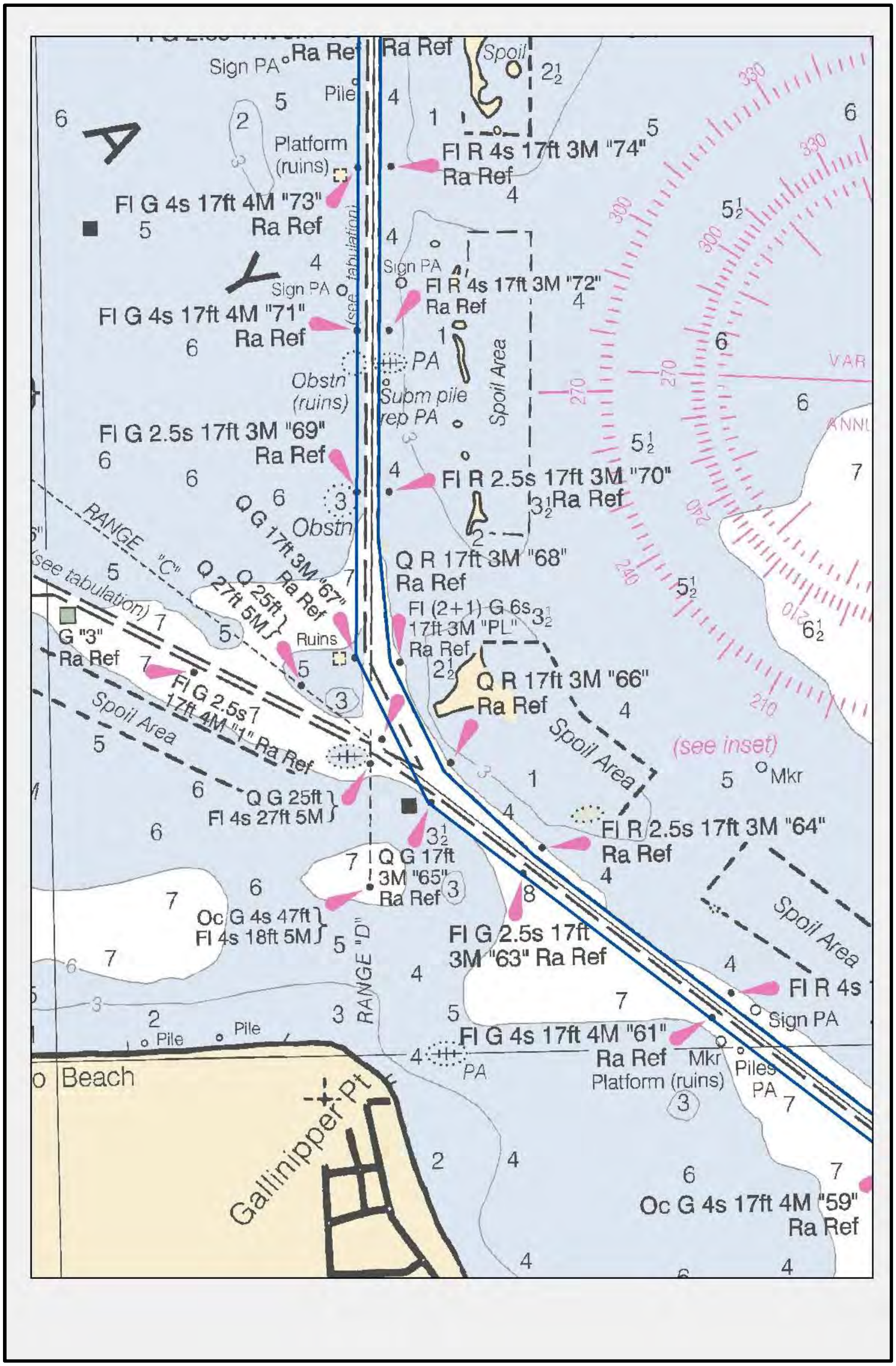

Figure 3. Draft Plan prior to FLSSP Ship Simulations, Matagorda Bay Reach with Elbow Bend

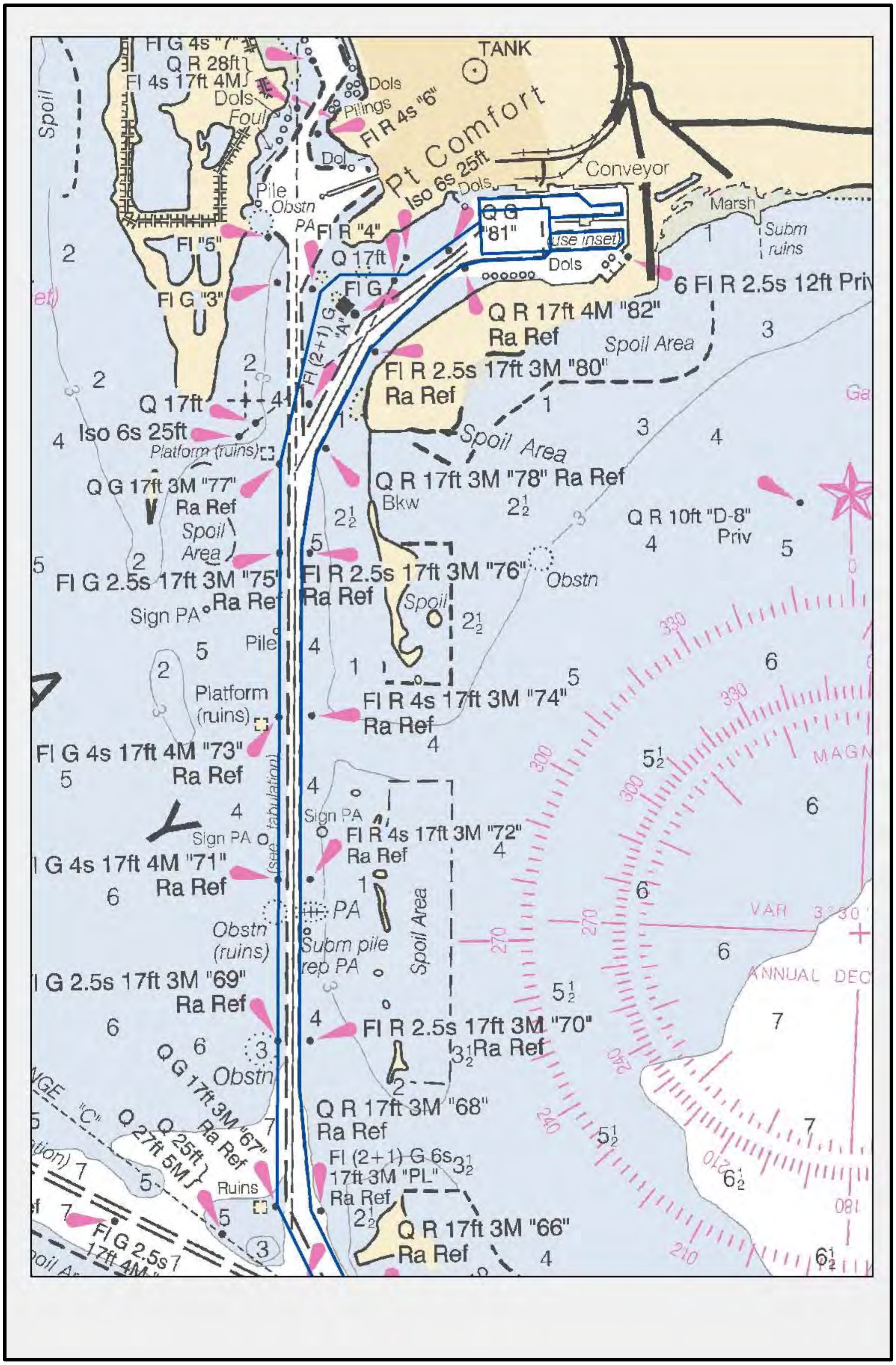

Figure 4. Draft Plan prior to FLSSP Ship Simulations, Matagorda Bay Reach with Turning Basins

3. PURPOSE

The FLSSP provides a means of conducting expert elicitations. The use of real-time simulation provides an iterative framework within which to examine ideas and possible solutions within the confines of a laboratory experiment. At the conclusion of each simulation, results from the simulation can be discussed, modifications made, and then the simulation rerun. The FLSSP is conducted in order to provide essential information for the study process and to stay within the time and cost constraints of USACE's SMART Planning. To reduce time and cost, lower resolution databases are used for ship simulation and data processing is minimized. Lower resolution databases require less costly development and also allow database modification to be done quickly during the simulation week. A low resolution database can be modified (widened, re-aligned, tapered, etc.) within a few hours. This is critical so that ideas suggested by the pilots or others can actually be tested with the same pilots. Conclusions drawn from actual data should be limited and done very carefully due to the low resolution modeling and the assumptions used during modeling. In addition, once the meetings occur, the pilots often perform "what if" tests to check bank effects and other forces. Data processing is limited to presentation of track plots and run sheets, Appendix A, to document results. The most important analysis is the group discussion at the conclusion of the FLSSP.

4. PARTICIPANTS

The FLSSP included representatives from ERDC, the Matagorda Bay Pilots (MBP), and CESWG. The individuals listed participated for the duration of the simulation testing unless otherwise noted.

ERDC: Mario J. Sanchez, Mary Claire Allison, Morgan Johnston, and Keith Martin

MBP: Captain David Adrian

CESWG: Thomas White, PhD, PE, D.CE and Michael Garske, EIT

5. CONSIDERATIONS

For reasons previously stated, model development is done in fairly low resolution. Below are the parameters and assumptions for testing:

a. Currents for max ebb and flood were obtained from a Coastal Modeling System (CMS) model that was run for existing and future conditions with updated current maxima increased by 18.56%, based on August 20118 field measurements on the same transects measured in 2005.

b. The visual scenes consist of the background terrain and a few selected building/facility features.

c. Wind conditions are set at run time at 24 knots out of the Southeast.

d. Simulated ships are limited to ships already in ERDC's ship database. The ships for testing are listed in Table 1. Pilot cards are included in Appendix B. The MT Brittania, VLCC15L, is used to simulate the correct draft for large vessels transiting the Matagorda

Entrance Chanel. The Eagle Kangar, TANK25T, is used as the design ship for the FLSSP for its LOA and Beam dimensions better represent future ships transiting along the Matagorda Bay and Lavaca Bay reaches. The ballast version of the Eagle Kangar, TANK23B, is used for simulations using wind conditions of 24 knots out of the Northeast.

e. Only one pilot from MBP participates in the FLSSP study. This is due to the size of the pilots association (3 pilots). Due to the fact that the pilots all interact with one another on a daily basis, using one pilot is deemed sufficient for FLSSP. More pilots will be used during testing in the PED phase of the project.

Table 1. Simulated Ships for Simulation Tests

Model	Name	LOA (Feet)	BEAM (Feet)	DRAFT (Feet)
VLCC15L	MT Brittania	859.6	137.8	49.2
TANK25T	Eagle Kangar	799.9	137.8	40.0
TANK23B	Eagle Kangar	799.9	137.8	28.2

6. SIMULATED SCENARIOS

The draft plan channel widths, and turning basin dimensions are developed by CESWG personnel in coordination with the Matagorda Bay Pilots. The draft plan channel width is 600 feet in the entrance/offshore channel and the jetties with a tapering to 350 feet into the Lavaca Bay reach, and 350 feet at the Matagorda Bay and Lavaca Bay reaches (Figures 2 and 3). The draft plan for the turning basins is illustrated in Figure 4. A 1200-foot turning basing is located in the approach channel to the docks. Two proposed turning basin sizes (693- and 990-foot) will be evaluated at the docks area. The proposed depth for testing is 49 feet MLLW in the entrance channel and 47 feet in the Bay.

7. RESULTS

a. Monday morning is primarily devoted to pilot familiarization and model adjustment. Data is recorded during these exercises but has little value in channel width evaluation because the purpose of the runs is to evaluate the simulator databases, and not the actual channel configurations. As such, this data is not included with this report. Thirty seven recorded testing runs are performed by the end of the week.

b. The environmental (wind and currents) and visual databases are deemed adequate for feasibility level testing.

c. Tug operations are carried out by ERDC personnel at simulator operational stations. The operator receives tug commands from the pilots via radio as they do in real life.

d. Track plots and run sheets for the FLSSP are included as an attachment to this memorandum. All exercises are one-way transits, either inbound or outbound. All turning basin runs start inbound toward the docks. Figure 5 is a photograph taken from the bridge of the design ship along the entrance channel.

e. On the run sheets, note that the “Time” blank is not always complete. This blank is used as bookkeeping tool for simulator personnel while post-processing the data.

Figure 5. View from Bridge B. Inbound ship along the Matagorda Entrance Channel

8. DISCUSSION

The final FLSSP discussion is held on the Friday morning, 9 November 2018, after completion of the exercises the day before. Everyone from paragraph 4 except Mr. Martin attended the discussion.

The simulation program is a screening tool for determining the channel width of the Tentatively Selected Plan (TSP). Friday morning's discussion represents the conclusions of the FLSSP.

9. TURNING BASIN DISCUSSION

In the initial plan for the 1200-ft turning basin, the channel width of the approach reach to the docks is 400 feet (see Figure 4 above). After some preliminary simulation runs and discussions with the pilot, it is determined that with an additional 300 feet of widening, the approach channel dimensions will better suit ship maneuvering. This modification is recommended over the design in the original proposal. The recommended approach channel configuration is shown in Figure 6. For the turning basin in the docks, the 693-foot configuration was deemed not feasible for a ship with an 800-ft LOA. The 990-foot configuration was feasible, but not recommended when there are ships already at the docks.

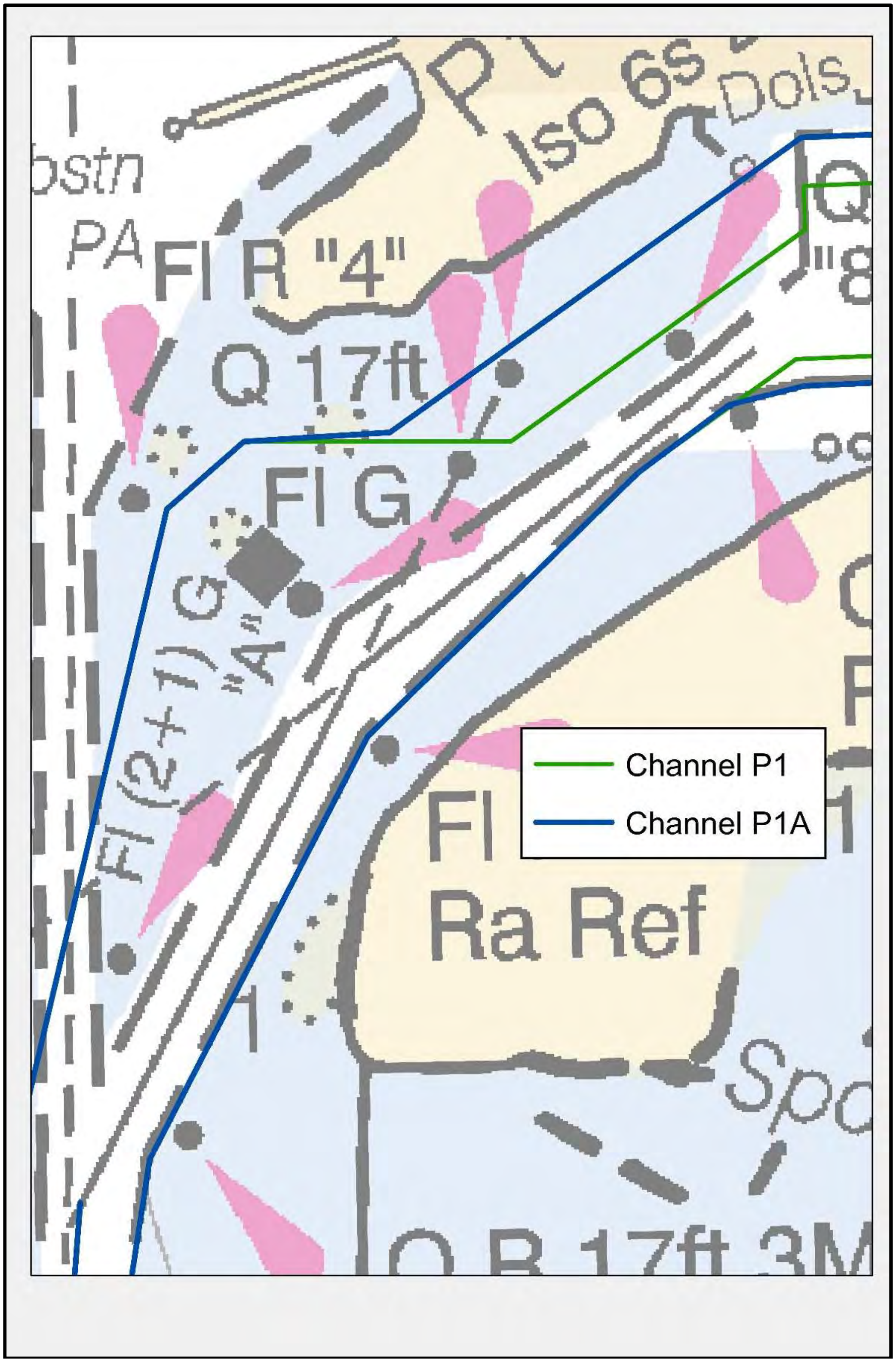

Figure 6. Recommended configuration of the 1200-ft Turning Basin and dock approach channel (P1A) vs. original design (P1)

10. CHANNEL DISCUSSION

The following conditions are agreed upon, discussed, and recommended for the feasibility level design.

a. The proposed 600-foot width in the entrance channel is deemed feasible. This assertion is a result of the simulation tests including the transition into the Lavaca Bay reach.

b. The proposed 350-foot width in the Main Channel for both the Matagorda Bay and Lavaca Bay reaches is deemed feasible. This assertion is a result of simulation tests including inbound and outbound runs.

c. During the course of simulations, a 300-foot width is considered for the Matagorda Bay and Lavaca Bay Reaches. When tested, this new channel configuration is deemed feasible and is recommended moving forward. While the potential savings to the project in dredging costs is significant by this reduction in width, more testing in the design phase is needed to determine the safety of this channel configuration.

d. Also during the course of simulations, a 550-foot width is considered for the entrance channel. This configuration is tested with a transition into the 300-foot Lavaca Bay reach. It is deemed feasible and recommended moving forward. Capt. Adrian mentioned that this transition seems well designed and increases the margin of feasibility with the CMS current model that is used for testing. The pilot could not stress enough that the transition from the Entrance Channel into the Lavaca Bay reach is the gauntlet of the whole design.

e. Initial runs on the 400-foot wide elbow section of the Matagorda Bay reach (Figure 3) are unsuccessful with the design ship. Maneuverability is difficult through the proposed design configuration with its sharp edges and the pilot runs aground by leaving the channel extents on every attempt.

f. After discussion with the pilots and SWG, a bend easing alternative is proposed, keeping the width at 400 feet but with a smooth curve configuration (Figure 7). As a result of the bend easing, subsequent runs are deemed feasible through the elbow section but more testing in the design phase is needed to determine the safety of this width.

g. The optimal turning basin configurations, as a result from the FLSSP, are the 990-foot turning basin at the docks and the 1200-foot turning basin with the modifications of the approach channel shown in Figure 6.

h. Six additional runs are performed on Thursday afternoon to evaluate navigation conditions on the Matagorda Bay and Lavaca Bay reaches with a wind configuration of 24 knots from the Northeast, using the Eagle Kangar in loaded and ballast conditions. These last set of runs are deemed feasible for the channel configurations tested.

No data analysis is included as part of the FLSSP as the purpose is to examine the feasibility of various aspects of the Matagorda design proposal in the CHL simulator, and to use pilot feedback as input for developing a range for feasible widening options. A more rigorous testing of the design is to be conducted during the PED. The visual databases are to be updated to include more detail.

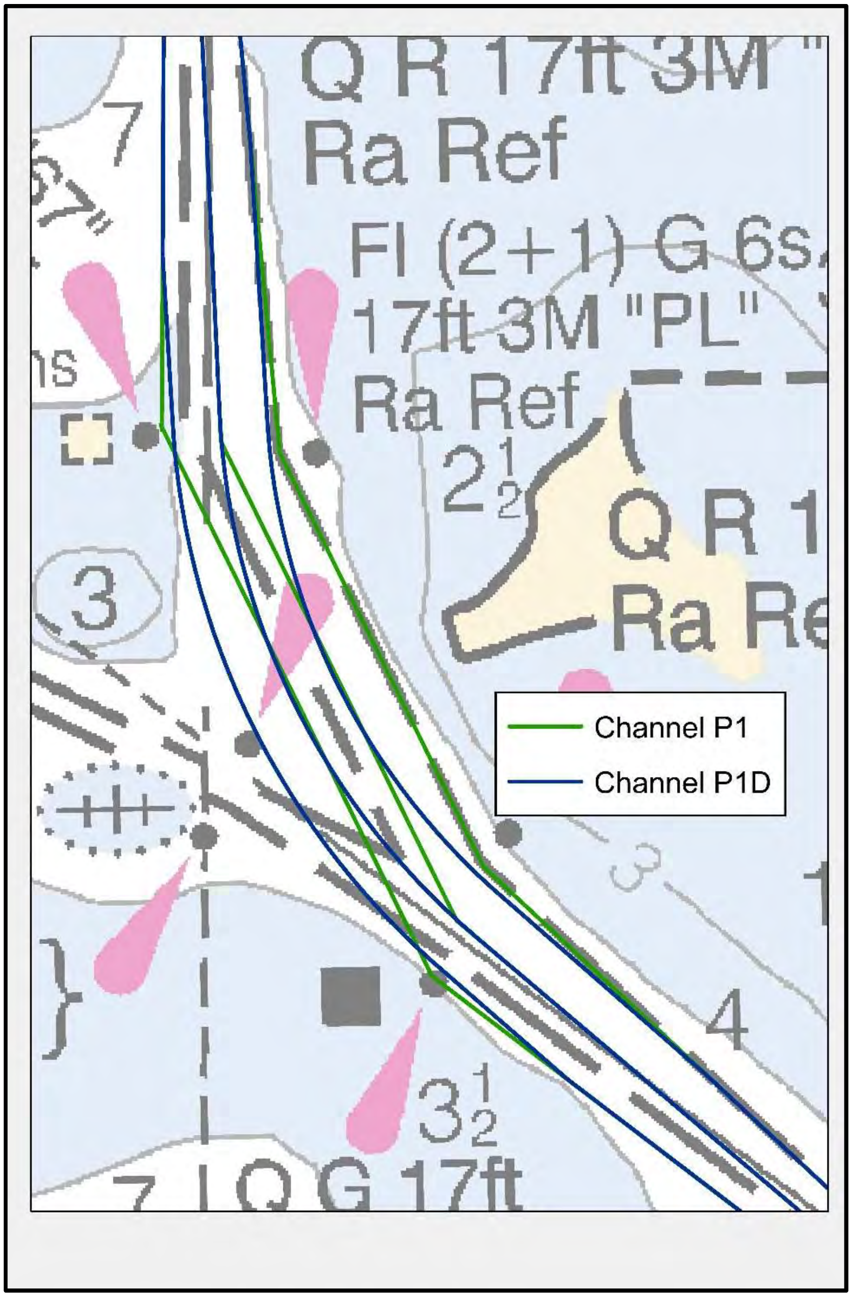

Figure 7. Bend Easing of the Matagorda Bay Reach Elbow Bend (P1D) vs. Original Design (P1)

11. FEASIBILITY PHASE RECOMMENDATIONS

For the feasibility phase, USACE SWG should consider using the following project dimensions. These dimensions can be refined further in the PED phase ship simulations.

a. Entrance Channel Width – 550 Feet

b. Channel Width through Matagorda Bay and Lavaca Bay Reaches – 300 Feet

c. Turning Basins – 990-Foot Basin at the docks and the 1200-Foot Basin with 700-foot Dock Approach Channel (see Figure 6)

d. Elbow Section in Matagorda Bay Reach – 400-Foot wide curved section (Figure 7)

e. Project Depth – 49 Feet MLLW in the entrance channel and 47 Feet in the Bay

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2.15 SQUAT COMPUTATIONS SHEETS

The case of maximum draft (49ft) at the minimum entrance channel cross-section at Station 2+150 with depth 78ft with no waves (H = 0) produces:

Case 1: Maximum Draft at Entrance Channel with no Waves

Equations V-5-1 to 5-5
Vessel Equations

Input Parameter	Value	Units
Vessel speed (V)	10	knots
Vessel beam (B)	143.7	ft
Vessel draft (T)	49.1	ft
Vessel length (L)	784	ft
Block coefficient (C_B)	0.74	
Channel depth (h)	78	ft
Channel cross-sectional area (Ac)	61620	ft^2
Wave height (H)	0	ft
Channel depth Froude number (Fh)	0.336967	
Vessel submerged cross-sectional area (As)	7055.67	ft^2
Block ratio (B_R)	8.7334	
Guidance for minimum depth clearance (h/T) must be > AA	1.58859	
AA	1.3	ft
Max squat in fairway (Z)	1.81434	ft
Rectangular Canal		
Schijf Limits:		
Froude number [V_L/sqrt(gh)]	0.597327	
Vessel speed (V_L)	17.717	knots
Maximum squat (Z_L)	2.19612	ft

In the computation sheet, input values are in white background, and outputs are in blue background. The final result for the navigation channel's case of a **trench** is the average of the squat values for the **fairway** and **canal**:

trench Z = (1.81434ft + 2.19612ft) / 2 = 2.01 ft (entrance with no waves)

The case of maximum draft (49ft) at the minimum entrance channel cross-section at Station 2+150 with depth 78ft with medium waves (H = 4ft) produces:

Case 2: Maximum Draft at Entrance Channel with 4ft Waves

Equations V-5-1 to 5-5
Vessel Equations

Input Parameter	Value	Units
Vessel speed (V)	10	knots
Vessel beam (B)	143.7	ft
Vessel draft (T)	49.1	ft
Vessel length (L)	784	ft
Block coefficient (C_B)	0.74	
Channel depth (h)	78	ft
Channel cross-sectional area (Ac)	61620	ft²
Wave height (H)	4	ft
Channel depth Froude number (Fh)	0.336967	
Vessel submerged cross-sectional area (As)	7055.67	ft²
Block ratio (B_R)	8.7334	
Guidance for minimum depth clearance (h/T) must be > AA	1.58859	
AA	1.5	ft
Max squat in fairway (Z)	1.81434	ft
Rectangular Canal		
Schijf Limits:		
Froude number [V_L/sqrt(gh)]	0.597327	
Vessel speed (V_L)	17.717	knots
Maximum squat (Z_L)	2.19612	ft

This produces the same result as the no-waves case. The ICEM software has little documentation. This case was run to determine how the software handled waves. Apparently squat is handled completely separately from waves. Figure 4.3 illustrates how the different factors are added up. The engineer is apparently expected to account for “Squat Underway” and “Ship Motion from Waves” separately in the final underkeel clearance recommendations for authorized maximum draft.

trench Z = (1.58859ft + 2.19612ft) / 2 = 2.01 ft (not influenced by waves)

Case 3: Maximum Draft at Entrance Channel with 10ft Waves The case of maximum draft (49ft) at the minimum entrance channel cross-section at Station 2+150 with depth 78ft with high waves (H = 10ft) produced the same 2.01ft squat results as the no-waves case.

In all of the above scenarios the actual surveyed channel cross-section was used. The following three scenarios consider the possibility that the entrance channel has shoaled in and must be dredged to the authorized dimensions of h = 49ft and W = 600ft plus sideslopes. The cross-sectional area A_C = 600ft x 49ft + (580ft - 150ft) x 49ft = 50,470 ft^2.

The maximum draft is limited by the dredged depth minus the 6ft of required clearances. For T = 49 - 6 = 43ft with depth 49ft with no waves (H = 0) produces:

Case 4: Maximum Draft in Shoaled & Dredged Entrance Channel with no Waves

Equations V-5-1 to 5-5
Vessel Equations

Input Parameter	Value	Units
Vessel speed (V)	10	knots
Vessel beam (B)	143.7	ft
Vessel draft (T)	43	ft
Vessel length (L)	784	ft
Block coefficient (C_B)	0.74	
Channel depth (h)	49	ft
Channel cross-sectional area (Ac)	50470	ft²
Wave height (H)	0	ft
Channel depth Froude number (Fh)	0.425144	
Vessel submerged cross-sectional area (As)	6179.1	ft²
Block ratio (B_R)	8.16786	
Guidance for minimum depth clearance (h/T) must be > AA	1.13953	
AA	1.3	ft
Max squat in fairway (Z)	2.52932	ft
Rectangular Canal		
Schijf Limits:		
Froude number [V_L/sqrt(gh)]	0.584137	
Vessel speed (V_L)	13.7323	knots
Maximum squat (Z_L)	1.37156	ft

FH > 0.4. Answer is out of range.

trench Z = (2.52932ft + 1.37156ft) / 2 = 1.95 ft

For the maximum draft being limited by both the 6ft of required clearances plus a wave height of 4ft (the hindcast Hmo), the maximum draft is 49 - 6 - 4 = 39ft with depth 49ft and waves (H = 4ft):

Case 5: Maximum Draft in Shoaled & Dredged Entrance Channel with 4ft Waves

Equations V-5-1 to 5-5
Vessel Equations

Input Parameter	Value	Units
Vessel speed (V)	10	knots
Vessel beam (B)	143.7	ft
Vessel draft (T)	39	ft
Vessel length (L)	784	ft
Block coefficient (C_B)	0.74	
Channel depth (h)	49	ft
Channel cross-sectional area (Ac)	50470	ft^2
Wave height (H)	4	ft
Channel depth Froude number (Fh)	0.425144	
Vessel submerged cross-sectional area (As)	5604.3	ft^2
Block ratio (B_R)	9.00558	
Guidance for minimum depth clearance (h/T) must be > AA	1.25641	
AA	1.5	ft
Max squat in fairway (Z)	2.29403	ft
Rectangular Canal		
Schijf Limits:		
Froude number [V_L/sqrt(gh)]	0.603242	
Vessel speed (V_L)	14.1814	knots
Maximum squat (Z_L)	1.38237	ft

FH > 0.4. Answer is out of range.

Unlike Cases 1-3, waves matter here, because the authorized draft T is limited by the shoaled channel bottom and vertical excursions of the ship due to waves.

trench Z = (2.29403ft + 1.38237ft) / 2 = 1.84 ft

For the maximum draft being limited by both the 6ft of required clearances plus a wave height of 10ft (the Hmo reported by the pilots), the maximum draft is 49 - 6 - 10 = 33ft and waves (H = 10ft):

Case 6: Maximum Draft in Shoaled & Dredged Entrance Channel with 10ft Waves

Equations V-5-1 to 5-5
Vessel Equations

Input Parameter	Value	Units
Vessel speed (V)	10	knots
Vessel beam (B)	143.7	ft
Vessel draft (T)	33	ft
Vessel length (L)	784	ft
Block coefficient (C_B)	0.74	
Channel depth (h)	49	ft
Channel cross-sectional area (Ac)	50470	ft²
Wave height (H)	10	ft
Channel depth Froude number (Fh)	0.425144	
Vessel submerged cross-sectional area (As)	4742.1	ft²
Block ratio (B_R)	10.643	
Guidance for minimum depth clearance (h/T) must be > AA	1.48485	
AA	1.5	ft
Max squat in fairway (Z)	1.94111	ft
Rectangular Canal		
Schijf Limits:		
Froude number [V_L/sqrt(gh)]	0.634021	
Vessel speed (V_L)	14.905	knots
Maximum squat (Z_L)	1.38784	ft
FH > 0.4. Answer is out of range.		

trench Z = (1.94111ft + 1.38784ft) / 2 = 1.66 ft

In the Bay, the maximum draft is limited by the 6ft of required clearances, so draft T = 47 - 6 = 41ft. The cross-sectional area of the dredged trench is A_C = 22,090 ft^2. With no waves (H = 0), the result is:

Case 7: Maximum Draft in Bay with no Waves

Equations V-5-1 to 5-5 Vessel Equations		
Input Parameter	**Value**	**Units**
Vessel speed (V)	10	knots
Vessel beam (B)	143.7	ft
Vessel draft (T)	41	ft
Vessel length (L)	784	ft
Block coefficient (C_B)	0.74	
Channel depth (h)	47	ft
Channel cross-sectional area (Ac)	22090	ft²
Wave height (H)	0	ft
Channel depth Froude number (Fh)	0.434095	
Vessel submerged cross-sectional area (As)	5891.7	ft²
Block ratio (B_R)	3.74934	
Guidance for minimum depth clearance (h/T) must be > AA	1.14634	
AA	1.3	ft
Max squat in fairway (Z)	2.5143	ft
Rectangular Canal		
Schijf Limits:		
Froude number [V_L/sqrt(gh)]	0.398916	
Vessel speed (V_L)	9.1846	knots
Maximum squat (Z_L)	0.986743	ft
FH > 0.4. Answer is out of range.		

trench Z = (2.5143ft + 0.986743ft) / 2 = 1.75 ft

In the Bay, the maximum draft is limited by the 6ft of required clearances and by waves (from the CEDAS/ACES software with medium strength storms). Thus draft T = 47 - 6 - 3 = 38ft. With waves (H = 3ft), the result is:

Case 8: Maximum Draft at Entrance Channel with 3ft Waves

Equations V-5-1 to 5-5 Vessel Equations		
Input Parameter	**Value**	**Units**
Vessel speed (V)	10	knots
Vessel beam (B)	143.7	ft
Vessel draft (T)	38	ft
Vessel length (L)	784	ft
Block coefficient (C_B)	0.74	
Channel depth (h)	47	ft
Channel cross-sectional area (Ac)	22090	ft²
Wave height (H)	3	ft
Channel depth Froude number (Fh)	0.434095	
Vessel submerged cross-sectional area (As)	5460.6	ft²
Block ratio (B_R)	4.04534	
Guidance for minimum depth clearance (h/T) must be > AA	1.23684	
AA	1.3	ft
Max squat in fairway (Z)	2.33033	ft
Rectangular Canal		
Schijf Limits:		
Froude number [V_L/sqrt(gh)]	0.419731	
Vessel speed (V_L)	9.66384	knots
Maximum squat (Z_L)	1.04029	ft
FH > 0.4. Answer is out of range.		

trench Z = (2.33033ft + 1.04029ft) / 2 = 1.69 ft

3.0 SURVEYING, MAPPING, AND OTHER GEOSPATIAL DATA REQUIREMENTS

3.1 SURVEYS

Condition hydrographic channel surveys performed in November of 2018 by the Southern Area Office of the Galveston District were used for this study. Surveys were imported into Hypack to create ground surfaces along the proposed new channel alignments that were used to determine the dredging quantities for channel design. As the preliminary designs progressed, these surveys were manipulated for volumes to address different depths and channel widths. During the Preconstruction Engineering & Design (PED) phase, updated hydrographic surveys will be done and topographic surveys will be performed to better define the proximity of channel to land, docks and jetties.

3.2 MAPPING

Existing maps, from Galveston District's historical files, of the vicinity were used during the initial and plan formulation phases. Updated mapping was developed for the Detail phase, to include proposed conditions.

3.3 DATUM

3.3.1 Horizontal

The North American Datum of 1983 (NAD 83) Texas State Plane Coordinate System, Texas South Zone was used during all phases of the Feasibility Study for all drawings.

3.3.2 Vertical

The vertical datum of Mean Lower Low Water (MLLW) were used in calculating new work volumes. Land surveys performed for the upland placement areas were referenced to the American Vertical Datum of 1988 (NAVD 88). Refer to Section 6-Hydrology and Hydraulics Section for additional information on the MLLW Datum used.

4.0 GEOTECHNICAL

4.1 OVERVIEW

In this section, all existing and available geotechnical information within USACE and Non-Federal Sponsor was collected and reviewed in order to determine its relevance to the feasibility of this study. Existing data was utilized as available; however, should sufficient data not be available for final design, then additional field studies may be required in PED. This section contains various discussions regarding the available geotechnical information and geotechnical investigations for the project. Based on these discussions, the appropriate design features along with the geotechnical considerations related to the dredged material and placement areas are described. In addition, the results of the geotechnical analyses performed in an existing report (URS 2014) were referred to for physical and engineering characteristics of the anticipated new work materials from channel excavation, which is necessary to determine proper placement schemes.

4.2 EXISTING GEOTECHNICAL INFORMATION

4.2.1 Review and Inventory of Existing Subsurface Data

Data was obtained from both public and private sources. The original geotechnical investigation (USACE 1962a) provides a boring log database (80 total), including boring identification, station locations, elevation, and strata descriptions (Attachment A). Based on the stations, all locations of the above 80 borings can be distributed in the three reaches as follow:

- Lavaca Bay Reach – Station 118+502 to 75+000
(Boring Series: 3ST-43, 3ST-40, 3ST-37, 3ST-34, 3ST-31, 3ST-28, 3ST-25, 3ST-22, 3ST-19, 3ST-16, 3ST-13, 3ST-10, 3ST-7, 3ST-4, 3ST-1, 3ST-45, 3ST-48, 3ST-51, 3ST-54, 3ST-57, 3ST-60, 3ST-63, and 3ST-65)

- Matagorda Bay Reach – Station 75+000 to 0+000; and
(Boring Series: 3ST-67, 3ST-70, 3ST-73, 3ST-76, 3ST-79, 3ST-82, 3ST-85, 3ST-88, 3ST-91, 3ST-94, 3ST-97, 3ST-100, 3ST-103, 3ST-106, 3ST-109, 3ST-112, 3ST-115, 3ST-118, 3ST-121, 3ST-124, 3ST-127, 3ST-130, 3ST-133, and 3ST-136)

- Offshore Reach – Station 0+000 to -33+000
(Boring Series: 6ST-161, 6ST-163, 6ST-165, 6ST-168, 6C-10, 6C-11, 6C-12, 6C-13 6C-14, 6C-15, 6C-16, 6C-17, 6C-18, 6C-19, 6C-1, 6C-2, 6C-3, 6C-4, 6C-5, 6C-6, 6C-7, 6C-8, 6C-9, 6C-20, 6C-21, 6C-22, 6C-23, 6C-24, 6C-25, 6C-26, 6C-27, 6C-28, and 6C-29)

This information can be used to confirm side slopes, material type and estimate quantities for the improved channel. The borings were drilled to obtain 3-inch-diameter undisturbed continuous samples of cohesive materials and split-spoon, disturbed samples of cohesionless materials. Where cohesionless materials were encountered, disturbed samples were taken at approximately 5-foot depth intervals during the performance of standard penetration tests.

4.2.2 Cone Penetration Testing

Three Cone Penetration Tests (CPTs) were performed to confirm the soil descriptions. The locations of the CPTs are shown in Attachment B. The tests indicated very soft material near the surface, with stiffer material at greater depths. The investigation confirmed the information in USACE (1962a) and provided a good correlation for use of this information for the design of the channel improvements. However, there were no CPT tests covering Offshore Reach areas. Thus, additional CPT tests are needed around these Offshore areas to verify existing soil data in PED. CPT tests were conducted by Southern Earth Sciences, Inc. under subcontract to URS who reviewed the data. The CPT tests were performed according to ASTM D-3441 and D 5778 and consisted of pushing a cylindrical steel probe into the ground at a constant rate of 20 mm/sec and measuring the resistance to penetration. The standard penetrometer has a conical tip with 60 degrees angle apex, 35.7-mm diameter body (10-cm^2 projected area), 150-cm^2 friction sleeve. The measure point or tip resistance is designated qc and the measured sleeve resistance is fs. Most of CPT also can measure penetration porewater pressures during the advancement of the probe by the addition of sensor for pressure transducer inside of the CPT body.

4.2.3 Sampling and Testing of Shoaled Sediments

Sediment samples were taken at three locations within the MSC, and the Turning Basin in May of 2006 to characterize the material that will be placed in placement areas. The three samples were obtained using an Ekman sampler. The Ekman sampler was selected as the most appropriate method of sampling the soft sediments while maintaining their *in situ* moisture content and excluding the addition of extraneous water from the overlying water column into the sampler. The samples were submitted to a geotechnical testing laboratory to determine moisture content, specific gravity, Atterberg limits, and percentage passing the No. 200 sieve. The dry densities of the samples were calculated using the moisture content and specific gravity, under the assumption that the samples were saturated. Table 4-1 displays the test results for these sediment samples and the calculated dry densities.

Table 4.1 – Geotechnical Laboratory Testing for Samples of Sediment Obtained by URS									
Sample Number	Moisture Content (%) ASTM D- 2216	Specific Gravity	Atterberg Limits ASTM D=4318			Percentage Passing No. 200 Sieve (%)	Unified Soil Classification ASTM D-2487	Dry Density Calculated (pcf)	Calculated Void Ratio
			Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)				
Sta. 85+000	164	2.65	68	25	43	92.7	Gray Fat Clay(CH)	30.94	4.35
Sta. 90+000	226.6	2.72	75	30	45	-	Gray Fat Clay(CH)	23.7	6.17
Sta. 118+000	268.4	2.69	82	34	48	-	Gray Fat Clay(CH)	20.42	7.22

4.3 DREDGED MATERIAL

4.3.1 New Work

The total volume of new work material to be dredged for the Matagorda Ship Channel Improvement Project (MSCIP) was estimated using geometric analysis based on average elevations from existing topographic surveys, field data, and the channel dimensions. The calculation method does not account for potential variations within each project feature or changes since the topographic surveys were performed. The volume calculations are based on the channel dimensions, and include both the overdepth and advance maintenance requirements. Table 4.2 provides an approximate soil classifications of the new work dredged material from the 2009 FEIS. These quantities are from the 2009 EIS and do not reflect current new work quantities, but the ratio of classification between soils should remain comparable.

Table 4.2 New Work Soil Classification (2009 FEIS)

Station	to Station	Sand (CY)	Stiff to Hard Clay	Soft Clay or Silt (CY)
CPA Facilities		0	1,342,079	494,806
Proposed Turning Basin		0	2,453,451	1,046,549
116+593	107+000	0	2,667,470	644,645
107+000	92+000	1,164,000	324,000	5,316,000
92+000	88+000	297,000	671,000	475,000
88+000	82+000	1,113,000	251,000	831,000
82+000	75+000	471,000	0	1,699,000
75+000	71+000	0	0	1,699,000
71+000	67+000	687,000	454,000	364,000
67+000	54+000	1,434,000	320,000	2,804,000
54+000	46+000	1,779,000	0	885,000
46+000	40+000	780,000	1,338,000	153,000
40+000	6+000	5,933,000	207,000	3,226,000
6+00	-5+000	0	0	0
-5+000	-23+000	3,206,000	0	0
Total		**16,864,000**	**10,028,000**	**19,638,000**

The dredge prism soil classification is based on available boring logs from the USACE as shown in Attachment A – Galveston District's General Design Memorandum No. 3 finalized in January 1962 (USACE 1962b), and provides adequate information for estimating the soil condition for the baseline cost estimate. Additional soil investigations will be necessary during PED for the channel to further delineate the stiff clay and sand deposits. In areas where there is limited information, it was assumed that the soil conditions were similar to the closest available boring log. Between boring locations in the existing information, it is assumed that the depths of material layers changed linearly. The boring logs did not show vertically for the depths extending fully to the bottom of the proposed channel. The assumption is that the last shown material layer continued to the proposed depth. Table 4.3 provides a summary of the new work placement plan. Further breakout of the placement plan can be found in the Dredged Material Management Plan (DMMP) Appendix.

Table 4.3 - Revised Placement Features for New Least Cost Plan

Applicant's Preferred Alternative

Feature Identity	Feature Description	New Work (mcy)
O5	Offshore Dispersive Site	3.2
Sand Engine	New Unconfined Area for Work and Maintenance Material	1.4
Sundown Island	Existing Unconfined Area along GIWW	2.3
NP1 to NP7	New Unconfined Areas	14.0
TOTAL	New Work Material	21.0

4.3.2 Maintenance Dredging

The total volume of maintenance material to be dredged for the MSCIP was calculated utilizing CSAT modeling software in coordination with using geometric analysis based on average elevations from existing topographic surveys, field data, and channel dimensions. The maintenance material for the MSC is sampled periodically for chemical and physical properties. Generally, the maintenance material is characterized as fine-grained, clay and silt in Lavaca Bay and Matagorda Bay. Clay and silt are prevalent in the offshore maintenance material as well, but the sand content increases. Maintenance material sampling was performed in Lavaca Bay to analyze the confined placement areas. The materials may be generally categorized as clay (CH). Projected 50 years of maintenance material for each reach of the channel are provided in Table 4.4. The numbers in this table were generated by the Galveston Hydraulics and Hydrology Branch utilizing the CSAT shoaling modeling software. Table 4.4 provides a summary of the maintenance material placement plan. Further breakout of the placement plan can be found in the DMMP Appendix.

Table 4.4 - Revised Placement Features for New Least Cost Plan

Applicant's Preferred Alternative

Feature Identity	Feature Description	Maintenance (mcy)
Sand Engine	New Unconfined Area for Work and Maintenance Material	9.0
Sundown Island	Existing Unconfined Area along GIWW	12.9
OP 1 to OP 10	New Unconfined Areas	114.2
PA 1	Existing Offshore Dispersive Site	17.9
TOTAL	Maintenance Material	154.0

4.3.2.1 With Project vs. Without Project O&M Quantities

The projected annual maintenance estimated With Project O&M Quantities were refined to cubic yardage per dredging cycle and compared to the Without Project O&M Quantities per dredge cycle in Table 4.5. Cost is provided for the increase in the O&M quantities in Table 3 of the Cost Section in the Engineering Appendix.

Table 4.5- With Project vs. Without Project O&M Quantities.

	Estimated		
Stationing	**Without Project O&M per Cycle (CY)**	**With Project O&M per Cycle (CY)**	**Frequency (years)**
-6+000 to 118+502	3,320,000	5,086,000	2
-33+000 to -6+000	1,530,000	2,151,000	4

4.3.3 Quality of Dredged Material

The subsurface soil conditions of the project site dictate the type of dredge that will be utilized to perform the excavation for DMMP. The physical characteristics of the soil can affect its placement options due to varying strength and compressibility. The subsurface soils in the turning basin and channel consist of soft clays, very stiff to hard clays, and sand. Section 4.0 (Geotechnical Engineering) describes the detailed geotechnical properties of the material requiring excavation as a result of continued sedimentation or maintenance material.

4.4 GEOTECHNICAL ENGINEERING ANALYSIS AND DESIGN

The proposed side slopes of the designed channel are at 3H:1V in Matagorda Bay and Lavaca Bay, and 10H:1V Offshore. A geotechnical engineering evaluation of the slope stability of the channel cut was conducted based on existing soil information from Cone Penetrometer Test at Station 100+000 and existing soil borings in the vicinity. The stability analysis for the channel cut was performed with the GeoStudio 2018 – Slope/W computer program utilizing the Modified Bishop method. Results consisted of a factor of safety above 1.3 for circular failure and wedge failure for designed slope. Results of slope stability models are documented in Attachment C. Additional stability analyses will be completed for a detailed design in PED.

Although the analysis confirms a stable slope under steady-state static conditions, it is acknowledged that the channel slopes will frequently be subject to significant pressure waves when loaded deep-draft vessels pass, and that the pressure wave can cause significant temporary fluctuation in the pore pressure well below the surface of the slope. This pore pressure fluctuation may result in shallow-slope slides at locations where the slope material is closer to a critical FS. The depths of the slides are limited by the depth of pore pressure fluctuation due to the pressure waves. The potential depths and locations of the slides will be highly variable along the channel, as can be ascertained by a review of previous slope changes, with time, along the channel slopes, which were originally dredged to a uniform slope. Since the sloughing could occur in various places along the channel and on portions of the slopes it is not practical to find all shallow slides that will occur. Historically, the USACE Galveston District designs the slopes for the steady-state static condition, and will remove the sloughed material from the channel bottom during the maintenance-dredging cycles, along with shoaled material.

4.5 ADDITIONAL GEOTECHNICAL INVESTIGATION AND ANALYSIS

Sand and stiff to hard clay are key resources that play an integral role in the project. Additional soil borings and potentially CPTs need to be performed to further define the limits of the sand and stiff to hard clay deposits for the contract documents. Additional soil borings will be drilled at Placement Area P1, if placement area is to be utilized. PA P1 is the only placement area that will have a levee constructed. All other placement areas are open water or unconfined and should not need borings or levees. This information will allow refinement of the estimate of dike and provide the contractor with a better estimate for bidding and execution of the dike construction.

Additional geotechnical analyses may be needed for the placement area sites in PED. From USACE Galveston District reports, the use of the Primary consolidation, Secondary compression and Desiccation of dredged Fill (PSDDF) model, based on self-weight consolidation test results, appears to be the best approach to determining the final fill quantities for the placement area sites. Although the results have been verified as accurate under controlled conditions at a well-monitored experimental fill site, it appears that additional calibration efforts are needed to achieve accuracy for areas such as possible marsh mitigation sites. Use of the refined and calibrated model, and additional experience in material placement will allow the accurate determination of the dredged material quantity required to attain the target elevations for the desired site topography. Currently oyster mitigation sites assume 6 inches of subsidence of placed limestone and 6 inches of placement above existing bay bottom until further geotechnical information can be gathered in PED.

4.6 REFERENCE

"General Design Memorandum - Boring Layout and Soil Profile, Matagorda Ship Channel, Texas", January 1962 by U.S. Army Corps of Engineers, Galveston District.

EM 110-2-5027 "Confined Disposal of Dredged Material", September 1987, by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

"Corpus Christi Ship Channel Improvement Project, Final Engineering Appendix", 2003, by U.S. Army Corps of Engineers Galveston District.

"Geotechnical Laboratory Testing for URS Soil Samples – Lavaca Bay Dredge Soils", May 4, 2006, by Aviles Engineering Corp.

PBS&J. 2009. Final Environmental Impact Statement (FEIS) for USACE regarding The Proposed Matagorda Ship Channel Improvement Project, Austin, TX

"Dredged Material Management Plan for the Matagorda Ship Channel Improvement Project", URS 2014

URS. 2014. Section 204(f) Feasibility Report for Calhoun Port Authority, Matagorda Ship Channel Improvement, Houston, TX

Moffatt and Nichol**.** 2006. Sedimentation Study, Matagorda Ship Channel Improvement Project. Prepared by Mofatt and Nichol. 11011 Richmond Avenue, Suite 200, Houston, TX 77042. October, 2006.

URS. 2006. Matagorda Sedimentary Analysis. Prepared by: URS Corporation, 10550 Richmond Avenue, Suite 155, Houston, TX 77042. October, 2006.

USACE. 1962a. Design Memorandum No. 3. USACE Galveston District, Galveston, TX.

USACE. 1962b. General Design Memorandum. Appendix B - Boring Layout and Soil Profile, Matagorda Ship Channel, Texas. January 1962. USACE, Galveston District.

USACE. 1983. EM 1110-2-5025. Dredging & Dredged Material Disposal. Washington, D.C.

USACE, 1990, EM 1110-1-1904. Settlement Analysis, Washington, D.C.

5.0 ENVIRONMENTAL ENGINEERING

5.1 USE OF ENVIRONMENTALLY RENEWABLE MATERIALS

Not applicable.

5.2 DESIGN OF POSITIVE ENVIRONMENTAL ATTRIBUTES INTO THE PROJECT

In deciding the proposed alignments for the channel improvements, decisive measures were taken to avoid environmentally protected species such as oyster beds, etc. By chance if they were impacted, mitigation measures were taken. Potential environmental attributes for this project include increasing navigational efficiency of vessels using the channel, increasing ability of the channel to accommodate offshore rigs for maintenance and repair and fabrication of new rigs, and beneficially using sediments from channel modifications and maintenance for environmental restoration.

5.3 INCLUSION OF ENVIRONMENTALLY BENEFICIAL OPERATIONS AND MANAGEMENT FOR THE PROJECT

Operation and maintenance dredging of the newly created channel is an opportunity to positively benefit the environment. Dredging the channel and removing the sediment will reduce the risks of pilots moving off course. The operation and management plan consisted of utilizing existing and newly created placement areas.

5.4 BENEFICIAL USES OF DREDGED MAINTENANCE MATERIAL OR OTHER PROJECT REFUSE DURING CONSTRUCTION AND OPERATION

The beneficial use of dredged maintenance material was used to create new placement areas, open water and upland for this project.

5.5 ENERGY SAVINGS FEATURES OF THE DESIGN

Energy saving features of the design include shortening pumping distances between dredge vessels and the placement areas. This reduces the load on the pump and minimizes the amount of fuel needed.

5.6 MAINTENANCE OF ECOLOGICAL CONTINUITY IN THE PROJECT WITH THE SURROUNDING AREA AND WITHIN THE REGION

The ecological continuity in the project with the surrounding area and within the region should not be interrupted permanently with the current dredging and material placement plans.

5.7 CONSIDERATION OF INDIRECT ENVIRONMENTAL COSTS AND BENEFITS

Indirect environmental costs and benefits were considered in the preliminary layout of the proposed channel improvement. The proposed channel alignment improvement was routed to avoid environmental habitats as much as possible. The water quality may be affected by turbidity and the exhaust from the dredge during construction and future maintenance may have a minor effect on the degradation of air quality. Improvements to the existing Matagorda Ship Channel is not expected to significantly disrupt the environment. The proposed project does not impact Federally listed threatened or endangered species or their designated critical habitat.

5.8 INTEGRATION OF ENVIRONMENTAL SENSITIVITY INTO ALL ASPECTS OF THE PROJECT

Consideration has been given to environmental, social and economic effects of proposed project modifications in accordance with the National Environmental Policy Act (NEPA) in all aspects of the project.

5.9 PERUSAL OF THE ENVIRONMENTAL SENSITIVITY INTO ALL ASPECTS OF THE PROJECT

Lessons learned from similar existing projects by using The Environmental Review Guide for Operations (ERGO) will be considered in this design. Environmental issues for this project will be addressed.

5.10 INCORPORATION OF ENVIRONMENTAL COMPLIANCE MEASURES INTO THE PROJECT DESIGN

USACE Environmental Operating Principles (EOP) were incorporated into the project design. The EOP principles ensure conservation, environmental preservation and restoration. Coordination with the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) under the Endangered Species Act will be done, thereby removing risks of impacts to endangered species or their habitats. Nevertheless, there may be a potential impact to sea turtles during hopper dredging in the offshore channel. Regulations are stipulated to avoid or minimize any impacts.

6.0 CIVIL DESIGN

6.1 EXISTING MATAGORDA SHIP CHANNEL

The existing channel dimensions are shown below in Table No. 6-1.

Table 6.1 Existing Matagorda Ship Channel Dimensions

Channel Reach	**Station**	**to**	**Station**	**Bottom Width (FT)**	**Project Depth (FT)**	**Channel Depth (FT)**	**A.O. (FT)**	**Side Slope**
Entrance Channel	-20+000		-6+000	300	40	43	2	1V:10H
Jetty Channel	-6+000		0+000	300	40	43	2	1V:10H
Matagorda Bay	0+000		75+000	200	38	40	2	1V:3H
Lavaca Bay	75+000		116+223	200	38	40	2	1V:3H
Point Comfort Turning Basin	116+223		117+223	1000	38	40	2	1V:3H
Point Comfort North and South Basins	117+223		118+502	Varies 159-344	38	40	2	1V:3H

A.O. = ALLOWABLE OVERDEPTH
-Channel Depth includes Advance Maintenance.

6.1.1 Existing Port Facilities

The existing port facilities are designed for a project depth of 47 feet, 2 feet advanced maintenance and 2 feet of allowable overdepth. Port modifications will not be necessary.

6.2 PROJECT DESIGN AND DEVELOPMENT

6.2.1 Initial and Plan Formulation

Non-structural measures such as light loading and split deliveries were considered by the Project Delivery Team (PDT). After discussion, non-structural measures were not deemed viable for channel improvement evaluation because they had already been implemented and were not successful at improving navigational efficiency and safety. Structural measures such as the deepening and widening of the existing channel, the addition of a vessel passing lane, modification of the existing turning basin and the addition of a new turning basin were analyzed by the PDT. However, because there wasn't sufficient space to expand the existing turning basin, it was eliminated from further discussion.

During the preliminary study, two alternative plans were put together from the structural measures brought forward. Based on the dimensions of both the existing and potential vessels projected to use the MSC, widths and depths for the two channel improvement alternatives were developed and listed in Table 6-2. The PDT took into consideration that the depths for the Matagorda Entrance and Jetty Channel have historically been an additional 2 feet deeper than the main channel to allow for the effects of vessel pitch, roll, and heave occurring there as a result of strong currents, waves and wind. The largest potential design vessel to transit the channel is a mid-size Aframax with a 800 ft LOA (length overall) x 138 ft beam and a design draft of 48-ft. The construction of the new 1,200-foot turning basin in the Lavaca Bay reach was chosen to accommodate the larger vessels needing to navigate to the Port. Based on the beam of the proposed design vessel, a 1,200 ft wide turning basin will be sufficient for maneuverability. The size of the turning basin should provide a minimum turning diameter of at least 1.2 times the length of the design ship where prevailing currents are 0.5 knot or less. Recent ERDC/WES simulator studies have shown that turning basins should provide minimum turning diameters of 1.5 times the length of the design ship setup where tidal currents are less than 1.5 knots. 1.5 multiplied by the 800-ft length would give us a 1200-ft diameter. Alternative A consisted of a range of six depths with bottom widths of 350' for the main channel and 600' for the entrance and jetty channel. Alternative B consisted of the same range of depths and widths but included a vessel passing lane. Pilots expressed that a vessel passing lane would not be advantageous to them, because it would not increase operational efficiencies through the Port. The vessel passing lane was not selected for further discussion and Alternative B was removed from the study. Alternative A was carried forward for further evaluation with six depth and width combinations as shown in Table 6-3.

Table 6.2 Initial Alternative A and B Plan Dimensions

Alternative Plans	Main Channel		Jetty/Entrance Channel		New Turning Basin	Passing Lane
	(ft) Depth	(ft) Width	(ft) Depth	(ft) Width	(ft) 1,200	NO
A	41	350	43	600	1,200	NO
A	43	350	45	600	1,200	NO
A	45	350	47	600	1,200	NO
A	47	350	49	600	1,200	NO
A	49	350	51	600	1,200	NO
A	51	350	53	600	1,200	NO
B	41	350	43	600	1,200	YES
B	43	350	45	600	1,200	YES
B	45	350	47	600	1,200	YES
B	47	350	49	600	1,200	YES
B	49	350	51	600	1,200	YES
B	51	350	53	600	1,200	YES

Table 6.3 Proposed Alternative A

Alternative A (ft)	Main Channel		Jetty/Entrance Channel	
	Depth (ft)	Width (ft)	Depth (ft)	Width (ft)
41	41	350	43	600
43	43	350	45	600
45	45	350	47	600
47	47	350	49	600
49	49	350	51	600
51	51	350	53	600

6.2.2 Preliminary Selection of TSP

Volumes were calculated for the 41 ft, 47 ft and 51 ft depth Alternatives as shown in Table 6.4. Cost estimates were created for the Alternative A depths of 41 ft, 47 ft and 51 ft. Those costs are listed in the Engineering Appendix, Section 12-Cost Estimate Section. During the economic evaluation, cost estimates for the 43 ft and 45 ft depths were interpolated between the 41 ft and 47 ft depth costs. The cost estimate for the 49 ft depth was interpolated between the 47 ft and 51 ft depths. During the final economic screening, the benefits and costs for the Alternative A were analyzed. The annualized benefits were compared with the annualized costs to calculate the net benefits for each depth in Alternative A. Refer to the Feasibility Report Appendix A-Economics for the details of the economic analysis.

Table 6.4 Proposed Alternative A Volumes

Alternative A (ft)	Main Channel		Jetty/Entrance Channel		Volumes
	Depth (ft)	**Width** (ft)	**Depth** (ft)	**Width** (Ft)	(CYS)
41	41	350	43	600	12,145,648
47	47	350	49	600	30,215,038
51	51	350	53	600	45,378,906

The net benefits were maximized at the Alternative A-47 ft plan, making it the NED plan. Initially the Alternative A-47 ft plan was selected as the TSP. It was reevaluated again and a decision was made to come up with additional plans to decrease the cost. It was decided to have a ship simulation done to determine the plan to go forward with.

6.2.3 Ship Simulation

Three alternative plans shown in Table 6.5 were submitted to the Engineer Research and Development Center (ERDC) and the Coastal and Hydraulics Laboratory (CHL) for evaluation of the safety and efficiency of ship maneuvering operations through the proposed channel. The plans with a 693-ft Point Comfort Turning Basin has a 400-ft approach channel reach. The 990-ft (1000-ft) Point Comfort Turning Basin has a 200-ft approach channel reach. A sediment trap between Sta -13+600 and Sta 15+200 is included with each of these plans but wasn't a part of the simulation.

Table 6.5 Proposed Ship Simulation Alternative Plans

Alternative Plans	Main Channel		Jetty/Entrance Channel		New Turning Basin	Point Comfort Turning Basin
	(FT) Depth	**(FT)** Width	**(FT)** Depth	**(FT)** Width	**(FT)** Diameter	**(FT)** Width
A	47	300	49	600	1,200	693
A	47	350	49	600	1,200	693
A	47	350	49	600	1,200	990

ERDC ran simulation tests on the three proposals submitted. The modified plan recommended is shown in Table 6.6. The modified plan consist of a proposed 550-ft wide entrance channel, 300-ft wide Matagorda and Lavaca Bay reaches, and an approximately 700-ft wide approach channel to the 990-ft (1,000-ft) Point Comfort turning. It provides adequate maneuvering dimensions for the proposed Aframax carrier to travel through the channel. A bend easing was recommended between Sta 101+514.62 and Sta 95+328.44, transitioning from 300 feet to 400 feet.

Table 6.6 Ship Simulation Recommended Plan

Alternative Plans	Main Channel		Jetty/Entrance Channel		New Turning Basin	Point Comfort Turning Basin
	(FT) Depth	(FT) Width	(FT) Depth	(FT) Width	(FT) Diameter	(FT) Width
A	47	300	49	550	1,200	990

The ship simulation proposed plan net benefits were maximized at the Alternative A-47 ft plan, making it the NED plan. The non-Federal sponsor had no objections to the Alternative A-47' MLLW plan. The Alternative A-47 ft plan was selected as the TSP. The TSP is technically viable, economically feasible, and environmentally acceptable in accordance with governing agency regulations and associated Federal statutes. The dimensions for the TSP 47 ft plan for the MSC are shown on Table 6-7. The channel depth column includes the advance maintenance for each reach.

Table 6.7 Alternative A-47 ft TSP Dimensions

Reach	Station	to	Station	Bottom Width (FT)	Project Depth (FT)	Channel Depth (FT)	A.O. (FT)	Side Slope
Entrance Extension Channel	-33+000		-20+000	550	49	52	2	1V:10H
Entrance Channel	-20+000		-15+200	550	49	52	2	1V:10H
Sediment Trap	-15+200		-13+600	550	62	--	--	1V:1H
Entrance Channel	-13+600		-6+000	550	49	52	2	1V:10H
Jetty Channel	-6+000		0+000	550	49	52	2	1V:10H
Matagorda Bay Channel Reach	0+000 4+319.91 12+600		4+319.91 12+600 75+000	550 550 300	47 47 47	49 49 49	2 2 2	1V:5H 1V:3H 1V:3H
Lavaca Bay with Proposed Turning Basin	75+000		116+223	300- 1200- 1000	47	49	2	1V:3H
Point Comfort Turning Basin	116+223		117+223	1000	47	49	2	1V:3H
Point Comfort North and South Basins	117+223		118+502	Varies	47	49	2	None

A.O. = ALLOWABLE OVERDEPTH
-Channel Depth includes Advance Maintenance.

6.2.4 Sediment Trap

To abate the rate of shoaling into the MSC Entrance channel, a sediment trap is proposed to trap the migrating sediment. A sediment trap, if effectively sized and positioned, has the potential of extending the dredging cycle because it would provide a repository for the sediment that would otherwise accumulate in the channel. The MSC Entrance channel was studied by the H&H Branch to ascertain the location of the principal sources of the shoaling. Based on the H&H analysis, the sediment trap will be rectangular, measuring 550 feet x 1,600 feet, and will be situated between channel stations -13+600 and -15+200. New work excavation for the trap was estimated to be 273,778 CYS. The sediment trap was not tested during the ship simulation but will be analyzed further in detail during PED.

6.3 TSP NEW WORK DREDGING QUANTITIES

The total amount of new work material to be dredged for the TSP is 21 MCY. The new work material volumes are shown by reaches in Table 6-8. New work material volumes do not contain maintenance material. The new work volumes include Advanced Maintenance as well as the recommended Allowable Overdepth.

Table 6.8 TSP-Dredging Quantities by Reaches

Reach	Station	To Station	Total New Work CYS*
New Matagorda Entrance Channel Extension	-33+000	-20+000	2,383,334
Matagorda Entrance Channel	-20+000	-6+000	2,265,543
Matagorda Jetty Channel	-6+000	0+000	549,977
Matagorda Bay Channel Reach	0+000	75+000	8,693,296
Lavaca Bay Channel Reach w/New 1,200 ft turning basin	75+000	116+223	6,500,970
Point Comfort Turning Basin	116+223	117+223	293,024
Point Comfort North and South Basins	117+223	118+502	277,253
MSC Total			20,963,397

6.4 ALLOWABLE OVERDEPTH

The allowable overdepth for the TSP is shown in Table 6.9. An additional depth outside the required template is permitted to allow for inaccuracies in the dredging process. District commanders may dredge a maximum of two feet of Allowable Overdepth in coastal regions, and in inland navigation channels. (ER 1130-2-520 Navigation and Dredging Operations and Maintenance Policies*)* This additional dredging allowance is referred to as Allowable Overdepth (AO). The MSC channel has historically been maintained and authorized at 2 feet allowable over depth. It is anticipated that large pipeline dredges will be utilized to construct the proposed waterway. District policy recommends 2 feet allowable overdepth in reaches where large dredges operate. The existing and proposed channel contain the same allowable overdepth for the entire length of the channel.

Table 6.9 TSP Allowable Overdepth

Reach	Allowable Overdepth(Ft)
MSC Entrance Extension/ Entrance (Sta -33+000 to Sta -6+000)	2
MSC Jetty Channel (Sta -6+000 to Sta 0+000)	2
Matagorda Bay (Sta. 0+000 to Sta 75+000)	2
Lavaca Bay w/new Turning Basin (Sta 75+000-Sta 116+223)	2
Point Comfort Turning Basin (Sta 116+223-Sta 117+223)	2
Point Comfort North and South Basins (Sta 117+223-Sta 118+502)	2

6.5 ADVANCED MAINTENANCE

Advance maintenance dredging, to a specified depth and/or width, may be performed in critical and/or fast-shoaling areas to avoid frequent redredging and ensure the least overall cost of maintaining the project. ER 1130-2-520 authorizes the Major Subordinate Command (MSC) Commander to approve the advance maintenance dredging for new work dredging and maintenance of the project. The existing Matagorda Entrance and Jetty Channel has a constant depth of 3 feet Advanced Maintenance. The existing Matagorda Main Channel has a constant depth of 2 feet Advanced Maintenance. These depths were assumed to remain constant for the proposed channel. Historical shoaling rates and frequency of dredging were initially analyzed in the determination to use the existing advance maintenance dredging values for the proposed channel. Further detailed design and cost analysis for the advance maintenance will be performed in PED if deemed necessary.

6.6 MITIGATION

There are possible impacts to the oyster reefs and marshes, therefore mitigation will most likely be required. Mitigation for these impacts are addressed in the Feasibility Report, Appendix B-Environmental Resources. Design plans will be addressed before detail design of this project.

6.7 AIDS TO NAVIGATION

We are assuming there are existing aids to navigation that will be affected by the proposed widening plan of the MSC that may require relocating or removal. There may also be a need for the installation of new aids to navigation. The U.S. Coast Guard (USCG) is responsible for installing, relocating and removing the aids to navigation. The MSC will be widened on both sides of the Entrance and Jetty Channel and on the west side of the channel through the Lavaca Bay and Matagorda Bay.

6.8 PROJECTED SHOALING RATES

The Hydrology, Hydraulics and Coastal Section 2.0 presents the shoaling rates. They used the historical survey data and the Corps Shoaling Analysis Tool (CSAT) system to produce updated estimates of shoaling. CSAT estimates average annual historical shoaling rates based on the hydrographic survey datasets. A multiplication factor, between 1.06 to 1.13 based on previous shoaling study reports for the dredging quantities and for the pre-deepening and pre-widening conditions (i.e., historical conditions) was applied to the CSAT-computed historical shoaling rate to estimate the future shoaling rate.

6.9 REAL ESTATE

All placement areas are owned or will be acquired by the CPA. Navigational servitude takes precedence for the extension of the Matagorda Entrance Channel. Refer to the Real Estate Appendix for more details.

6.10 PLACEMENT AREAS

The proposed MSC Project will utilize the existing Sundown (Chester) Island placement area (PA) for the storage of the new work dredging material. New Unconfined open water placement areas will also be constructed west of the existing Matagorda and Lavaca Bay channel such as NP1, NP2, NP3, NP4, NP5, NP6, NP7, Sand Engine (SE) and an Ocean Dredge Material Disposal Site (ODMDS) O5 to contain the new work material. New work material will be placed according to

Table 6-10. Details concerning all of the proposed placement areas can be found in the Appendix E, Dredged Material Management Plan (DMMP).

Table 6.10 TSP New Work Quantities with Placement Area

Reach Description	Reach Stationing	Dredging Quantity (cy)	Placement Area	Type of Dredge
New Entrance Channel Extension	-33+000 to -20+000	2,383,334	New Work ODMDS 05	Hopper
Entrance Channel	-20+000 to -6+000	2,265,543	ODMDS 05 SE	Hopper
Jetty Channel	-6+000 to 0+000	549,977	Sundown Island	Pipeline
Matagorda Bay	0+000 to 45+000	4,917,397	Sundown NP1,NP2	Pipeline
Matagorda Bay	45+000 to 75+000	3,775,899	NP2,NP3	Pipeline
Lavaca Bay	75+000 to 95+000	2,260,593	NP3,NP4, NP5	Pipeline
Lavaca Bay	95+000 to 105+000	1,532,673	NP5,NP6	Pipeline
Lavaca Bay and New 1,200’ Turning Basin	105+000 to 116+223	2,707,704	NP6,NP7	Pipeline
Point Comfort Turning Basin	116+223 to 117+223	293,024	NP7	Pipeline
Point Comfort North and South Basins	117+223 to 118+502	277,253	NP7	Pipeline
Total New Work		20,963,397		

6.11 RELOCATIONS

During the Planning Phase, twenty-two pipelines were identified in the Lavaca and Matagorda Bays and Entrance Channel. Real Estate has reduced this amount to sixteen pipelines. Only 13 of the 16 pipelines were located and shown on the drawings. Additional research will be done to verify the permits and the location of the remaining pipelines in PED. Refer to the Real Estate Appendix for additional details on the pipelines. Table 6.11 shows the Real Estate pipeline findings.

Table 6.11 Pipelines Crossing the Matagorda Ship Channel

	STA.	PIPELINE OPERATOR	USACE Permit No.	Number of Pipelines	Pipeline Size (inches)	Pipeline Depth(-) (FT)
Lavaca Bay	105+594	Neumin	-	1	4.5	-
	91+075	Texas Eastern Transmission Co	3560	1	30	50
	91+330	Ineos USA LLC	-	1	8.63	-
	91+330	Ineos USA LLC	-	1	8.63	-
	82+960	Onyz Pipeline	-	4	8.63	-
	76+314	Valero Interstate	82679	1	6.63	-
Matagorda Bay	72+949	Lavaca	4566	4	8.63	-
	43+000	High Island Gas	6729	1	16	-
	22+472	Union Oil	-	1	8.63	-
Offshore	18+472	Enterprise	14794	1	24	65

6.12 REFERENCES

ER 1110-2-1150 Engineering and Design for Civil Works Project, August 1999

ER 1130-2-520 Navigation and Dredging Operations and Maintenance Policies, November 1996

URS Corporation, Section 204(f) Feasibility Report for Matagorda Ship Channel Improvement Project, July 2014

URS Corporation, Engineering Appendix, Matagorda Ship Channel Improvement Project, July 2014

7.0 HAZARDOUS AND TOXIC MATERIALS

Finding contaminated sediments in the dredge template of this project is not anticipated. The Alcoa (Point Comfort)/Lavaca Bay Superfund Record of Decision (ROD) sediment remedial action objective (RAO) investigation determined mercury concentrations were below the remedial level of 0.25 mg/kg for cleanup. The sediment quality is deemed acceptable. If other contaminated sediments are found, terrestrial upland Placement Area P1 will be constructed south of the Alamo Beach on existing agricultural land and utilized for this material.

8.0 ENVIRONMENTAL OBJECTIVES AND REQUIREMENTS

Significant ecological, aesthetic and cultural values must be preserved and protected. Natural resources should also be conserved. The human and natural environments should be maintained and restored as needed. Plans implemented to improve navigation should avoid damaging the environment and contain methods to minimize or mitigate damages to the environment. The Environmental Operating Principles (EOP) provide measures on how to preserve, manage and improve our air, water and land resources.

9.0 OPERATION AND MAINTENANCE

The plan proposed for maintenance dredging is discussed in the Appendix E – DMMP.

10.0 ACCESS ROADS

Access roads are not required for the channel dredging. Channel deepening will be accomplished by a floating plant. Existing access roads for the project site are available for use during construction. Access to project site can be made by water.

11.0 PROJECT SECURITY

This project consists mainly of channel dredging and levee work. A security plan will not be needed.

12.0 COST ESTIMATE

12.1 COST ESTIMATE DESCRIPTION

The estimate was prepared in accordance with ER 1110-2-1302 Civil Works Cost Engineering, dated June 30, 2016. Costs were initially generated for dredging to the following depths: 41ft, 47ft, and 51ft. The Economist used interpolation of these costs to generate estimates for dredging to required depths of 43ft, 45ft, and 49ft. The 47-ft alternative was determined to be the NED Plan.

Subsequent to additional ship simulations, it was determined that the channel improvements would be revised to a width of 300-ft in the Bay and to 550-ft in the Entrance Channel. In addition, the PDT determined that other revisions would be made to the scope of work of the TSP. These included elimination of two upland placement areas, which resulted in shorter pipeline pump distances, and the addition of a Sedimentation Basin in the Entrance Channel.

An Abbreviated Risk Analysis (ARA) was developed with the participation of the PDT in October 2017, but was later revised in November of 2018 to take into account deleted and added Features of Work. For screening of alternatives for the TSP, an average risk contingency of 37% from the ARA was applied to the direct first construction costs, as well as for Planning, Engineering, & Design (PED) and Construction Management (CM). Since the total project cost of the TSP exceeds $40 million, a formal Cost and Schedule Risk Analysis (CSRA) was required. The CSRA was prepared by the Cost Center of Expertise in Walla Walla District, with participation from the PDT. Refined risk contingencies were developed using the risk modeling software, Crystal Ball. The resulting contingency markups of 30% was then applied to all Code of Accounts for features of work, as well as PED, and CM. However, the 25% risk contingency developed by Real Estate Section would continue to be utilized for the Lands and Damages Code of Account. Table 12-1 shows a summary breakdown of the Federal, Non-Federal, and Associated Costs for the TSP.

The cost estimate developed for the Tentatively Selected Plan was separated into five categories:

1) The New Work dredging to increase the depth and width in the MSC.
2) Relocation of pipelines to accommodate the improved channel.
3) Environmental mitigation costs.
4) Improvement of docks to accommodate the new channel dimensions.
5) 50 Year Operations and Maintenance of planned project.

Costs for required port improvements, considered “Associated Costs”, were generated by Calhoun Port Authority and reviewed appropriately by Cost Engineer.

ACCOUNT CODE 01 – LANDS AND DAMAGES: Pipeline relocation locations were provided by Real Estate Division and quantities were provided by Engineering Branch. The costs were estimated based on the linear feet and diameter of pipelines, using historical relocation costs for similar projects.

ACCOUNT CODE 06 – FISH AND WILDLIFE FACILITES (MITIGATION): Environmental Mitigation costs consist of the construction of 129 acres of new oyster habitat. Acreage quantities and design dimensions were provided by the Galveston District Environmental Branch.

ACCOUNT CODE 12 – NAVIGATION PORTS AND HARBORS: It was assumed that a 30-inch diameter cutter-head pipeline dredge would be used to excavate the improved channel in the Bay reaches, while a large hopper dredge would be used in the Entrance channel. A unit price of $3.00 per gallon for marine fuel was used for the dredging estimates.

New work dredging costs were generated utilizing the Corps of Engineers Dredge Estimating Program (CEDEP). It was assumed that material from the Entrance Channel would be placed in open water placement areas O5, PA 1, and in the surf zone near the beach south of the Jetty Channel. Dredged material from the channel improvements in the Bay would be placed by pipeline dredge at Sundown Island and in open water PA’s NP1 through NP7 near the MSC. The dredge estimates were based on standard operation practices for the Galveston District, which assumed conventional contractual practices of large business invitation for bids (IFBs’).

ACCOUNT CODE 30 – ENGINEERING AND DESGIN: The cost for this account was developed using the guidelines provided in the TPCS, with the agreement of the cost engineer and the project manager.

ACCOUNT CODE 31 – CONSTRUCTION MANAGEMENT: The cost for this account was developed using the guidelines provided in the TPCS, with the agreement of the cost engineer and the project manager.

A 50 Year O&M cost was generated for both With Project and Without Project dredging quantities. Quantities were provided by Engineering Branch and were based on historical dredge history of the existing channel and projected shoaling rates for the improved channel dimensions. Maintenance material would be placed in open water PA’s OP1 through OP10, adjacent to the new work placement areas. For the O&M costs, a contingency markup of 25% was used, along with a markup of 25% for PED and a 25% markup for Construction Management. O&M Costs were provided to the Economist, but are not included in the Code of Accounts in the TPCS for the Estimated Total Project Cost.

A CSRA Summary Report was provided and is shown in Attachment 1. A detailed breakdown of costs in MCACES (MII, Ver. 4.4) is provided in Attachment 2. In addition, the Total Project Cost Summary is shown in Attachment 3.

Table 12 – 1 Project Cost Estimate for Alternative Plan A (47-ft Depth, 300-ft width in Bay; 49-ft depth, 550-ft width in Entrance Channel)

Construction Item	Cost at 47'
01 - Lands and Damages	$ 1,373,000
02 - Relocations	$ 34,598,000
Non-Federal Costs:	**$ 35,971,000**
06 - Fish and Wildlife	$ 21,724,000
12 - Navigation Ports and Harbors	$ 140,022,000
30 - Planning, Engineering, and Design	$ 21,518,000
31 - Construction Management	$ 13,744,000
Federal Costs:	**$ 197,008,000**
PROJECT FIRST COST:	**$ 232,979,000**
12 - Navigation Ports and Harbors (Berthing Improvements / Dock Dredging)	$ 2,625,000
ASSOCIATED COST:	**$ 2,625,000**
TOTAL ECONOMIC COST:	**$ 235,604,000**

Table 12 – 2 Project First Cost Estimate for Alternative Plan A, Oct 2018 Price Level (47-ft Depth, 300-ft width in Bay; 49-ft depth, 550-ft width in Entrance Channel)

Construction Item	Project First Costs	Fully Funded Project Costs
01 - Lands and Damages	$ 1,554,000	$ 1,711,000
02 - Relocations	$ 31,061,000	$ 32,084,000
Non-Federal Costs:	**$ 32,615,000**	**$ 33,795,000**
06 - Fish and Wildlife	$ 26,257,000	$ 28,770,000
12 - Navigation Ports and Harbors	$ 121,494,000	$ 130,996,000
30 - Planning, Engineering, and Design	$ 19,615,000	$ 21,151,000
31 - Construction Management	$ 12,517,000	$ 13,765,000
Federal Costs:	**$ 179,883,000**	**$ 194,682,000**
TOTAL PROJECT COST:	**$ 212,498,000**	**$ 228,476,000**
12 - Navigation Ports and Harbors (Berthing Improvements / Dock Dredging)	$ 4,759,000	$ 4,916,000
12- Aids to Navigation	$ 1,883,000	$ 1,945,000
30 - Planning, Engineering, and Design	$ 642,000	$ 663,000
31 - Construction Management	$ 410,000	$ 428,000
ASSOCIATED COST:	**$ 7,694,000**	**$ 7,952,000**
TOTAL ECONOMIC COST:	**$ 220,192,000**	**$ 236,428,000**

13.0 DATA MANAGEMENT

The Engineering Appendix is located electronically and maintained on the shared drive at S:\shared files\Matagorda_Section_216_FY17\Engineering Appendix\MSC Draft Engineering Appendix Report\.

14.0 USE OF METRIC SYSTEM MEASUREMENTS

English units is the familiar system used in this area. Throughout the feasibility study, surveys, design, drawings and analyses were completed with the English unit system. Converting from the English to the Metric system would have caused impacts to the project schedule.

15.0 ATTACHMENTS

H&H ATTACHMENT NO.1

SEA LEVEL RISE

Attachment 1 to H&H Engineering Appendix:

Sea-Level Rise Effects

on the Matagorda Ship Channel's Deepening and Widening Project

Report SUMMARY

This report summarizes guidance for incorporating sea-level rise (SLR) into a navigation project. Specific SLR projections have been included for Matagorda Ship Channel.

Relative to 2017, the year in which survey, cost, and economic analyses were performed in this Feasibility Study, the Low and Intermediate SLR Curves produce:

Year	Low (feet)	Event	Intermediate (feet)
2017	0.00	Survey, cost, and economic analyses	0.00
2024	0.11	Anticipated end of project's four-year construction	0.20
2074	0.89	End of project 50-year "lifetime"	1.88
2124	1.67	End of 100-year planning period	3.22

The Low curve's numbers may be used as a conservative estimate for the **least** amount of dredging reduction that can be expected. The Intermediate Curve is to be used in numerical modeling for estimating expected maximum environmental impacts.

Projected sea-level rise has been computed for project durations of 25-year, 50-year, and 100-year timeframes. As a conservative approach, USACE's **Low** Sea-Level Curve should be used for the dredging part of this navigation project (since it provides deeper water and less dredging than other curves).

When considering channel depths (for dredging computations), both sea-level rise and subsidence are relevant. (Subsidence is more than twice the eustatic sea-level rise rate. However, eustatic SLR appears to be accelerating, while subsidence is decelerating.) SLR will effectively deepen the channel and therefore reduce dredging costs. This cost savings has **not** yet been included in the cost engineering and economic analysis.

Conversely, SLR effects on the non-federal sponsor's infrastructure will largely be detrimental. They should carefully consider which sea-level to plan for, and more importantly, what their adaptation measures should be.

Some deleterious effects due to sea-level rise may also occur within the federal project, such as:

Increased erosion at islands and levees surrounding placement areas
Increased ship wakes in barge lanes and mooring areas
Increased wind waves, especially in shallow areas (but not in the main channel)
Changes in water chemistry (increased salinity and dissolved oxygen)

For the first three items in the list above, some simple spreadsheet calculations can be performed to indicate a level-of-concern. For the last category, the numerical model should help quantify the effects. However, there will not be sufficient funds to run all possible combinations of: Low, Intermediate, and High SLR; effects from ship wakes; and waves. Only currents and salinity will be modeled. Waves were predicted in this project with simpler methods.

1 SUMMARY of Official Guidance on Sea-Level Change

General guidance for "Incorporating Sea-Level Change in Civil Works Programs" is given in the 3-pages plus appendices of ER 1100-2-8162. General concepts and analyses are expected to be applied to "every coastal activity as far inland as the extent of estimated tidal influence", which describes the Matagorda Ship Channel.

Relevant characteristics of the analyses may be summarized as:

- Consider SLR effects on the designs over the project life cycle (usually 50 years).
- Evaluate effects on the project for the three USACE sea-level curves: Low, Intermediate, and High. A sea-level calculator is at http://www.corpsclimate.us/ccaceslcurves.cfm
- Analyze effects for "With Project" and "Without Project".
- Evaluate how sensitive the alternatives and the selected design are to the different SLRs.
- List and describe the Risks due to SLR, estimate uncertainties, and plan measures to adapt to the rise: "decisions allowing for adaption based on evidence as the future unfolds." The approach of **adaptation** is recommended over the alternatives of **reaction** or **prediction**. (Our ability to predict is not good.)
- Sea level curve "selection should be tailored to each situation." However, guidance for **navigation projects** is to generally use the Low SLC, since it is the conservative choice (results in the least improvement to channel depth). (ref: Climate-Change CoP Subject Matter Expert, Patrick O'Brien, briefing to SWG H&H Branch on 10/21/2016)

2 Relative Sea-Level Change

This report uses current USACE guidance to assess relative sea-level change (RSLC). Current USACE guidance (ER 1100-2-8162, December 2013, and ETL 1100-2-1, June 2014) specifies the procedures for incorporating climate change and RSLC into planning studies and engineering design projects. Projects must consider alternatives that are formulated and evaluated for the entire range of possible future rates of RSLC for both existing and proposed projects. USACE guidance specifies evaluating alternatives using “low,” “intermediate,” and “high” rates of future sea level change.

- Low - Use the historic rate of local mean sea-level change as the “low” rate. The guidance further states that historic rates of sea-level change are best determined by local tide records (preferably with at least a 40-year data record).
- Intermediate - Estimate the “intermediate” rate of local mean sea-level change using the modified NRC Curve I. It is corrected for the local rate of vertical land movement.
- High - Estimate the “high” rate of local mean sea-level change using the modified NRC Curve III. It is corrected for the local rate of vertical land movement.

USACE (ETL 1100-2-1, 2014) recommends an expansive approach to considering and incorporating RSLC into civil works projects. It is important to understand the difference between the period of analysis (POA) and planning horizon. Initially, USACE projects are justified over a period of analysis, typically 50 years. However, USACE projects can remain in service much longer than the POA. The climate for which the project was designed can change over the full lifetime of a project to the extent that stability, maintenance, and operations may be impacted, possibly with serious consequences, but also potentially with beneficial consequences. Given these factors, the project planning horizon (not to be confused with the economic period of analysis) should be 100 years, consistent with ER 1110-2-8159. Current guidance considers both short- and long-term planning horizons and helps to better quantify RSLC. RSLC must be included in plan formulation and the economic analysis, along with USACE expectations of climate change and RSLC, and their impacts. Some key expectations include:

- At minimum 25-, 50-, and 100-year planning horizons should be considered in the analysis. (ETL 1100-2-1, p. C-3)
- A thorough physical understanding of the project area and purpose is required to effectively assess the project’s sensitivity to RSLC.
- Identify thresholds and tipping points within the impacted project area to inform both the selection of anticipatory/adaptive/reactive options and the timing strategies.
- Rather than attempt to predict climate change, it is more important to “provide a method to address uncertainty, describing a sequence of decisions allowing for adaptation based on evidence as the future unfolds.” (ER 1100-2-8162)

3 Historic (Low Curve) RSL for Matagorda

Historic rates are taken from the Center for Operational Oceanographic Products and Services (CO-OPS) at NOAA, which has been measuring sea level for over 150 years. Guidance is that changes in MSL should be computed using gages with a minimum 40-year span of observations. Unfortunately, the Matagorda tide gage has neither long records nor is it benchmarked. Thus the distant Freeport and Rockport data were averaged to create new Matagorda data. All of the tide data were obtained from the list of monthly averages, in order to eliminate the effect of higher frequency phenomena such as storm surge and compute an accurate linear sea-level trend.

The MSL trends presented are local relative trends, as opposed to the global (eustatic) sea-level trend. Tide gauge measurements are made with respect to a local fixed reference level on land; therefore, if there is some long-term vertical land motion occurring at that location, the relative MSL trend measured there is a combination of the global (eustatic) sea-level rate and the local vertical land motion (subsidence).

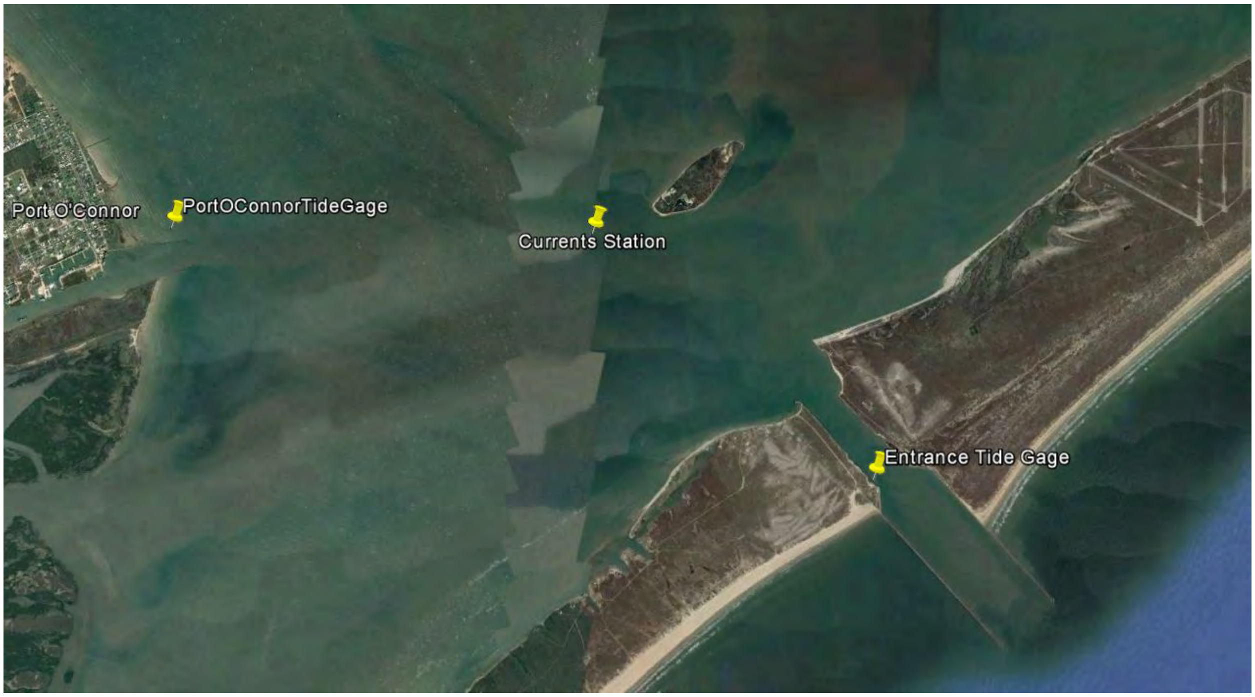
Matagorda has the following seven relevant gages. All but the Pass Cavallo gage are still active.

1. Rockport, 50 miles to the southwest: this is the only one of the gages surveyed into a land-based datum (NAVD88). All the other gages provide data relative to the Station Datum (station's ground elevation), which is then related to local Mean Sea Level (MSL).
2. Freeport, 70 miles to the northeast
3. Lavaca Tide Gage, at the northern edge of Port Lavaca and directly to the west of the Point Comfort Port
4. Port O'Connor
5. Bird Island
6. Matagorda Entrance Channel (which added current measurements in November 2017)
7. Pass Cavallo tide gage temporarily deployed during the 2005 field data collections, which the Port contracted Evans Hamilton, Inc. to perform (Puckette, 2006)

Gages 4-6 in this list are the ones near the entrance channel, shown in the map below:

Map 1: Active gages near Matagorda from https://www.tidesandcurrents.noaa.gov/map/

and plotted below on Google Earth:



The Port O'Connor gage is tides and winds only, and the Bird Island Currents gage is currents only. The Entrance Tide Gage recently (Nov 2017) had a current meter added.

3.1 Coastal Gages

The Port O'Connor and Lavaca tide stations do not have long records and have not been surveyed in by NOAA to primary benchmarks and are not even included in the Corps' climate-change website. Therefore there are no sea-level rise statistics in Matagorda Bay. Fortunately, there are two long-term gages northeast (Freeport) and southwest (Rockport) of Matagorda that show approximately the same rate of SLR. The conclusions are:

3.2 Rockport Tide Gage

Rockport is 50 miles southwest of Matagorda. The rate of relative sea level rise at Rockport is equal to 5.16±0.67 mm /yr (0.017 ± 0.002 ft/yr) with a 95% confidence interval.

The first half of the following table may be used for conversion between datums. The second half shows Extreme Water Levels (EWLs) that can be used to estimate worst conditions.

Table 1. Rockport Datums

Elevations on Station Datum

Station: 8774770, Rockport, TX
Status: Accepted (May 2 2011)
Units: Feet
T.M.: 0
Epoch: 2002-2006
Datum: STND

Datum	Value	Description
MHHW	6.82	Mean Higher-High Water
MHW	6.81	Mean High Water
MTL	6.63	Mean Tide Level
MSL	6.64	Mean Sea Level
DTL	6.63	Mean Diurnal Tide Level
MLW	6.46	Mean Low Water
MLLW	6.45	Mean Lower-Low Water
NAVD88	5.52	North American Vertical Datum of 1988
STND	0.00	Station Datum
GT	0.36	Great Diurnal Range
MN	0.36	Mean Range of Tide
DHQ	0.00	Mean Diurnal High Water Inequality
DLQ	0.00	Mean Diurnal Low Water Inequality
HWI		Greenwich High Water Interval (in hours)
LWI		Greenwich Low Water Interval (in hours)
Maximum	10.55	Highest Observed Water Level
Max Date & Time	08/10/1980 13:18	Highest Observed Water Level Date and Time
Minimum	3.83	Lowest Observed Water Level
Min Date & Time	02/29/1984 11:18	Lowest Observed Water Level Date and Time
HAT	7.31	Highest Astronomical Tide
HAT Date & Time	10/18/1989 09:54	HAT Date and Time
LAT	5.91	Lowest Astronomical Tide
LAT Date & Time	01/28/1987 18:06	LAT Date and Time

3.3 Freeport Tide Gage

Freeport is 70 miles northeast of Matagorda. The rate of relative sea level rise at Freeport is equal to 4.35±1.12 mm /yr (0.014 ± 0.004 ft/yr) with a 95% confidence interval. The station datums are shown below.

The first half of the following table may be used for conversion between datums. The second half shows Extreme Water Levels (EWLs) that can be used to estimate worst conditions.

Table 2. Freeport Datums

Elevations on Station Datum

Station: 8772447, Freeport, TX
Status: Accepted (Jun 9 2011)
Units: Feet

T.M.: 90
Epoch: 1983-2001
Datum: STND

Datum	Value	Description
MHHW	29.45	Mean Higher-High Water
MHW	29.29	Mean High Water
MTL	28.60	Mean Tide Level
MSL	28.62	Mean Sea Level
DTL	28.55	Mean Diurnal Tide Level
MLW	27.91	Mean Low Water
MLLW	27.65	Mean Lower-Low Water
NAVD88		
STND	0.00	Station Datum
GT	1.80	Great Diurnal Range
MN	1.39	Mean Range of Tide
DHQ	0.15	Mean Diurnal High Water Inequality
DLQ	0.26	Mean Diurnal Low Water Inequality
HWI		Greenwich High Water Interval (in hours)
LWI		Greenwich Low Water Interval (in hours)
Maximum	35.03	Highest Observed Water Level
Max Date & Time	09/12/2008 18:42	Highest Observed Water Level Date and Time
Minimum	24.93	Lowest Observed Water Level
Min Date & Time	03/22/2010 06:30	Lowest Observed Water Level Date and Time
HAT	30.19	Highest Astronomical Tide
HAT Date & Time	10/18/1989 01:12	HAT Date and Time
LAT	26.41	Lowest Astronomical Tide
LAT Date & Time	01/28/1987 13:42	LAT Date and Time

3.4 Matagorda Sea-Level Rise

Averaging the rates from the two gages, Matagorda's **SLR rate is 4.76 mm/yr** (0.0156 ft/yr). If the estimated historic eustatic rate equals that given by the modified NRC curves (1.70 mm/yr), the observed **subsidence rate for Matagorda would be 4.76 - 1.70 = 3.06 mm/yr**.

The present and future conditions for the project, using Matagorda's linear historic (**Low Curve**) SLR rate of 4.76 mm/yr (0.0156 ft/yr), all referenced to Local Mean Sea Level (LMSL) are:

Table 3. Matagorda Low-Curve Sea Levels

Part A

Year	Still Water Elevation (ft MSL)	Event
1992	0.00	NOAA-defined start point (midpoint of Freeport's tidal epoch)
2013	0.33	Measured data used by calculator ends at 8/01/2013.
2017	0.39	Year of bathymetric data (post-Harvey) & economics modeling in this study
2024	0.50	Anticipated end of project's four-year construction
2074	1.28	End of project 50-year "lifetime"
2124	2.06	End of 100-year planning period

Recomputing these values using 2017 as zero (year of survey, cost, and economic analyses),

Part B

Year	Still Water Elevation (ft MSL)	Event
1992	-0.39	NOAA-defined start point (midpoint of Freeport's tidal epoch)
2013	-0.06	Measured data used by calculator ends at 8/01/2013.
2017	0.00	Year of bathymetric data (post-Harvey) & economics modeling in this study
2024	0.11	Anticipated end of project's four-year construction
2074	0.89	End of project 50-year "lifetime"
2124	1.67	End of 100-year planning period

Recomputing with project start (2024) as zero,

Part C

Year	Still Water Elevation (ft MSL)	Event
1992	-0.50	NOAA-defined start point (midpoint of Freeport's tidal epoch)
2013	-0.17	Measured data used by calculator ends at 8/01/2013.
2017	-0.11	Year of bathymetric data (post-Harvey) & economics modeling in this study
2024	0.00	Anticipated end of project's four-year construction
2074	0.78	End of project 50-year "lifetime"
2124	1.56	End of 100-year planning period

4 Predicted Future SLR

Neither the Matagorda Entrance Channel tide gage nor the Port O'Connor gage can be used to compute sea-level rise for this project, since neither is benchmarked. Their years of record are also short. Instead the faraway Freeport and Rockport tide data were averaged to create water-level records for Matagorda. In addition to the project design period of 50 years and the project planning period of 100 years, the 25-year period will be calculated, per ETL 1100-2-1, p. C-3.
Procedure:

1. Tables and plots were created for each of the three time periods for the two gages.
2. These data from Freeport and Rockport were averaged to create the Matagorda Low Curve water levels in Table 3.
3. To create the Intermediate Curve water levels in the Summary at the start of this report, the differences between the Intermediate and Low levels were averaged and were then added to the Matagorda Low levels in Part B of Table 3.

4.1 Predicted Future Rates of RSLC for 25-Year Period of Analysis

The computed future rates of RSLC in this section give the predicted change between the years 2024 (estimated project start date) and 2049 for Matagorda Bay. RSLC values for this 25-year period are summarized in Figure 1 for Freeport and Figure 2 for Rockport. For comparison, both NOAA and USACE curves are shown. The **rates** that will be used in this navigation project are the USACE and NOAA Low curve and Intermediate curves, which are identical since they use the same historic rate. However, the computed **elevations** from the two calculators (NOAA and USACE) differ slightly, since the periods of analysis differ by two years.

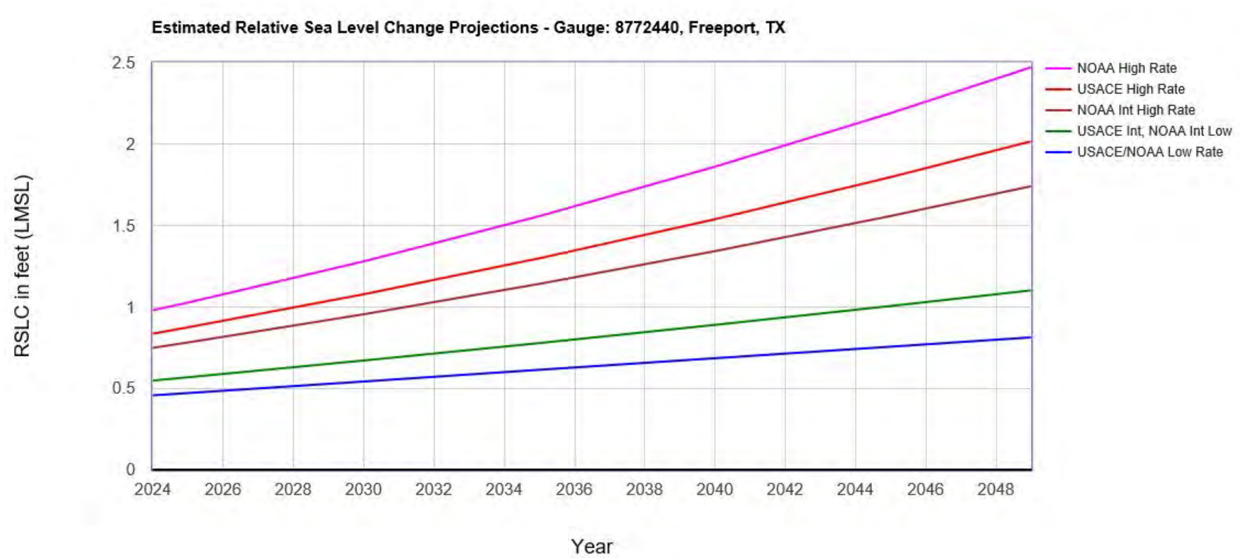


Figure 1: Freeport's Estimated SLR over the First 25 Years of Project Life (2024 - 2049) from both NOAA and Corps' Curves (Levels are relative to Freeport Zero Station Datum.)

Table 4: Freeport's Estimated SLR over the First 25 Years of Project Life (2024 - 2049) (Levels are relative to Freeport Zero Station Datum.)

Matagorda
8772440, Freeport, TX
NOAA's 2006 Published Rate: 0.01427 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2024	0.46	0.55	0.75	0.84	0.98
2025	0.47	0.57	0.78	0.88	1.03
2030	0.54	0.67	0.96	1.08	1.28
2035	0.61	0.78	1.14	1.30	1.56
2040	0.69	0.89	1.34	1.54	1.86
2045	0.76	1.01	1.56	1.80	2.19
2049	0.81	1.10	1.74	2.02	2.47

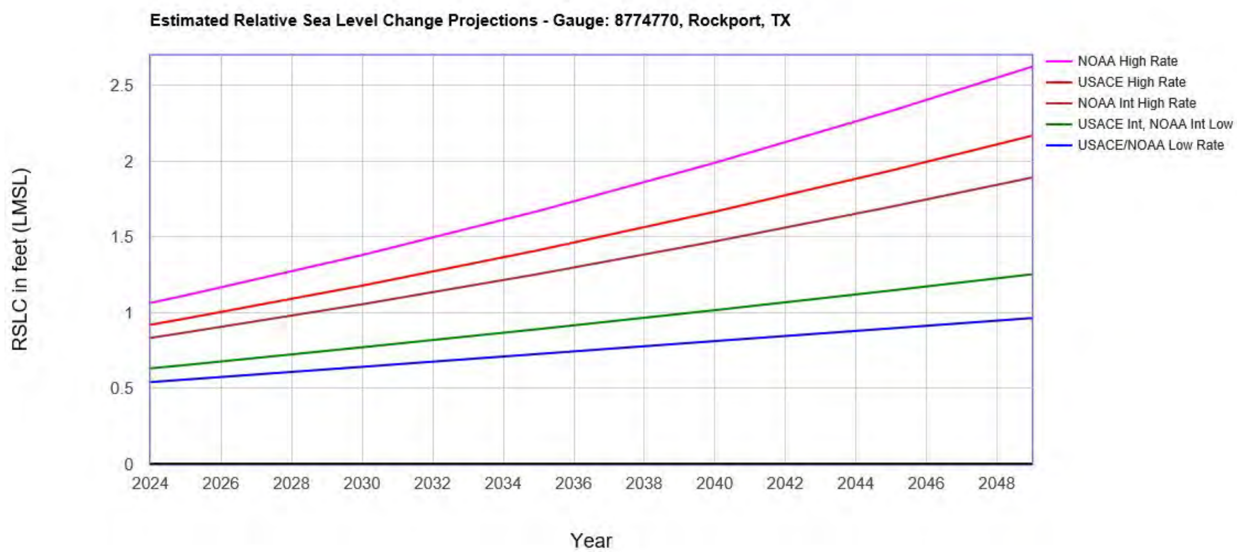


Figure 2: Rockport's Estimated SLR over the First 25 Years of Project Life (2024 - 2049) from both NOAA and Corps' Curves (Levels are relative to Rockport Zero Station Datum)

Table 5. Rockport's Estimated SLR for the 25-Year Period of Analysis (2024 - 2049) (Levels are relative to Rockport Zero Station Datum.)

Matagorda
8774770, Rockport, TX
NOAA's 2006 Published Rate: 0.01693 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2024	0.54	0.63	0.83	0.92	1.07
2025	0.56	0.66	0.87	0.96	1.12
2030	0.64	0.77	1.06	1.18	1.38
2035	0.73	0.89	1.26	1.41	1.67
2040	0.81	1.02	1.47	1.67	1.99
2045	0.90	1.15	1.70	1.94	2.33
2049	0.97	1.25	1.89	2.17	2.63

Results for the Low (Historic) rate were shown in Section 3.4 (Matagorda Historic Low-Curve SLR). Averaging the numbers from the Intermediate column in the Freeport and Rockport tables produces Intermediate Curve results for Matagorda:

Table 6. Matagorda Intermediate SLRC for the First 25 Years of Project Life (2024-2049)

Year	Still Water Elevation (ft MSL)	Event
2024	0.59	Anticipated end of project's four-year construction
2025	0.62	
2030	0.72	
2035	0.84	
2040	0.96	
2045	1.08	
2049	1.18	

4.2 Predicted Future Rates of RSLC for 50-Year (Project Design) Period of Analysis

The computed future rates of RSLC given here assume a 50-year period of analysis, and give the predicted change between the years 2024 and 2074. Relative sea level change values for the 50-year period are shown in Figure 3 and Table 3 for Freeport. The blue linear line is the historic rate for Freeport (4.35 mm/yr or 0.014 ft/yr). The green line is the Intermediate Curve that will be used in numerical modeling and for estimating environmental impacts.

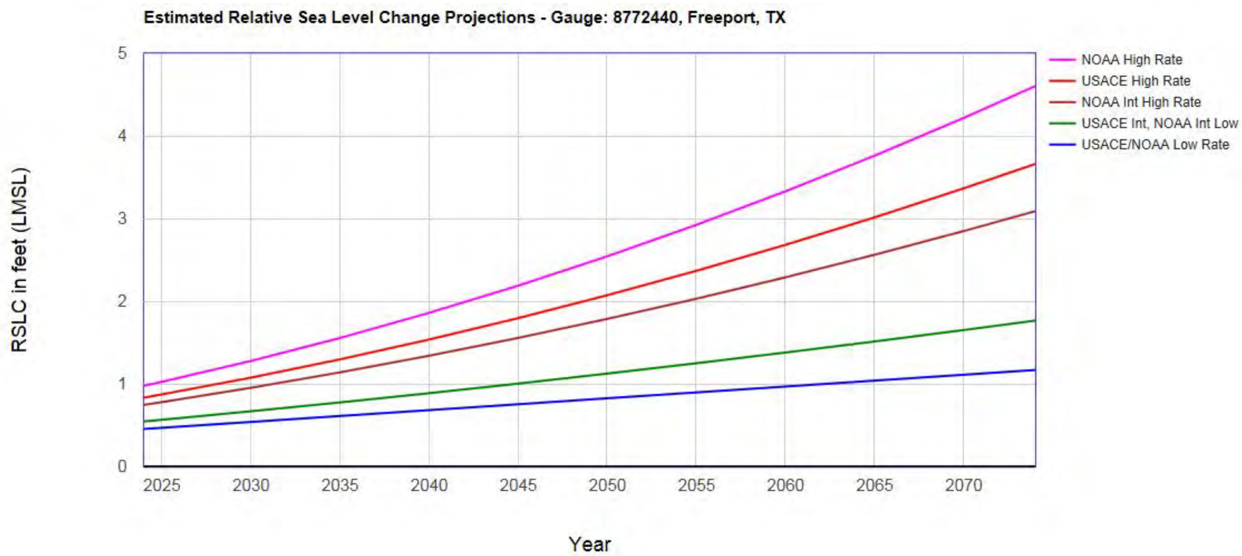


Figure 3: Estimated SLR for the first 50 Years of the Project Life (2024 - 2074) showing both NOAA and Corps' curves - Levels are relative to Local MSL at Freeport.

Table 7. SLR for the 50-Year Period of Analysis at Freeport (Levels are relative to Freeport local MSL.)

8772440, Freeport, TX
NOAA's 2006 Published Rate: 0.01427 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2024	0.46	0.55	0.75	0.84	0.98
2025	0.47	0.57	0.78	0.88	1.03
2030	0.54	0.67	0.96	1.08	1.28
2035	0.61	0.78	1.14	1.30	1.56
2040	0.69	0.89	1.34	1.54	1.86
2045	0.76	1.01	1.56	1.80	2.19
2050	0.83	1.13	1.79	2.08	2.55
2055	0.90	1.25	2.03	2.37	2.93
2060	0.97	1.38	2.29	2.69	3.33
2065	1.04	1.52	2.57	3.02	3.76
2070	1.11	1.65	2.85	3.37	4.22
2074	1.17	1.77	3.09	3.66	4.61

The computed future rates of RSLC given here assume a 50-year period of analysis, and give the predicted change between the years 2024 and 2074. Relative sea level change values for the 50-

year period are shown in Figure 3 and Table 3 for Rockport. The blue linear line is the historic rate for Rockport (5.16 mm/yr or 0.017 ft/yr). The green line is the Intermediate Curve that will be used in numerical modeling and for estimating environmental impacts.

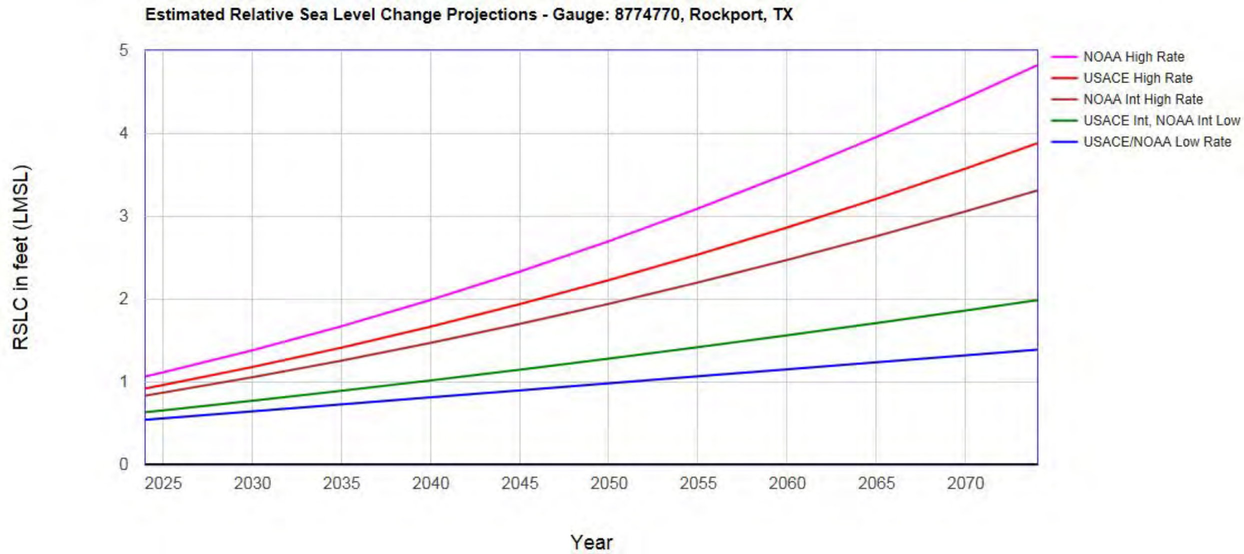


Figure 4: Estimated SLR over the First 50 Years of the Project Life (2024 - 2074) showing both NOAA and Corps' curves - Levels are relative to Local MSL at Rockport.

Table 8. SLR for the 50-Year Period of Analysis at Rockport (Levels are relative to Rockport local MSL.)

8774770, Rockport, TX
NOAA's 2006 Published Rate: 0.01693 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2024	0.54	0.63	0.83	0.92	1.07
2025	0.56	0.66	0.87	0.96	1.12
2030	0.64	0.77	1.06	1.18	1.38
2035	0.73	0.89	1.26	1.41	1.67
2040	0.81	1.02	1.47	1.67	1.99
2045	0.90	1.15	1.70	1.94	2.33
2050	0.98	1.28	1.94	2.23	2.70
2055	1.07	1.42	2.20	2.54	3.09
2060	1.15	1.56	2.47	2.87	3.51
2065	1.24	1.71	2.76	3.21	3.96
2070	1.32	1.86	3.06	3.58	4.43
2074	1.39	1.99	3.31	3.88	4.82

For purposes of modeling (currents and salinity) the Intermediate SLRC is used in order to gage the maximum environmental effects. Using Matagorda's **Intermediate Curve** (the average of the Rockport and Freeport curves), project conditions are:

Table 9. Matagorda Intermediate SLRC for the First 50 Years of Project Life (2024-2074)

Year	Still Water Elevation (ft MSL)	Event
2024	0.59	Anticipated end of project's four-year construction
2025	0.62	
2030	0.72	
2035	0.84	
2040	0.96	
2045	1.08	
2050	1.21	
2055	1.34	
2060	1.45	
2070	1.76	
2074	1.88	End of project 50-year "lifetime"

4.3 Predicted Future Rates of RSLC – 100-year Sea-Level Change (Planning Period)

The planning, design, and construction of a large water project can take decades. Though initially justified over a 50-year economic period of analysis, USACE projects often remain in service much longer. The climate for which the project was designed can change over the full lifetime of the project to the extent that stability, maintenance, and operations may be affected. These changes can cause detrimental or beneficial consequences. Given these factors, the project planning horizon should be 100 years, consistent with ETL-1110-2-1.

The period of economic analysis for USACE projects has generally been limited to 50 years, because economic forecasts beyond that time frame were not considered reliable. However, the potential impacts of SLC over a 100-year period can be used in the formulation of alternatives and for robustness and resiliency comparisons. ETL 1100-2-1 recommends predicting how the project or system might perform, as well as its ability to adapt beyond the typical 50-year economic analysis period and that this be considered in the decision-making process.

The initial assessment that evaluates the exposure and vulnerability of the project area over the 100-year planning horizon was used to assist planners and engineers in determining the long-term approach that best balances risks for the project. The three (3) general approaches are anticipatory, adaptive, and reactive strategies. These strategies can be combined, or they can change over the life cycle of the project. Key factors in determining the approach include consequences, cost, and risk. This consideration is particularly important under a climate-change condition, where loading and response mechanisms are likely to transition over the life of the project.

Plots and tables for the 100-year period for Freeport are:

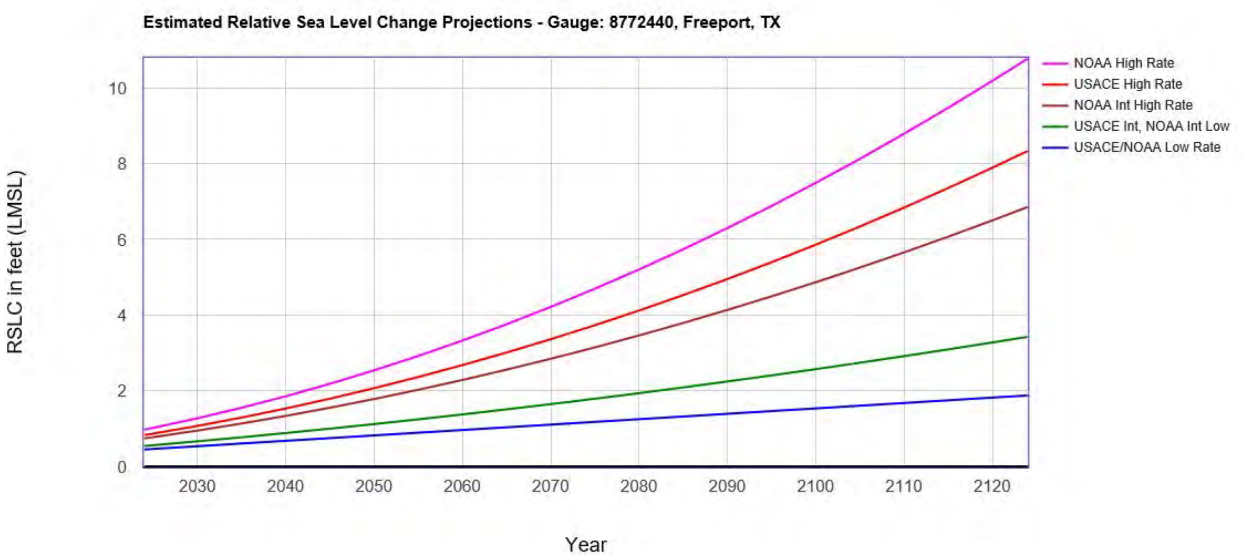


Figure 5: Estimated SLR for the first 100 Years of the Project Life (2024 - 2124) showing both NOAA and Corps' curves - Levels are relative to Local MSL at Freeport.

Table 10. SLR for the 100-Year Period of Analysis at Freeport

(Levels are relative to local MSL.)

8772440, Freeport, TX
NOAA's 2006 Published Rate: 0.01427 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2024	0.46	0.55	0.75	0.84	0.98
2025	0.47	0.57	0.78	0.88	1.03
2030	0.54	0.67	0.96	1.08	1.28
2035	0.61	0.78	1.14	1.30	1.56
2040	0.69	0.89	1.34	1.54	1.86
2045	0.76	1.01	1.56	1.80	2.19
2050	0.83	1.13	1.79	2.08	2.55
2055	0.90	1.25	2.03	2.37	2.93
2060	0.97	1.38	2.29	2.69	3.33
2065	1.04	1.52	2.57	3.02	3.76
2070	1.11	1.65	2.85	3.37	4.22
2075	1.19	1.80	3.15	3.74	4.70
2080	1.26	1.94	3.47	4.13	5.21
2085	1.33	2.10	3.80	4.53	5.75
2090	1.40	2.25	4.14	4.96	6.31
2095	1.47	2.41	4.50	5.40	6.89
2100	1.54	2.58	4.87	5.87	7.50
2105	1.61	2.75	5.26	6.35	8.14
2110	1.68	2.92	5.66	6.85	8.80
2115	1.76	3.10	6.08	7.36	9.48
2120	1.83	3.28	6.51	7.90	10.20
2124	1.88	3.43	6.86	8.34	10.78

Plots and tables for the 100-year period for Rockport are:

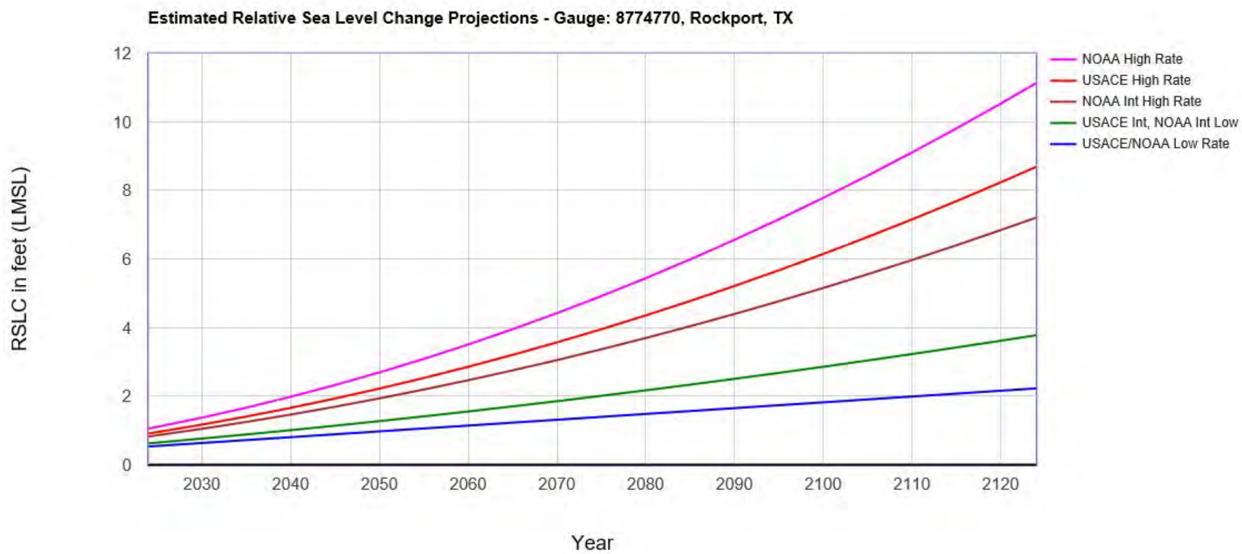


Figure 6: Estimated SLR for the first 100 Years of the Project Life (2024 - 2124) showing both NOAA and Corps' curves - Levels are relative to Local MSL at Rockport.

Table 11. SLR for the 100-Year Period of Analysis at Rockport (Levels are relative to local MSL.)

8774770, Rockport, TX
NOAA's 2006 Published Rate: 0.01693 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2024	0.54	0.63	0.83	0.92	1.07
2025	0.56	0.66	0.87	0.96	1.12
2030	0.64	0.77	1.06	1.18	1.38
2035	0.73	0.89	1.26	1.41	1.67
2040	0.81	1.02	1.47	1.67	1.99
2045	0.90	1.15	1.70	1.94	2.33
2050	0.98	1.28	1.94	2.23	2.70
2055	1.07	1.42	2.20	2.54	3.09
2060	1.15	1.56	2.47	2.87	3.51
2065	1.24	1.71	2.76	3.21	3.96
2070	1.32	1.86	3.06	3.58	4.43
2075	1.41	2.02	3.37	3.96	4.92
2080	1.49	2.18	3.70	4.36	5.45
2085	1.57	2.34	4.05	4.78	5.99
2090	1.66	2.51	4.40	5.22	6.57
2095	1.74	2.69	4.78	5.68	7.16
2100	1.83	2.87	5.16	6.15	7.79
2105	1.91	3.05	5.56	6.65	8.44
2110	2.00	3.24	5.98	7.16	9.11
2115	2.08	3.43	6.41	7.69	9.81
2120	2.17	3.62	6.85	8.24	10.54
2124	2.24	3.78	7.21	8.69	11.14

For purposes of modeling (currents and salinity) the Intermediate SLRC is used in order to gage the maximum environmental effects. Using Matagorda's **Intermediate Curve** (the average of the Rockport and Freeport curves), project conditions are:

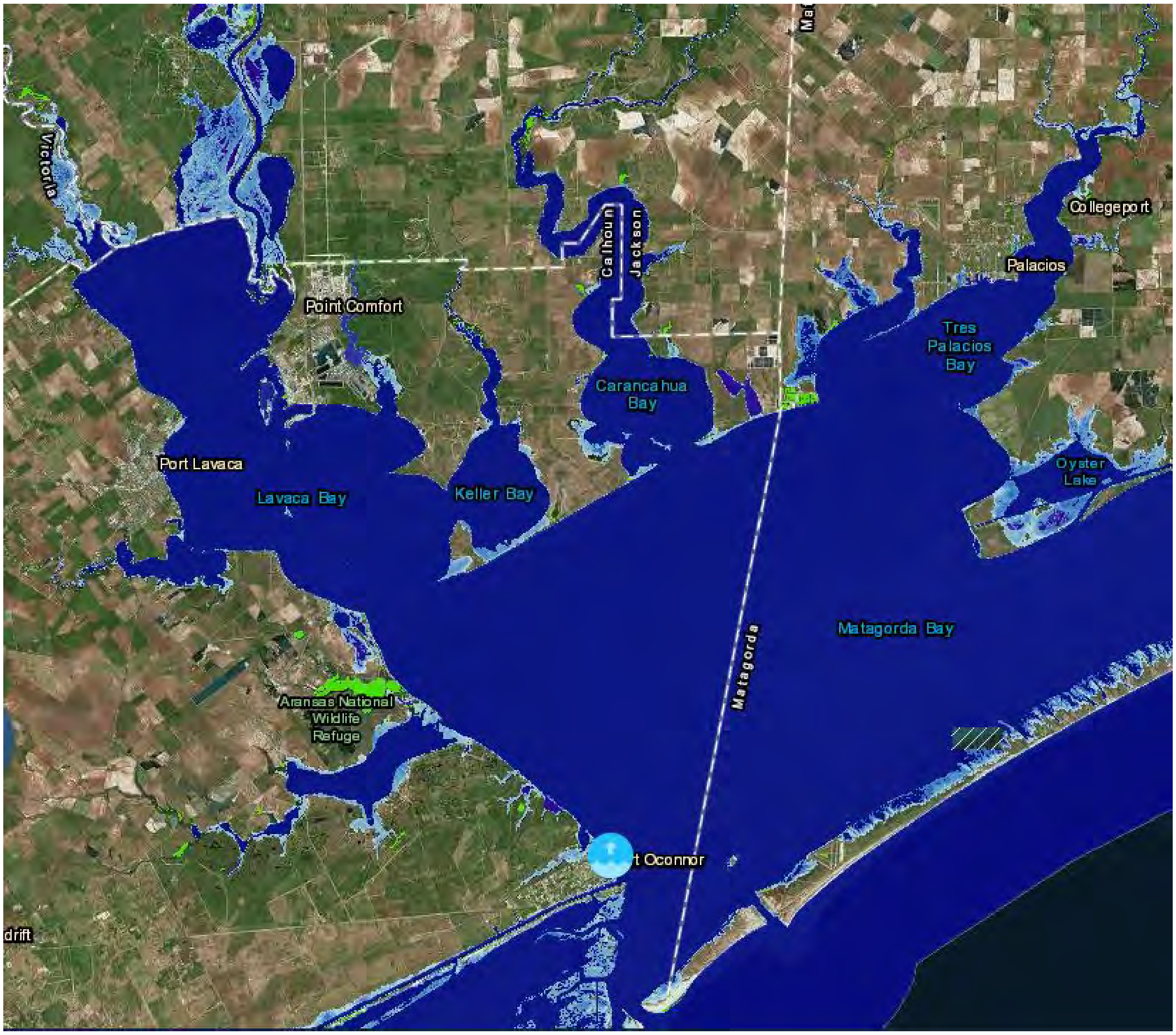
Table 12. Matagorda Intermediate SLRC for First 100 Years of Project Life (2024-2124)

Year	Still Water Elevation (ft MSL)	Event
2024	0.59	Anticipated end of project's four-year construction
2025	0.62	
2030	0.72	
2035	0.83	
2040	0.96	
2045	1.08	
2050	1.21	
2055	1.34	
2060	1.47	
2065	1.62	
2070	1.76	
2075	1.91	
2080	2.06	
2085	2.22	
2090	2.38	
2095	2.55	
2100	2.73	
2105	2.90	
2110	3.08	
2115	3.27	
2120	3.45	
2124	3.61	End of 100-year planning period

5 Planning for Sea-Level Rise

Note that near the end of the project's planning period, sea level has risen about 2 feet (between years 2075 and 2080 in the above table). In order to visualize this effect, NOAA's inundation plotter was used to show the effects of a 2ft rise. (NOAA's inundation plotter will only plot integral numbers of feet of inundation.) NOAA's "Sea Level Rise and Coastal Flooding Impacts

Viewer" can be used to view the inundation occurring in whole numbers of feet. As seen below in Map 2, it is apparent that several of the peninsulas in the Bay will become islands.



Map 2: Extent of Inundation (light blue) with 2-foot Rise (in year 2088)
Shown in bright green are low-lying areas that are occasionally inundated even before the project start. Light blue shows areas inundated at 2ft SLR.

6 Subsidence

From Brown (2011): "Ratzlaff (1982) published a survey of the observed subsidence rates along the Texas coast thought to be associated primarily with anthropogenic activities. The rates of local subsidence given for the Matagorda Bay region are similar to those observed at the coastal gages. This may be evidence that the observed coastal gage subsidence is correlated with these anthropogenic activities, but further research is needed to establish this link with confidence.

Several studies of basal peat layers have been conducted in the Texas and Louisiana coastal region to determine estimates of the long term average rates of subsidence. These rates are generally on the order to 0.5 mm/yr (0.0016 ft/yr) (Tornqvist et al (2006)). This rate is significantly lower than the observed tide gage rates. Therefore, if historic anthropogenic activities are largely responsible for the accelerated rates observed in the tide records, then one would expect the projected rates to decelerate rapidly over the next several decades."

Land subsidence in the past has been much higher than is projected for the future. (See Map 3 showing subsidence in Harris and Galveston Counties where subsidence is measured directly.) The main reason for subsidence is thought to be groundwater extraction. As supporting groundwater is removed, sediments compact. This extraction has now been severely curtailed (but not eliminated). Since the extraction occurred over such a long period of time, subsidence will continue for the near future (decades). There is evidence that subsidence is decelerating, although still continuing at a high rate that is double the rate of eustatic sea-level rise. If the estimated historic eustatic rate equals that given for the modified NRC curves (1.70 mm/yr), the observed **subsidence rate for Matagorda would be 4.76 - 1.70 = 3.06 mm/yr.** For the channel itself, the effect will be largely beneficial, by deepening the channel. Of more concern are effects on docks and other support facilities and in low-lying environments, such as marshes.

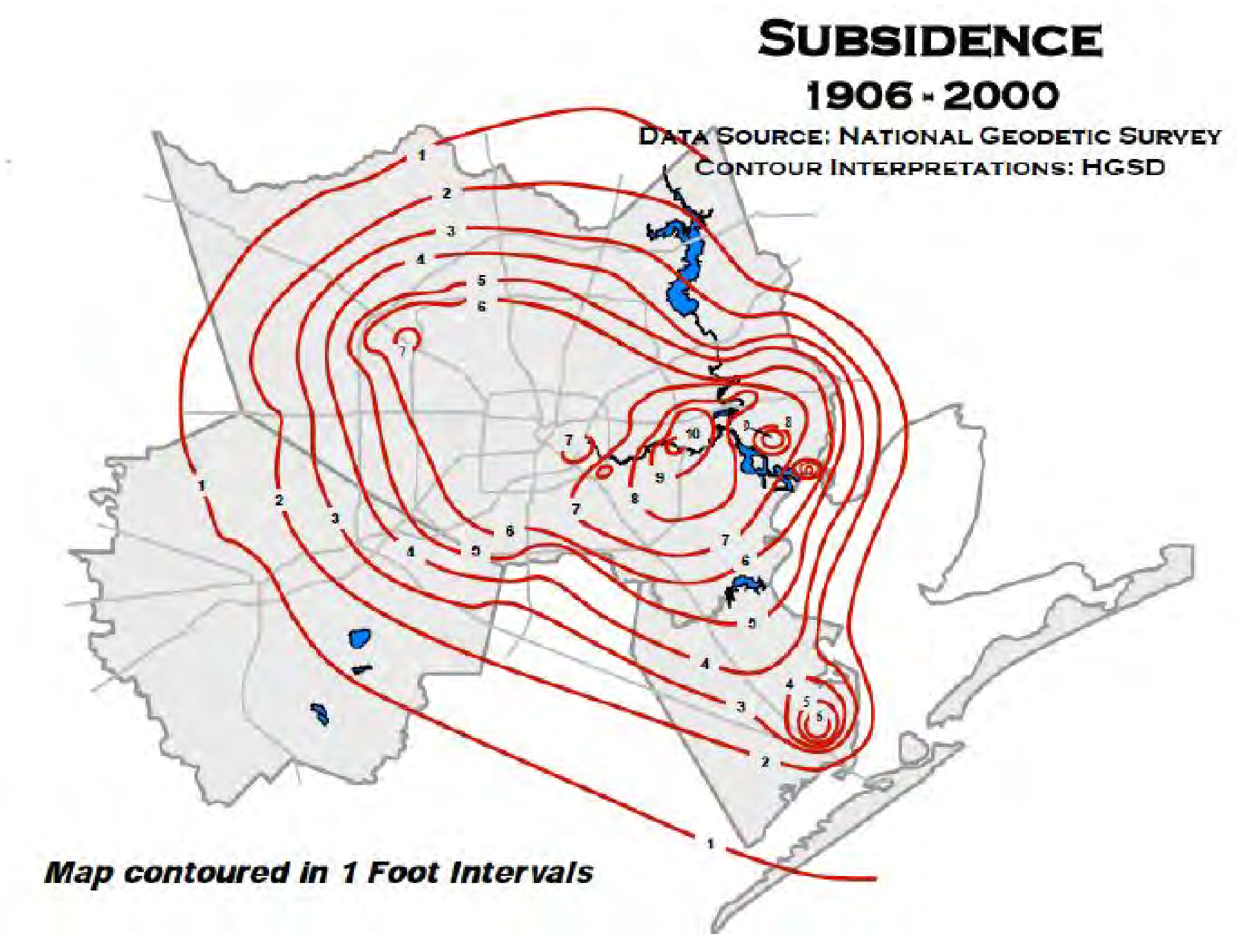
Matagorda, Rockport, and Freeport do not have direct measurements of subsidence. However, long-term measurements of tides in Galveston Bay and direct land-based measurements of subsidence in Galveston and Harris Counties suggest that subsidence is decelerating at a rate of 0.01 mm/yr^2. Caveat: examination of subsidence rates along the Texas coast shows that it does not vary linearly along the coast.

Of more concern to this project is future subsidence. Matagorda and Calhoun Counties do not measure subsidence. However, there is evidence from another coastal Texas area that shows subsidence is slowing. The Harris-Galveston Subsidence District has been able to forecast future subsidence based on planned amounts of future extraction, plotted here as Map 4.

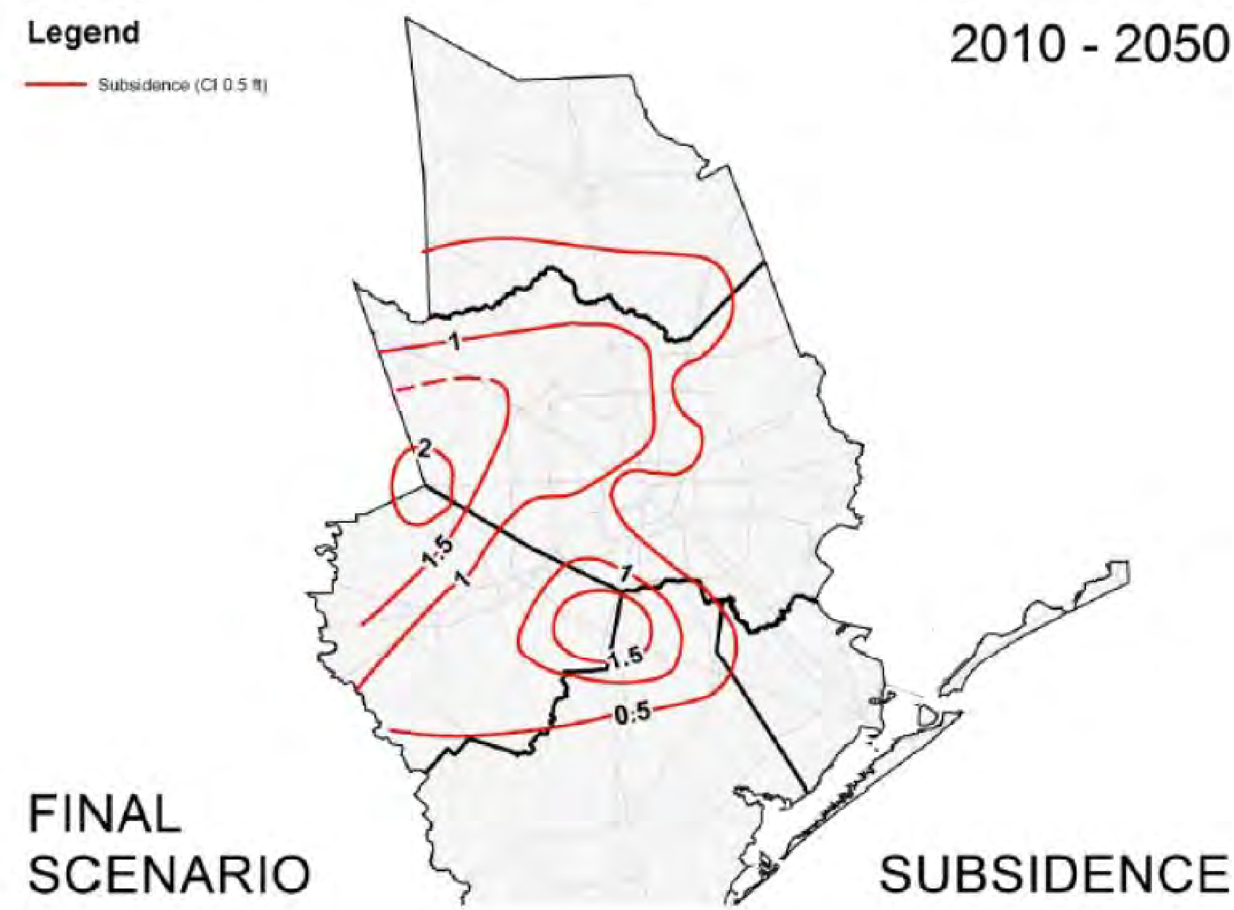
6.1 Evidence of Subsidence Deceleration from Galveston Bay

Near the Houston Ship Channel, subsidence has ranged to over 10 feet. As a result a subsidence district was formed to curtail groundwater extraction, and a suite of hundreds of land-based subsidence gages were deployed. In that area is also Texas' longest-running (106 years) tide gage in Galveston Bay at Pier 21 in Galveston which is still active (unlike the Gulf side gage at Galveston Pleasure Pier). The USACE calculation for NOAA gage 8771450's (Galveston Pier 21, computed from 1908 to 2013) has a mean sea-level trend of 6.39 mm/yr with a 95% confidence interval of ± 0.24 mm/yr. (The NOAA site shows 6.37 mm/yr, whereas the Corps site shows 6.39

mm/yr, presumably because the NOAA data are computed through 2015, whereas the Corps data are through 2013.) If the estimated historic eustatic rate equals that given for the modified NRC curves, the observed subsidence rate would be 4.69 mm/yr (6.39 mm/yr - 1.70 mm/yr), but that subsidence is decelerating at the rate of (6.39mm/yr – 6.37mm/yr)/2yrs = 0.01 mm/yr^2. However, this deceleration is based on only a two-year period of difference in computations and may not be reliable long term. Whether to include decelerating subsidence in final sea levels for the project will be determined in final design phase after more recent sea-level data accumulate.



Map 3: Past Subsidence in Galveston and Harris Counties
(from GCCPRD Phase 2 Report, 02/23/2016)



Map 4: Anticipated Future Subsidence in Galveston and Harris Counties (from GCCPRD Phase 2 Report, 02/23/2016)

The river in the lower part of the figure (where subsidence can exceed 1.5 ft) is Clear Creek. The river in the upper portion is Houston Ship Channel (where subsidence is between 0.5 and 1 ft).

7 SLR Guidance Specific to Navigation Projects (ETL 1100-2-1's Appendix C)

Appendix C of the ETL "Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation" is titled "Navigation Projects" and specifically addresses only those. The general conclusion about sea-level rise effects on navigation projects is that it is a **benefit** to the project itself (providing deeper channel water), but is a potential **threat or cost** to related infrastructure. For federal projects, it is important to know which mitigations or adaptations can be made with federal funds and which cannot. Table 13 below provides general guidance on these two categories.

The primary federal structure for MSC is the entrance jetties. Therefore in the numerical model runs, it will be important to study changes in the project's currents in the jettied entrance. However, it is by no means certain that the project will induce stronger currents. If the tidal flux through the entrance remains constant, then one might expect a reduced current as a result of increased channel cross-sectional area (Q = V A). Simple desk-top numerical models (Interactive Coastal Engineering Manual) can then be used to estimate increased scour, although this desktop study is not included in the Feasibility phase.

Deleterious effects on the navigation channel itself can occur however, and three of those areas are listed in the bottom left corner of Table 13. Physically the effect is primarily due to higher waves being able to form and propagate in the deeper channel, and probably more important for this channel, changes in currents. Since the deepening planned for MSC will be a relatively small portion of the entire depth, it is expected that this will have little effect and thus not become a risk that the project need address. A clearer quantitative answer to this question should be available when comparing the numerical-model and ship-simulation runs between the "no rise" and "sea-level rise" scenarios.

Table 13: Federal and non-Federal navigation project features at risk from sea-level change (from ETL 1100-2-1 Table C-1)

Federal	Non-Federal
Structures Locks Breakwaters Jetties Groins Revetments Wave absorbers Disposal areas	Waterside Berthing areas Docks Wharfs Bulkheads Seawalls Dolphins
Channels Entrance channels Access channels Turning basins	Landside Storage areas Warehouses Roads Utilities Bridges

Table 14 below lists the various physical processes that sea-level rise can affect in navigation projects. The impacts (on the right side of the Table) that are most likely to affect specifically the Ship Channel are:

1. Increased ship-wake impacts
2. Vessel excursion and movement
3. Adjacent shoreline change (due to increased propagation of ship wakes)
4. Less dredging needed to maintain the same depth (a benefit)
5. Dredged material placement site capacity

The first two of these should be addressed by the ship simulations. The last two should be quantifiable with simpler spreadsheet computations, once this report's sea-level numbers have been adopted.

Table 14: Physical Processes Sensitive to Sea-Level Rise in Navigation Projects (from ETL 1100-2-1 Table C-3)

Process	Impact
Wave attack	Wave run-up and overtopping Wave transformation Depth-limited wave Wave and storm surge Rubblemound damage rate Increased ship wake impacts
Inundation	Wave run-up and overtopping Wave and storm surge
Short- and long-term erosion	Wave run-up and overtopping Depth-limited wave Wave and storm surge Shoreline change rates (storm event, seasonal, long term)
Inland waterways and drainage hydraulics	Canal and drainage system profiles
Harbor, basin, and channel hydrodynamics	Harbor resonance Vessel excursion and movement Wave transmission (diffraction, overtopping, permeability) Water quality circulation characteristics
Morphological change and shoaling	Foundation scour Adjacent shoreline change Disposal site dispersiveness Sediment transport and deposition (subaqueous and subaerial) Subsidence and uplift
Water quality changes (surface and ground)	Salinity Circulation Mixing of ocean, estuarine, and river water
Management practices	Catchment management Dredging Dredged material placement site capacity Groundwater or fluid withdrawal Shoreline stabilization measures

Table 15 below is a qualitative matrix for evaluating the level of risk of sea-level rise to a navigation project. The numerical scores on the left indicate the relative importance of density of each resource in a navigation project. The scores on the right indicate how at-risk that resource is to sea-level rise. Note that the two scores are different. For example, channel dimensions (length, depth, mooring areas) are of high importance or density in the project, but are expected to suffer little impact from sea-level rise. Note that the non-federal port facilities (wharves, docks, etc.) have both a high density and may be at high-risk from sea-level rise. Unfortunately for the local sponsor, sea-level rise scenarios may have much more impact on port facilities than on federal channel dimensions.

Table 15: Qualitative Matrix for Determining Risk Level (from ETL 1100-2-1 Table C-4)

Critical resources in study area	Density of resource*	Relevant notes	Risk from SLC*
Length and type of primary Federal navigation structures	3	The length and type of navigation structure will determine stability and maintenance impacts (age, last maintained).	3
Length and type of secondary Federal navigation structures (groins, spur jetties, dikes, etc.)	2	The length and type of navigation structure will determine stability and maintenance impacts (age, last maintained).	2
Length and type of Federal shoreline protection structures	1	The length and type of shoreline protection structure will determine stability and maintenance impacts (age, last maintained).	2
Channel length and authorized depth, mooring areas and basins	3	Sea level rise may impact this favorably; sea level fall may require adjustments to authorized lengths and depths. Harbor and entrance resonance and performance issues may arise (length, area).	1
Dredged material management sites	1	Sites may become more or less dispersive and/or have changes in capacity (number, area).	1
Port facilities (bulkheads, wharves, docks, piers, etc.)	3	Performance of existing Federal structures under modified ocean conditions will result in increased magnitude and frequency of impacts to associated project features (length, type, seasons of use).	3
Commercial infrastructure	3	Performance of existing Federal structures under modified ocean conditions will result in increased magnitude and frequency of impacts to associated project features (type, value).	2
Transportation infrastructure (roads, rail, etc.)	2	Impacts to transportation infrastructure can impact benefits realized (length, type).	2
Utilities, drainage systems, communication	2	Connectivity and support systems may be affected resulting in decreased project benefits (length, type).	2
Coast Guard presence	2	Potential operational impacts. Harbor of refuge?	2
Environmental and habitat areas	1	Assessment of any environmental systems in project area (type, sensitivity).	1

*3 = high, 2 = medium, 1 = low, X = none present.

7.1 Physical Processes at Navigation Projects affected by Sea-Level Rise (ETL 1100-2-1's Tables 6 and 8)

In deciding which processes should be evaluated for their effects on the project, due to sea-level rise, the following Table 16 provides a checklist to apply to specific projects. Note that the only doubly important marking is for "depth-limited waves", which means that wave heights can be expected to increase.

Within the main channel, the depth increase caused by sea-level rise will be small compared to the total depth, so this effect will be small. However, this is NOT the case with mooring basins (and barge lanes, for those channels that have them), where sea-level rise will be a much larger percentage of the total depth, and where it is known that waves are "depth limited". (For background information, wave heights are determined by wind speed, but can be limited in three ways: depth, fetch length, and wind duration. There is usually only one of these three factors which controls or "limits" the wave height. In shallow Texas bays, waves are usually depth limited.)

Table 16: Physical Processes Affected by Sea-Level Rise in Navigation Projects (from ETL 1100-2-1's Table 6)

All Processes	Navigation
Wave Attack	
wave runup and overtopping	X
wave transformation	X
depth-limited wave	XX
surge	X
rubblemound damage rate	X
ship wake impacts	X
Inundation	
wave runup and overtopping	X
wave and storm surge	X
tailwater effects	
hydrologic regime	
Short- and Long-Term Erosion	
wave runup and overtopping	X
depth-limited wave	X
wave and storm surge	X
shoreline change rates (storm event, seasonal, longterm)	X
Inland Waterways/Drainage Hydraulics	
seasonal and extreme backwater profiles	
canal/drainage system profiles	X
groundwater flow characteristics	
Harbor, Basin, Channel Hydrodynamics	
harbor resonance	X
vessel excursion and movement	X
wave transmission (diffraction, overtopping, permeability)	X
water quality circulation characteristics	X
Morphological Change and Shoaling	
foundation scour	X
adjacent shoreline change	X
disposal site dispersiveness	X
sediment transport and deposition (subaqueous and subaerial)	X
subsidence/uplift	X
Water Quality Changes (surface and ground)	
salinity	X
nutrients and dissolved oxygen	
circulation	X
mixing of ocean/estuarine/river water	X
Management Practices	
catchment management	X
dredging and material placement	X
groundwater or fluid withdrawal	X
beach nourishment	X
shoreline stabilization measures	X

To quantify the effect of sea-level rise on depth-limited wave heights and other factors, Table 17 below provides a useful matrix of specific quantifiable effects. Most of the Table applies to structures. Except possibly at the jetties, the only significant relevance of this Table for this project is that **wave height increases in depth-limited (shallow) areas.** (The Table's example shows that the depth-limited wave height increases by the same amount as the sea-level rise, in this case from 6 ft to 6.7 ft.)

Corresponding to three different values of sea-level rise, percentage changes are computed for various forces used to compute damaging effects such as wave attack, armor-unit stability, morphology change, and wave run-up on structures and shores.

Table 17: Example Case: Quantified Changes in Loading Conditions due to Sea-Level Rise (from ETL 1100-2-1's Table 8)

Physical Process or Loading Condition at a nearshore location where PRESENT Wave action is depth-limited	Performance Function cast in terms of SLR-affected parameters	Potential Sea Level Rise (SLR), ft		
		Low Value	Intermediate Value	High Value
		0.7	1.1	2.4
		Depth-Limited Wave Height (H_{SLR}) due to SLR, ft		
Present Depth-Limited Wave Height (H_p), ft = 6	$H_{SLR} \sim= H_p + SLR$	6.7	7.1	8.4
Present Water Depth @ Structure ($Depth_p$), ft = 10	$Depth_{SLR} = Depth_p + SLR$	Relative Change in Performance Function due to SLR		
Conventional Structure Stability (rigid)				
Wave Loading - Dynamic Pressure	Minikin: f(H)	12%	18%	40%
Wave Loading - Total Dynamic Force	Minikin: f(H^2, Depth)	33%	45%	119%
Compliant Structures (Armor Unit Stability)				
Direct Wave Action (armor unit weight)	Hudson Equation: f(H^3)	39%	66%	174%
Overtopping (wave action) - Volume	USACE: f($H^{1.5}$, $exp^{(freeboard)}$)	88%	152%	522%
Overtopping Wave Action (armor unit weight)	Van Gent: f(exp^H, $exp^{(freeboard)}$)	56%	95%	250%
Nearshore and Structure Foundation Stability				
Foreshore Slope (rise/run)	Kamphuis: f($H^{-0.5}$)	-5%	-8%	-15%
Sediment Transport Potential (morphology change)	Kamphuis: f(H^2)	25%	40%	96%
Wave Run-up, Along Shoreface				
Run-up Distance	USACE: f(H)	12%	18%	40%
Run-up Speed	USACE: f($H^{0.5}$)	6%	9%	18%

Note: The increase in coastal infrastructure loading or effects on the "performance function" are shown in terms of the increase in nearshore wave height (H) due to sea level rise (SLR). For this case, the nearshore wave height (H) is depth-limited, and an increase in water level of by SLR will increase the depth-limited wave height by a corresponding Δ value. For "overtopping" and "lee-side armor" performance functions, the following values were used: Water level = 7.1ft (2.2m), incident wave height/period = 6ft (1.8m)/12 s, structure crest elevation = 10ft (3m), to elevation = –2.9ft (0.9m), structure slope = 1v:3h. All other performance functions were evaluated on a relative basis using the change in depth-limited wave height due to SLR, compared to the present condition (p). Relative change in performance function = [(future value – present value)/present value] × 100.

The numerical model's comparison of "with sea-level rise" to "without (or present-day)" scenarios should provide quantitative results for estimating the project's risk to sea-level rise.

7.2 SLR Risks and Adaptations for Navigation Projects (ETL 1100-2-1's Tables 1 and 7)

An essential element of developing a good understanding of the project area's exposure and vulnerability is assessing how quickly the individual scenarios might necessitate an action due to thresholds and tipping points. It is important to identify key milestones in the project timeline when impacts are expected. This involves inputs from all members of the PDT, since the threshold or tipping point could be a variety of different items or combinations of items.

Response strategies for the project planning horizon range from a conservative **anticipatory** approach, which constructs a resilient project at the beginning to last the entire life cycle (and possibly beyond), to a **reactive** approach, which would simply be to do nothing until impacts are experienced. Between these extremes is an **adaptive** management strategy, which incorporates new assessments and actions throughout the project life based on timeframes, thresholds and triggers. A plan may include multiple measures adaptable over a range of SLC conditions and over the entire timeline, with different measures being executed as necessitated.

For a feasibility-level design, it is important to identify potential cost-risk items and **adaptation** costs to the stakeholders and decision makers. Further detailed design and analysis may be undertaken during the pre-construction engineering and design phase to optimize project features sensitive to relative sea level change. In this phase, the question of further adaptability beyond the 50-year economic analysis period may be addressed as part of the design optimization. The economic and cost formulation for the project should account for uncertainty in critical design items.

Hard structures (rock or concrete) are difficult to alter to accommodate changing conditions, unless they have been designed with that in mind from the beginning. Examples of the three types of approaches are listed below in Table 18. Since this navigation project does not include improvements to hard structures (in the federal part of the project), then it will be relatively easy to design protections and solutions. In contrast, it is difficult to **accommodate** hard structures that have not been designed from the beginning with adaptation in mind. For example, a dock that has been designed from the beginning with the intention that it will eventually need to be jacked up is much cheaper in the long-run than a dock that has to be torn down and rebuilt. So again, this planning for an adaptive strategy will be much more important to the non-federal part of the project.

Table 18: Adaptive Approaches to Navigation Projects
(from ETL 1100-2-1's Table 1)

Project Type	Protect	Accommodate	Retreat
Navigation	Upgrade and strengthen existing primary structures Expand design footprint and cross section of existing structures, including raising for clearance and access Add secondary structures Add structures to protect backshore Improve resilience of backshore facilities	Upgrade drainage systems Increase maintenance and dredging Adjust channel location and dimensions Modify operational windows Flood proof interior infrastructure Add sediment to shoreline or underwater morphology	Relocate interior harbor infrastructure due to relative sea level rise or fall Abandon harbor/port Re-purpose project area

In planning an adaptation strategy, Table 19 below provides a useful method of selecting the kind of adaptation to use (P = Protect, A = Accommodate, R = Retreat) and also provides a list of specific solutions to pick from. Both the kind of adaptation and specific solutions are shown in the right-most column.

The two categories of sea-level effects in the left-most column that are more likely to affect this project are **"wetland loss" (federal)** and **"infrastructure damage" (non-federal).** Therefore both the entire team and the non-federal team should plan their adaptation strategies.

Table 19: Systems Affected by Sea-Level Rise and Adaptation Approaches (from ETL 1100-2-1's Table 7)

<table>
<tr><th colspan="2" rowspan="2">System Effects</th><th colspan="2">Possible Interacting Factors</th><th rowspan="2">Possible Adaptation Approaches</th></tr>
<tr><th>Climate</th><th>Non-Climate</th></tr>
<tr><td rowspan="2">Increased Frequency / Severity of Storm Inundation</td><td>a. Coastal (flooding directly from the sea)</td><td>Waves, storm climate, erosion, rainfall, runoff, sediment supply, wetland loss and change</td><td>Sediment supply, flood management, erosion, land reclamation, land management</td><td>Revetments, seawalls, surge barriers (P-hard)
Dune/beach construction, vegetation (P-soft)
Building codes, flood-proof buildings (A)
Land-use planning, hazard mapping, flood warnings (A/R)
Abandonment, re-purpose (R)</td></tr>
<tr><td>b. Inland (flooding due to tailwater effects)</td><td>Rainfall, runoff, wetland loss and change</td><td>Catchment management, land use, river and canal system, drainage system, geology</td><td>Dikes, surge barriers, closure dams (P-hard)
Building codes, flood-proof buildings (A)
Land-use planning, hazard mapping, flood warnings (A/R)
Abandonment, re-purpose (R)</td></tr>
<tr><td colspan="2">Accelerated Wetland loss and change</td><td>CO2 fertilization, sediment supply, migration space, rainfall, runoff</td><td>Sediment supply, migration space, land reclamation (i.e. direct destruction), species population changes</td><td>Nourishment/ sediment management, hydraulic adjustments (P-soft) Land-use planning (A/R)
Realignment, forbid hard defenses (R)
Abandonment, re-purpose (R)</td></tr>
<tr><td colspan="2">Accelerated Erosion (of "soft" morphology)</td><td>Sediment supply, wave/storm climate, wetland loss and change</td><td>Sediment supply, structural measures</td><td>Coastal defenses / seawalls / land claim (P-hard)
Nourishment, vegetation (P-soft)
Building setbacks (R)</td></tr>
<tr><td colspan="2">Infrastructure Damage</td><td>Sediment supply, wave/storm climate, wetland loss and change</td><td>Structure type, erosion, secondary structures</td><td>Coast defenses, seawalls, adjust/improve structures (P-hard) Nourishment (P-soft)
Building setbacks (R)</td></tr>
<tr><td rowspan="2">Salt water intrusion</td><td>a. Surface waters</td><td>Runoff, saltwater intrusion to ground water, temperature</td><td>Catchment management (over-extraction), land use</td><td>Salt water intrusion barriers (P)
Change water extraction (A/R)</td></tr>
<tr><td>b. Groundwater</td><td>Rainfall, saltwater intrusion to surface waters, temperature</td><td>Land use, aquifer use (over-pumping)</td><td>Freshwater injection (A)
Change water extraction (A/R)</td></tr>
<tr><td colspan="2">Impeded drainage, higher water tables</td><td>Rainfall, runoff</td><td>Land use, acquifer use, catchment management</td><td>Drainage systems / polders (P-hard)
Change land use (A)
Land-use planning / hazard delineation (A/R)</td></tr>
</table>

Example adaptation approaches are coded: P = Protect (Hard, Soft), A = Accommodate, R = Retreat

8 Recommendations

As a conservative approach (not exaggerating benefits from sea-level rise), USACE's **Low** Sea-Level Curve should be used for the navigation portion of this project. In order to gage environmental impacts, the **Intermediate** Level Curve should be used (in the numerical model of currents and salinity).

Including sea-level rise and subsidence in the project design will result in **less dredging** than otherwise anticipated, since the channel depth is increasing due to both of these factors. (This factor has not been used in this project's cost analysis.) At the end of the 50-year project life, channel depth will have increased by 0.78 ft (since construction) and by 0.89 ft since dredging costs were estimated in 2017 in this Feasibility Study.

At the end of the 100-year planning period, channel depth will have increased by 1.56 ft (since construction) and by 1.67 ft since dredging costs were estimated in 2017 in this Feasibility Study. If sea level rises faster than the historic "Low" rate, then channel depth will increase even more, so necessary dredging will be even less.

Conversely, SLC effects on the non-federal sponsor's **infrastructure** will largely be detrimental. They should carefully consider which sea level to plan for, and more importantly, what their adaptation measures should be (Table 19).

Some **deleterious effects** due to sea-level rise may also occur within the federal project. Many of the general categories of effects listed in the Tables will not apply to this project, but most likely there will be some deleterious effects in some of the following categories:

Increased erosion at islands
Increased ship wakes affecting recreational boating and mooring areas
Increased wind waves, especially in shallow areas (but not in the main channel)
Changes in water chemistry (salinity, dissolved oxygen)

For the first three items in the list above, some simple spreadsheet calculations can be performed to indicate a level-of-concern. For the last category, the **numerical model runs** should help quantify the effects. In the numerical model, there are not likely to be sufficient funds to run all possible combinations of: Low, Intermediate, and High SLR; their effects on multiple ship sizes; and runs both with and without project. The current plan is to make four runs with the Intermediate SLRC with no ship (wake) effects: Present Condition, Present With Project, Future WithOut Project, and Future With Project.

The primary federal structures for MSC are the entrance jetties. Therefore in the numerical model runs, it will be important to study the effects of with-project construction, along with sea-level rise on the jettied entrance.

9 References

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H&H ATTACHMENT NO.2

CLIMATE CHANGE

Attachment 2 to H&H Engineering Appendix: Climate Change

The specific aspect of climate change that is sea level is a complex subject addressed separately in the H&H Attachment (Relative Sea Level Rise) to the H&H Engineering Appendix. This section discusses other future climate changes (mainly precipitation) based on current scientific evidence and studies. Climate change is expected to pose several challenges along the Texas coast. It is expected to vary greatly along the extensive Texas coast from the Mexican border to the Louisiana border. These challenges will unfold against a backdrop that includes a growing urban population, incentives for energy production, and advances in technology.

For the current study area, the primary climatic forces with potential to affect the project are changes in temperature, sea and inland water levels, precipitation, storminess, ocean acidity, and ocean circulation. Air temperatures in the Houston-Galveston mean statistical area, on average, increased about 1 degree Centigrade over the past 20 years, a pattern that is expected to continue. Sea surface temperatures have risen and are expected to rise at a faster rate over the next few decades. Global average sea level is rising and has been doing so for more than 100 years. Greater rates of sea-level rise are expected in the future (Parris 2012). Higher sea levels cause more coastal erosion, changes in sediment transport and tidal flows, more frequent flooding from higher storm surges, and saltwater intrusion into aquifers and estuaries.

Patterns of precipitation change are affecting coastal areas in complex ways. The Texas coast saw a 10 to 15 percent increase in annual precipitation between 1991 and 2012 compared to the 1901-1960 average, Figure 1. Texas coastal areas are predicted to experience heavier runoff from inland areas, with the already observed trend toward more intense rainfall events continuing to increase the risk of extreme runoff, flooding, and possibly creating safety issues.

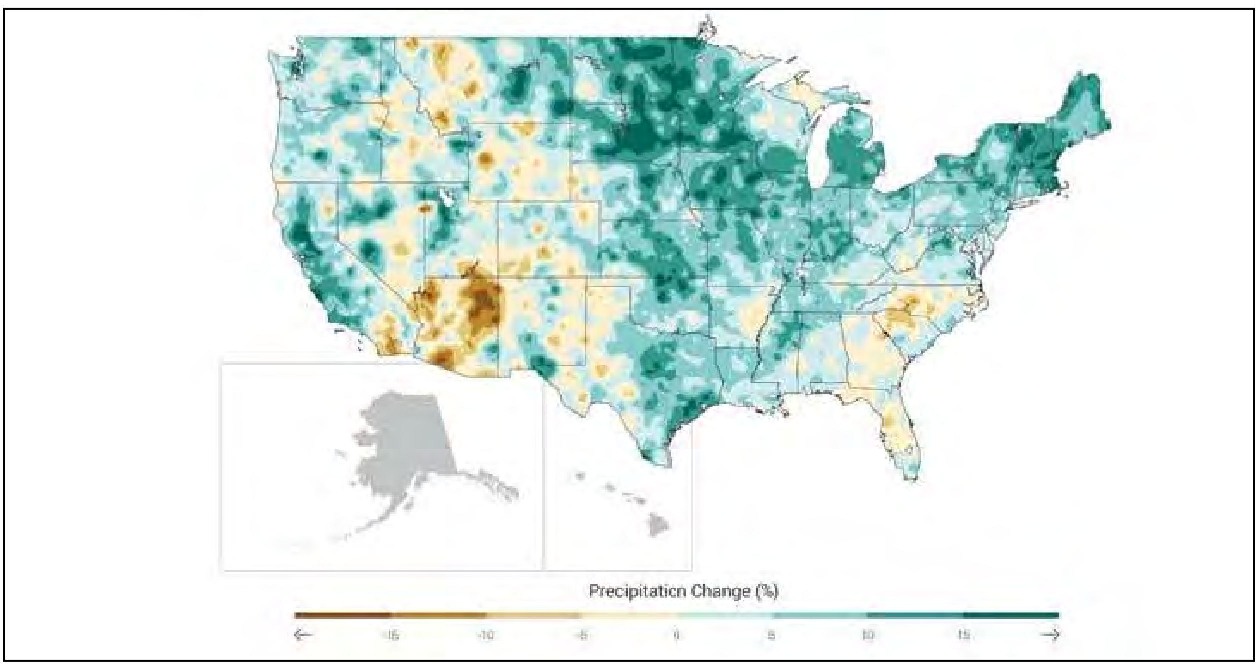

Figure 1: Percent Change in Annual Precipitation for 1991-2012 Compared to 1901-1960 (adapted from Peterson et al. 2013)

Texas' Gulf Coast historically averages three tropical storms or hurricanes every four years (annual probability of 75%), generating coastal storm surges and sometimes bringing heavy rainfall and damaging winds hundreds of miles inland. The estimated rise in sea level will result in an effective increase in storm surge along the Texas Gulf coast and miles inland. Tropical storms have increased in intensity in the last few decades. Future projections suggest increases in hurricane rainfall and intensity (with a greater number of the strongest - Category 4 and 5 - hurricanes) (Melillo 2014).

As the concentration of carbon dioxide in the atmosphere increases, the oceans will continue to absorb CO_2, resulting in increased ocean acidification. This threatens coral reefs and shellfish (Hoegh-Guldberg 2007). Coastal fisheries are also affected by rising water temperatures and climate-related changes in oceanic circulation. Wetlands and other coastal habitats are threatened by sea-level change, especially in areas of limited sediment supply or where barriers prevent onshore migration. The combined effects of saltwater intrusion, reduced precipitation, and increased evapotranspiration will elevate soil salinities and lead to an increase in salt-tolerant vegetation (Craft 2009). For additional information, reference the Environmental section of the FIFR-EIS. None of these changes operate in isolation. The combined effects of climate changes with other human-induced stresses make predicting the effects of climate change on coastal systems challenging. However, it is certain that these factors will create increasing hazards to the Texas coast. Heavily industrialized cities and ports containing critical infrastructure along the Texas coast, including Freeport, Port Arthur, Galveston, Corpus Christi, Matagorda, Brazos Island Harbor, Houston, Port Orange, and additional areas will be adversely affected by climate change.

The projected change in sea level will result in the potential for greater damage from storm surge along the Texas coast. About a third of the GDP for the state of Texas is generated in coastal counties. Coastal areas in Alabama, Mississippi, Louisiana, and Texas already face losses that annually average $14 billion from hurricane winds, land subsidence, and sea-level change. According to a recent study, projected sea-level change increases average annual losses from hurricanes and other coastal storms (Building 2010).

Diminishing water supplies and rapid population growth are critical issues in Texas. Along the coast, climate change-related saltwater intrusion into aquifers and estuaries poses a serious risk to local populations. In 2011, many locations in Texas experienced more than 100 days over 100°F, as the state set high temperature records. Rates of water loss were double the long-term average, depleting water resources. This contributed to more than $10 billion in direct losses to agriculture alone (Melillo 2014). Typically, many of the water shortages occur in the drier west parts of Texas.

The agricultural economy along the Texas coast, including livestock, rice, cotton, and citrus cultivation, is threatened by the combination of salt or brackish water from sea-level change and reduced freshwater levels from changes in temperature and precipitation. Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human interventions creating additional stresses. Climate change will result in further reduction or loss of functions these ecosystems provide.

Successful adaptation of human and natural systems to climate change will require commitment to addressing these challenges. Regional-scale planning and local-to-regional implementation will prove beneficial. Finding a way to mainstream climate planning into existing processes will save time and money. It is important that information be continually shared among decision-makers to facilitate the alignment of goals.

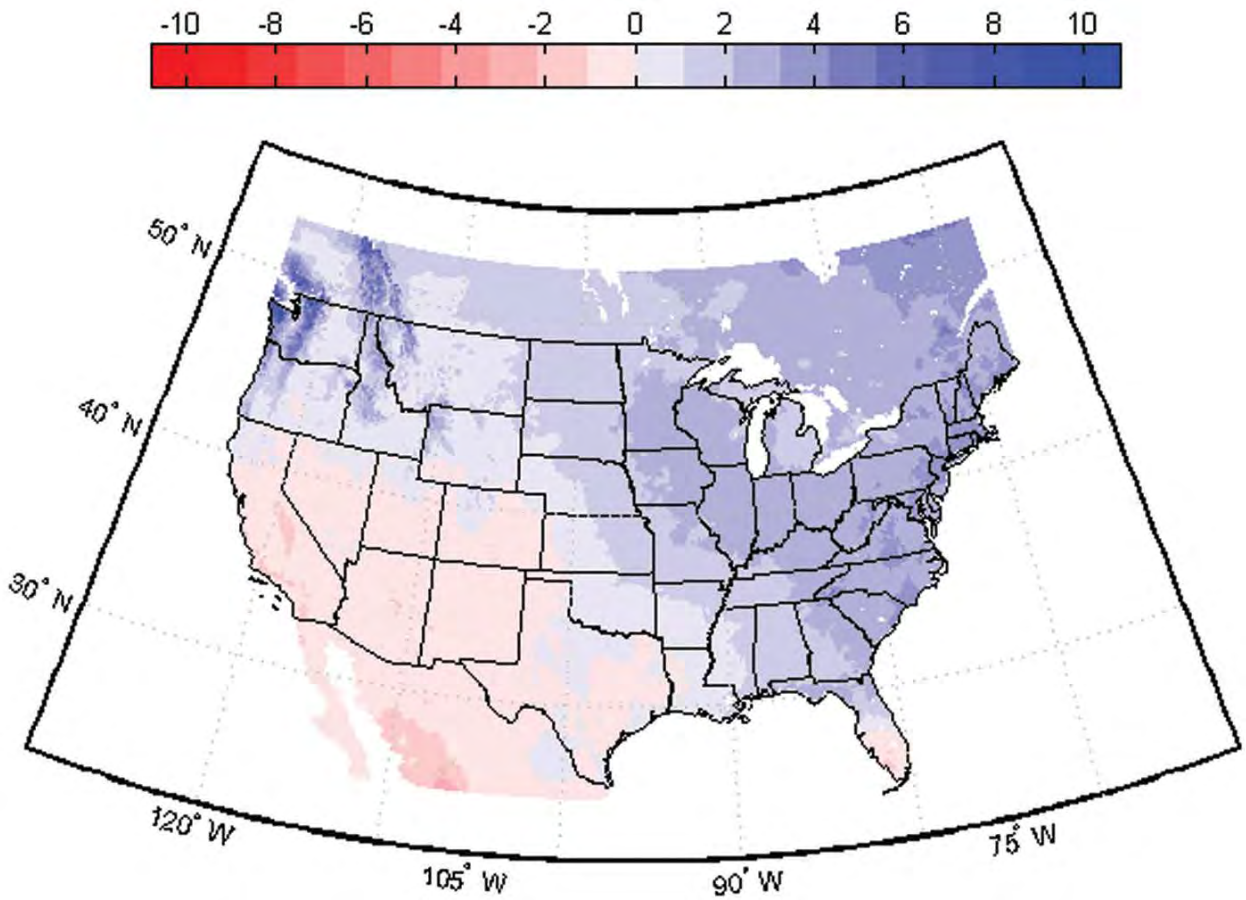

Figure 2: Change in 30-year mean annual precipitation, measured in centimeters per year (cm/year). The median difference between 1971–2000 and 2041–2070 is based on 112 projections obtained from "Statistically Downscaled WCRP CMIP3 Climate Projections" (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections).

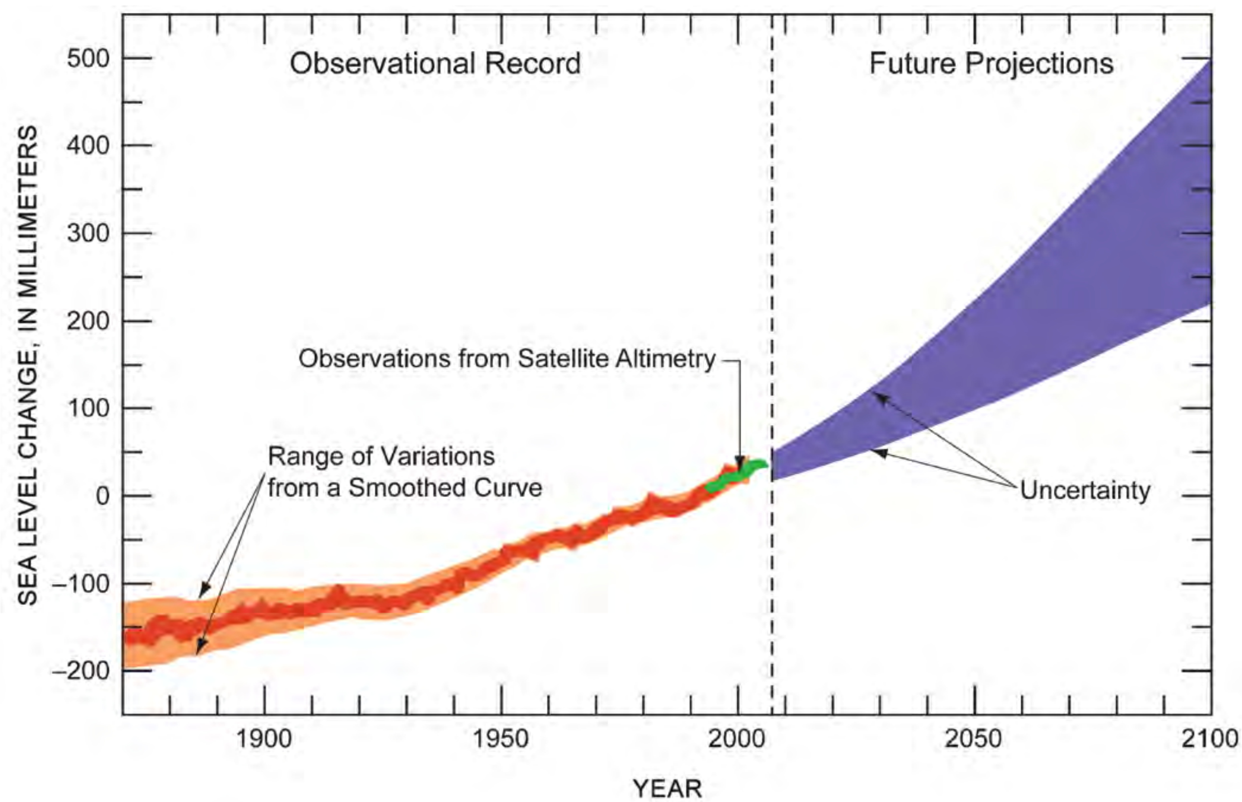

Figure 3: Global mean sea level (GMSL) observed since 1870 and projected for the future (deviation from the 1980–1999 mean). [For illustrative purposes only, from U.S. Army Corps of Engineers (2008); Intergovernmental Panel on Climate Change (2007, FAQ 5.1, fig. 1).]

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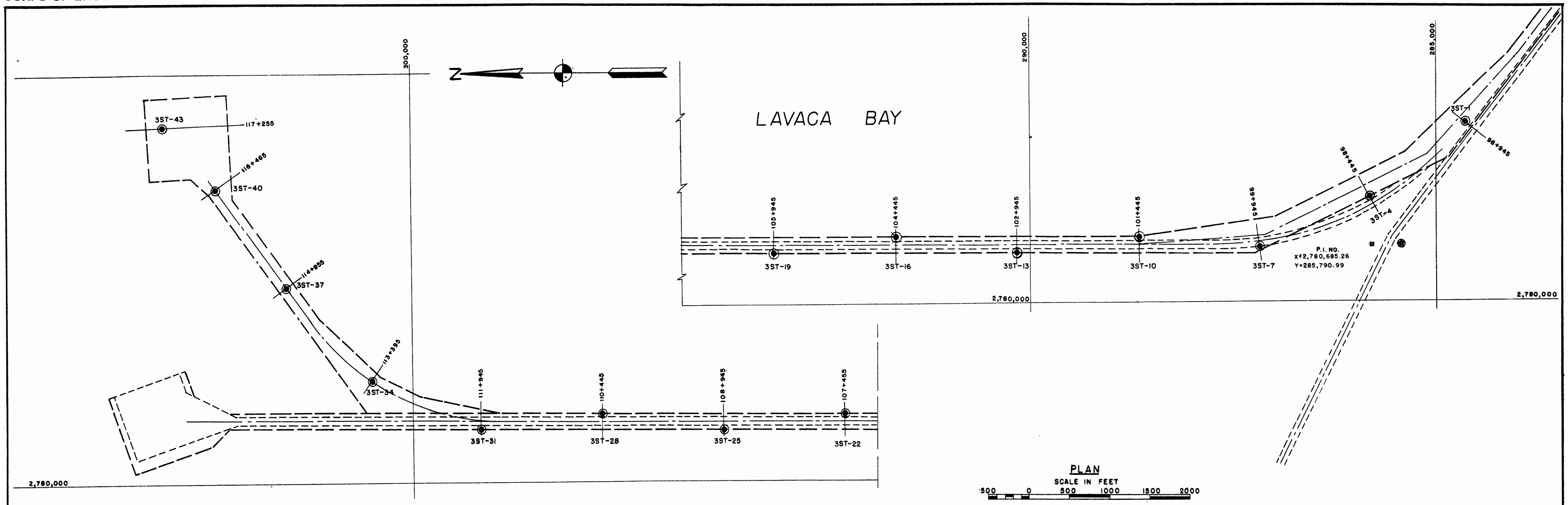
GEOTECHNICAL ATTACHMENT A

SOIL BORING RESULTS



PLAN
SCALE IN FEET
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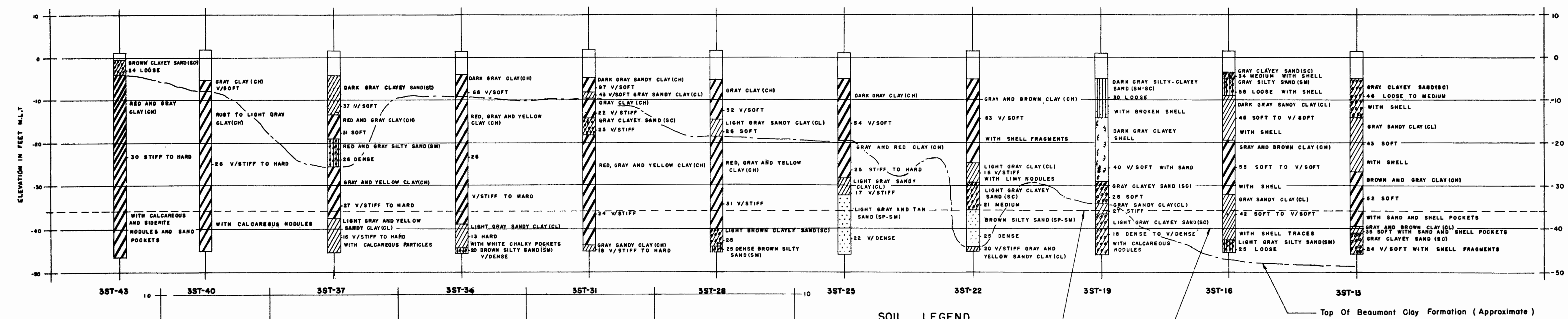
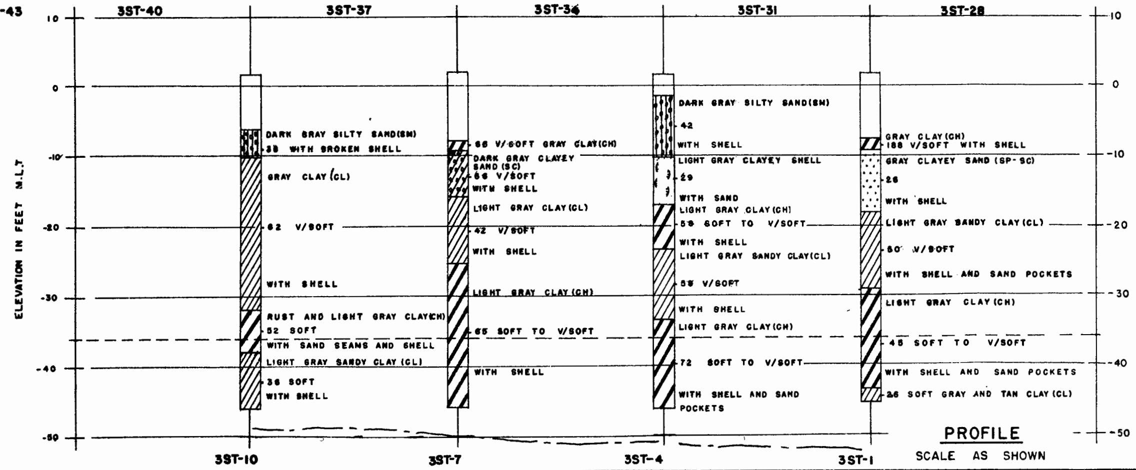




PROFILE
SCALE AS SHOWN

SOIL LEGEND

WATER SURFACE
MOISTURE CONTENT
CONSISTENCY

	SAND-SHELL, SILT-SAND-SHELL, OR CLAY-SAND-SHELL MIXTURES
GM	SILTY GRAVEL, GRAVEL-SAND-SILT MIXTURES
SP	POORLY-GRADED SANDS, LITTLE OR NO FINES
SM	SILTY SANDS, SAND-SILT MIXTURES
SC	CLAYEY SANDS, SAND-CLAY MIXTURES
ML	INORGANIC SILTS
CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY
CH	INORGANIC CLAYS OF HIGH PLASTICITY
OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY

NOTE:

1. SOIL HAS BEEN CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM PUBLISHED BY THE CORPS OF ENGINEERS MARCH 1953.
2. CONSISTENCY OF SOILS SUCH AS V/SOFT (VERY SOFT), STIFF AND DENSE ARE RELATIVE TERMS BASED ON UNDISTURBED SHEAR STRENGTH OF THE MATERIALS AS DETERMINED BY VISUAL CLASSIFICATION, POCKET PENTROMETER TESTS, AND PENETRATION RESISTANCE DURING SAMPLING.

MATAGORDA SHIP CHANNEL, TEXAS

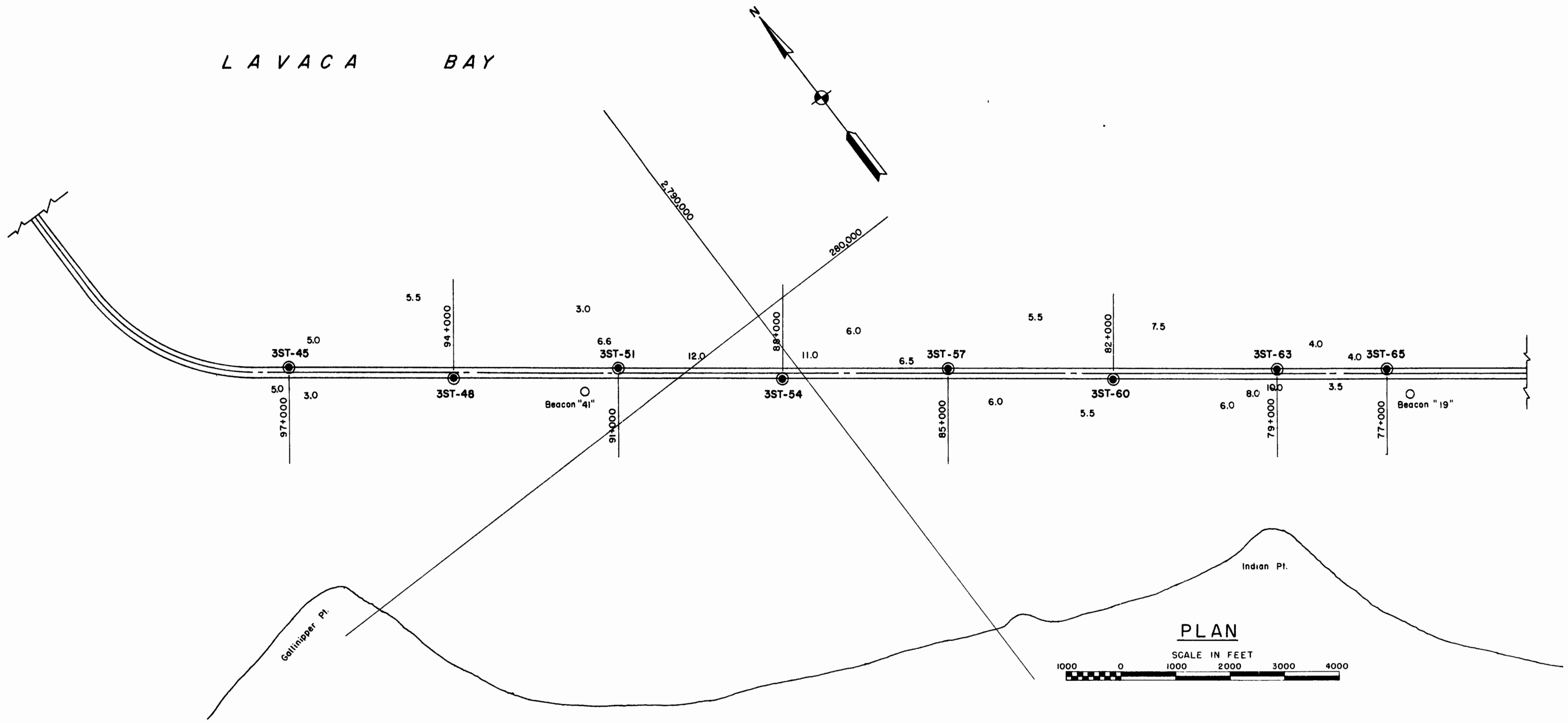
BORING LAYOUT AND SOIL PROFILE

IN 8 SHEETS — SHEET NO. 1

U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS — JANUARY 1962

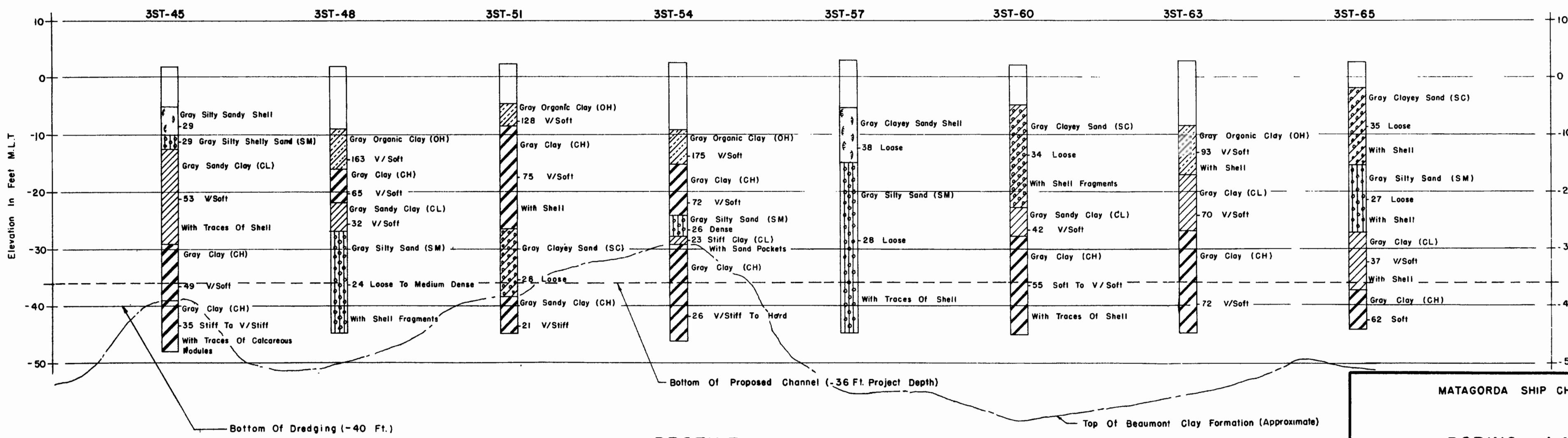
TO ACCOMPANY GENERAL DESIGN MEMORANDUM DATED: JANUARY 1962

EXHIBIT: 1 — APPENDIX 8 — FILE NO. GUAD.705-112



PLAN

SCALE IN FEET 1000 0 1000 2000 3000 4000



PROFILE

SCALE AS SHOWN

NOTE:
See Sheet No. 1 of 8
For Soil Legend
And Soil Note

MATAGORDA SHIP CHANNEL, TEXAS

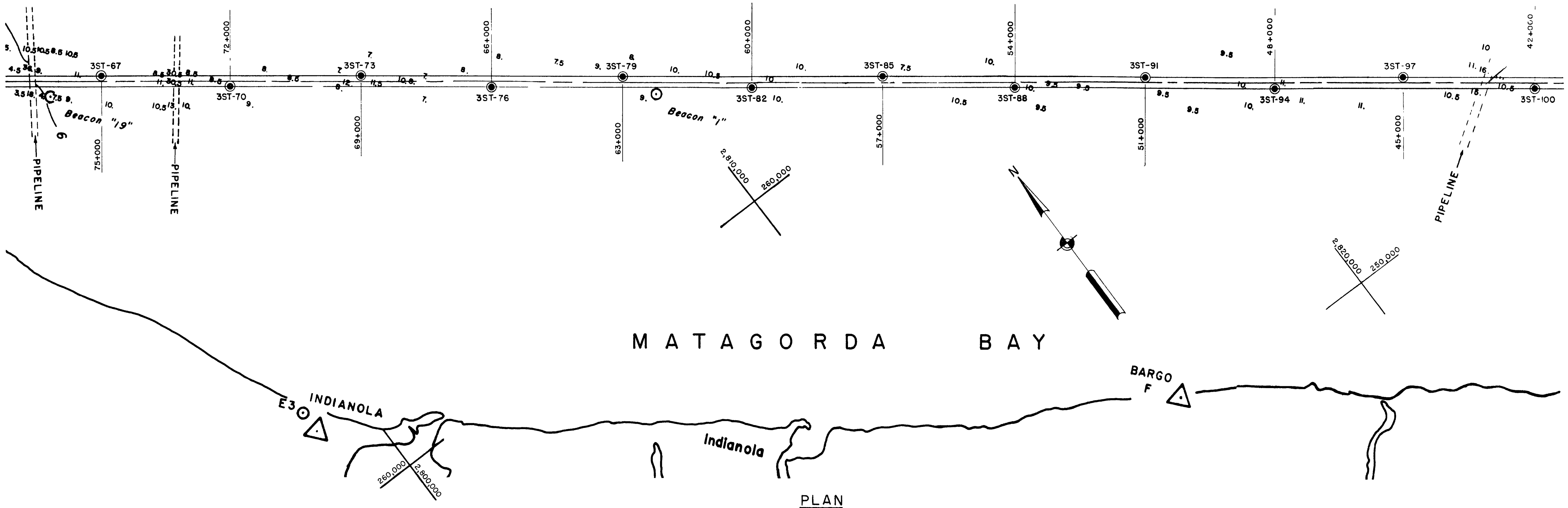
BORING LAYOUT AND SOIL PROFILE

IN 8 SHEETS — SHEET NO. 2

U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS — JANUARY, 1962

TO ACCOMPANY GENERAL DESIGN MEMORANDUM
DATED: JANUARY 1962

EXHIBIT: I — APPENDIX: B — FILE NO. GUAD 705-112



PLAN

SCALE IN FEET
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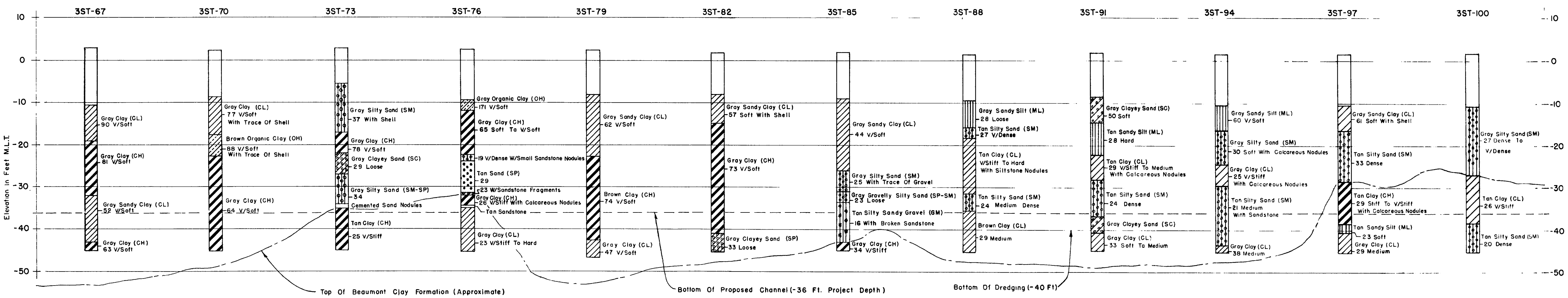


PROFILE

SCALE AS SHOWN

NOTE:
See Sheet 1 of 8 for Soil Legend and Soil Note.

MATAGORDA SHIP CHANNEL, TEXAS

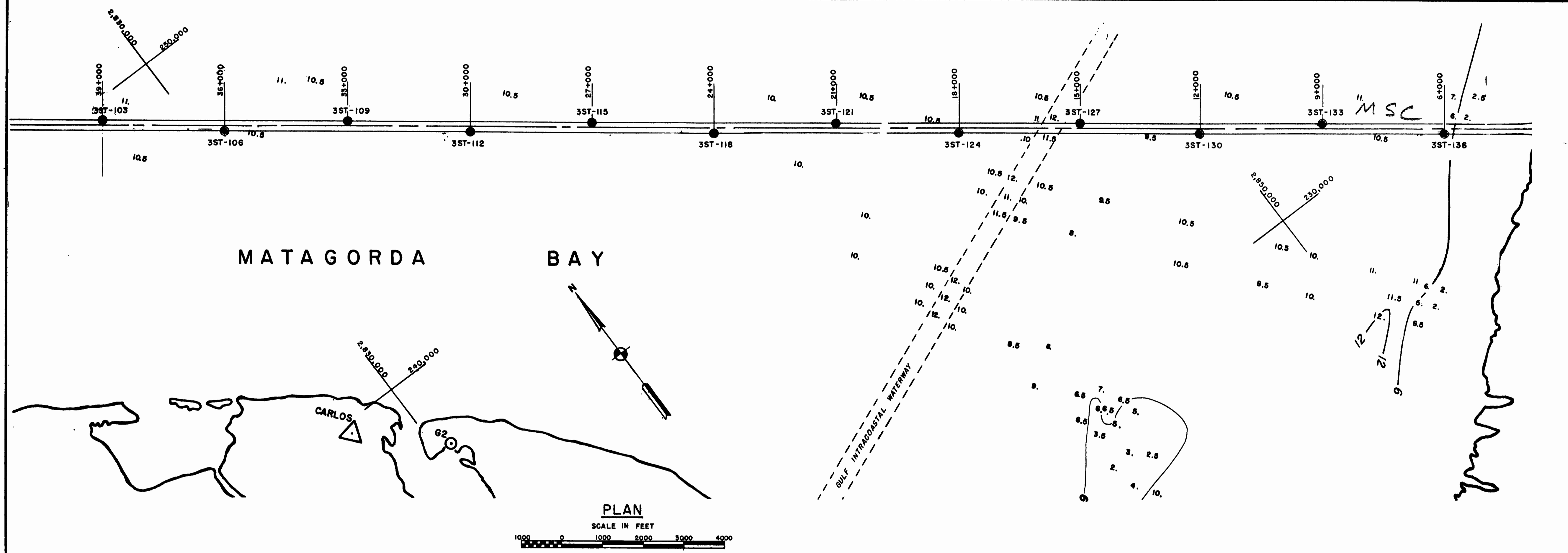
BORING LAYOUT
AND
SOIL PROFILE

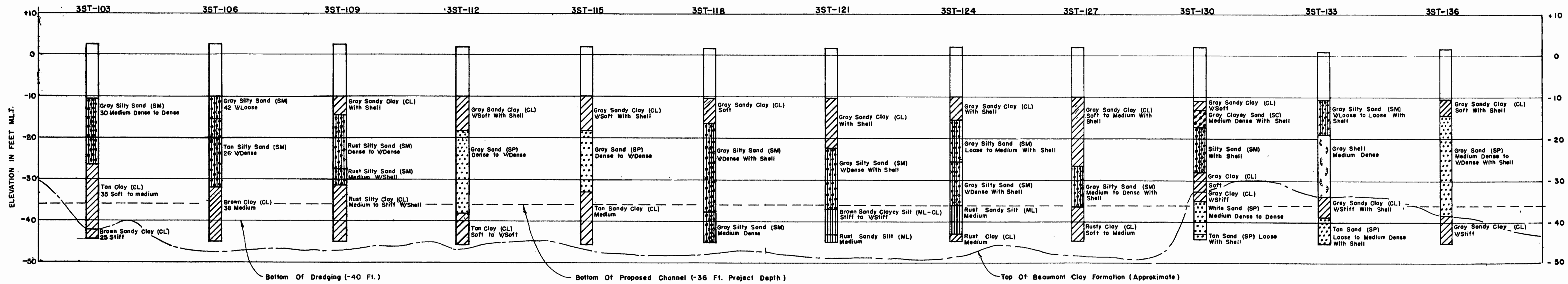
IN 8 Sheets Sheet No. 3

U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS JANUARY, 1962

TO ACCOMPANY GENERAL DESIGN MEMORANDUM
JANUARY 1962

EXHIBIT I APPENDIX "B" FILE NO. GUAD 705-112





PROFILE

SCALE AS SHOWN

Note:
See Sheet 1 of 8 for Soil Legend and Soil Note.

MATAGORDA SHIP CHANNEL, TEXAS

BORING LAYOUT
AND
SOIL PROFILE

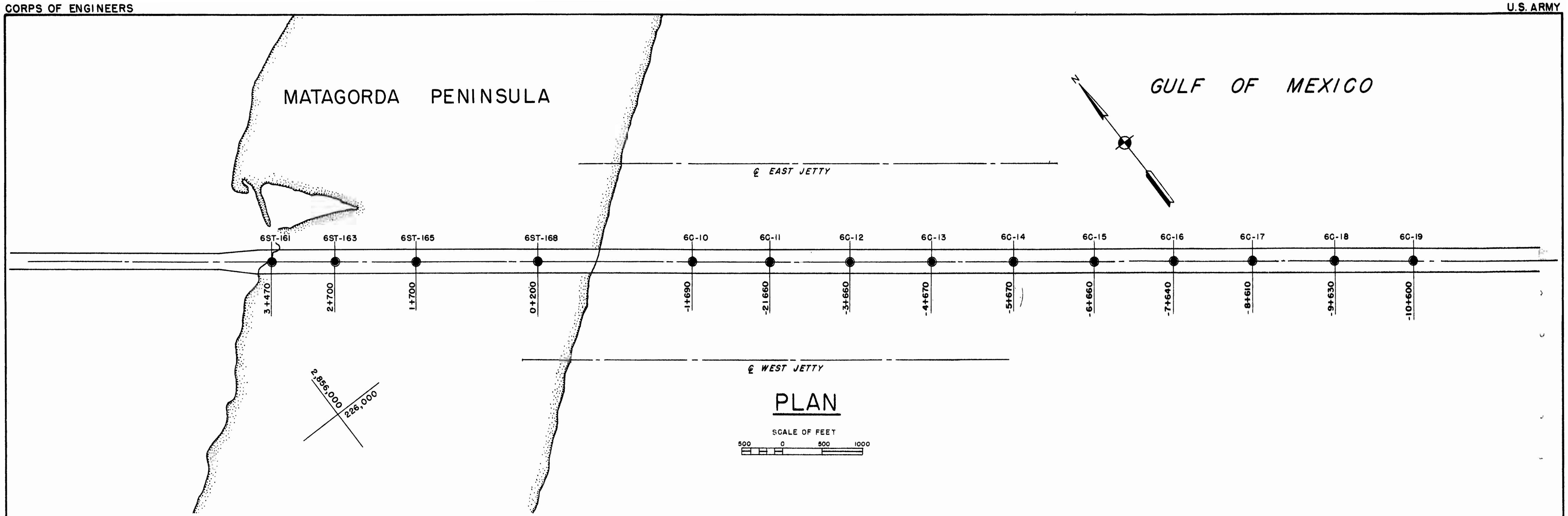
IN 8 SHEETS | SHEET NO. 4

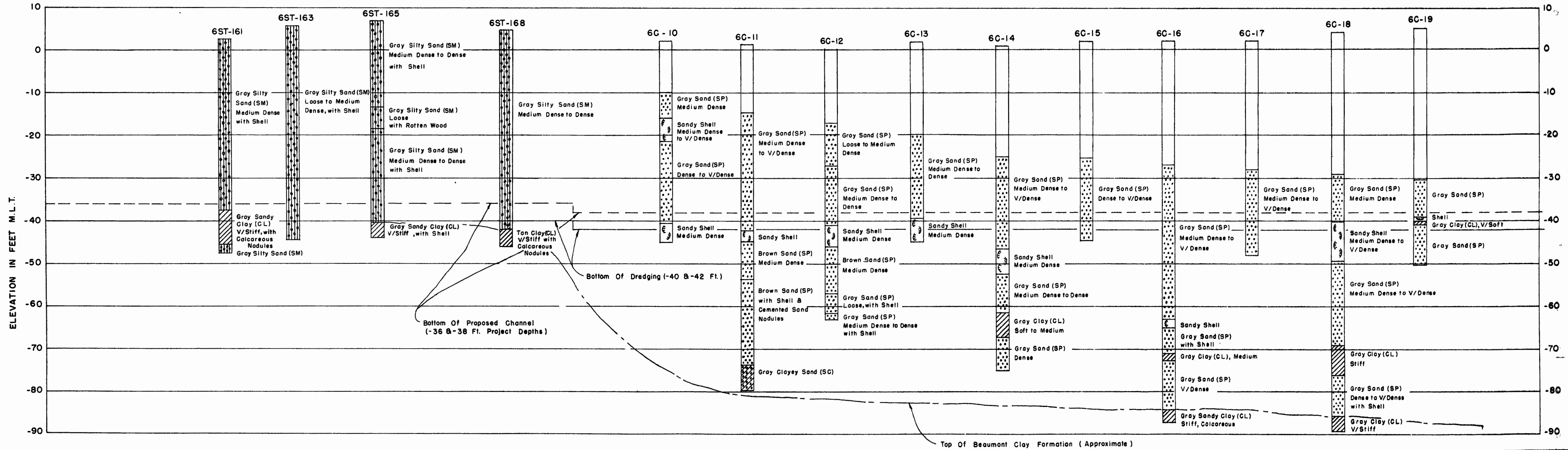
U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS | JANUARY 1962

TO ACCOMPANY GENERAL DESIGN MEMORANDUM
DATED: JANUARY 1962

EXHIBIT: I | APPENDIX: 8 | FILE: GUAD. 705-112

CORPS OF ENGINEERS U.S. ARMY





PROFILE

SCALE AS SHOWN

Note:
See Sheet 1 of 8 for Soil Legend and Soil Note.

MATAGORDA SHIP CHANNEL, TEXAS

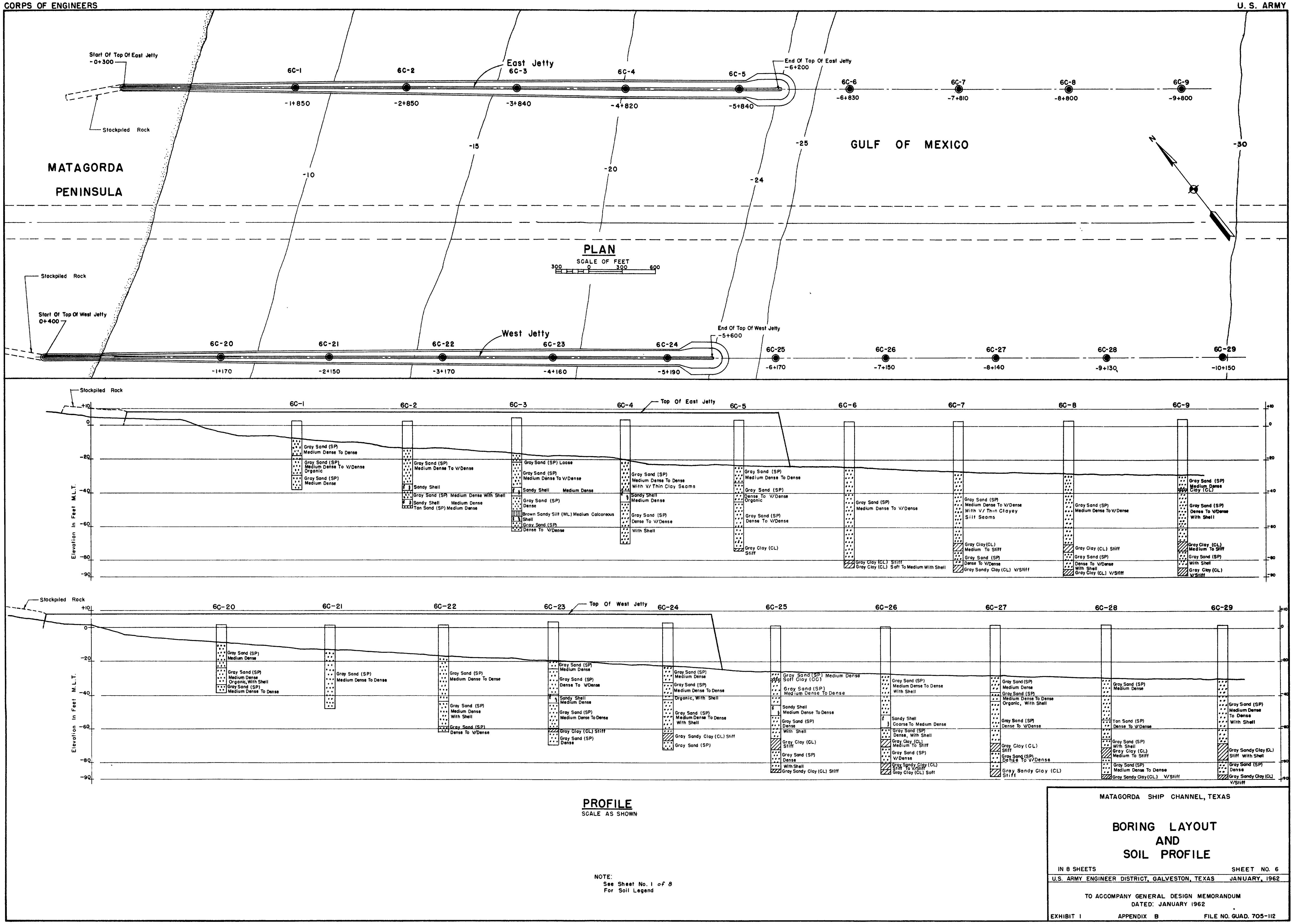
BORING LAYOUT AND SOIL PROFILE

IN 8 SHEETS SHEET NO. 5

U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS JANUARY 1962

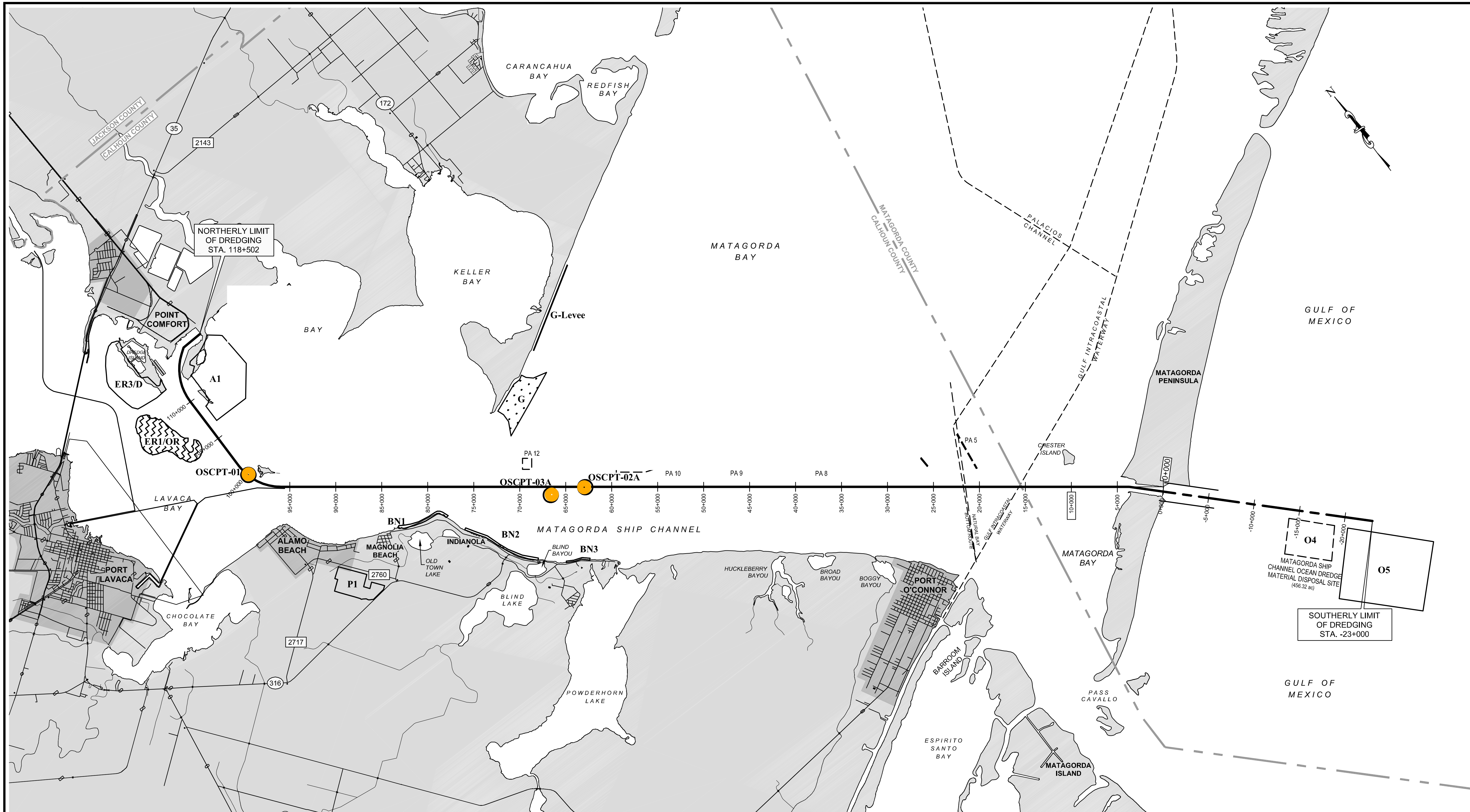
TO ACCOMPANY GENERAL DESIGN MEMORANDUM
DATED: JANUARY 1962

EXHIBIT: 1 APPENDIX: 8 FILE: GUAD. 705-112


Start Of Top Of East Jetty
-0+300
Stockpiled Rock
East Jetty
6C-1
6C-2
6C-3
6C-4
6C-5
6C-6
6C-7
6C-8
6C-9
-1+850
-2+850
-3+840
-4+820
-5+840
-6+830
-7+810
-8+800
-9+800
End Of Top Of East Jetty
-6+200
GULF OF MEXICO
MATAGORDA
PENINSULA
-10
-15
-20
-24
-25
-30
PLAN
SCALE OF FEET
300 0 300 600
Start Of Top Of West Jetty
0+400
West Jetty
6C-20
6C-21
6C-22
6C-23
6C-24
6C-25
6C-26
6C-27
6C-28
6C-29
-1+170
-2+150
-3+170
-4+160
-5+190
-6+170
-7+150
-8+140
-9+130
-10+150
End Of Top Of West Jetty
-5+600
Top Of East Jetty
Top Of West Jetty
Elevation In Feet M.L.T.
+10
0
-20
-40
-60
-80
-90
PROFILE
SCALE AS SHOWN
NOTE:
See Sheet No. 1 of 8
For Soil Legend
MATAGORDA SHIP CHANNEL, TEXAS
BORING LAYOUT
AND
SOIL PROFILE
IN 8 SHEETS
SHEET NO. 6
U.S. ARMY ENGINEER DISTRICT, GALVESTON, TEXAS
JANUARY, 1962
TO ACCOMPANY GENERAL DESIGN MEMORANDUM
DATED: JANUARY 1962
EXHIBIT 1
APPENDIX B
FILE NO. GUAD. 705-112

GEOTECHNICAL ATTACHMENT B

CONE PENETROMETER TESTS



LEGEND:

SUBMERGED OYSTER REEF

CPT LOCATION

0 3333 6666 10000 20000

APPROXIMATE SCALE IN FEET

COORDINATE SYSTEM BASED ON NAD83, TEXAS STATE PLANES, SOUTH CENTRAL ZONE, US FOOT.

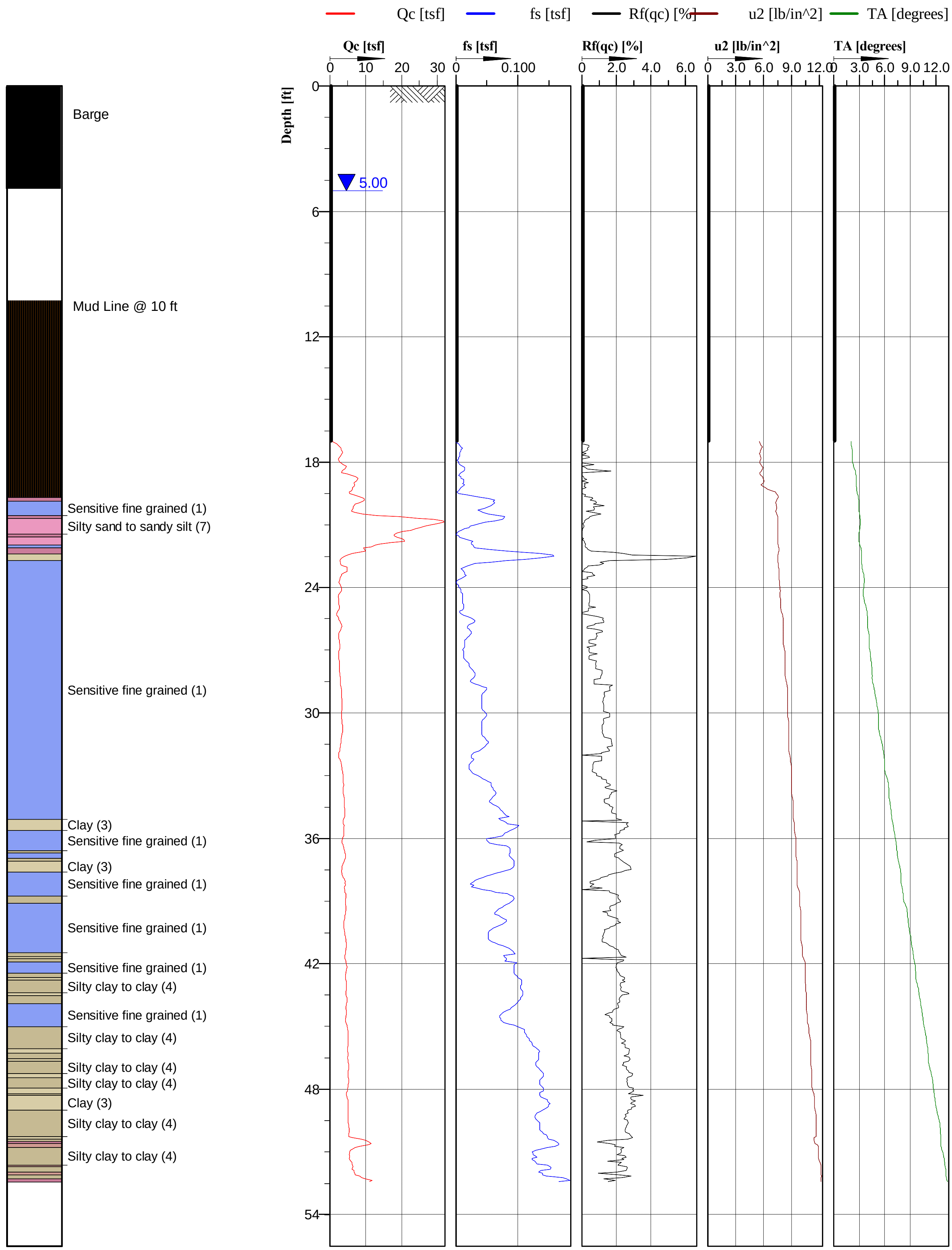
CPT LOCATIONS

MATAGORDA SHIP CHANNEL IMPROVEMENT PROJECT

MATAGORDA AND CALHOUN COUNTIES, TEXAS

URS

Plate G-01

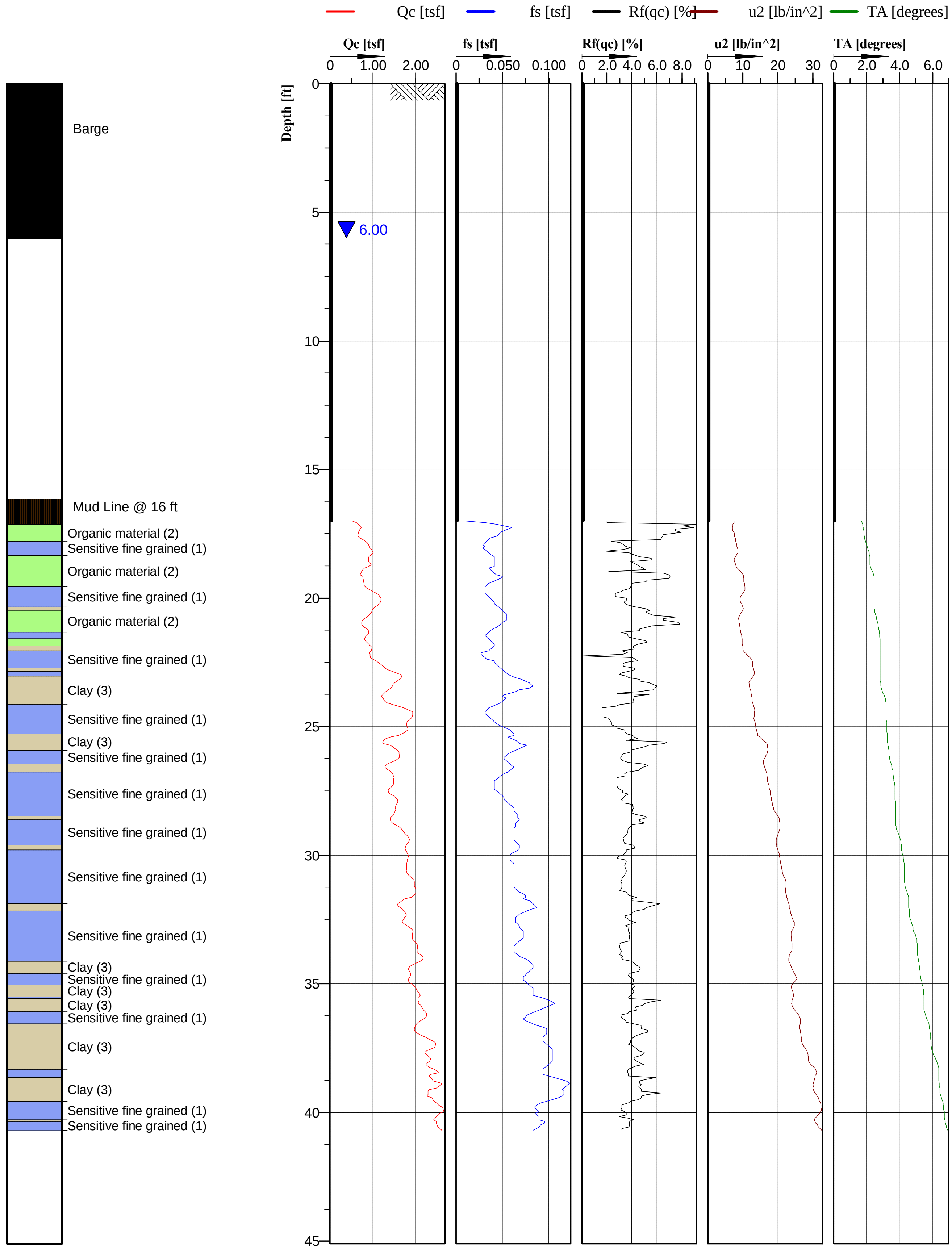


SOUTHERN EARTH SCIENCES, Inc.

U2

Cone No: 3466-mem
Tip area [cm2]: 10
Sleeve area [cm2]: 150

Location: Matagorda Bay, TX	Position:	Ground level:	Test no: OSCPT-01
Project ID: B06-195	Client: PSI	Date: 5/18/06	Scale: 1 : 80
Project: Matagorda Ship Channel Improvement Project		Page: 1/1	Fig:
GPS N 28 36.0759253 W 96 33.9871343		File: B06_195_OSCPT_01_m.cpd	

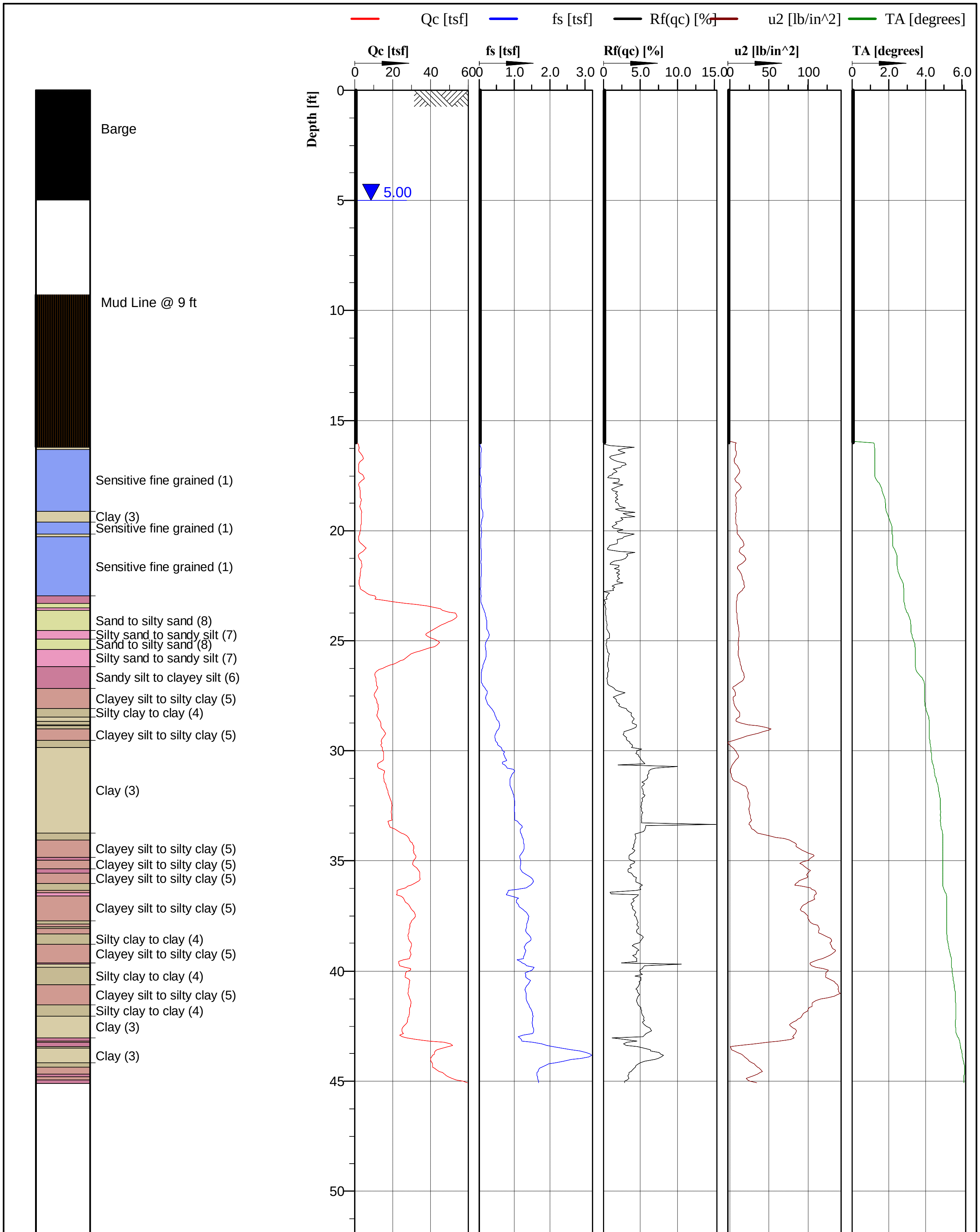


SOUTHERN EARTH SCIENCES, Inc.

U2

Cone No: 3466-mem
Tip area [cm2]: 10
Sleeve area [cm2]: 150

Location: Matagorda Bay, TX	Position:	Ground level:	Test no: OSCPT-02A
Project ID: B06-195	Client: PSI	Date: 5/19/2006	Scale: 1 : 65
Project: Matagorda Ship Channel Improvement Project		Page: 1/1	Fig:
GPS N 28 32.1373547 W 96 28.7866290		File: B06_195_OSCPT_02A_m.cpd	



SOUTHERN EARTH SCIENCES, Inc.

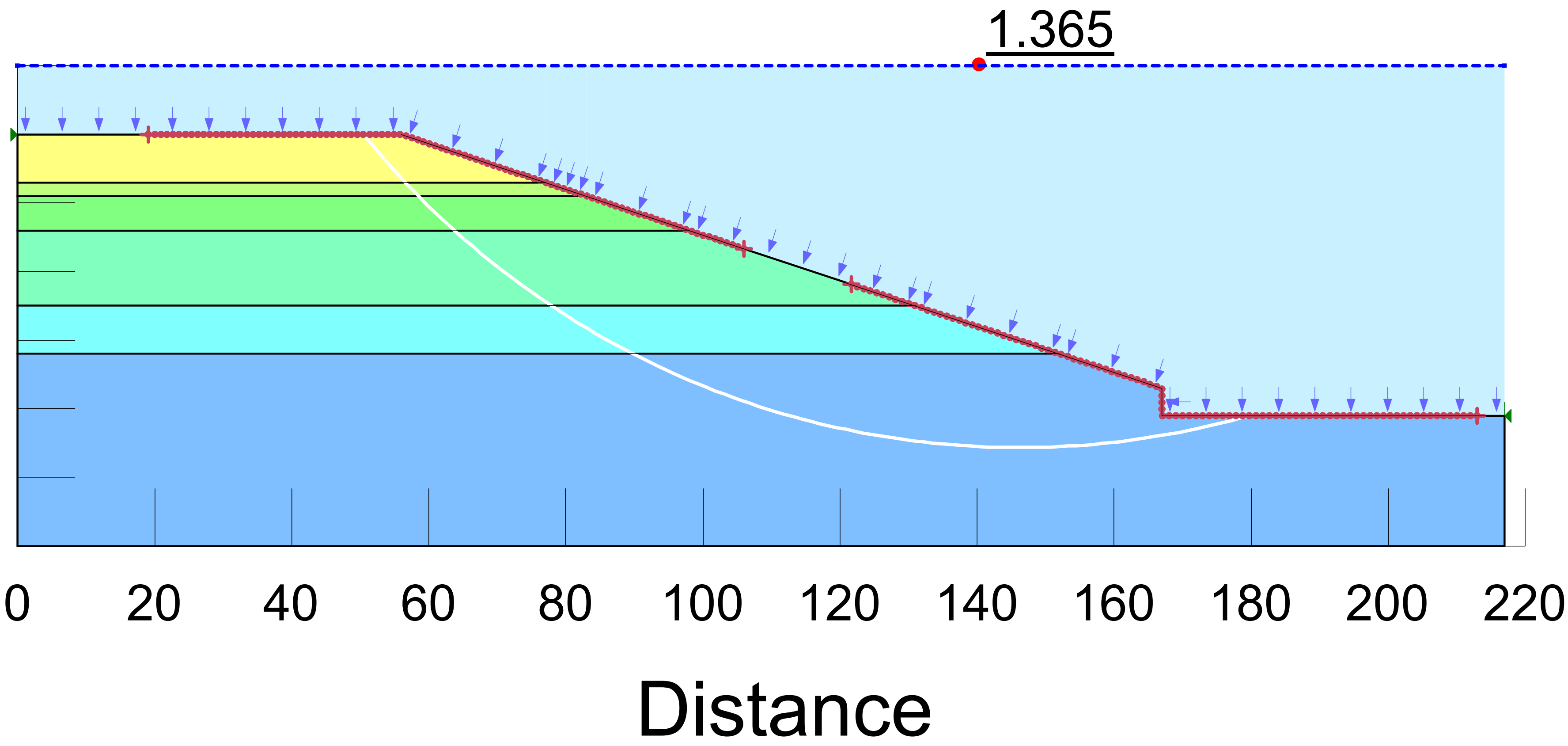
U2

Cone No: 3466-mem
Tip area [cm2]: 10
Sleeve area [cm2]: 150

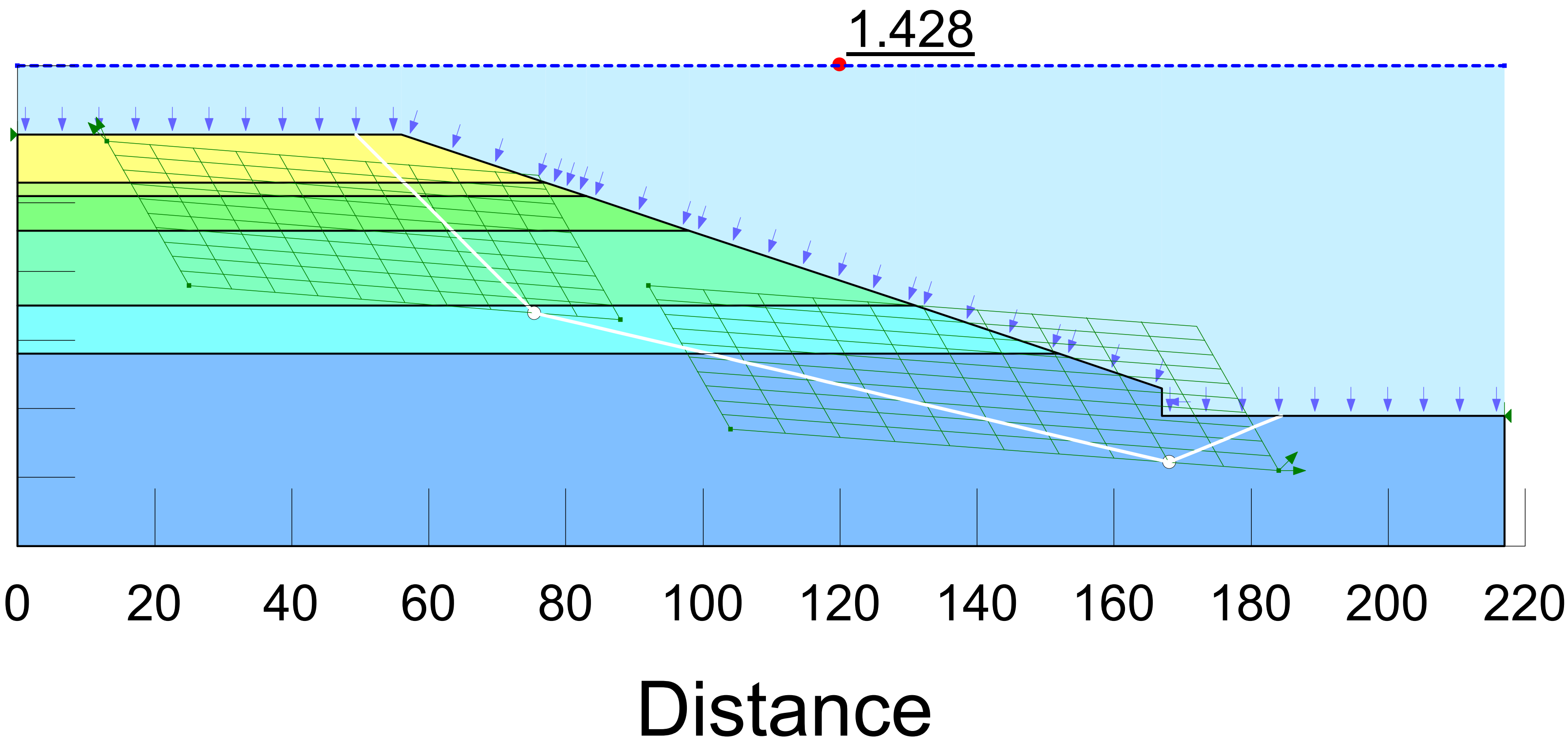
Location: Matagorda Bay, TX	Position:	Ground level:	Test no: OSCPT-03A
Project ID: B06-195	Client: PSI	Date: 5/21/06	Scale: 1 : 75
Project: Matagorda Ship Channel Improvement Project		Page: 1/1	Fig:
GPS N 28 32.4121851 W 96 29.43467681		File: B06_195_OSCPT_03A_m.cpd	

GEOTECHNICAL ATTACHMENT C

CHANNEL SLOPE ANALYSIS



Circular Failure Mode	
MSC Slope Stability Analysis with potental lowest strength parameters.gsz	
03/28/2019	1:297



Wedge Failure Mode	
MSC Slope Stability Analysis with potental lowest strength parameters.gsz	
03/28/2019	1:297

COST ENGINEERING ATTACHMENT NO.1

FINAL TPCS COST APPENDIX

WALLA WALLA COST ENGINEERING
MANDATORY CENTER OF EXPERTISE

COST AGENCY TECHNICAL REVIEW

CERTIFICATION STATEMENT

For Project No. 451954

SWG – Matagorda Ship Channel, Port Lavaca, Texas
Feasibility Study

The Matagorda Ship Channel, Port Lavaca, Texas 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 March 22, 2019, the Cost MCX certifies the estimated total project cost:

FY19 Project First Cost: $ 212,498,000
Fully Funded Amount: $ 228,476,000

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.

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

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

PROJECT: **MSC Feasibility**
PROJECT NO: P2 451954
LOCATION: Matagorda County, TX

DISTRICT: Galveston District **PREPARED: 3/13/2019**
POC: CHIEF, COST ENGINEERING, Willie J. Honza, P.E.

This Estimate reflects the scope and schedule in report; MSC Feasibility

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	$20,198	$6,059	30.0%	$26,257	0.0%	$20,198	$6,059	$26,257	$0	$26,257	9.6%	$22,131	$6,639	$28,770
12	NAVIGATION PORTS & HARBORS	$93,457	$28,037	30.0%	$121,494	0.0%	$93,457	$28,037	$121,494	$0	$121,494	7.8%	$100,766	$30,230	$130,996
02	RELOCATIONS	$23,893	$7,168	30.0%	$31,061	0.0%	$23,893	$7,168	$31,061	$0	$31,061	3.3%	$24,680	$7,404	$32,084
	CONSTRUCTION ESTIMATE TOTALS:	$137,548	$41,264		$178,812	0.0%	$137,548	$41,264	$178,812	$0	$178,812	7.3%	$147,577	$44,273	$191,850
01	LANDS AND DAMAGES	$1,243	$311	25.0%	$1,554	0.0%	$1,243	$311	$1,554	$0	$1,554	10.1%	$1,369	$342	$1,711
30	PLANNING, ENGINEERING & DESIGN	$15,092	$4,523	30.0%	$19,615	0.0%	$15,092	$4,523	$19,615	$0	$19,615	7.8%	$16,273	$4,878	$21,151
31	CONSTRUCTION MANAGEMENT	$9,628	$2,889	30.0%	$12,517	0.0%	$9,628	$2,889	$12,517	$0	$12,517	10.0%	$10,588	$3,177	$13,765
	PROJECT COST TOTALS:	$163,511	$48,987	30.0%	$212,498		$163,511	$48,987	**$212,498**	$0	**$212,498**	7.5%	$175,807	$52,669	$228,476

____________________ **CHIEF, COST ENGINEERING, Willie J. Honza, P.E.**

____________________ **PROJECT MANAGER, Franchelle Craft**

____________________ **CHIEF, REAL ESTATE, Timothy Nelson**

____________________ **CHIEF, PLANNING, Rob Newman**

____________________ **CHIEF, ENGINEERING, Joe King , R.A.**

____________________ **CHIEF, OPERATIONS, Joe Hrametz. P.E.**

____________________ **CHIEF, CONSTRUCTION, Donald Carelock, P.E.**

____________________ **CHIEF, CONTRACTING, Jeffrey Neill**

____________________ **CHIEF, PM-G, Valerie Miller**

____________________ **CHIEF, DPM, Edmund P. Russo, Jr., PHD, P.E., D.CE, D.NE.**

ESTIMATED TOTAL PROJECT COST: $228,476

ASSOCIATED COSTS: $7,952

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

**** CONTRACT COST SUMMARY ****

PROJECT: MSC Feasibility
LOCATION: Matagorda County, TX
This Estimate reflects the scope and schedule in report; MSC Feasibility

DISTRICT: Galveston District PREPARED: 3/13/2019
POC: CHIEF, COST ENGINEERING, Willie J. Honza, P.E.

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared: 13-Mar-19				Program Year (Budget EC): 2019								
		Effective Price Level: 1-Oct-18				Effective Price Level Date: 1 OCT 18								
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	RISK BASED 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													
12	NAVIGATION PORTS & HARBORS	$22,007	$6,602	30.0%	$28,608	0.0%	$22,007	$6,602	$28,608	2020Q2	3.3%	$22,731	$6,819	$29,550
	CONSTRUCTION ESTIMATE TOTALS:	$22,007	$6,602	30.0%	**$28,608**		$22,007	$6,602	$28,608			$22,731	$6,819	$29,550
01	LANDS AND DAMAGES	$0	$0	25.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
30	PLANNING, ENGINEERING & DESIGN													
1.0%	Project Management	$220	$66	30.0%	$286	0.0%	$220	$66	$286	2019Q4	2.9%	$226	$68	$294
0.5%	Planning & Environmental Compliance	$110	$33	30.0%	$143	0.0%	$110	$33	$143	2019Q4	2.9%	$113	$34	$147
5.0%	Engineering & Design	$1,100	$330	30.0%	$1,430	0.0%	$1,100	$330	$1,430	2019Q4	2.9%	$1,132	$340	$1,472
0.5%	Reviews, ATRs, IEPRs, VE	$110	$33	30.0%	$143	0.0%	$110	$33	$143	2019Q4	2.9%	$113	$34	$147
1.0%	Life Cycle Updates (cost, schedule, risks)	$220	$66	30.0%	$286	0.0%	$220	$66	$286	2019Q4	2.9%	$226	$68	$294
0.5%	Contracting and Repographics	$110	$33	30.0%	$143	0.0%	$110	$33	$143	2019Q4	2.9%	$113	$34	$147
1.0%	Engineering During Construction	$220	$66	30.0%	$286	0.0%	$220	$66	$286	2020Q2	4.8%	$231	$69	$300
0.5%	Planning During Construction	$110	$33	30.0%	$143	0.0%	$110	$33	$143	2020Q2	4.8%	$115	$35	$150
0.0%	Adaptive Management & Monitoring	$0	$0	30.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
1.0%	Project Operations	$220	$66	30.0%	$286	0.0%	$220	$66	$286	2019Q4	2.9%	$226	$68	$294
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$1,100	$330	30.0%	$1,430	0.0%	$1,100	$330	$1,430	2020Q2	4.8%	$1,153	$346	$1,500
1.0%	Project Operation:	$220	$66	30.0%	$286	0.0%	$220	$66	$286	2020Q2	4.8%	$231	$69	$300
1.0%	Project Management	$220	$66	30.0%	$286	0.0%	$220	$66	$286	2020Q2	4.8%	$231	$69	$300
	CONTRACT COST TOTALS:	$25,968	$7,790		$33,758		$25,968	$7,790	**$33,758**			$26,843	$8,053	**$34,896**

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

**** CONTRACT COST SUMMARY ****

PROJECT: MSC Feasibility
LOCATION: Matagorda County, TX
This Estimate reflects the scope and schedule in report; MSC Feasibility

DISTRICT: Galveston District PREPARED: 3/13/2019
POC: CHIEF, COST ENGINEERING, Willie J. 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:			13-Mar-19 1-Oct-18	Program Year (Budget EC): 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 2													
12	NAVIGATION PORTS & HARBORS	$40,134	$12,040	30.0%	$52,174	0.0%	$40,134	$12,040	$52,174	2021Q2	6.4%	$42,694	$12,808	$55,502
	CONSTRUCTION ESTIMATE TOTALS:	$40,134	$12,040	30.0%	**$52,174**		$40,134	$12,040	$52,174			$42,694	$12,808	$55,502
01	LANDS AND DAMAGES	$0	$0	25.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
30	PLANNING, ENGINEERING & DESIGN													
1.0%	Project Management	$401	$120	30.0%	$522	0.0%	$401	$120	$522	2020Q4	6.8%	$429	$129	$557
0.5%	Planning & Environmental Compliance	$201	$60	30.0%	$261	0.0%	$201	$60	$261	2020Q4	6.8%	$214	$64	$279
5.0%	Engineering & Design	$2,007	$602	30.0%	$2,609	0.0%	$2,007	$602	$2,609	2020Q4	6.8%	$2,144	$643	$2,787
0.5%	Reviews, ATRs, IEPRs, VE	$201	$60	30.0%	$261	0.0%	$201	$60	$261	2020Q4	6.8%	$214	$64	$279
1.0%	Life Cycle Updates (cost, schedule, risks)	$401	$120	30.0%	$522	0.0%	$401	$120	$522	2020Q4	6.8%	$429	$129	$557
0.5%	Contracting & Reprographics	$201	$60	30.0%	$261	0.0%	$201	$60	$261	2020Q4	6.8%	$214	$64	$279
1.0%	Engineering During Construction	$401	$120	30.0%	$522	0.0%	$401	$120	$522	2021Q2	8.8%	$437	$131	$568
0.5%	Planning During Construction	$201	$60	30.0%	$261	0.0%	$201	$60	$261	2021Q2	8.8%	$218	$66	$284
0.0%	Adaptive Management & Monitoring	$0	$0	30.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
1.0%	Project Operations	$401	$120	30.0%	$522	0.0%	$401	$120	$522	2020Q4	6.8%	$429	$129	$557
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$2,007	$602	30.0%	$2,609	0.0%	$2,007	$602	$2,609	2021Q2	8.8%	$2,184	$655	$2,839
1.0%	Project Operation:	$401	$120	30.0%	$522	0.0%	$401	$120	$522	2021Q2	8.8%	$437	$131	$568
1.0%	Project Management	$401	$120	30.0%	$522	0.0%	$401	$120	$522	2021Q2	8.8%	$437	$131	$568
	CONTRACT COST TOTALS:	$47,358	$14,207		$61,566		$47,358	$14,207	**$61,566**			$50,479	$15,144	**$65,622**

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

**** CONTRACT COST SUMMARY ****

PROJECT: MSC Feasibility
LOCATION: Matagorda County, TX
This Estimate reflects the scope and schedule in report; MSC Feasibility

DISTRICT: Galveston District
POC: CHIEF, COST ENGINEERING, Willie J. Honza, P.E.
PREPARED: 3/13/2019

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared: 13-Mar-19 Effective Price Level: 1-Oct-18				Program Year (Budget EC): 2019 Effective Price Level Date: 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													
12	NAVIGATION PORTS & HARBORS	$31,316	$9,395	30.0%	$40,711	0.0%	$31,316	$9,395	$40,711	2023Q2	12.9%	$35,342	$10,603	$45,945
	CONSTRUCTION ESTIMATE TOTALS:	$31,316	$9,395	30.0%	**$40,711**		$31,316	$9,395	$40,711			$35,342	$10,603	$45,945
01	LANDS AND DAMAGES	$881	$220	25.0%	$1,102	0.0%	$881	$220	$1,102	2023Q2	12.9%	$995	$249	$1,243
30	PLANNING, ENGINEERING & DESIGN													
1.0%	Project Management	$313	$94	30.0%	$407	0.0%	$313	$94	$407	2022Q2	12.8%	$353	$106	$459
0.5%	Planning & Environmental Compliance	$157	$47	30.0%	$204	0.0%	$157	$47	$204	2022Q2	12.8%	$177	$53	$230
5.0%	Engineering & Design	$1,566	$470	30.0%	$2,036	0.0%	$1,566	$470	$2,036	2022Q2	12.8%	$1,767	$530	$2,297
0.5%	Reviews, ATRs, IEPRs, VE	$157	$47	30.0%	$204	0.0%	$157	$47	$204	2022Q2	12.8%	$177	$53	$230
1.0%	Life Cycle Updates (cost, schedule, risks)	$313	$94	30.0%	$407	0.0%	$313	$94	$407	2022Q2	12.8%	$353	$106	$459
0.5%	Contracting & Reprographics	$157	$47	30.0%	$204	0.0%	$157	$47	$204	2022Q2	12.8%	$177	$53	$230
1.0%	Engineering During Construction	$313	$94	30.0%	$407	0.0%	$313	$94	$407	2023Q2	17.1%	$367	$110	$477
0.5%	Planning During Construction	$157	$47	30.0%	$204	0.0%	$157	$47	$204	2023Q2	17.1%	$183	$55	$238
0.0%	Adaptive Management & Monitoring	$0	$0	30.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
1.0%	Project Operations	$313	$94	30.0%	$407	0.0%	$313	$94	$407	2022Q2	12.8%	$353	$106	$459
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$1,566	$470	30.0%	$2,036	0.0%	$1,566	$470	$2,036	2023Q2	17.1%	$1,834	$550	$2,384
1.0%	Project Operation:	$313	$94	30.0%	$407	0.0%	$313	$94	$407	2023Q2	17.1%	$367	$110	$477
1.0%	Project Management	$313	$94	30.0%	$407	0.0%	$313	$94	$407	2023Q2	17.1%	$367	$110	$477
	CONTRACT COST TOTALS:	$37,834	$11,306		**$49,141**		$37,834	$11,306	**$49,141**			$42,812	$12,794	**$55,605**

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

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

PROJECT: MSC Feasibility
LOCATION: Matagorda County, TX
This Estimate reflects the scope and schedule in report; MSC Feasibility

DISTRICT: Galveston District PREPARED: 3/13/2019
POC: CHIEF, COST ENGINEERING, Willie J. 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:			13-Mar-19 / 1-Oct-18	Program Year (Budget EC): 2019 / 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													
06		FISH & WILDLIFE FACILITIES	$20,198	$6,059	30.0%	$26,257	0.0%	$20,198	$6,059	$26,257	2022Q2	9.6%	$22,131	$6,639	$28,770
		CONSTRUCTION ESTIMATE TOTALS:	$20,198	$6,059	30.0%	**$26,257**		$20,198	$6,059	$26,257			$22,131	$6,639	$28,770
01		LANDS AND DAMAGES	$0	$0	25.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
30		PLANNING, ENGINEERING & DESIGN													
	1.0%	Project Management	$202	$61	30.0%	$263	0.0%	$202	$61	$263	2021Q4	10.8%	$224	$67	$291
	0.5%	Planning & Environmental Compliance	$101	$30	30.0%	$131	0.0%	$101	$30	$131	2021Q4	10.8%	$112	$34	$146
	5.0%	Engineering & Design	$1,010	$303	30.0%	$1,313	0.0%	$1,010	$303	$1,313	2021Q4	10.8%	$1,119	$336	$1,455
	0.5%	Reviews, ATRs, IEPRs, VE	$101	$30	30.0%	$131	0.0%	$101	$30	$131	2021Q4	10.8%	$112	$34	$146
	1.0%	Life Cycle Updates (cost, schedule, risks)	$202	$61	30.0%	$263	0.0%	$202	$61	$263	2021Q4	10.8%	$224	$67	$291
	0.5%	Contracting & Reprographics	$101	$30	30.0%	$131	0.0%	$101	$30	$131	2021Q4	10.8%	$112	$34	$146
	1.0%	Engineering During Construction	$202	$61	30.0%	$263	0.0%	$202	$61	$263	2022Q2	12.8%	$228	$68	$296
	0.5%	Planning During Construction	$101	$30	30.0%	$131	0.0%	$101	$30	$131	2022Q2	12.8%	$114	$34	$148
	0.0%	Adaptive Management & Monitoring	$0	$0	30.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
	1.0%	Project Operations	$202	$61	30.0%	$263	0.0%	$202	$61	$263	2021Q4	10.8%	$224	$67	$291
31		CONSTRUCTION MANAGEMENT													
	5.0%	Construction Management	$1,010	$303	30.0%	$1,313	0.0%	$1,010	$303	$1,313	2022Q2	12.8%	$1,140	$342	$1,481
	1.0%	Project Operation:	$202	$61	30.0%	$263	0.0%	$202	$61	$263	2022Q2	12.8%	$228	$68	$296
	1.0%	Project Management	$202	$61	30.0%	$263	0.0%	$202	$61	$263	2022Q2	12.8%	$228	$68	$296
		CONTRACT COST TOTALS:	$23,834	$7,150		**$30,984**		$23,834	$7,150	**$30,984**			$26,195	$7,858	**$34,053**

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

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

PROJECT: MSC Feasibility
LOCATION: Matagorda County, TX
This Estimate reflects the scope and schedule in report; MSC Feasibility

DISTRICT: Galveston District
POC: CHIEF, COST ENGINEERING, Willie J. Honza, P.E.
PREPARED: 3/13/2019

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
		Estimate Prepared: / Effective Price Level:			13-Mar-19 / 1-Oct-18	Program Year (Budget EC): / 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													
02	RELOCATIONS	$23,893	$7,168	30.0%	$31,061	0.0%	$23,893	$7,168	$31,061	2020Q2	3.3%	$24,680	$7,404	$32,083.51
	CONSTRUCTION ESTIMATE TOTALS:	$23,893	$7,168	30.0%	**$31,061**		$23,893	$7,168	$31,061			$24,680	$7,404	$32,084
01	LANDS AND DAMAGES	$362	$91	25.0%	$453	0.0%	$362	$91	$453	2020Q2	3.3%	$374	$94	$468
30	PLANNING, ENGINEERING & DESIGN													
1.0%	Project Management	$239	$72	30.0%	$311	0.0%	$239	$72	$311	2019Q4	2.9%	$246	$74	$320
0.5%	Planning & Environmental Compliance	$119	$36	30.0%	$155	0.0%	$119	$36	$155	2019Q4	2.9%	$123	$37	$160
5.0%	Engineering & Design	$1,195	$358	30.0%	$1,553	0.0%	$1,195	$358	$1,553	2019Q4	2.9%	$1,229	$369	$1,598
0.5%	Reviews, ATRs, IEPRs, VE	$119	$36	30.0%	$155	0.0%	$119	$36	$155	2019Q4	2.9%	$123	$37	$160
1.0%	Life Cycle Updates (cost, schedule, risks)	$239	$72	30.0%	$311	0.0%	$239	$72	$311	2019Q4	2.9%	$246	$74	$320
0.5%	Real Estate	$81	$20	25.0%	$101	0.0%	$81	$20	$101	2019Q4	2.9%	$83	$21	$104
1.0%	Engineering During Construction	$239	$72	30.0%	$311	0.0%	$239	$72	$311	2020Q2	4.8%	$250	$75	$326
0.5%	Planning During Construction	$119	$36	30.0%	$155	0.0%	$119	$36	$155	2020Q2	4.8%	$125	$38	$163
0.0%	Adaptive Management & Monitoring	$0	$0	30.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
1.0%	Project Operations	$239	$72	30.0%	$311	0.0%	$239	$72	$311	2019Q4	2.9%	$246	$74	$320
31	CONSTRUCTION MANAGEMENT													
5.0%	Construction Management	$1,195	$358	30.0%	$1,553	0.0%	$1,195	$358	$1,553	2020Q2	4.8%	$1,252	$376	$1,628
1.0%	Project Operation:	$239	$72	30.0%	$311	0.0%	$239	$72	$311	2020Q2	4.8%	$250	$75	$326
1.0%	Project Management	$239	$72	30.0%	$311	0.0%	$239	$72	$311	2020Q2	4.8%	$250	$75	$326
	CONTRACT COST TOTALS:	$28,517	$8,533		**$37,050**		$28,517	$8,533	**$37,050**			$29,479	$8,821	**$38,300**

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

**** CONTRACT COST SUMMARY ****

PROJECT: MSC Feasibility
LOCATION: Matagorda County, TX
This Estimate reflects the scope and schedule in report; MSC Feasibility

DISTRICT: Galveston District PREPARED: 3/13/2019
POC: CHIEF, COST ENGINEERING, Willie J. 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:			13-Mar-19 / 1-Oct-18	Program Year (Budget EC): 2019 / 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*
		Associated Costs													
12		NAVIGATION PORTS & HARBORS	$3,807	$952	25.0%	$4,759	0.0%	$3,807	$952	$4,759	2020Q2	3.3%	$3,933	$983	$4,916
12		AIDS TO NAVIGATION	$1,506	$377	25.0%	$1,883	0.0%	$1,506	$377	$1,883	2020Q2	3.3%	$1,556	$389	$1,944
		CONSTRUCTION ESTIMATE TOTALS:	$5,313	$1,328	25.0%	**$6,642**		$5,313	$1,328	$6,642			$5,488	$1,372	$6,860
01		LANDS AND DAMAGES	$0	$0	0.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
30		PLANNING, ENGINEERING & DESIGN													
	1.0%	Project Management	$53	$5	10.0%	$58	0.0%	$53	$5	$58	2019Q4	2.9%	$55	$5	$60
	0.5%	Planning & Environmental Compliance	$27	$3	10.0%	$29	0.0%	$27	$3	$29	2019Q4	2.9%	$27	$3	$30
	5.0%	Engineering & Design	$266	$27	10.0%	$292	0.0%	$266	$27	$292	2019Q4	2.9%	$273	$27	$301
	0.5%	Reviews, ATRs, IEPRs, VE	$27	$3	10.0%	$29	0.0%	$27	$3	$29	2019Q4	2.9%	$27	$3	$30
	1.0%	Life Cycle Updates (cost, schedule, risks)	$53	$5	10.0%	$58	0.0%	$53	$5	$58	2019Q4	2.9%	$55	$5	$60
	0.5%	Contracting & Reprographics	$27	$3	10.0%	$29	0.0%	$27	$3	$29	2019Q4	2.9%	$27	$3	$30
	1.0%	Engineering During Construction	$53	$5	10.0%	$58	0.0%	$53	$5	$58	2020Q2	4.8%	$56	$6	$61
	0.5%	Planning During Construction	$27	$3	10.0%	$29	0.0%	$27	$3	$29	2020Q2	4.8%	$28	$3	$31
	0.0%	Adaptive Management & Monitoring	$0	$0	10.0%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
	1.0%	Project Operations	$53	$5	10.0%	$58	0.0%	$53	$5	$58	2019Q4	2.9%	$55	$5	$60
31		CONSTRUCTION MANAGEMENT													
	5.0%	Construction Management	$266	$27	10.0%	$292	0.0%	$266	$27	$292	2020Q2	4.8%	$278	$28	$306
	1.0%	Project Operation:	$53	$5	10.0%	$58	0.0%	$53	$5	$58	2020Q2	4.8%	$56	$6	$61
	1.0%	Project Management	$53	$5	10.0%	$58	0.0%	$53	$5	$58	2020Q2	4.8%	$56	$6	$61
		CONTRACT COST TOTALS:	$6,270	$1,424		**$7,694**		$6,270	$1,424	**$7,694**			$6,481	$1,471	**$7,952**

COST ENGINEERING ATTACHMENT NO. 2

MSC IMPROVEMENTS MCACES

SUMMARY

COE Standard Report Selections

The following Codes of Account are not accounted for in this Mii report.

30 - Planning, Engineering, and Design

31 - Construction Management

Estimated by	G. Dale Williams
Designed by	Brandon Crawford
Prepared by	G. Dale Williams
Preparation Date	3/22/2019
Effective Date of Pricing	10/1/2018
Estimated Construction Time	1,005 Days

Description	Quantity	UOM	DirectCost	ContractCost	ProjectCost
Project Cost Summary Report			**127,031,182**	**137,547,978**	**137,547,978**
Alternative A2 (TSP)	**1.00**	**LS**	**127,031,182**	**137,547,978**	**137,547,978**
01 Contract 1 (2020)	**1.00**	**EA**	**22,006,519**	**22,006,519**	**22,006,519**
01-01 Fed	**1.00**	**EA**	**22,006,519**	**22,006,519**	**22,006,519**
02 Contract 2 (2021)	**1.00**	**EA**	**40,134,135**	**40,134,135**	**40,134,135**
02-01 Fed	**1.00**	**EA**	**40,134,135**	**40,134,135**	**40,134,135**
03 Contract 3 (2022)	**1.00**	**EA**	**31,316,193**	**31,316,193**	**31,316,193**
03-01 Fed	**1.00**	**EA**	**31,316,193**	**31,316,193**	**31,316,193**
04 Contract 4 (2022)	**1.00**	**EA**	**15,919,599**	**20,197,991**	**20,197,991**
04-01 Fed	**1.00**	**EA**	**15,919,599**	**20,197,991**	**20,197,991**
05 Contract 5 Relocations (2020)	**1.00**	**EA**	**17,654,735**	**23,893,139**	**23,893,139**
05-01 Non-Fed	**1.00**	**EA**	**17,654,735**	**23,893,139**	**23,893,139**

COST ENGINEERING ATTACHMENT NO. 3

Project Cost and Schedule Risk Analysis Summary Report

US Army Corps
of Engineers®

Matagorda Ship Channel Modification
Project Cost and Schedule Risk Analysis Report

Prepared for:

U.S. Army Corps of Engineers,
Galveston District

Prepared by:

Phillip C. Ohnstad, CPC, CCC

March 2019

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EXECUTIVE SUMMARY

The US Army Corps of Engineers (USACE), District, presents this cost and schedule risk analysis (CSRA) report regarding the risk findings and recommended contingencies for the Matagorda Ship Channel Modification Feasibility 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.

The project involves the deepening of the 26-mile existing Federal Matagorda Shipping Channel (MSC) beginning at the Gulf of Mexico, through Matagorda Bay and Lavaca Bay to the Port. The plan is for deepening to 47’ MLLW.

Alternative	Depth Main / Entrance	Width Main / Gulf	Turning Basin
A	47’ / 49’	350’ / 600’	1,200’

Specific to the Matagorda Ship Channel Modification Feasibility Study, the current project base Construction cost estimate, pre-contingency, approximates $137M. This CSRA study excludes contingencies and is expressed in FY 2019 dollars. The Real Estate office provided a separate 25% contingency for its estimated $1.24M Land and Damages and the Cost MCX performed study on the estimated remaining construction costs of $137M. 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 $41M or approximately 30% of the base project cost at an 80% confidence level of successful execution. The 30% contingency is applied to the Engineering and Design (30 Account) and Construction Management (31 Account).

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, and cost values rounded.

Table ES-1. Construction Contingency Results

Base Case Construction Cost Estimate	$137,547,000	
Confidence Level	**Construction Value ($$) w/ Contingencies**	**Contingency (%)**
50%	$31,636,000	23%

80%	**$41,264,000**	**30%**
90%	$46,766,000	34%

KEY FINDINGS/OBSERVATIONS RECOMMENDATIONS

The PDT worked through the risk register in December, 2018. The base construction cost estimate reduced from $181M to $152M following the risk analysis meeting. During the ATR review the estimate was further refined to $137M. That period of time allowed improved project scope definition, investigations, design and cost information, and resulted in reduced risks in certain project areas. The key risk drivers identified through sensitivity analysis suggest a cost contingency of $41M and schedule contingency adding another 6 months, both at an 80% confidence level.

The risk of Contaminated Soil discovered in the turning basin remains unresolved and poses a marginal risk to the project. If contaminated soil is discovered, the PAP1 disposal site will need the real estate acquired and a portion of the upland disposal site constructed. Currently, the risk of occurrence is considered unlikely but if it does occur would cause a moderate cost impact.

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

- EX-2: Fuel – Fuel is a volatile cost and can greatly affect the cost of this project.
- ES-8: Specialty Equipment – A spill barge may be required to place in NP1-6. A price is included in the estimate but the actual equipment or dredging productivity costs have not been established.
- CA2: Market Conditions and Bidding Competition – There is the possibility of having a limited number of contractors bid which would increase the cost.
- LD2: Relocation Pricing (Scope) – Based on available information, approximately 16 pipeline relocations are assumed. Original report indicated there were 22 pipelines. The estimate includes a lump sum cost. Potential to find additional pipelines and/or deeper depths. Unknowns always exist when dealing with underground utilities.
- CO1: Modifications and Claims – Technical complexities and site conditions could result in increased risk of contract modifications. Will impact costs, but little overall impact to larger project timeline.
- ES4: Relocation Pricing (Estimate) – Relocation costs based on historical costs. Actual costs may vary from escalated price included in estimate. CSI items are

included but do not include contractor markups. Lump sum pricing scaled from original estimate of 22 pipeline relocations to an assumed 16 relocations.

- CO1: Modifications and Claims – Technical complexities and site conditions could result in increased risk of contract modifications. Will impact costs, but little overall impact to larger project timeline.

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:

- PM2: Non Federal Sponsor Funding – If the non-federal sponsor cannot cost share the project a Project Partnership Agreement may not be signed and project could not start.
- PM1: Federal Funding - Annual appropriations for Design and Construction could be delayed.
- ES7: Construction Schedule - Construction Schedule is a bar chart that is outdated and needs to be updated with the correct contract assumptions. The schedule is likely to change.
- LD2: Pipeline Relocations (Scope) - The estimate includes a lump sum cost. Potential to find additional pipelines and/or deeper depths. Unknowns always exist when dealing with underground utilities and could lead to schedule delays.
- ES8: Specialty Equipment - A spill barge may be required to place in NP1-6. Specialty equipment costs and the associated productivity could increase costs and cause schedule delays.

Recommendations: Recommend further site investigation to assess the contaminated material within the entrance channel dredging prism. 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), Galveston District, this report presents the efforts and results of the cost and schedule risk analysis for The Matagorda Ship Channel Deepening. 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

The project involves the deepening of the 26-mile existing Federal Matagorda Shipping Channel (MSC) beginning at the Gulf of Mexico, through Matagorda Bay and Lavaca Bay to the Port. The plan is for deepening to 47' MLLW.

Alternative	Depth Main / Entrance	Width Main / Gulf	Turning Basin
A	47' / 49'	350' / 600'	1,200'

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 webinar/teleconference with the Walla Walla Cost Engineering MCX facilitator on December 4, 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.

Participants in the risk identification meeting of December 4, 2018 included:

Attendance	Name	Office	Representing
Full	Dale Williams	CESWG-EC-PS	Cost Engineering
Full	Brandon Crawford	CESWG-EC-PS	Geotechnical
Full	Brenda Hayden	CESWG-EC-EG	Civil
Full	Harmon Brown III	CESWF-PEC	Biologist
Full	Thomas White	CESWG-EC-HB	Civil
Full	Franchelle Craft	CESWG-AO-NH	Civil
Full	Kathryn Skalbeck	CESWF-PER-PF	Planning
Full	Aron Edwards	CESWG-OD-N	Operations
Full	Nicole Schlund	CESWG-RES	Real Estate
Full	Jennifer Purcell	CESWF-PEC-PE	Economist

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 December 4, 2018) 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, informal meetings were conducted throughout the risk analysis process to provide risk clarification and assessments. Finalization of the risk register led to developing the resultant CSRA model, findings and results.

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. A key risk, contaminated dredge material, remains as an unlikely risk but has a critical cost and schedule risk if it should occur.

b. The Galveston District provided MII MCACES (Micro-Computer Aided Cost Estimating Software) files electronically. The MII and CWE files transmitted and downloaded on December 14, 2018 was the basis for the initial cost and schedule risk analyses. An updated estimate was provided on 13March 2019 and used for the final CSRA.

c. 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 10% design stage.

d. 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.

e. 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.

f. 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 1 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) was quantified as approximately $41 Million at the P80 confidence level (30% of the baseline construction cost estimate).

Table 1. Construction Cost Contingency Summary

Base Case Construction Cost Estimate	**$137,547,000**	
Confidence Level	**Construction Value ($$)**	**Contingency (%)**
50%	$31,636,000	23%
80%	**$41,264,000**	**30%**
90%	$46,766,000	34%

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.

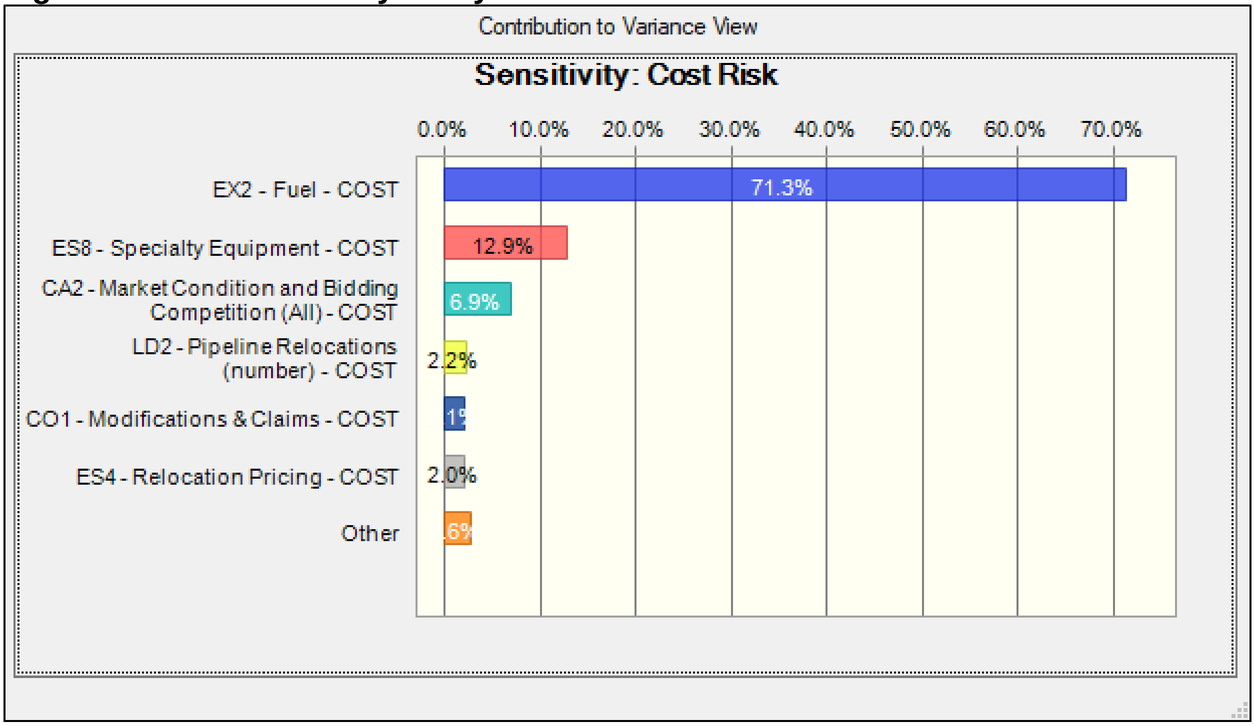
Key cost drivers identified in the sensitivity analysis can be used to support development of a risk management plan that will facilitate control of risk factors and their potential impacts throughout the project lifecycle. Together with the risk register, sensitivity analysis results can also be used 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 1 presents a sensitivity analysis for cost growth risk from the high level cost risks identified in the risk register. Likewise, Figure 2 presents a sensitivity analysis for schedule growth risk from the high level schedule risks identified in the risk register.

Figure 1. Cost 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 2 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.

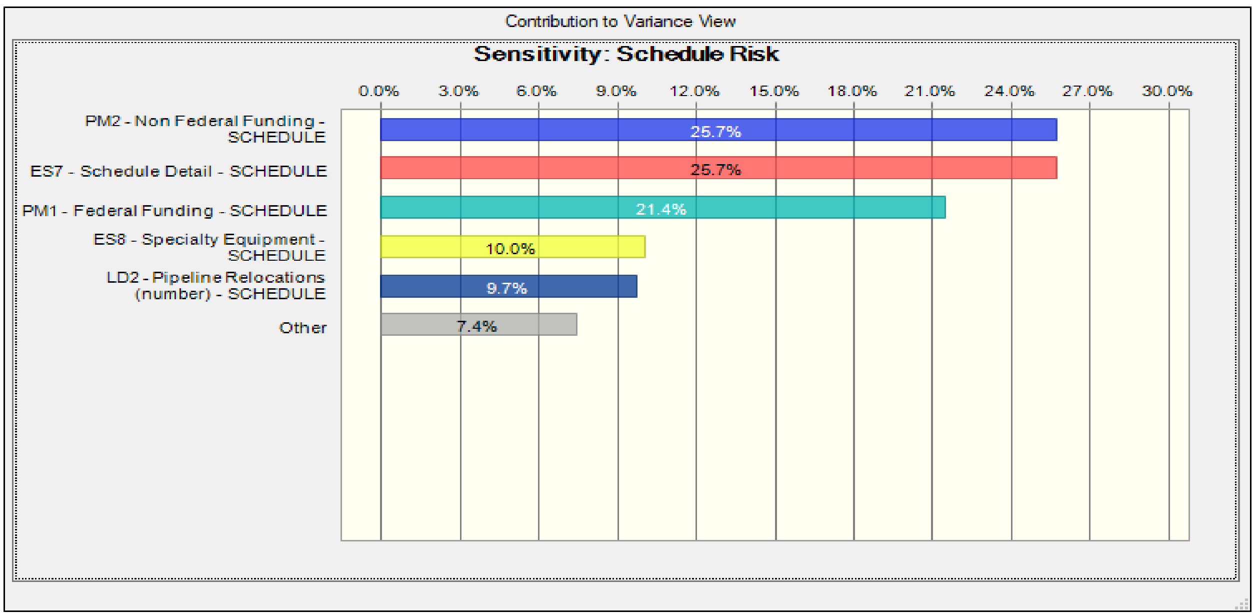
Schedule duration contingency was quantified as 6 months based on the P80 level of confidence. These contingencies were used to calculate the projected residual fixed cost impact of project delays that are included in the Table 1 presentation of total cost contingency. The schedule contingencies were 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.

Table 2. Schedule Duration Contingency Summary

Risk Analysis Forecast (base schedule of 57 months)	Duration w/ Contingencies (months)	Contingency[1] (months)
50% Confidence	44	5
80% Confidence	45	6
90% Confidence	46	7

Figure 2. Schedule Sensitivity Analysis



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 3 and Table 4 respectively. Additional major findings and observations of the risk analysis are listed below.

The PDT worked through the risk register in December 2018. The key risk drivers identified through sensitivity analysis suggest a cost contingency of $41M and schedule risks adding another potential of 6 month, both at an 80% confidence level.

A key risk, the risk of Contaminated Soil discovered in the turning basin remains unresolved and poses a risk to the project. If contaminated soil is discovered, the PAP1 disposal site will need the real estate acquired and a portion of the upland disposal site constructed. Currently, the risk of occurrence is considered unlikely but if it does occur would cause a moderate cost impact.

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

- EX-2: Fuel – Fuel is a volatile cost and can greatly affect the cost of this project.
- ES-8: Specialty Equipment – A spill barge may be required to place in NP1-6. A price is included in the estimate but the actual equipment or dredging productivity costs have not been established.
- CA2: Market Conditions and Bidding Competition – There is the possibility of having a limited number of contractors bid which would increase the cost.
- LD2: Relocation Pricing (Scope) – Based on available information, approximately 16 pipeline relocations are assumed. Original report indicated there were 22 pipelines. The estimate includes a lump sum cost. Potential to find additional pipelines and/or deeper depths. Unknowns always exist when dealing with underground utilities.
- CO1: Modifications and Claims – Technical complexities and site conditions could result in increased risk of contract modifications. Will impact costs, but little overall impact to larger project timeline.

- ES4: Relocation Pricing (Estimate) – Relocation costs based on historical costs. Actual costs may vary from escalated price included in estimate. CSI items are included but do not include contractor markups. Lump sum pricing scaled from original estimate of 22 pipeline relocations to an assumed 16 relocations.
- CO1: Modifications and Claims – Technical complexities and site conditions could result in increased risk of contract modifications. Will impact costs, but little overall impact to larger project timeline.

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:

- PM2: Non Federal Sponsor Funding – If the non-federal sponsor cannot cost share the project a Project Partnership Agreement may not be signed and project could not start.
- PM1: Federal Funding - Annual appropriations for Design and Construction could be delayed.
- ES7: Construction Schedule - Construction Schedule is a bar chart that is outdated and needs to be updated with the correct contract assumptions. The schedule is likely to change.
- LD2: Pipeline Relocations (Scope) - The estimate includes a lump sum cost. Potential to find additional pipelines and/or deeper depths. Unknowns always exist when dealing with underground utilities and could lead to schedule delays.
- ES8: Specialty Equipment - A spill barge may be required to place in NP1-6. Specialty equipment costs and the associated productivity could increase costs and cause schedule delays.

Table 3. Construction Cost Comparison Summary (Uncertainty Analysis)

INITIAL CONSTRUCTION

Contingency Analysis

Base Case Estimate (Excluding 01)	$137,547,978	
Confidence Level	ıntingency Val	Contingency
0%	6,877,399	5%
10%	19,256,717	14%
20%	23,383,156	17%
30%	26,134,116	19%
40%	28,885,075	21%
50%	31,636,035	23%
60%	34,386,994	25%
70%	37,137,954	27%
80%	41,264,393	30%
90%	46,766,312	34%
100%	66,023,029	48%

Table 4. Construction Schedule Comparison Summary (Uncertainty Analysis)

Contingency Analysis

Base Case Schedule	39.0 Months	
Confidence Level	ntingency Val	Contingency
0%	2 Months	4%
10%	3 Months	8%
20%	4 Months	9%
30%	4 Months	10%
40%	4 Months	11%
50%	5 Months	12%
60%	5 Months	13%
70%	5 Months	14%
80%	6 Months	15%
90%	7 Months	17%
100%	10 Months	26%

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. 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

	Project Cost			Project Schedule			Other Information	
PDT Discussions on Impact and Likelihood	**Likelihood ©**	**Impact ©**	**Risk Level ©**	**Likelihood (S)**	**Impact (S)**	**Risk Level (S)**	**Cost Variance Distribution**	**Schedule Variance Distribution**
Due to the priority of the project it is likely that the project may not receive adequate funding annually.	Possible	Negligible	**Low**	Likely	Critical	**High**	N/A -Not Modeled	Triangular
If the non federal sponsor cannot cost share the project a Project Partnership Agreement may not be signed and project could not start.	Unlikely	Negligible	**Low**	Unlikely	Critical	**Medium**	N/A -Not Modeled	Triangular
We expect to have enough people to work on this project with the Galveston district.	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
This is a go-no go risk. Currently (12/4/2018) the BCR ratio is low and could cancel project.	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
No risk of changes.	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled

PDT discussed this topic. There is no reason for this project to fall under any special programs.	Unlikely	Negligible	Low	Unlikely	Negligible	Low	N/A -Not Modeled	N/A -Not Modeled
Having limited competition would likely increase the cost. Corps studies have resulted in an expected dredge shortage as compared to the many anticipated projects in the Gulf region. Less competition is likely, resulting in higher bids. Must be able to dredge up to 60' and may have limited availability of large plants. Maximum digging depth for largest hopper dredges is up to 90' depth. Limited number of hopper dredges and there could be limited availability for the entrance channel dredging.	Likely	Significant	High	Unlikely	Negligible	Low	Triangular	N/A -Not Modeled
6 contracts planned and most is planned for IFB dredging contracts. Small business could be added for mitigation (oyster beds).	Possible	Marginal	Low	Unlikely	Marginal	Low	N/A -Not Modeled	N/A -Not Modeled
Method of calculation of dredging quantities and surveying is well established from dredge history. Updating conditional surveys but there could be changes between feasibility level and PED. Quantities included over depth dredging. Estimate is conservative and do not expect additional quantities.	Possible	Marginal	Low	Possible	Marginal	Low	N/A -Not Modeled	N/A -Not Modeled

Historical methods for PAP1 construction have been assumed and may not reflect unique problems due to material strength or foundation stability. The construction elements have been assumed with limited geotechnical information and may not reflect unforeseen site conditions. The quantity to build dike may change due to selected depth to dredge. Quality of sediment from dredge material could affect quality and design of dike. PAP1 owned by sponsor and a non standard perpetual material placement easement will be required plus a pipeline easement agreement. PAP1 will have 1.5 AC of mitigation if it used. PAP1 included in original estimate and removed in December 2018. PAP1 not anticipated to be required. Risk level lower to Not Likely and not modeled.	Unlikely	Moderate	**Low**	Unlikely	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled
This is a long term O&M costs due to material washing into the channel. This would not affect the base cost and therefore is not modeled. There is no plan for installing any additional design features for confining the material.	Unlikely	Marginal	**Low**	Unlikely	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled
Restricted to 2 dredges and 2 nautical mile spacing. The PDT feel this will require coordination but will not be a cost or schedule risk to the project.	Unlikely	Marginal	**Low**	Unlikely	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled
This specialty equipment could add $1/CY for the use of a spill barge in NP1-6.	Possible	Marginal	**Low**	Possible	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled

The non-Federal sponsor (NFS) is required to furnish all Lands, Easements, Rights-of-way, Relocations, and Disposal areas (LERRDs) for the proposed cost-shared project. All placement areas for maintenance material placement are in place.	Unlikely	Marginal	**Low**	Unlikely	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled
Based on available information, approximately 16 pipeline relocations are assumed. Original report indicated there were 22 pipelines. The estimate includes a lump sum cost. Potential to find additional pipelines and/or deeper depths. Unknowns always exist when dealing with underground utilities.	Likely	Moderate	**Medium**	Possible	Moderate	**Medium**	Triangular	Triangular
There's the possibility of some shipwrecks on the site but none of historical or cultural reference.	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
No beach disposal would be allowed during nesting time. (APR 1 to SEP 15) . There is no beach disposal on this project. Sea turtle avoidance measures would include an avoidance plan for hopper dredge impacts to sea turtles. Sundown Island has a restricted timeframe of Nov-December. The PDT feels coordination can be done with other agencies and either allow work outside the window or schedule work in the 2 month work window. Manatees are possible but not normally this far South. The last sighting was decades ago. Risk very low.	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled

Site used to be a bombing range in the late 40's. No ordinance has been encountered since the construction of the original Ship Channel in the 60's. Any UXO's would be on barrier island and not an issue for this project.	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
Sundown island is closed from 1 Marc - 31 Aug but lately the Audubon Society has asked that work be complete before mid-January because birds start scouting the island. PDT feels additional wildlife work windows is unlikely and a low risk. Work can be scheduled to avoid impacts during Turtle window (mid Nov-mid March typically).	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
This risk could be eliminated during the design phase. This could decrease the project cost due to less required dredging. Less dredging would also decrease the project schedule.	Unlikely	Negligible	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
Oyster survey based on 1985 survey and 130 AC may change based on new survey data.	Likely	Marginal	**Medium**	Possible	Negligible	**Low**	Triangular	N/A -Not Modeled
In attainment zone and do not foresee having any issue with EPA.	Unlikely	Marginal	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled

The only contamination that is anticipated is in the area of the Alcoa docks and is not part of the shipping channel project. Sediment testing has been done and no contamination was present except near the plant and these were below the threshold value. Current sediment sampling indicates this is a very low risk but if it occurred it could be a moderate cost. The PAP1 disposal site would require real estate, constructing the site, and additional dredging costs. The PDT feels this an unlikley risk for the project but has moderate cost risks. If there was an oil spill that occurred during construction it could lead to additional disposal costs.	Unlikely	Moderate	**Low**	Unlikely	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled
Technical complexities and site conditions could result in increased risk of contract modifications. Will impact costs, but little overall impact to larger project timeline.	Very Likely	Significant	**High**	Possible	Negligible	**Low**	Uniform	N/A -Not Modeled
Gulf region labor rates are fairly low when compared to national rates. Busy economy may require paying extra for skilled labor. Estimate labor conservative and typically higher than actual costs.	Unlikely	Marginal	**Low**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
Disposal pipe would have to be broken during the day to allow for ship passage. EWT accounted for in CEDEP estimate and is based on historical productivity. Additional cost and schedule risks are minimal. A ship accident or oil spill within the channel could lead to standby costs and schedule delays.	Possible	Marginal	**Low**	Possible	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled

Entrance channel is all sand and inside the Bay is a high percentage of sand. Stiff clay/Silt in turning basin. Boring depths do not go down to full depth and there is an additional 9' of depth that could be stiff clay (approximately 50% of the volume). The pump distance is short but could add up to $2/cy.	Possible	Marginal	**Low**	Possible	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled
PDT feels this is not likely to be an issue. There is always a chance of a disaster response that would occupy the available dredge fleet. Historically this has not been a problem.	Unlikely	Marginal	**Low**	Likely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
Material types affect dredging efficiency which drives the costs. Limited Geotechnical data of the dredged material may result in encountering unanticipated materials that could be more difficult to dredge that would impact productivity.	Likely	Marginal	**Medium**	Possible	Moderate	**Medium**	Triangular	Triangular
Environmental group provided lump sum mitigation pricing that is scaled from historical data. Estimate updated in March 2019 and includes breakdown of pricing for 129 acres of oyster reef pad construction.	Very Likely	Marginal	**Medium**	Unlikely	Negligible	**Low**	Triangular	N/A -Not Modeled

Relocation costs based on historical costs from 2009. Actual costs may vary from escalated price included in estimate. CSI items are included but do not include contractor markups. Lump sum pricing scaled from original estimate of 22 pipeline relocations to an assumed 16 relocations. Relocations based on land based equipment and may need to be barge mounted. Barge mounted directional drilling cost may be higher than the estimated costs. Relocations need to be completed prior to work and could delay the contract. May require divers. Scope and method of construction is not defined and costs likely change.	Very Likely	Marginal	**Medium**	Unlikely	Negligible	**Low**	Triangular	N/A -Not Modeled
10% bond rate is included for the prime subcontractor and may be overstated.	Very Likely	Marginal	**Medium**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
Labor/equipment pricing is outdated and could be underestimated.	Very Likely	Marginal	**Medium**	Unlikely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
Estimate assumes 4 separate contracts. The current schedule has 5 separate contracts and still includes PAP1. The construction schedule needs to be updated to the latest plan. Total dredging time, based on quantities, is 66 months. Schedule likely to change.	Unlikely	Marginal	**Low**	Likely	Marginal	**Medium**	N/A -Not Modeled	Triangular
The use of a specialty spill barge could affect dredge efficiency. Estimate includes $0.50/Cy but actual cost could increase.	Possible	Moderate	**Medium**	Possible	Marginal	**Low**	Triangular	Triangular

Storms/hurricanes could limit number of dredges available close to project site during performance period, increasing distance to mobilize. Contractor would have to demobilize in case of a hurricane. This would increase the cost and delay the project. Storms could bring additional dredging quantities.	Likely	Negligible	**Low**	Likely	Negligible	**Low**	N/A -Not Modeled	N/A -Not Modeled
Fuel could increase or decrease altering the cost. We assume an increase of $1.40 or a decrease of $0.60 based price fluctuation in the past years. Estimate assumes $3/gallon and is conservative.	Likely	Significant	**High**	Unlikely	Negligible	**Low**	Triangular	N/A -Not Modeled
There is concern in needing more dredges to complete dredging in a required timeframe. Dredges must be spaced a minimum distance, as per USCG (2 nautical miles). PDT feels this is not likely to be an issue. There is always a chance of a disaster response that would occupy the available dredge fleet. Historically this has not been a problem.	Unlikely	Moderate	**Low**	Possible	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled
Project is for 2020-2023 and inflation could exceed CWCCIS tables. Since this is dredging the risks for fuel and labor have already been accounted and therefore this risk is not modeled.	Possible	Marginal	**Low**	Unlikely	Marginal	**Low**	N/A -Not Modeled	N/A -Not Modeled