APPENDIX A
ENGINEERING

FINAL REPORT

MOBILE HARBOR, MOBILE, ALABAMA

Integrated General Reevaluation Report
With Supplemental Environmental Impact Statement

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SECTION 1. INTRODUCTION

The purpose of this appendix is to present the results of the engineering studies, investigations, modeling, and analyses conducted to develop the recommended project improvements for the Bar Channel, Bay Channel, Choctaw Pass Turning Basin, and a portion of the River Channel of the Mobile Harbor Federal Navigation Project. Engineering evaluations were performed for channel deepening and widening measures up to the fully authorized dimensions of the three channel segments. The turning basin was also evaluated to determine its adequacy in accommodating the selected design vessel(s). Detailed efforts included (1) a geotechnical investigation to characterize the subsurface conditions; (2) hydrodynamic, water quality, sediment transport, and groundwater modeling to characterize the physical conditions and processes of the study area and determine the relative changes due to widening and deepening the navigation channel; (3) a vessel generated wave energy assessment to quantify the relative changes in wave energy due to vessels calling the port in the future, with and without the proposed channel modifications; (4) a feasibility level ship simulation study to evaluate channel width for one-way traffic, turning basin dimensions, bend easing widths, and lengths and widths for a portion of the channel for two-way traffic; and (5) cost estimating to identify the total project costs for all alternatives considered. The details of these efforts and other supplementary engineering assessments are discussed in this appendix.

1.1. Project Area Description

A visualization of the overall Mobile Harbor Federal Navigation Project, including the existing and authorized dimensions, is shown in Figure 1-1. Further descriptions of the various Mobile Harbor Channel segments evaluated as part of this study are provided in the following paragraphs. The study did not evaluate modifications to the upper approximately 4.3 miles of the River Channel (i.e., north of station 226+16) because that portion of the channel is already constructed to its fully authorized dimensions.

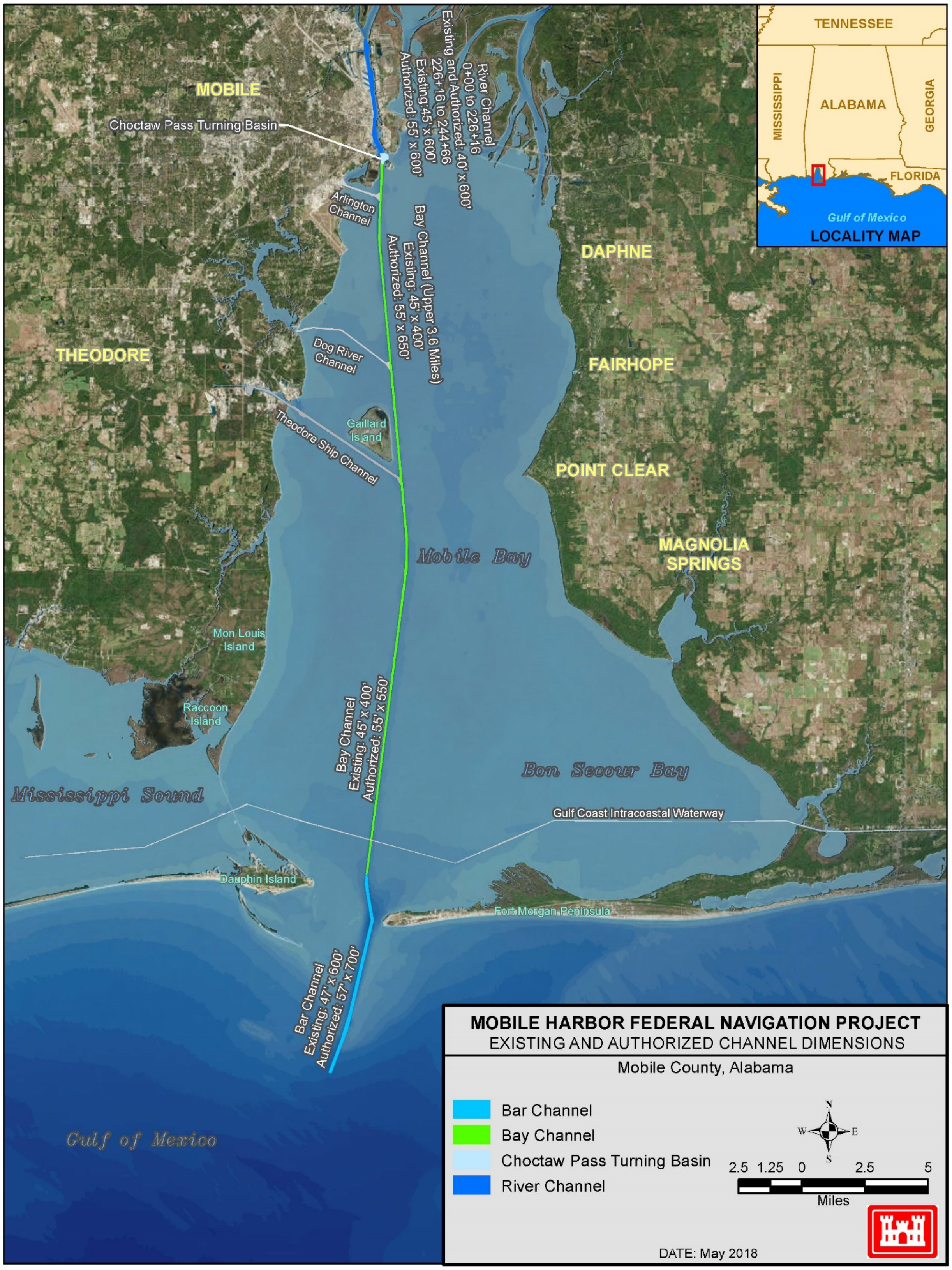


Figure 1-1. Mobile Harbor Federal Navigation Project Limits and Dimensions

1.1.1. Bar Channel

The Bar Channel is currently 47 feet deep by 600 feet wide for a length of approximately 8.1 miles across the Mobile Outer Bar, from the Gulf of Mexico through the double channel bends in Mobile Pass to the southern extents of the Bay Channel. The authorized dimensions of this channel segment, per Section 201 of the Water Resources Development Act (WRDA) of 1986, Public Law (PL) 99-662, are 57 feet deep by 700 feet wide. Construction to the current depth was completed in 1990. The channel stationing for the Bar Channel is 1760+10 to 2189+59. This channel segment includes three bends and a sediment trap feature. The bends (and associated wideners) are located at stations 1775+43, 1854+69, and 2089+54 and the sediment trap (47 feet deep by 100 feet wide resulting in a channel width of 700 feet) is located from station 2029+60 to 2149+60. The Bar Channel alignment and stationing are shown in Figure 1-2 along with the locations of the Sand Island Beneficial Use Area (SIBUA), the SIBUA Northwest Extension, and the Ocean Dredge Material Disposal Site (ODMDS). SIBUA and the Northwest Extension are currently used for placement of material dredged as part of routine maintenance of the Bar Channel (predominately sandy material). The ODMDS has been used historically for the placement of material dredged from the Bay Channel (predominantly fine grained silts and clays).

1.1.2. Bay Channel

The Bay Channel is currently 45 feet deep by 400 feet wide for a length of approximately 28.7 miles from the northern end of the Bar Channel through Mobile Bay to the mouth of Mobile River. The authorized dimensions of this channel segment, per Section 201 of WRDA 1986, PL 99-662, are 55 feet deep by 550 feet wide, except for the upper 3.6 miles which are authorized to 650 feet. Construction to the current depth was completed in 1990. The channel stationing for the Bay Channel is 244+66 to 1760+10. This channel segment includes a turning basin feature (i.e., the Choctaw Pass Turning Basin as described in the following paragraph) and three bends (and associated wideners). The turning basin is located between stations 244+66 and 273+21 and the bends (and associated wideners) are located at stations 423+47, 1055+43, and 1115+68. The Bay Channel alignment and stationing are shown in Figure 1-3 along with the locations of the open water dredged material placement areas in Mobile Bay. These areas (1E – 29E, 2W – 6W, and 14W – 29W) are used for placement of material dredged as part of routine maintenance of the Bay Channel (predominately fine grained silts and clays).

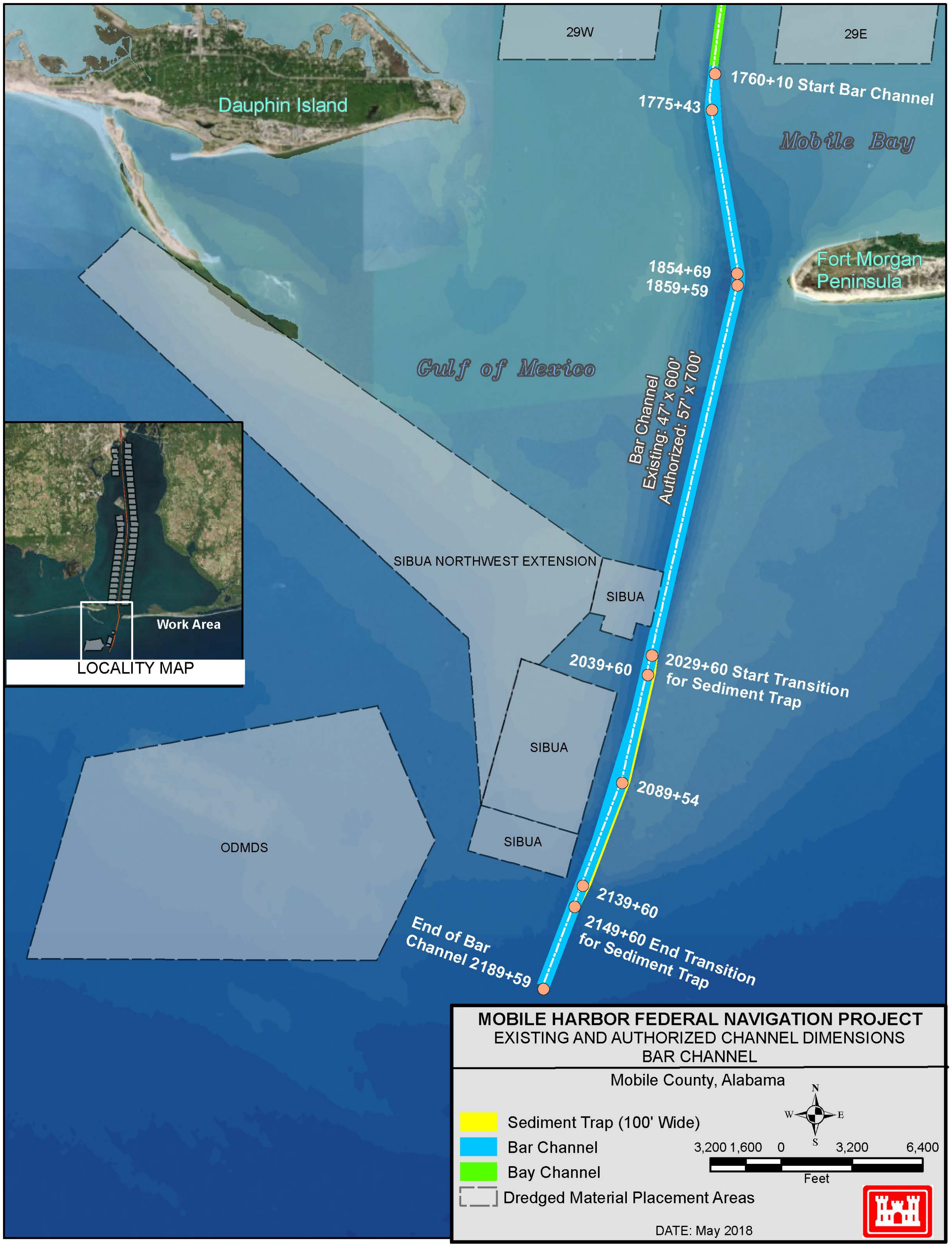


Figure 1-2. Bar Channel Alignment and Stationing

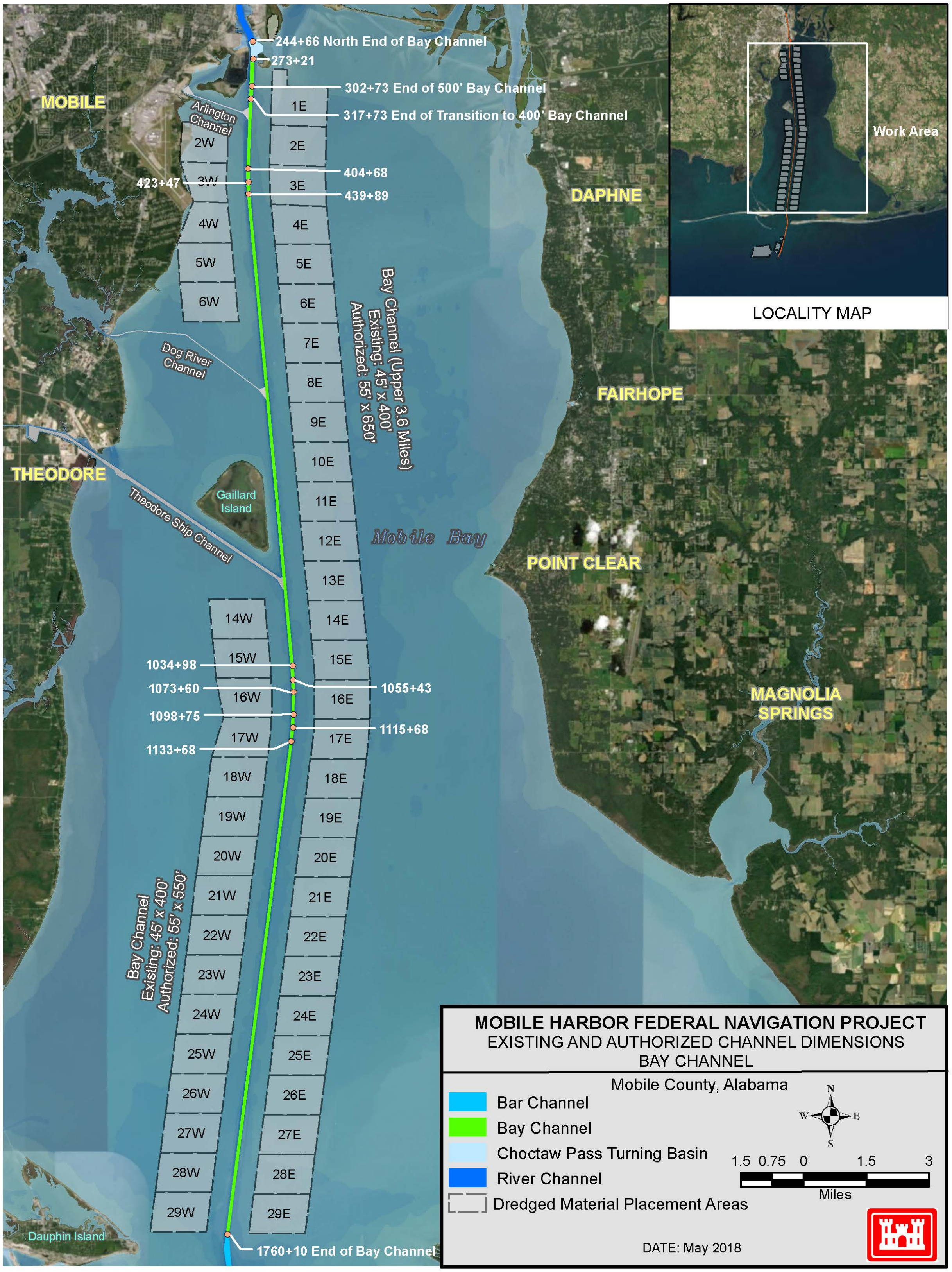


Figure 1-3. Bay Channel Alignment and Stationing

1.1.3. Choctaw Pass Turning Basin

The Choctaw Pass Turning Basin is currently 45 feet deep by approximately 1,570 feet long (including the 400-foot width of the existing Bay Channel) by 715 feet wide at its easternmost extent. Additionally, it contains a 100-foot widener/transition section about 3,500 feet in length along the eastern edge of the existing Bay Channel immediately south of the basin to improve basin access, reduce the basin size needed for turning, and increase vessel maneuverability. The authorized dimensions of the turning basin, per Section 201 of WRDA 1986, PL 99-662, were 40 feet deep by 1,500 feet square, located opposite to the McDuffie Coal Terminal; however, it was not constructed with the other project improvements during the late 1980s/early 1990s at the request of the non-Federal sponsor (NFS) (i.e., the Alabama State Port Authority (ASPA)). A General Reevaluation Report (GRR) was later prepared (in May 2007), per the ASPA's request, to re-evaluate the turning basin. The 2007 GRR recommended the turning basin be moved north to Choctaw Pass and deepened to 45 feet to match the adjacent channel dimensions. Construction to the recommended dimensions was completed in 2011. The turning basin is located between stations 244+66 and 273+21 and the widener/transition along the eastern edge of the existing Bay Channel is located between stations 273+21 and 317+73. The turning basin alignment and stationing are shown in Figure 1-4.

1.1.4. River Channel

The River Channel is currently 40 feet deep by 600 feet wide for a length of approximately 4.3 miles from the Cochrane-Africatown Bridge at the northern end of the harbor, over the Bankhead and Wallace Tunnels, to an area just upstream of the APM container terminal near the southern extents of the harbor. The channel then transitions to 45 feet deep by 600 feet wide for a length of approximately 1,850 feet, terminating at the northern end of the Bay Channel and Choctaw Pass Turning Basin. The upper (i.e., northern) approximately 4.3 miles of the channel, including the turning basins contained within this section, are currently constructed to the authorized dimensions due to depth and width limitations from the two tunnels that run underneath and the surrounding harbor infrastructure; therefore, modifications to this portion of the channel were not evaluated as part of this study. The authorized dimensions of the lower (i.e., southern) approximately 1,850 feet, per Section 201 of WRDA 1986, PL 99-662, are 55 feet deep by 600 feet wide. Construction of the lower 1,850 feet to the 45-foot depth was completed in 2008. The channel stationing for the upper (i.e., 40-foot deep) portion of the River Channel is 0+00 (at the Cochrane-Africatown Bridge) to 226+16 and the stationing for the lower (45-foot deep) portion is 226+16 to 244+66. The River Channel alignment and stationing are shown in Figure 1-5 along with the upland dredged material placement sites at Blakeley and Pinto Islands. These sites are used for the disposal of fine-grained material dredged as part of the routine maintenance of the River Channel.

Figure 1-4. Choctaw Pass Turning Basin Alignment and Stationing

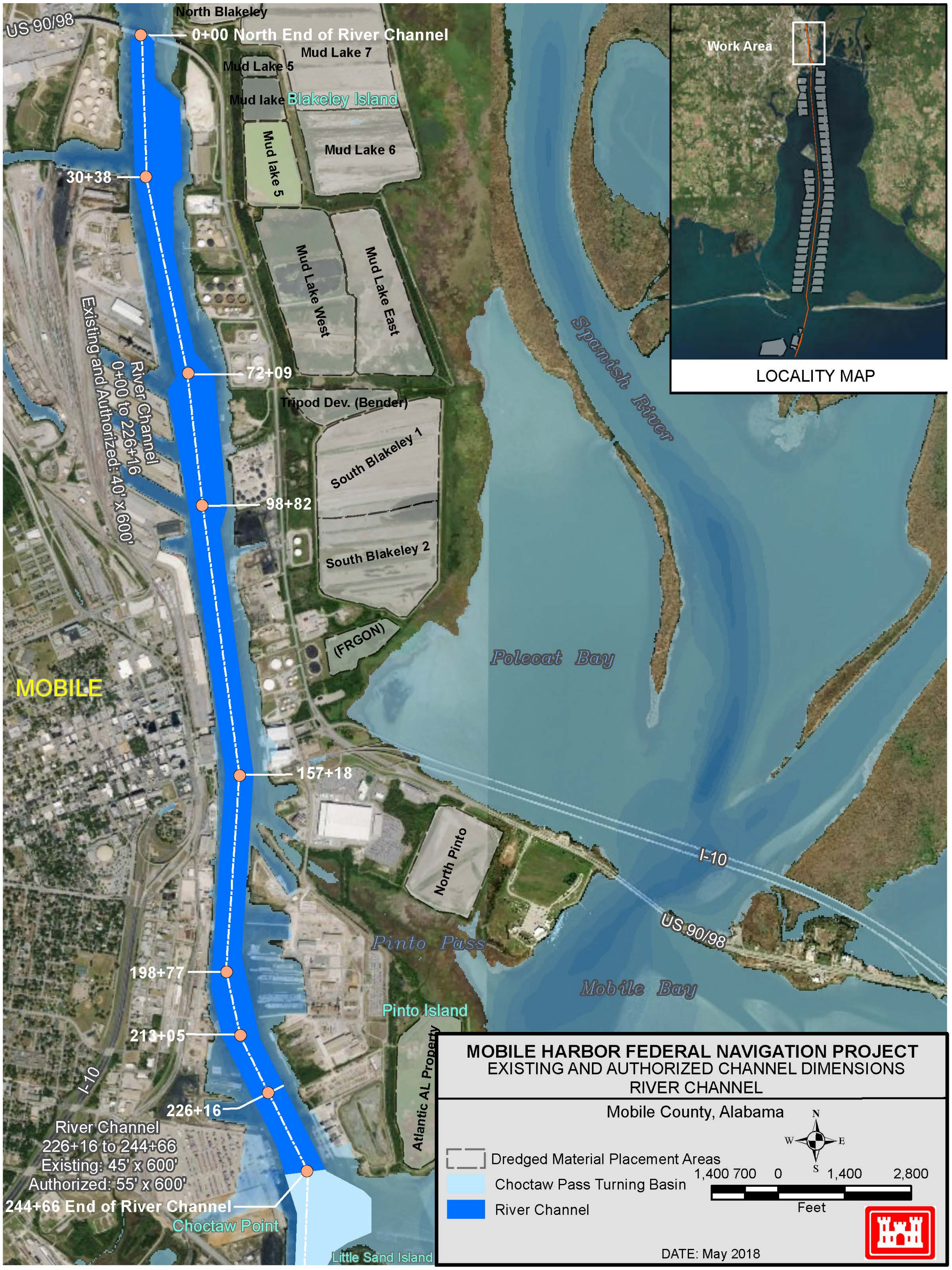
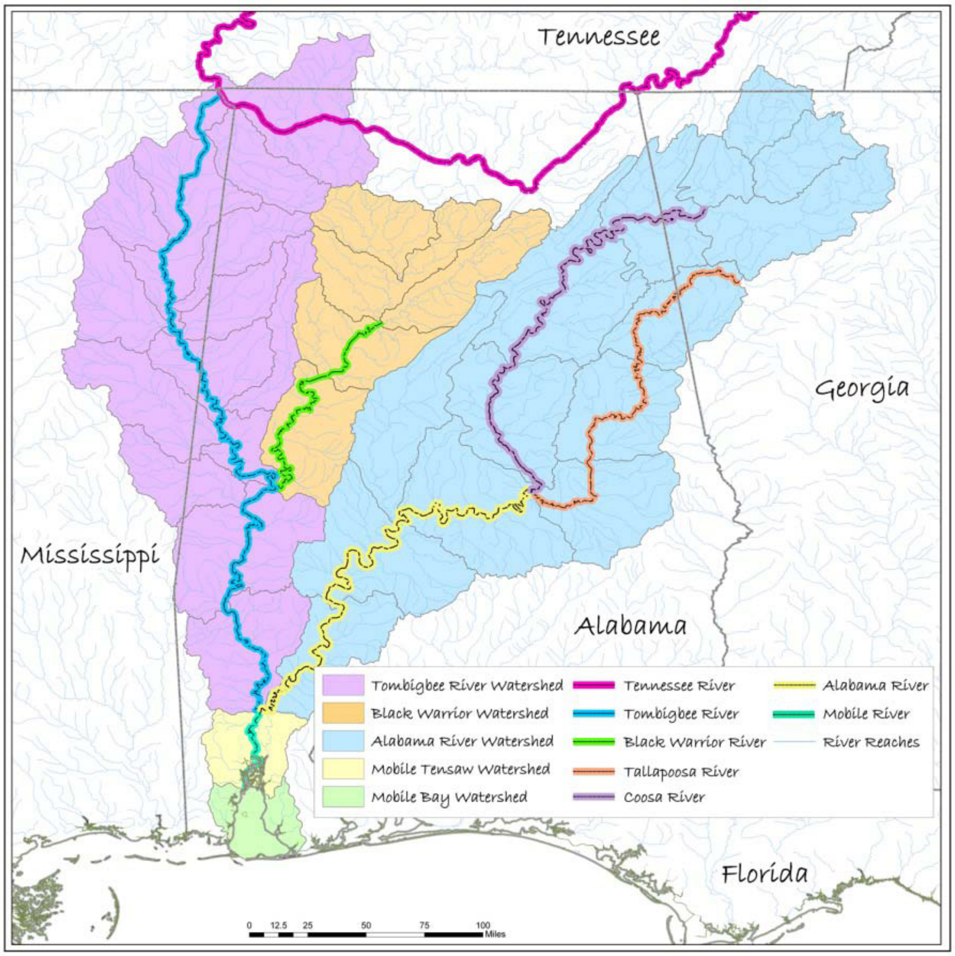


Figure 1-5. River Channel Alignment and Stationing

SECTION 2. PHYSICAL CONDITIONS

Mobile Harbor is a Federally authorized Navigation Project located on the south coast of Alabama (see Figure 1-1). It provides a deep draft channel through Mobile Pass and Bay that connects the Alabama, Tombigbee, and Mobile Rivers to the Gulf of Mexico. Mobile Bay measures about 31 miles in length; not including the Mobile-Tensaw River Delta, which extends northward from Mobile Bay to the confluence of the Alabama and Tombigbee Rivers. Mobile Bay is the terminus of the Mobile-Tensaw River System (see Figure 2-1), the Nation's sixth largest river system in terms of total discharge area and the fourth largest in terms of discharge (Isphording and Flowers, 1987). The width of the bay varies from approximately 8 miles at its northern end to 20 miles in its lower portion with an average depth of 10 feet (excluding the navigation channels) and a maximum of about 60 feet off Fort Morgan near the Gulf entrance to the bay. It has a surface area of more than 390 square miles, and a volume of 122 billion cubic feet (Jarrell, 1981).



Source: Northern Gulf Institute (2010)

Figure 2-1. Mobile Basin Watershed 8-digit Hydrologic Unit Codes (HUCs) Delineation

2.1. Climate

The climate in the project area is subtropical, characterized by warm summers and short, mild winters. The average daily temperature ranges in the summer and winter are 81– 91 and 42– 63 degrees Fahrenheit (°F), respectively. The average annual rainfall is about 66 inches and is well distributed throughout the year. Precipitation records indicate July as the wettest month, while October is the driest. The National Climatic Data Center climate summary for Mobile is shown on Table 2-1.

Table 2-1. Climate Summary, Mobile Regional Airport, Alabama (Station No. 015478)

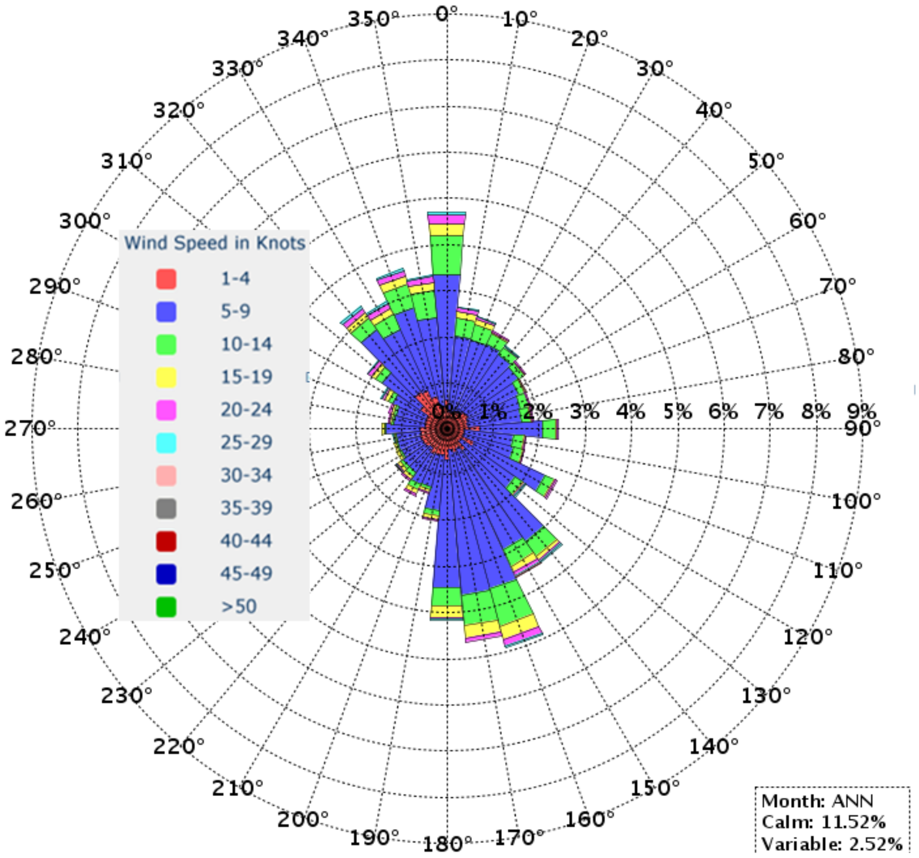
Period of Record: 01/01/1948 to 6/10/2016													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (°F)	60.9	64.2	70.6	77.9	84.7	90.0	91.0	90.7	86.8	79.3	69.8	63.0	77.4
Average Min. Temperature (°F)	40.8	43.5	49.6	56.7	64.4	70.7	73.0	72.6	68.5	57.4	48.1	42.9	57.3
Average Total Precipitation (in.)	4.99	5.21	6.50	5.03	5.54	5.30	7.51	6.96	5.99	2.93	4.15	5.43	65.56
Average Total Snow Fall (in.)	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4
Average Snow Depth (in.)	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Southeast Regional Climate Center.

2.2. Winds

Prevailing winds for the Alabama coast are produced by two pressure ridges which dominate weather conditions: the Bermuda High, centered over the Bermuda-Azores area of the Atlantic and the Mexican Heat Low centered over Texas during warm months. Prevailing winds are predominately from the east and south east during spring and summer months, and from the north and north east during fall and winter months. The strongest winds are recorded in February and March with the exception of frontal storms and tropical systems.

Wind data are readily available from the U.S. Air Force's 14th Weather Squadron. The nearest location for which the 14th publishes data is Brookley Field (a.k.a. "Downtown") Alabama. In many instances, for lack of local long-term records elsewhere, wind data obtained at Brookley Field in Mobile, Alabama has been adapted by the USACE, Mobile District for some coastal and navigation channel investigation design tasks. A graphical representation of the wind regime in the area (i.e., wind rose data) is shown in Figure 2-2. The data shows wind speeds rarely exceed 25 knots.



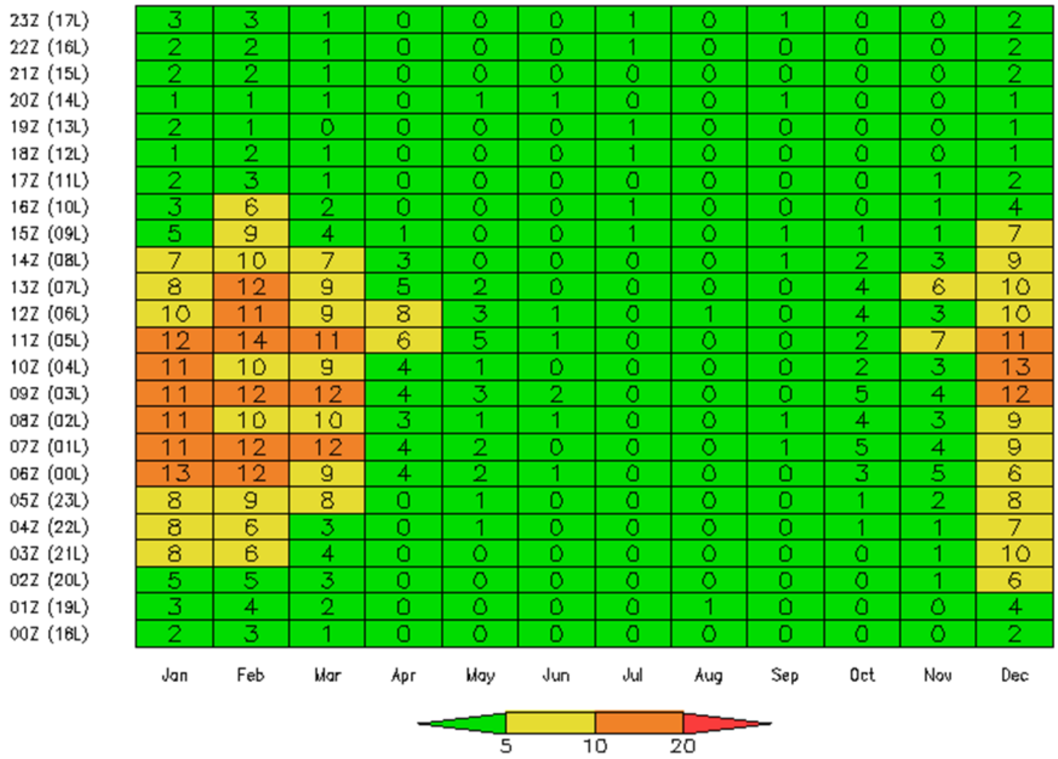
Source: 14 Weather Squadron, USAF.

Figure 2-2. Wind Rose Data at Brookley Field, Mobile, AL

2.3. Visibility

A visibility chart (the format shown is referred to as "stoplight charts") for Mobile, Alabama is presented in Figure 2-3. Visibility equal to or less than one mile is apt to trigger navigation restrictions for nearly all commercial vessels transiting the navigation channel. The charts show the percent of time during each hour of the day for a given month that visibility is less than or equal to one statute mile (5,280 feet). Time is given in Greenwich

(‘Zulu, e.g. 20Z being 8:00 pm Greenwich) and local (e.g. 05L being 5:00 a.m.) formats. The displays suggest visibility of less than one mile might be expected about 10 percent of evenings and mornings during the winter months.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
23Z (17L)	3	3	1	0	0	0	1	0	1	0	0	2
22Z (16L)	2	2	1	0	0	0	1	0	0	0	0	2
21Z (15L)	2	2	1	0	0	0	0	0	0	0	0	2
20Z (14L)	1	1	1	0	1	1	0	0	1	0	0	1
19Z (13L)	2	1	0	0	0	0	1	0	0	0	0	1
18Z (12L)	1	2	1	0	0	0	1	0	0	0	0	1
17Z (11L)	2	3	1	0	0	0	0	0	0	0	1	2
16Z (10L)	3	6	2	0	0	0	1	0	0	0	1	4
15Z (09L)	5	9	4	1	0	0	1	0	1	1	1	7
14Z (08L)	7	10	7	3	0	0	0	0	1	2	3	9
13Z (07L)	8	12	9	5	2	0	0	0	0	4	6	10
12Z (06L)	10	11	9	8	3	1	0	1	0	4	3	10
11Z (05L)	12	14	11	6	5	1	0	0	0	2	7	11
10Z (04L)	11	10	9	4	1	0	0	0	0	2	3	13
09Z (03L)	11	12	12	4	3	2	0	0	0	5	4	12
08Z (02L)	11	10	10	3	1	1	0	0	1	4	3	9
07Z (01L)	11	12	12	4	2	0	0	0	1	5	4	9
06Z (00L)	13	12	9	4	2	1	0	0	0	3	5	6
05Z (23L)	8	9	8	0	1	0	0	0	0	1	2	8
04Z (22L)	8	6	3	0	1	0	0	0	0	1	1	7
03Z (21L)	8	6	4	0	0	0	0	0	0	0	1	10
02Z (20L)	5	5	3	0	0	0	0	0	0	0	1	6
01Z (19L)	3	4	2	0	0	0	0	1	0	0	0	4
00Z (18L)	2	3	1	0	0	0	0	0	0	0	0	2

Source: 14 Weather Squadron, USAF.

Figure 2-3. One Mile Visibility Chart at Brookley Field, Mobile, AL

2.4. Tides

The tidal variation in the Mobile Bay and adjacent waters is diurnal with an average tide cycle of 24.8 hours. The mean tidal range within the bay varies from 1.6 feet at the head of the bay to 1.2 feet at the entrance, which is classified as microtidal. The daily mean water elevation averaged by month increases for half the year and then decreases over a range that is about the same amplitude as the diurnal range. As seen in Figure 2-4 during the fall, winter, and spring months, water levels frequently fall within a range between 0.5 and 1.0 foot below Mean Lower Low Water (MLLW). This annual cycle of water level is more regular at Mobile than at most U.S. tidal stations (Hands et. al, 1990). Although the tidal range caused by astronomical forces is relatively small winds, pressure gradients and river discharge can induce larger variations. Strong winds blowing from the north can force water out of the bay and result in current velocities of several knots in the passes. The reverse occurs with winds blowing from the southeast, which forces water shoreward toward the Mobile-Tensaw River Delta.

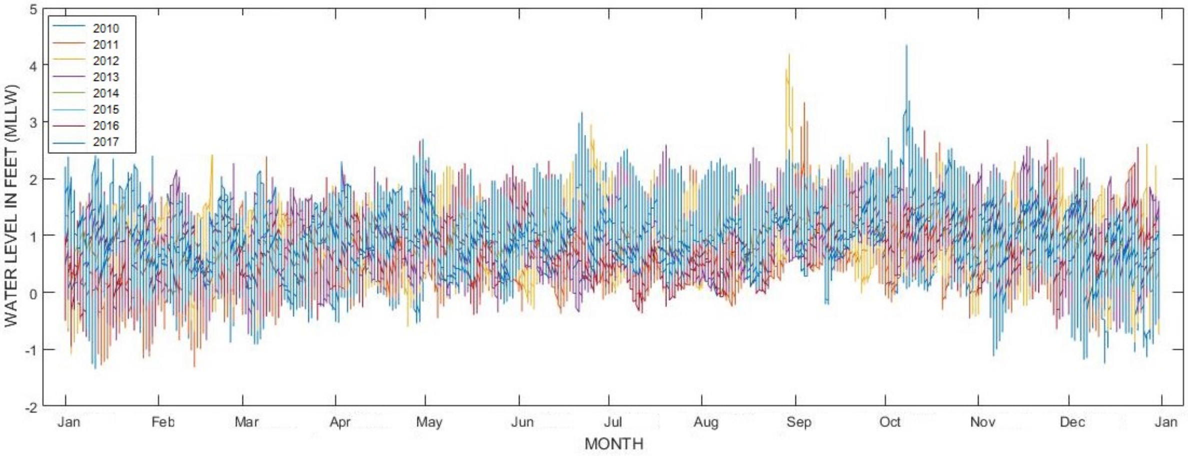


Figure 2-4. Hourly Water Levels 2010-2017, 08735180 Dauphin Island, AL

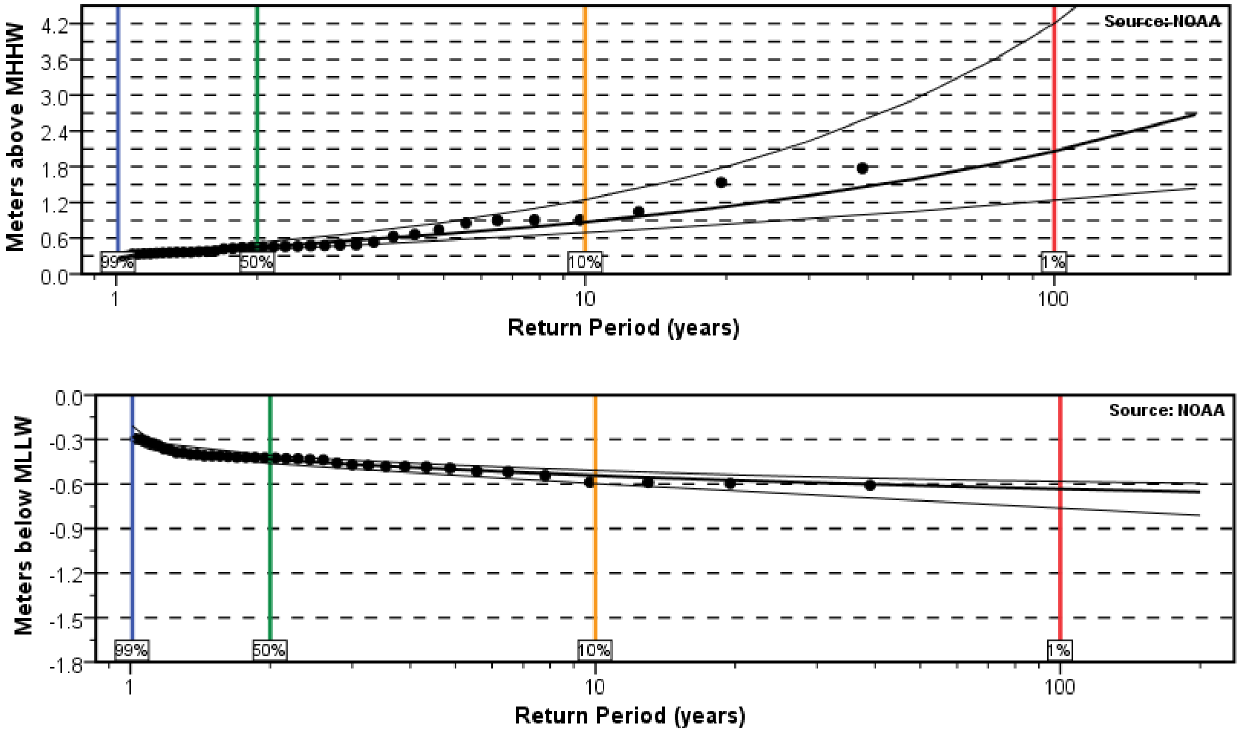
The nearest long-term tide gage is at Dauphin Island, Alabama. The top 10 storm surge values obtained at Dauphin Island (gage 8735180, period of record 1966 to 2017) are shown in Table 2-2. Annual exceedance probability curves with 95% confidence intervals shown below in Figure 2-5 indicate the highest and lowest water levels as a function of return period in years. The dots indicate the annual highest or lowest water levels after the Mean Sea Level trend was removed. The levels are in meters relative to the Mean Higher High Water (MHHW) or MLLW datum, established by CO-OPS (1 foot = 0.3 meters). The conversion to MLLW datum for this tide gage from the 1983 to 2001 epoch, is MLLW = -1.2 feet MHHW.

The exceedance probability curves were calculated by National Oceanic and Atmospheric Administration (NOAA) using the Extremes Toolkit software package which fits the three parameters of the Generalized Extreme Value (GEV) probability distribution function to annual maximum or annual minimum data using an iterative maximum likelihood estimation. The spread of the 95% confidence intervals depends on the variability of the source data and the length of the series used. The level of confidence in the exceedance probability level decreases with longer return periods and should always be used in conjunction with the confidence interval in the application of these data (NOAA, 2018).

Table 2-2. Ten Highest Water Levels, 08735180 Dauphin Island, AL (1966 to 2017)

Tropical Storm	Date	Elevation in feet above MHHW
Ivan	9/16/2004	5.94
Katrina	8/29/2005	5.17
Elena	9/2/1985	3.36
Ike	9/11/2008	3.13
Isaac	8/29/2012	3.08
Opal	10/4/1995	2.98
Isadore	9/26/2002	2.9
Camille	8/18/1969	2.75
Dennis	9/23/2005	2.72
Georges	11/10/2009	2.6

Source: NOAA/Center for Operational Oceanographic Products and Services



Source: NOAA/Center for Operational Oceanographic Products and Services

Figure 2-5. Annual Exceedance Probability Curves, 8735180 Dauphin Island, AL

2.5. Waves

Hindcast wave data is available through the Wave Information Study (WIS) off the coast of Alabama. Figure 2-6 shows the location and Figure 2-7 the wave rose for WIS Station 731513 selected due to its proximity to the Mobile Harbor Entrance (Bar)

Channel. The WIS hindcast data is provided at 1-hour intervals over the 34-year time period (1980-2014). It includes significant wave height H_s, peak period T_p, and peak direction θ_p. The θ_p represents the dominant wave direction for wave energy within the frequency band of peak energy. Wave directions in degrees are directions from which the waves are traveling, the same as meteorological conventions. In addition to WIS Station 73153, analysis of data from Mobile Bay Real-time Continuous Environmental Monitoring at Middle Bay Lighthouse and aquadopp data collected in 2016 at were made to determine potential significance of wind generated waves within the bay.

In general, wave intensity along coastal Alabama is low to moderate. For WIS 73153, the common wave direction is out of the southeast between 112.5 and 180 degrees. The most common peak wave periods fall between a range of 4 to 5 seconds, with an overall mean wave period of 4.9 seconds. Significant wave heights range from 0 to 16 feet, with the most common wave heights being less than 3 feet. Overall mean significant wave height is 2 feet.

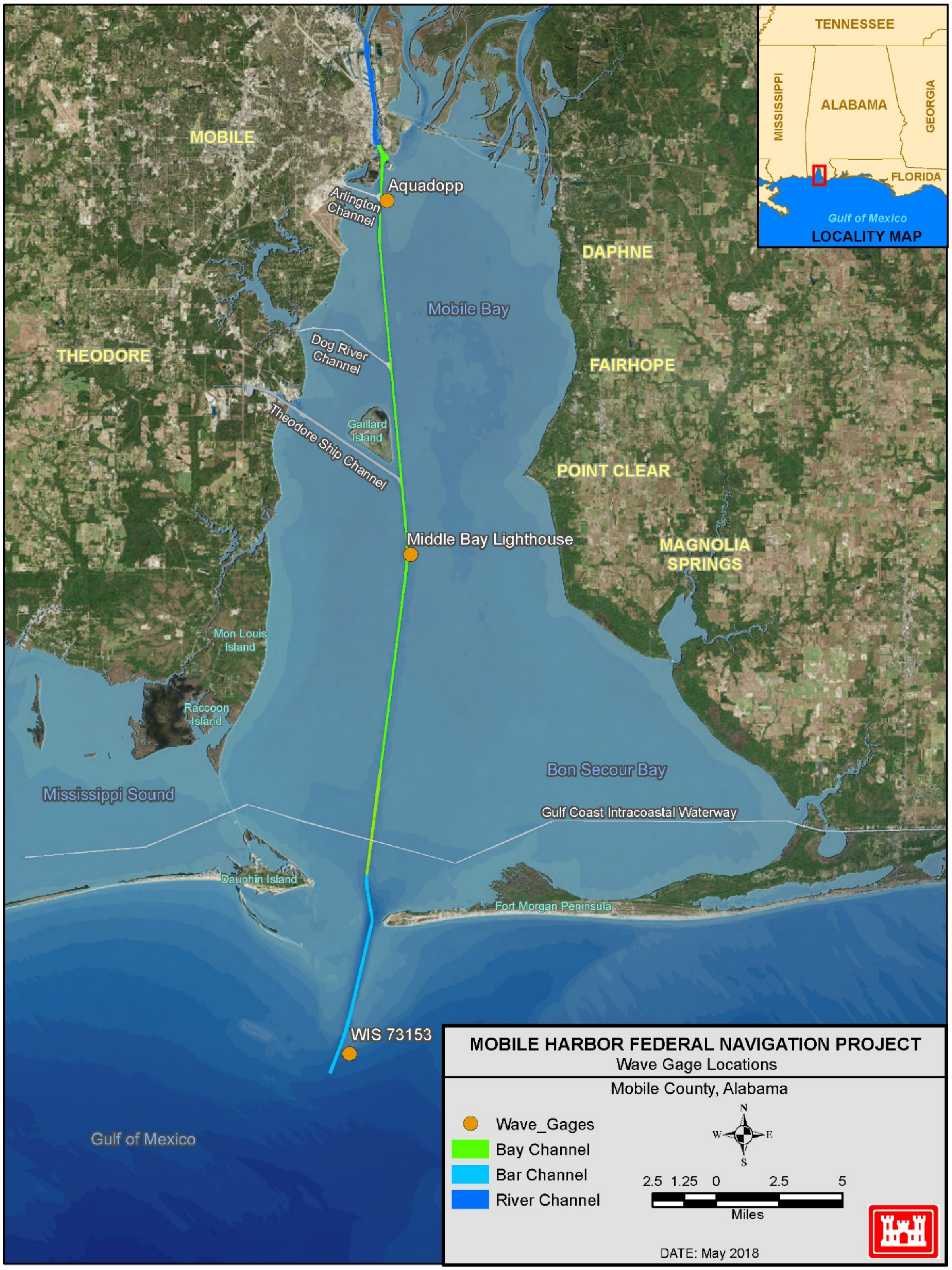


Figure 2-6. Wave Gage Locations

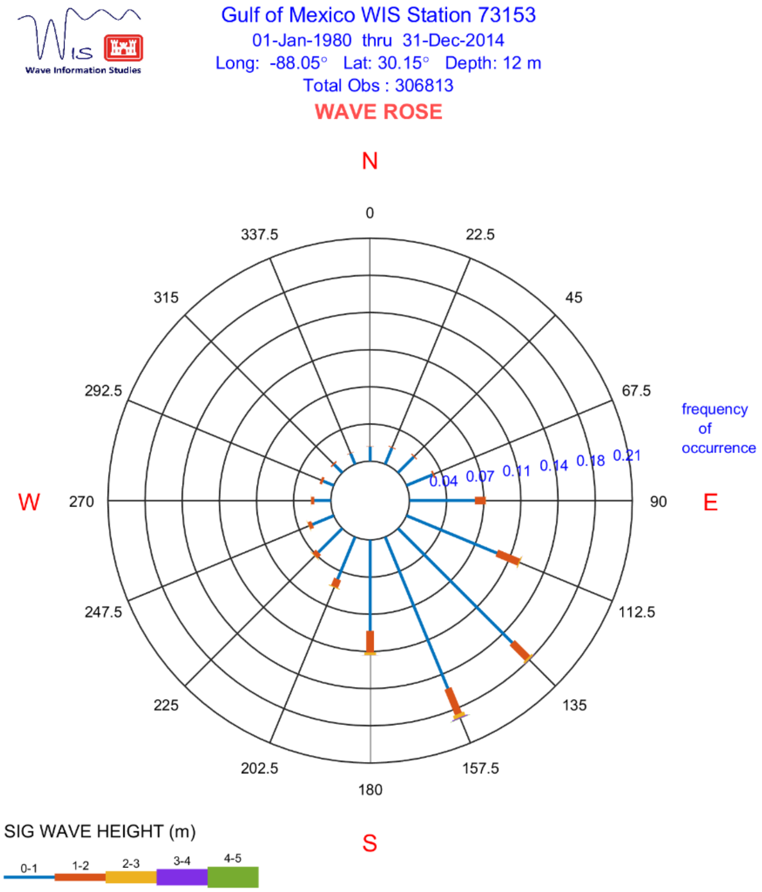


Figure 2-7. Wave Rose, WIS Station 73153

Wind induced waves within the bay are fetch and depth limited. Limited wave data collected at the Middle Bay Lighthouse as part of the Mobile Bay Real-time Continuous Environmental Monitoring in 2013, 2014, and 2016, as well as 2016 aquadopp data collected in the upper bay, indicate average significant wave heights generally less than 1.5 feet. Overall mean peak periods are less than four seconds; however, hurricane and storm conditions, and strong winter cold fronts can produce significant surges and much larger wave conditions within the bay and along the coastline. Zhao et. al, 2008 report 100-year return period maximum significant wave heights between approximately 8 and 10 feet, with maximum wave heights near the shoreline of approximately 5 feet. The maximum wave heights with the longest period occur near the bay entrance where they are influenced by swell from the Gulf of Mexico.

2.6. Currents

Tidal movement and freshwater discharge are the two most important factors that affect currents in Mobile Bay (Moser and Chermock, 1978). When the rate of freshwater discharge from the Mobile-Tensaw River System is high, flood tide velocity slows and ebb tide velocity increases. The reverse is true when freshwater discharge is low (Hummell, 1990). Tidal currents in the shallow part of the bay are typically less than 1 feet/second but are much higher in the navigation channels. Near the bay entrance, the maximum tidal currents occur with a magnitude up to 5 feet per second on both flood and ebb. In the navigation channel at the mouth of Mobile River, the surface currents are about 0.5 feet per second on flood and 2.5 feet per second on ebb. These velocities increase when river, wind and/or tide conditions align. There is also variation in current velocities with respect to depth, giving an increase on channel bottom in flood and a decrease in the channel bottom on ebb. The currents are fairly aligned with the channel. Exceptions to this relationship are in the north part of Mobile Bay in the vicinity of Choctaw Pass, Little Sand Island, and the Arlington Channel junction. Other regions in the navigation channel, where currents do not tend to align with the channel include the lower bay segment in the vicinity of Pass Aux Herons and the entrance to the bay.

Hydrodynamic modeling performed by the Engineer Research and Development Center (ERDC) is documented in Attachment A – 1 of this appendix. Results of the analysis show a negligible change in currents within and near the navigation channel for the alternatives investigated.

2.7. Freshwater Inflows

Freshwater inflow to Mobile Bay is dominated by the Alabama and Tombigbee Rivers, which account for 95% of the total flow (Schroeder, 1978). Marr (2013) computed long-term daily maximum, mean, and minimum cumulative inflow using U.S. Geological Survey (USGS) discharge records for the Alabama River at Claiborne Lock and Dam (USGS ID: 02428400) and the Tombigbee River at Coffeeville Lock and Dam (USGS ID: 02469761) using the respective length of record at each, resulting in 238,000 cubic feet per second (cfs) (maximum), 60,500 cfs (mean), and 8,700 cfs (minimum). In a similar methodology, freshwater inflow from the Mobile River Watershed was delineated by seasonal trends using a 35-year record (1976-2011) resulting in a mean daily discharge of 93,800 cfs in late winter to early spring and 28,800 cfs during late summer to early fall (Dzwonkowski et al., 2014). Alternatively, but equally important, describing freshwater discharge based on the 10 and 90 percent occurrence probability relationships indicate low flow conditions are defined as less than 17,600 cfs and flood conditions when in excess of 247,200 cfs (Schroeder, 1978; Schroeder and Lysinger, 1979). Notably, comparison shows the statistical exceedance for flood conditions is larger than the measured discharge found by Marr 2013 which is likely a result of data availability and processing methods. For the Mobile Harbor GRR these values are of importance when describing the long-term characteristics of the study area; however, numerical analyses were completed based on the 2010 calendar year and attention should be given to this period. Data for the 2010 calendar year were obtained from the USGS at stations 02428400 and 02469761 and the summary statistics and cumulative values are shown in Table 2-3 representing a large range of flows. More detailed summaries of the 2010 data and application to the numerical analysis are described in the ERDC Modeling Report (Attachment A-1).

Table 2-3. Summary Statistics of the 2010 calendar year for the Alabama River at Claiborne Lock and Dam (USGS ID: 02428400) and the Tombigbee River at Coffeeville Lock and Dam (USGS ID: 02469761)

	Alabama River at Claiborne Lock and Dam (USGS ID: 02428400)	Tombigbee River at Coffeeville Lock and Dam (USGS ID: 02469761)	Cumulative
Annual Total (ft^3)	10,120,300	8,818,910	18,939,210
Annual Mean (cfs)	27,730	24,160	51,890
Highest Daily Mean (cfs)	145,000 (16 Mar)	136,000 (10 Feb)	
Lowest Daily Mean (cfs)	2,410 (05 Oct)	1,340 (16 Sep)	
10 percent Exceedance (cfs)	76,900	75,400	152,300
50 percent Exceedance (cfs)	11,400	9,690	21,090
90 percent Exceedance (cfs)	4,560	1,960	6,520

2.8. Salinity Conditions

Salinity distribution in Mobile Bay and the study area is a result of the interaction of freshwater discharge, tides, currents, winds, circulation, evaporation, and bathymetry (Hummell, 1990); however, the most important factor affecting salinity is the fresh-water discharge from the Mobile-Tensaw River System (USACE, 1946 and Chermock and others, 1974). Investigations to determine the salinity line in the Mobile River and its tributaries (1944 through 1946) found that north of Government Street, salinity was affected only slightly by daily tidal variations. The USACE (1946) study, found saltwater intrusion (Chloride > 25 parts per million (ppm)) extended approximately 21 miles upstream from the Cochrane-Africatown Bridge but only lasted a short period of time. Additionally, salinity concentrations were found to be dependent on daily average discharge based on a combined sreamflow on the Tombigbee River at Leroy and Alabama River at Claiborne. Concentrations of chloride at river mile 21 never exceeded 25 parts per million (ppm) when the discharge was less than 10,000 cubic feet per second and when discharge exceeded 50,000 cubic feet per second chloride concentrations did not exceed 12 ppm (equivalent to inland streams) upstream from the confluence of Chickasaw Creek on the Mobile River (USACE, 1946).

In the north end of the bay, flood-tidal waters continue to influence salinity as they are forced eastward by incoming freshwater from the Mobile-Tensaw River System (U.S. Department of the Navy, 1986; and Hummell, 1990). Lowest salinities average 15 parts per thousand (ppt) in the southern part of Mobile Bay and are typically present sometime between January and May, when river discharge and flooding ordinarily occur (Boone, 1973; Schroeder and Lysinger, 1979). During floods, surface salinities can be reduced from 20 ppt to nearly 0 ppt in the southernmost part of the bay (USACE, 1979; Department of the Navy, 1986). The highest salinities average 30 ppt in the southern part of Mobile Bay and are typically found sometime between June and November, when low river discharges normally occur (Bonne, 1973; Schroeder and Lysinger, 1979). Tidal action normally results in a daily north-south shifting of salinity fields, which can range from little or no movement up to 3.7 to 6.2 miles (Schroeder and Lysinger, 1979).

In general average annual bottom salinities are higher than those at the surface (Chermock and others, 1974). During low river discharges, the salinity concentrations of the highly saline lower part and mouth of Mobile Bay approach vertical homogeneity, whereas, during high discharges, salinity concentrations in these areas become stratified (Vittor and Associates, Inc., 1985). Vertical salinity stratification is variable seasonally, becoming more pronounced in late summer and fall (Vittor and Associates, Inc., 1985).

Salinity modeling performed by ERDC is documented in Attachment A – 1 of this appendix. Results of simulations representing the existing/current conditions of the bay indicate similar horizontal and vertical salinity distributions as discussed above.

2.9. Sediment Transport

2.9.1. Riverine

Seven major rivers supply water and sediment to the Mobile-Tensaw River System that ultimately empties into the Mobile-Tensaw River Delta and Mobile Bay. Based on the USGS fluvial sediment sampling on the lower Alabama and Tombigbee Rivers, Isphording et al. (1996) estimated an average fluvial sediment load to the delta of about 4.78 million tons per year (MT/yr). Twenty-five percent of this sediment deposits as delta fill (1.2 MT/yr), resulting in an average discharge of about 3.58 million tons of suspended sediment to the bay each year (Byrnes et al., 2012). Based on long-term deposition trends, Byrnes et al. (2012) estimated that approximately 100,000 cubic yards per year of sediment entered the bay from the Tensaw River; 200,000 cubic yards per year from the Apalachee River/Chacaloochee Bay area; and 350,000 cubic yards per year from the Blakeley River on the east side of the bay. According historic dredge records detailed in section 4.9 Maintenance Dredge Material Quantity, roughly 1.3 million cubic yards per year is deposited and dredged from the lower River Channel annually.

In an effort to help better understand the system and improve the sediment transport modeling of Mobile Bay, remote monitoring stations were installed as part of this GRR study. Data collection was used to help quantify sediment fluxes into the bay from riverine sources and measure the discharge of the primary rivers entering north Mobile Bay. Details of this data collection and analysis can be found within Ramirez, M. et. al (2018) *Draft Mobile Harbor Study Quantifying Sediment Characteristics and Discharges into Mobile Bay*. These stations were equipped with physical samplers, optical turbidity sensors, and acoustic instruments for measuring water velocity and acoustic backscatter, and the long-term datasets were augmented with local, boat-based measurements of the same quantities to calibrate the remote records. The combined datasets were used to derive calibrated, continuous time series of water discharge and suspended sediment concentrations at each of the remote sites shown in Figure 2-8.

Figure 2-8. Mobile-Tensaw River Delta Remote Monitoring Sites

2.9.2. Bay

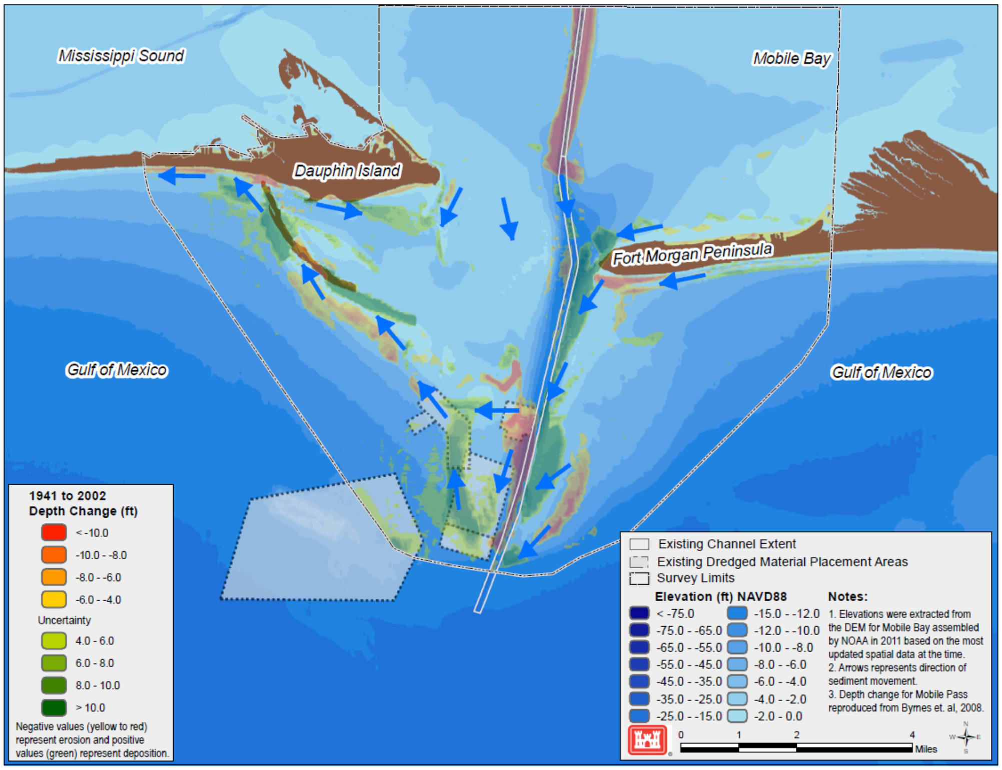
Long-term regional sediment transport patterns within the bay, developed from multiple bathymetric surveys for the periods of 1917–1918, 1984–1987, and 2004–2011are documented in Byrnes et al. (2013) “Sediment Dynamics in Mobile Bay, Alabama: Development of an Operational Sediment Budget” and Byrnes et al. (2017) “Regional Sediment Dynamics in Mobile Bay, Alabama; A Sediment Budget Perspective.” Byrnes et al. (2013 and 2017) found that the most significant changes occurring during the intervals evaluated were associated with deposition in the northern portion of the bay at the mouth of the Mobile-Tensaw River Delta (fluvial sedimentation described in 2.9.1 above); deposition in the southern part of the bay resulting from current flow and sediment movement at Mobile Pass, including sand transport into Mobile Bay along the north side of Mobile Point (Morgan Peninsula); and erosion and deposition associated with navigation channel dredging and placement. Elsewhere in the bay, only minor deposition and erosion patterns were identified within a large estuarine system that is net depositional (Byrnes et. al, 2013). In all the study found that deposition in the bay accounts for approximately 72 percent of sediment input with 28 percent transported from the bay through Pass aux Herons and Mobile Pass through natural transport processes and offshore placement of dredged sediment.

While the rivers dominate sediment input, wind-induced waves and hurricanes have a significant impact on resuspension and redistribution of sediments and shoreline changes in Mobile Bay (e.g. Sapp et al. 1976, van Rijn 1984; Isphording and Imsand 1991; Isphording 2994; Schroeder et al. 1998, Chen et al. 2003, Jung et al. 2004; Zhao et al. 2011, Byrnes et al. 2012). Strong winds associated with tropical cyclones and winter cold fronts impart significant energy on this shallow-water estuarine system, resulting in substantial changes in flow magnitude and sediment resuspension (Isphording, 1994; Schroeder et. al, 1998; Zhao et. al, 2008; Zhao et. al, 2011). Chen et al. (2012) found during hurricanes maximum shear stresses are primarily along the nearshore regions of the bay and near the navigation channel, expecting that these events can have a significant impact on sediment re-suspension in those areas. Using Moderate Resolution Imaging Spectroradiometer (MODIS) red-channel reflectance to estimate suspended sediment concentration (SSC) and three dimensional modeling of sediment dynamics in the Mobile Bay, Zhao et. al (2011) found that wind-induced resuspension lead to high inorganic suspended sediments (ISS) throughout the year. Zhao et. al. (2011) further found that the rapid fall of ISS seen in the imagery was primarily resettling within the eastern side of the bay rather than flushing from the bay.

High sediment loads from the rivers and sediment resuspension both contribute to the four million cubic yards of material dredged annually from the Bay Channel per year. Byrnes et al. (2013 and 2017) estimated that, on an annualized basis, 2,191,000 cubic yards of sediment was supplied to the Mobile Harbor Federal Navigation Channel by the Mobile-Tensaw River Delta. The annualized maintenance dredging quantity for the northern Bay Channel was estimated at 3,376,000 cubic yards. The remaining 1,285,000 cubic yards per year of sediment (38% of the maintenance dredging quantity) was concluded to be a result of bay sediment transported into the channel. Both Byrnes et al. (2013) and USACE (2014) suggest contributions from resuspended sediments to dredging. Through field data collection and sediment transport modeling conducted as part of a multi-agency regional sediment management effort evaluating thin layer placement of dredged sediments within Mobile Bay, Gailani, J. Z., et. al (2014) found that the contribution from resuspended sediments occurred with or without placement of dredge material within the bay. In addition, two hurricane events Gustav (2008) and Hurricane Ida (2009) were simulated and sedimentation rates of a typical month compared to one including the simulated hurricanes. This analysis found that the simulated hurricanes can contribute to channel shoaling rates 83% over that of the average monthly channel sedimentation rates. Although impacts associated with tropical cyclones do not occur yearly, those within a 40 to 60 mile radius of the Mobile Bay entrance occur of average every 3 to 4 years, emphasizing the importance of event-driven coastal processes on water circulation patterns and sediment transport processes within Mobile Bay (Byrnes et. al, 2012).

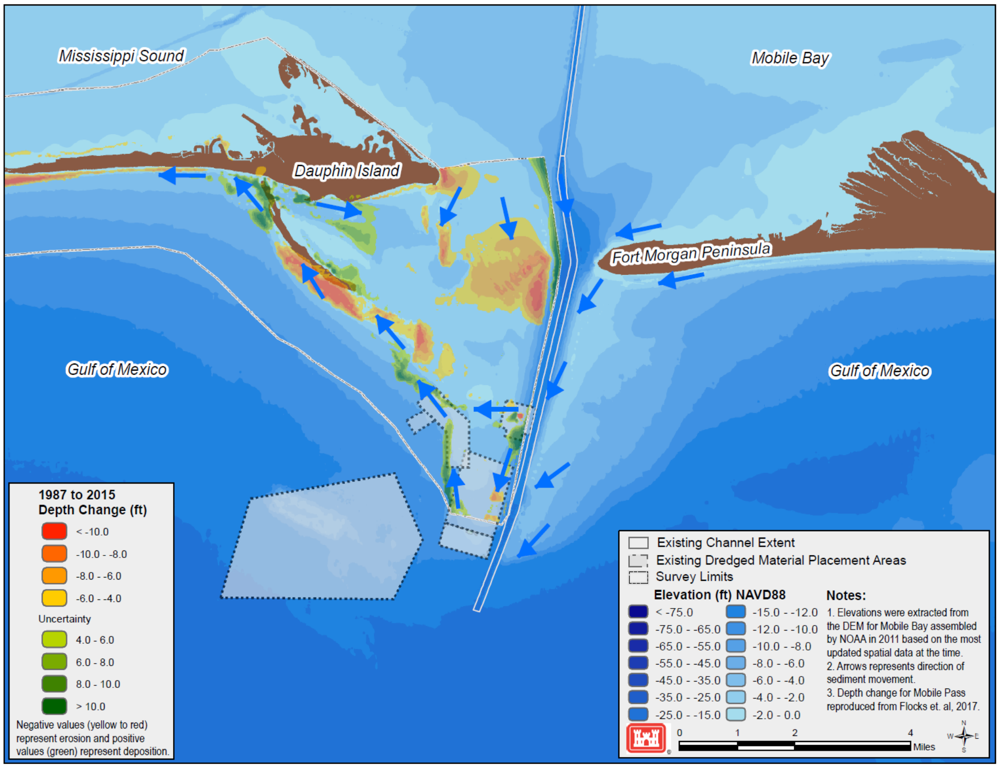
2.9.3. Ebb Tidal Delta

The analysis of multi-decadal seafloor change of the western ebb tidal shoal and the nearshore area around Dauphin Island, Alabama during periods of intense and non-intense tropical storms are documented in Flocks, J.G. et. al (2017) “Analysis of Seafloor Change around Dauphin Island, Alabama, 1987–2015.” In addition long-term regional sediment transport patterns are evaluated during two distinct time periods; one representing conditions prior to significant construction and maintenance dredging activities to determine natural changes (1847/48 to 1917/20) and another representing conditions after significant changes to the outer Bar Channel were made (1917/20 to 2002) are documented in Byrnes et al. (2008 and 2010) “Evaluation of Channel Dredging on Shoreline Response at and Adjacent to Mobile Pass, Alabama.” These studies found that sediment erosion, transport and deposition is controlled by storm wave and current process that produce net littoral transport to the west. Despite differences in time periods and methods of analysis, both studies find consistent patterns of erosion and deposition of major features as demonstrated in Figure 2-9 and Figure 2-10. Flocks et al. (2017) found that geomorphologic features identified in the study respond differently over the stormy and non-stormy time periods, and that these can be quantified through variations in erosion and accretion rates. Byrnes et al. (2008 and 2010) had similar findings revealing a common link associated with geomorphic evolution including island breaching and island roll over associated with storms. Both these studies found that despite large volumes of sediment being dredged from the ship channel the ebb-tidal delta retains a state of dynamic equilibrium, with areas of the ebb tidal shoal recovering through time from hurricanes.



Source: Depth change reproduced from Byrnes et. al, 2008

Figure 2-9. Mobile Pass Bed Level Change 1941 to 2002 (+/- Erosion/Deposition)



Source: Depth change reproduced from Flocks, et. al, 2017.

Figure 2-10. Mobile Pass Bed Level Change 1987 to 2015 (+/- Erosion/Deposition)

2.10. Climate Change

Both qualitative and quantitative analyses were conducted to detect the direction of change in climate variables relevant to elements of the GRR study in accordance with Engineering Construction Bulletin (ECB) 2016-25 *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs and Projects* and Engineering Regulation (ER) 1100-2-8162 *Incorporating Sea level Changes in Civil Works Programs*.

Based on the information contained within the Third National Climate Assessment; climate change is expected to affect seasonal and annual precipitation trends in the Southeast region, and is likely to affect the timing, duration, intensity and frequency of extreme heat, storm events, flooding and droughts. Runkle, J., K. et al. (2017) provides information on historical climate variations and trends along with future realizations of climate conditions within Alabama. Information contained within the state summary were built on data provided in the Third National Climate Assessment. In addition, the U.S. Department of Transportation Federal Highway Administration conducted a study in 2015 (known as the Gulf Coast Phase 2 study) to evaluate the impacts of climate change and variability on transportation infrastructure within Mobile County, Alabama (U.S. DOT, 2015). In this study, temperature and precipitation realizations were downscaled from global climate models and streamflows were simulated using the USGS's modified Thornwaite monthly water balance model, fed by projected temperature and precipitation. Key take-aways from these reports include projected warming despite long-term temperature trends in Alabama due to the influence of greenhouse gases; projected increases in extreme precipitation with seasonal variations as a result of increased atmospheric water vapor with warmer temperatures; and rates of sea level change higher than the global rates due in part to naturally occurring land subsidence.

2.10.1. Temperature

The Third National Climate Assessment projects that temperatures across the Southeast will increase over the century with shorter-term (year-to-year and decade-to-decade) fluctuations over time due to natural climate variability. Major consequences of warming include significant increases in the number of hot days (95 ^{o}F or above) and decreases in freezing events. Although projected increases for some parts of the region by the year 2100 are generally smaller than for other regions of the U.S., the projected increases in the regional average are anticipated in the range of 4 ^{o}F to 8 ^{o}F (combined 25th to 75th percentile range for A2 and B1 emissions scenarios).

Increases in temperature can have implications on infrastructure and services that the port relies on. These include increased deterioration of pavements and buckling of rail. Increased temperatures will also result in increases in energy requirements for buildings associated with air conditioning and refrigeration. Extreme events can also have health and safety implications for personnel, although to date no safety issues due to periods of extreme heat have been reported. In addition, no port facilities have reported experiencing disruptions due to extreme heat in the past. Screening conducted as part of the Gulf Coast Phase 2 study rated the vulnerability of port facilities to projected temperature increases as low to moderate based primarily on historical accounts and port infrastructure being designed to withstand extreme high temperatures. The only port asset to rank high under the most extreme temperature projections at the end of the century was Pinto Island due to lack of operational redundancy and high reliance on electricity.

As mentioned above, pavement can be sensitive to increased temperatures and heavy loads, which can lead to ruts or cracks. Based on the findings of the Gulf Coast Phase 2 case study, current pavement specifications recommended by the Alabama Department of Transportation for high traffic loads should be sufficient under projected increases in temperature, and no adaption measures were identified.

Steel rail will expand with heat, possibly resulting in track displacement. Based on a the findings of the Gulf Coast Phase 2 case study, the projected temperature was in the neutral range for the Mobile's class I railroads continuous welded tracks; except for the "hotter" 95th percentile outputs from the climate models. Recommended adaption options from the study included the use of higher natural rail temperature for new or reinstalled track or blasted tracks with shoulders that are at least one-foot wide.

2.10.2. Precipitation

The projections of future precipitation patterns from the Third National Climate Assessment are less certain than projections for temperature increases. This is because the Southeast is located in the transition zone between projected wetter conditions to the north and drier conditions to the Southwest (Melillo, J.M. et. al, 2014). The Gulf Coast Phase 2 study, found that while the annual precipitation in Mobile County was not projected to change significantly, the two and four-day precipitation events are estimated to become more frequent and intense. The projected increases in precipitation during 24-hour storm events range between one to eight inches, with the highest increases associated with the lower probability storms.

Increases in the frequency and intensity of precipitation events can have implications on infrastructure and services the port relies on. Screening conducted as part of the Gulf Coast Phase 2 study rated the vulnerability of port facilities to projected precipitation events as low to moderate based primarily on historical accounts of flooding, location within the 100-year flood zone, and the adaptive capacity of a facility. While some ports have reported problems with drainage during heavy rains, these issues have not generally been disruptive to port activities in the past. The only port asset to rank high under the most extreme precipitation projections was the Shell Chemical Company due to its low adaptive capacity.

The Gulf Coast Phase 2 Study determined that some storm drainage systems used on local roads were vulnerable to climate change and may not fully function under the larger projected extreme precipitation events. Increases in frequency and intensity of storms could overwhelm drainage capacity and result in increases in localized flooding, road closures and maintenance. However, findings of the Gulf Coast Phase 2 case study indicate structural modifications as a potential cost effective adaptation method.

2.10.3. Streamflow

Classic hydrology is based on basin area, topography, land use, land use changes, and rainfall. Historic hydrologic records capture stationary rainfall and discharge within a fixed range of natural variability. However, this baseline assumption may no longer be appropriate for long-term project design as the baseline as well as the range of variability may be changing.

River flooding, which is related to extreme precipitation, is projected to decline in the southern parts of the Southeast region but increase somewhat in the northern areas (Villarini et al 2009 and 2010, Hirsch and Ryberg 2010, Gutowski et al 2008). This is due in part to projected precipitation patterns for the Southeast, but is also affected by seasonal timing of rains. In the Gulf Coast Phase 2 study, changes in stream discharges are projected to differ seasonally with a decrease in the summer months and an increase during the winter and early spring. The Corps Climate Hydrology Assessment tool was also used to assess data concerning historic changes as well as future projected changes relevant to the hydrologic inputs of two 4-digit Hydrologic Unit Code watersheds (HUC 0316 Mobile-Tombigbee and 0315 Alabama) that drain to Mobile Bay. Despite historic declines in annual maximum monthly flows, future projections for both watersheds indicate similar trends of increased annual maximum monthly flows. The implications of larger flow events on infrastructure and services the port relies on are similar to those found under projected changes in precipitation. An additional area for which the port may be exposed is a potential increase in shoaling associated with erosion and runoff that can build up in the waterways following heavy rain and flow events. As summarized in section 4.10, the annual dredged rate for the river has averaged 1.3 million cubic yards per year and the bay approximately four million cubic yards per year since the 1960s, with maintenance dredge records showing varying dredge rates through time associated with natural variability. An exception to this is a short period between 2009 and 2012 within the river segment. The reason for the increase in dredge rate within the river during this time period is unclear but may be associated with the incorporation of some new work dredge volumes into maintenance dredge volume estimates, temporarily altered sediment transport patterns in the channel after completion of channel extensions and/or high river flows events, which occurred during this time period. While this may be an indication of the sensitivity of the river segment to increased sedimentation rates due to changes in flow, the project is not expected to be highly vulnerable to these changes given the already occurring annual dredge frequency and the small change in shoaling rates seen during this time.

2.10.4. Sea Level

USACE guidance ER 1100-2-8162, *Incorporating Sea Level Changes in Civil Works Programs*, requires consideration of projected future sea-level changes and impacts in project planning, design, operations, and maintenance. Because future sea level change rates are uncertain, planning and design should consider project performance for a range rates. Historic rates are used as the lower bound sea level change rate. Predictions of future sea level due to intermediate and high rates of sea level change are to be developed in accordance with USACE guidance by extension of rate Curve 1 and Curve 3 respectively from the National Research Council's 1987 report *Responding to Changes in Sea Level: Engineering Implications.*

Historic rates of sea level change are determined from tide gage records. Long-term tide gage records on the order of at least 40 years are preferred over shorter term records because the sea level change rate estimate error decreases as the period of record increases. There is one long-term tide gage in the vicinity of Mobile Harbor at Dauphin Island, Alabama (gage number 8735180). Sea level change (i.e., rise) rates for this location are shown in Table 2-4.

Table 2-4. Historic Relative Sea Level Rise Rate (1966 to 2017)

Location	Rise in ft/yr	Std. Error of Rise
Dauphin Island, AL	0.01184	0.00194

Projections for the relative rise in sea level for Dauphin Island was computed in accordance with current USACE guidance and shown in Figure 2-11. Projected rise between 2018 and 2100 varies from roughly 1 foot (0.3 meters) for the low current rate curve to 5 feet (1.5 meters) for the high rate curve.

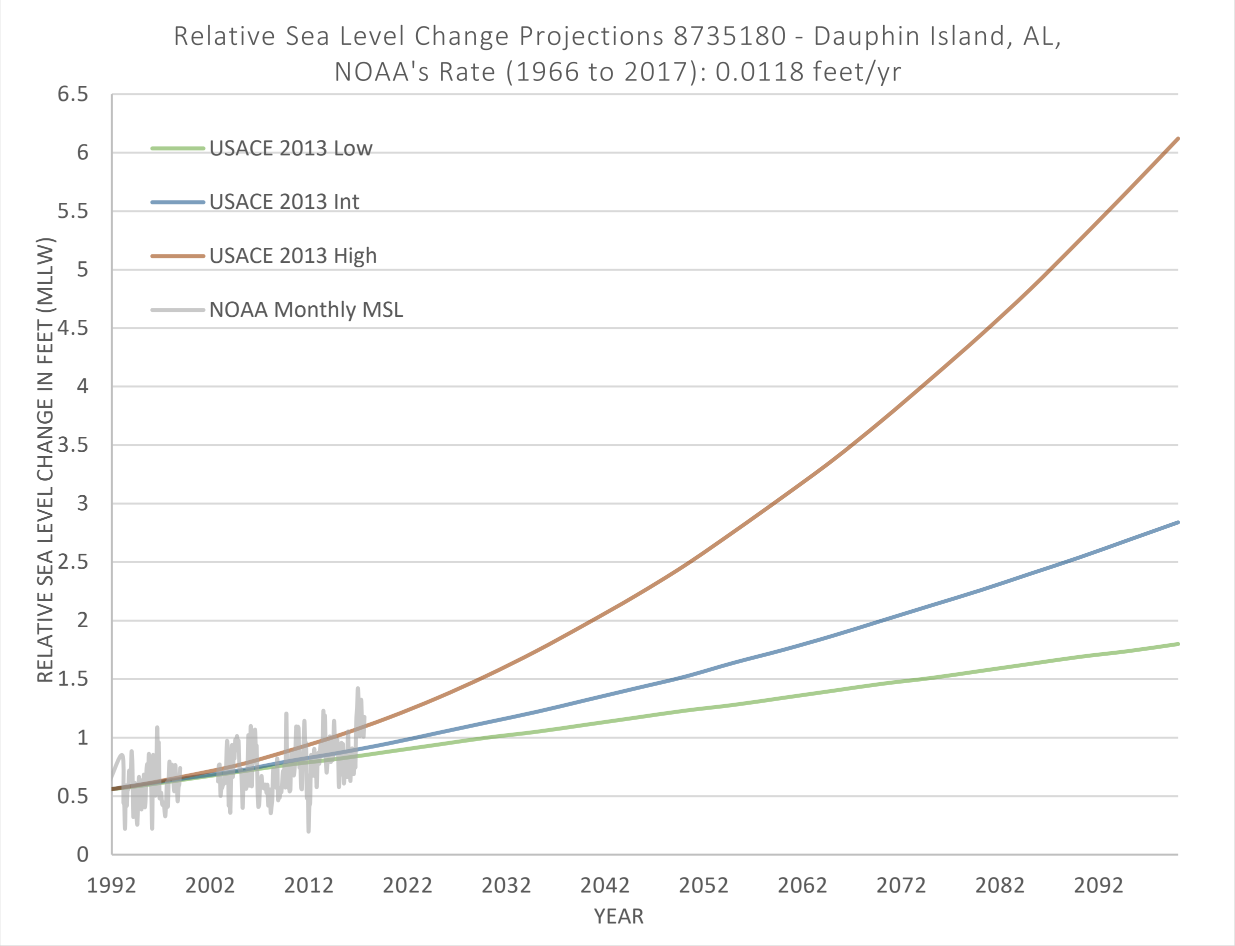
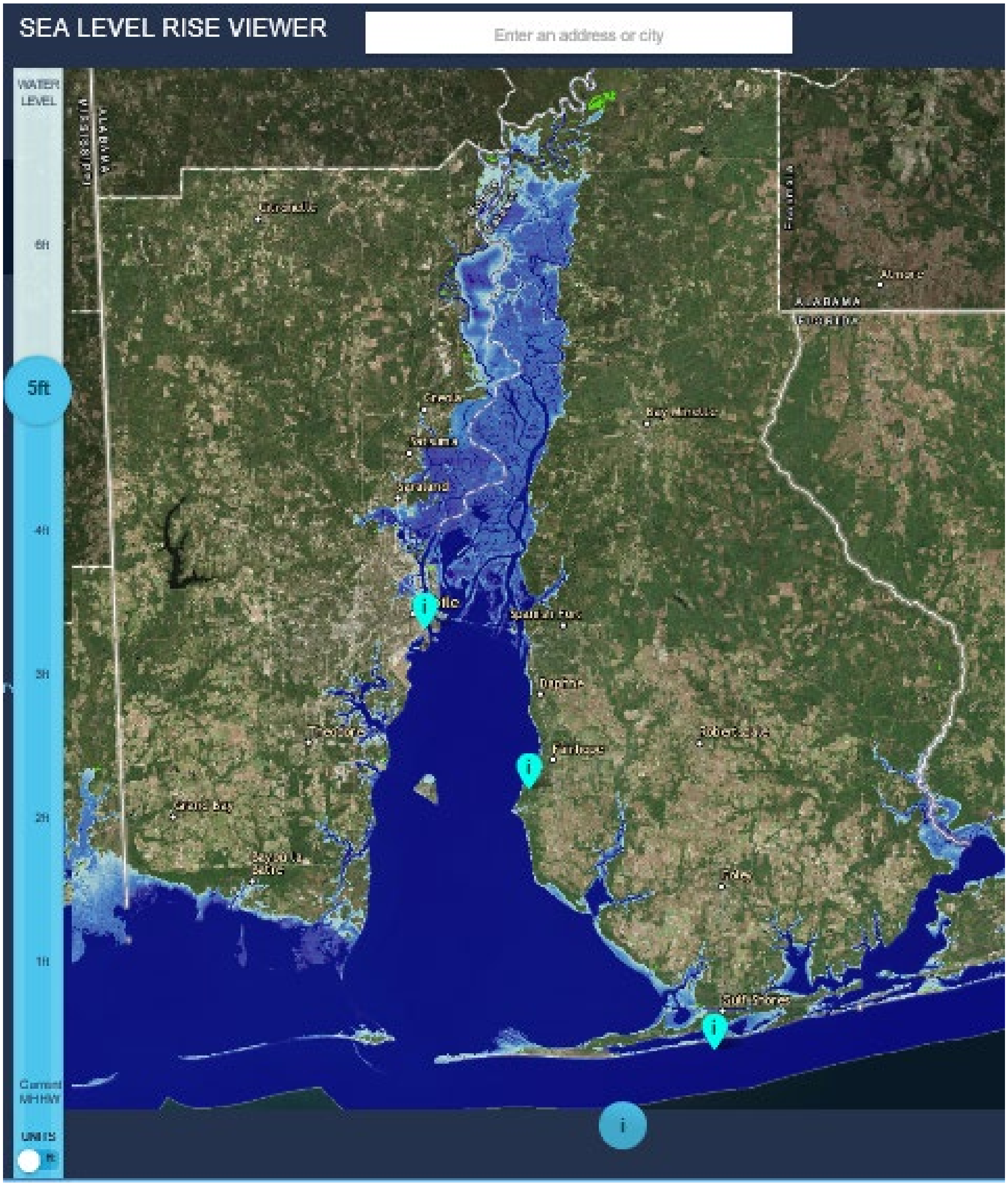


Figure 2-11. Sea Level Rise Projections, 8735180 Dauphin Island, AL

2.10.4.1. Project Area Vulnerability

Based on an extrapolation of the high curve values, elevations for sea level in the project area would be approximately 6.2 feet higher in the year 2100 relative to MLLW (5 feet relative to MHHW). The NOAA Digital Coast Sea Level Rise Viewer (NOAA Office for Coastal Management, 2011) was utilized to visualize the first estimate of the vertical and horizontal extents of the potential sea level change impacts. Figure 2-12 shows the potential future affected areas used in the initial screening to conduct an inventory of infrastructure and resources and to gauge the sensitivity of the study area. Table 2-5 provides a qualitative assessment of critical resources in the area that are exposed over a 100 year horizon with a high rate of sea level rise.



Source: NOAA Sea Level Rise Viewer

Figure 2-12. First estimate of project area horizontal and vertical effects of 100-year high rate curve for sea-level change impacts

Table 2-5. Qualitative Inventory of Critical Resources in the Study Area

Critical Resources in Study Area	Density of Resource	Relevant Notes	Risk from Sea Level Rise*
Residential structures	2	Residential areas on and next to low lying lands and tidally influenced rivers and creeks in Chickasaw, Satsuma, Creola, Bayou Coden, Bayou La Batre, Orange Beach, Perdido Beach and Magnolia Springs. In addition to, development along Dog River and Fowl River and their tributaries, Dauphin Island, Morgan Peninsula and Ono Island. The greatest hazard to these facilities is storm surge combined with sea level rise. With sea level rise nuisance flooding will increase.	3
Commercial structures	2	Several industrial plants and other commercial facilities including freight and non-freight facilities located and/or next to low lying lands and tidally influenced rivers and creeks. The greatest hazard to these facilities is storm surge combined with sea level rise. With sea level rise nuisance flooding will increase.	3
Environment and habitat	3	Freshwater, brackish and saltwater marshes, mixed wetland forests, bottom-land hardwood swamp, non-forested vegetation, tidal flats, barrier islands, sea grasses and oyster reefs surround the project area. Critical habitat areas for several endangered or protected species such as the beach mouse and piping plover are within the project area. In addition, significant areas of existing protected public lands including research reserves, wildlife refuges and management areas and parks with diverse habitat are located along the coast. The greatest hazards to these habitats are changes in hydro periods, wave energy and salinity increases associated with sea level rise.	3
Ports and navigation structures	2	Ports facilities that vary from commercial commodities to industrial goods and wastes border the project area. The majority are located at the Alabama Main Port Complex and to a lesser extent Theodore Complex. Port facilities that are exposed include: Gulf Atlantic Oil Refining, Kimberly-Clark Corporation, BP Oil Company, Plains Marketing, Alabama State Docks Main Complex, Shell Chemical Co., Atlantic Marine, Austal, Gulf Coast Asphalt Co., McDuffie Terminals, Pinto Island, Mobile Container Terminal, U.S. Coast Guard Pier, Mobile Cruise Terminal, Alabama Bulk Terminal, Oil Recovery Company, Standard Concrete, Environmental Treatment, Evonik Industries, Holcim Cement Warf, TransMontaigne Products, Martin Marietta Aggregates, Crecent Towing and Salvage, and Middle Bay Port. Dredged material placement sites including North Blakeley, Mud Lake 6, Mud Lake 7, South Blakeley and North Pinto as well as Gaillard Island. The greatest hazard to these facilities is nuisance flooding and storm surge combined with sea level rise.	2

Infrastructure (roads, water/sewer lines, boardwalks, railroads, airports)	2	Several county roads, state highways interstates such as I-10 bridge and bayway as well as intermodal connectors are located within the project study area. Majority of marinas, docks, and/or piers found in the area are at risk of inundation. Railroads located within the city and at port authority facilities are at risk. These include the Burlington Northern Santa Fe, Canadian Northern, CSX, Norfolk Southern and Kansas City Southern. In addition to roads and railroads some water and sewer lines are located in low lying areas. The greatest hazard to these facilities are storm surge combined with sea level rise as well as increases in nuisance flooding that can overwhelm drainage capacity and result in road closures.	3
Critical facilities (police, fire, schools, hospitals, nursing homes)	1	Assessment of police, fire departments, hospitals, schools, and nursing homes indicate that most areas are located at higher elevations. Exceptions to this are Dauphin Island's elementary school, police department and water and wastewater facilities. In addition to the Bayou La Batre's wastewater facility and senior living facilities located along the coast in Baldwin County. The greatest hazard to these facilities is storm surge combined with sea level rise.	2
Evacuation routes	3	Multiple spans of I-10 and the Bayway, Water Street, 110, Dauphin Island Parkway, AL-59, 180 and 182 including inundation occurring at the bases of multiple bridge spans. Local roadways located in low-lying residential areas prone to increased flooding and inundation. The greatest hazard to these facilities nuisance flooding and storm surge combined with sea level rise.	3
Recreation	3	Large areas of river, bays and bayous and fringing marsh habitat, which are used for fishing, bird watching, and various recreational and ecotourism activities are within the study area along with islands and beaches. Significant areas of existing protected public lands including research reserves, wildlife refuges and management areas and parks. The greatest hazards to these habitats are changes in hydro periods, wave energy and salinity increases associated with sea level rise.	3
***3=high, 2=medium, 1=low**			

2.10.4.2. Performance Impact Register

Separable elements of the Federal navigation project that have functions necessary to the overall project were evaluated for exposure and vulnerability. Individual elements of the Mobile Harbor Project that are exposed to the high rate of sea level rise curve over a 100-year horizon are:

- Upland Dredged Material Placement Areas
- Open Water Dredged Material Placement Areas
- Channel Depth

The critical Federal project features are identified in Figure 1-2, Figure 1-3, and Figure 1-5. These include containment dikes of the upland dredge material placement sites at North Blakeley, Mud Lake 6, Mud Lake 7, South Blakeley, and North Pinto as well as numerous open water sites and the navigation channel. In addition, critical port facilities that are exposed are listed in Table 5-2. Increases in sea level rise combined with storm surge can have implications on infrastructure and services the port relies on. Screening conducted as part of the Gulf Coast Phase 2 study rated the vulnerability of port facilities to projected sea level rise low to moderate based primarily on elevation, infrastructure age, historical accounts of flooding, location within the 100-year flood zone and the adaptive capacity of a facility. The only port asset to rank high under the sea level rise projections was the ASPA Main Docks Complex due to it being a site of one of the most extreme projected inundations under the storm surge modeling. In addition, it is an older facility in less-than-optimal condition with little shoreline protection.

The Gulf Coast Phase 2 case study evaluated the most exposed southern pier at McDuffie Island to quasi-static hydraulic loadings of the waves under storm surge and sea level rise due to its economic importance. The quasi-static loading consisted of the wave's pulsing action in addition to the buoyancy force of the sea water. Overall the case study found that piers tend to be fairly resilient against storm surges as they are designed with significant mass and strength to withstand berthing and mooring loads, which are typically much greater than the loads produced during storms. The study, however, noted that the equipment on the piers (i.e. access bridges, mooring dolphins, access walkways, etc.) were the most vulnerable and suggested measures to protect and reinforce the equipment, in order to reduce overall vulnerability of the port.

Each of the upland dredged material placement sites as well as the channel depths were assessed through a Level 1 qualitative assessment for robustness to expected changes in sea level over the 50-year project horizon by considering the critical performance elevation that acts as a threshold between full performance and decreased levels of performance, and the total water level that controls performance.

For the level 1 analysis, relative sea level change is applied to the total water level component by linear superposition for each of the three sea level change scenarios over the 50-year project horizon. The point where performance is expected to be impacted is when the projected total water level intersects the critical or controlling elevation.

In addition, a Level 3 quantitative assessment using the intermediate relative sea level rise scenario was included in the assessments performed by ERDC and the USGS to evaluate the relative differences in hydrodynamics, water quality, and sediment transport within the study area, to include the channel and open water placement sites for future with and without channel improvement alternative conditions (see Attachments A – 1 and A – 2 of this appendix). Results of their analyses show a negligible change in the difference of With- and Without-Project scenarios due to sea level rise. The decision to use the intermediate relative sea level rise scenario (0.5 meter) over the 50-year project horizon for these quantitative assessments was twofold: (1) the running average in mean sea level falls between the intermediate and the high level projections in recent years at the Dauphin Island gage as assessed using the USACE SeaTracker and (2) concern that any potential relative differences in the With- and Without-Project conditions combined with sea level rise may not be discernable in the models at the highest projected rate.

2.10.4.3. Tidal Datum

Tidal Datum and annual exceedance information from generalized extreme value (GEV) curves produced by NOAA for station #8735180 gage data were used to assess robustness. This information is shown in Figure 2-13.

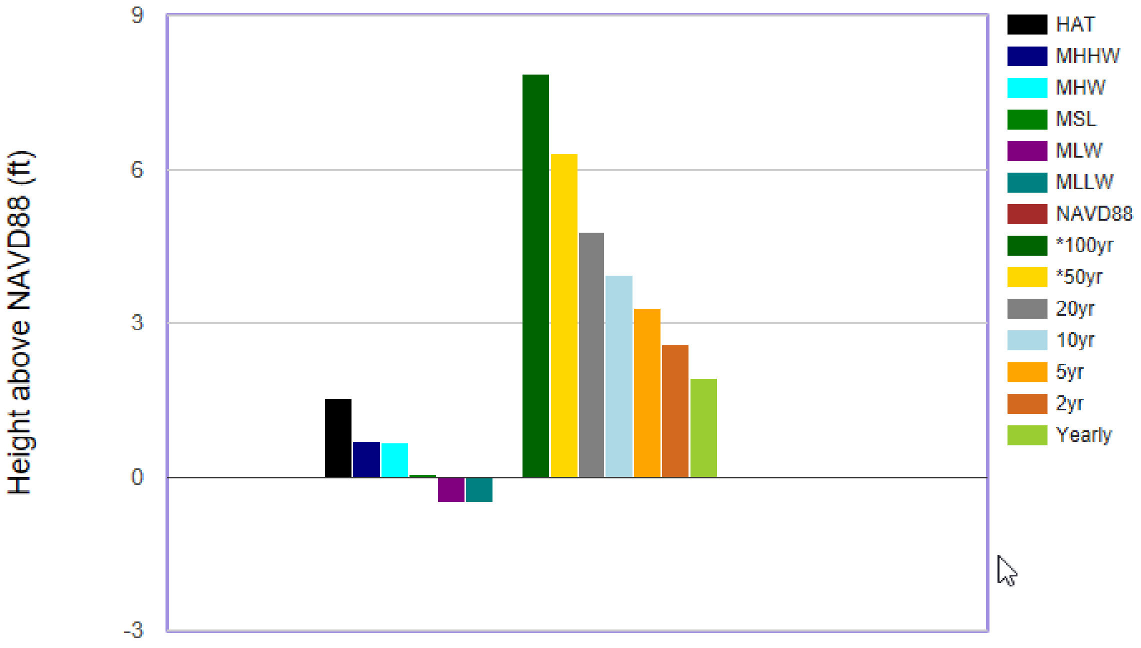


Figure 2-13. Total Water Levels (NAVD 88) – Tidal Datum and Extreme High Water Annual Exceedance Probability (AEP), Gage 8735180 at Dauphin Island, AL

2.10.4.4. Upland Dredged Material Placement Areas

Dredge material containment dikes are expected to perform under cases of extreme high water and should include the dynamic wave component. An one percent annual exceedance probability still-water level was used as a proxy to screen for overtopping of the structure crest elevations, in which associated forces can lead to surficial erosion. Based on the one percent annual exceedance probability still-water level, there is not an anticipated decreased level of performance expected for the containment dikes over the remaining serviceable life. Therefore, the impacts of sea level change to these sites are anticipated to be minimal. With sea level rise and the vulnerability of adjacent marsh habitat, future opportunities for beneficial use of dredge material is likely to increase.

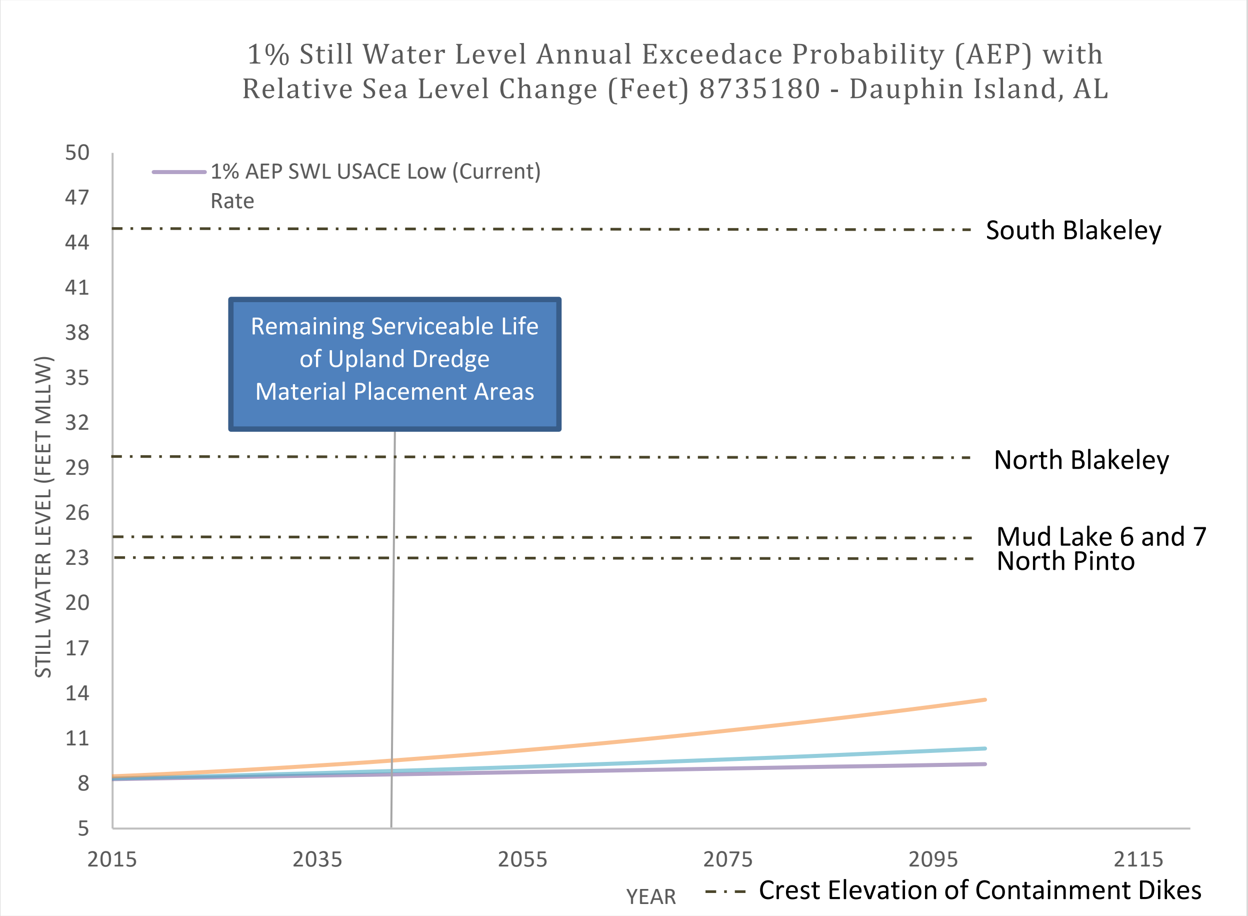


Figure 2-14. Performance Thresholds for Dredged Material Containment

2.10.4.5. Channel Depth

The most obvious effect of increased sea level with respect to performance is increased depth. Since the authorized project is referenced to MLLW, which is a tidal datum, and because this tidal datum is adjusted periodically (on the order of 17 to 19 years based on celestial cycles, which are primarily responsible for the daily and seasonal variation in the tide signal), it is possible that dredging efforts could be decreased due to sea level rise. However, with rising sea level there could also be some shifts in the magnitude, location, and characteristics of river-borne sediment deposition, and the ability to accurately assess these types of potential impacts to determine if they outweigh the benefits of tidal datum shifts are currently limited.

In addition to channel depth, reductions in navigational clearances are also a concern with changing sea levels. With increasing sea level navigational clearances over the

George C. Wallace Tunnel (lower) and the Bankhead Tunnel (upper) on the Mobile River would increase and therefore are not expected to be negatively affected. However, clearances under the Cochrane-Africatown Bridge, which is the first bridge crossing over the Mobile River navigation segment maybe affected overtime depending on the rate of sea level rise. The Gulf Coast Phase 2 study evaluated navigational clearances, finding expected sea level rise will not affect the Cochrane-Africatown Bridge within its design life.

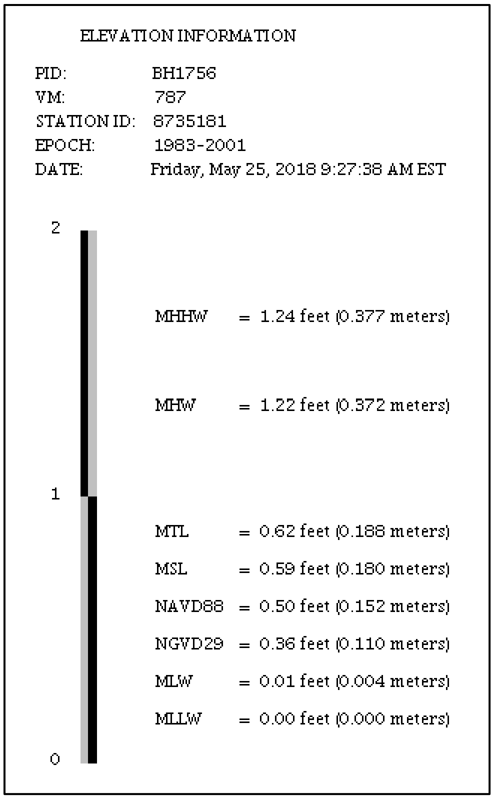
SECTION 3. SURVEYS

3.1. Hydrographic Surveys

Hydrographic surveys of the Mobile Harbor Navigation Channels were completed in 2016 following operation and maintenance dredging. The surveys were taken from the start of the river out to the end of the Bar Channel. The surveys consisted of cross-sections (100-foot centers) of the existing channel width and extended roughly 50 feet on either side of the channel. Additional surveys used to augment analyses, beyond the surveys described above, are detailed within the associated sections herein and reports provided in Attachments A – 1 through A – 5 of this appendix.

3.2. Datum Planes

All vertical elevations are referenced to the MLLW tidal datum. Local gages installed at the project along the channel segments are used to support routine operations and maintenance dredging activities. The nearest long-term NOAA tide gage is at Dauphin Island, Alabama (NOAA Station No. 8735180). Figure 3-1 displays, tidal datum information referenced to MLLW, 1983-2001 epoch. All horizontal coordinates are referenced to the Alabama State Plane Coordinate System NAD 83, West Zone.



ELEVATION INFORMATION

PID: BH1756
VM: 787
STATION ID: 8735181
EPOCH: 1983-2001
DATE: Friday, May 25, 2018 9:27:38 AM EST

MHHW = 1.24 feet (0.377 meters)
MHW = 1.22 feet (0.372 meters)
MTL = 0.62 feet (0.188 meters)
MSL = 0.59 feet (0.180 meters)
NAVD88 = 0.50 feet (0.152 meters)
NGVD29 = 0.36 feet (0.110 meters)
MLW = 0.01 feet (0.004 meters)
MLLW = 0.00 feet (0.000 meters)

Source: National Geodetic Survey.

Figure 3-1. Tidal Datum Information, Gage 8735180 at Dauphin Island, AL

SECTION 4. CHANNEL DESIGN

4.1. Existing Channel Design

A description of the existing and authorized dimensions of the various components of the Mobile Harbor Federal Navigation Project are provided in Section 1.1. The project was last modified in 2011, with the addition of the Choctaw Pass Turning Basin (45 feet deep by approximately 1,570 feet long by 715 feet wide at its easternmost extent) with a 100-foot wide by 3,500-foot long widener/transition section along the eastern edge of the Bay Channel to station 317+73. Construction of the channel to 45 deep by 400 feet wide in the bay and 47 feet deep by 600 feet wide in the Bar was completed 1990. Three approved extensions of 1,300, 1,200 and 2,100 feet, as detailed in Limited Reevaluation Reports (LRRs), were completed in 1999 (the 1,300-foot extension) and 2008 (the 1,200- and 2100-foot extensions). These extended the 45-foot deep channel north into the lower Mobile River to station 226+16. In addition, a 100-foot wide by 1,200-foot long advance widener (shown as the sediment trap in Figure 1-2) was constructed on the east side of the Bar Channel as a result of rapid channel shoaling in the vicinity of the Dixie Bar in 1999. The existing channel depths include an additional 2 feet of advanced maintenance and 2 feet of allowable overdepth with the exception of the Choctaw Pass Turning Basin, which includes 4 feet of advanced mainteance. In accordance with ER 1130-2-520, the advanced maintenance depths and widths, as well as the allowable overdepth, were requested by the USACE, Mobile District and approved by the USACE, South Atlantic Division (SAD) in 1996, 1999 and 2007. Channel design side slopes are one vertical to five horizontal in the bay and one vertical to seven horizontal in the Bar.

According to the 1986 General Design Memorandum (GDM), the channels were designed in accordance with design standards in effect at the time, and reflect consideration of bathymetry, project operations, future traffic projections, and vessel characteristics. Supplemental design information for the project area is contained in the 1984 Computer Aided Operations Research Facility (CAORF) ship simulations report, the 1985 Waterways Experiment Station (now known as the Engineer Research and Development Center, or ERDC) ship simulation study, the 1985 GDM, the 1995 GDM supplement, the 1997 LRR, the 2000 LRR and the 2007 GRR.

The vessels governing the design of the authorized Mobile Harbor Federal Navigation Project include a 150,000 deadweight tonnage (DWT) vessel with a draft of 51 feet (light-loaded 5 feet), a beam of 142 feet, and a length of 953 feet. The design vessel governing the Choctaw Pass Turning Basin, as documented in the 2007 GRR and associated 2007 ERDC ship simulation study, is a post-panamax containership, with a length of 1,140 feet, a beam of 140 feet and a draft of 47.5 feet (light loaded to 42 feet). Ship simulation studies conducted at the Waterways Experiment Station (now known as ERDC) in

Vicksburg, Mississippi and CAORF showed that the vessels tested successfully transited the design (and presently existing) channel.

Documented depth allowances in the Bay Channel included one foot for squat, 0.5 foot for trim, 0.5 feet for low tide, and 2 feet for safety. An additional 2 feet was provided for pitch, roll, and heave in the Bar Channel. The existing subject channels were thus intended for operation of ships with a static draft of no greater than 41 feet.

4.2. Channel Improvement Measures for the Recommended Plan

The Bar, Bay, and River (lower 1,850 feet below station 226+16) Channels of the Mobile Harbor Federal Navigation Project are currently 47, 45, and 45 feet deep, respectively, (as shown in Figure 1-1) with an additional 2 feet for advanced maintenance plus 2 feet of allowable overdepth for dredging (total depths of 51, 49, and 49 feet, respectively). Those same channel segments are currently 600, 400, and 600 feet wide, respectively. In addition, the Choctaw Pass Turning Basin, located at the northern limit of the Bay Channel, is currently 45 feet deep (with an additional 4 feet for advanced maintenance plus 2 feet of allowable overdepth resulting in a total depth of 51 feet) by approximately 1,570 feet long (including the 400-foot width of the existing Bay Channel) by 715 feet wide at its easternmost extent. It also contains a 100-foot widener/transition section about 3,500 feet in length along the eastern edge of the existing Bay Channel immediately south of the basin to improve basin access, reduce the basin size needed for turning, and increase vessel maneuverability. Channel improvement measures to these channel features, as recommended in the Recommended Plan (RP), are as follows:

- Deepen the existing Bar, Bay, and River Channels (south of Station 226+16) by 5 feet to project depths of 52, 50, and 50 feet, respectively, with an additional 2 feet for advanced maintenance plus 2 feet of allowable overdepth for dredging (total depths of 56, 54, and 54 feet, respectively).
- Incorporate minor bend easing at the double bends (at stations 1857+00 and 1775+26) in the Bar Channel approach to the Bay Channel.
- Widen the Bay Channel from 400 to 500 feet at a depth of 50 feet (with an additional 2 feet for advanced maintenance plus 2 feet of allowable overdepth resulting in a total depth of 54 feet) from the mouth of Mobile Bay northward for 3 nautical miles to provide a two-way traffic area for passing.
- Expand the Choctaw Pass Turning Basin 250 feet to the south at a depth of 50 feet with an additional 4 feet for advanced maintenance plus 2 feet of allowable overdepth for dredging (total depth of 56 feet) to better accommodate safe turning of the design vessel and other large vessels.

Details of the RP components are shown in Figure 4-1 through Figure 4-5.

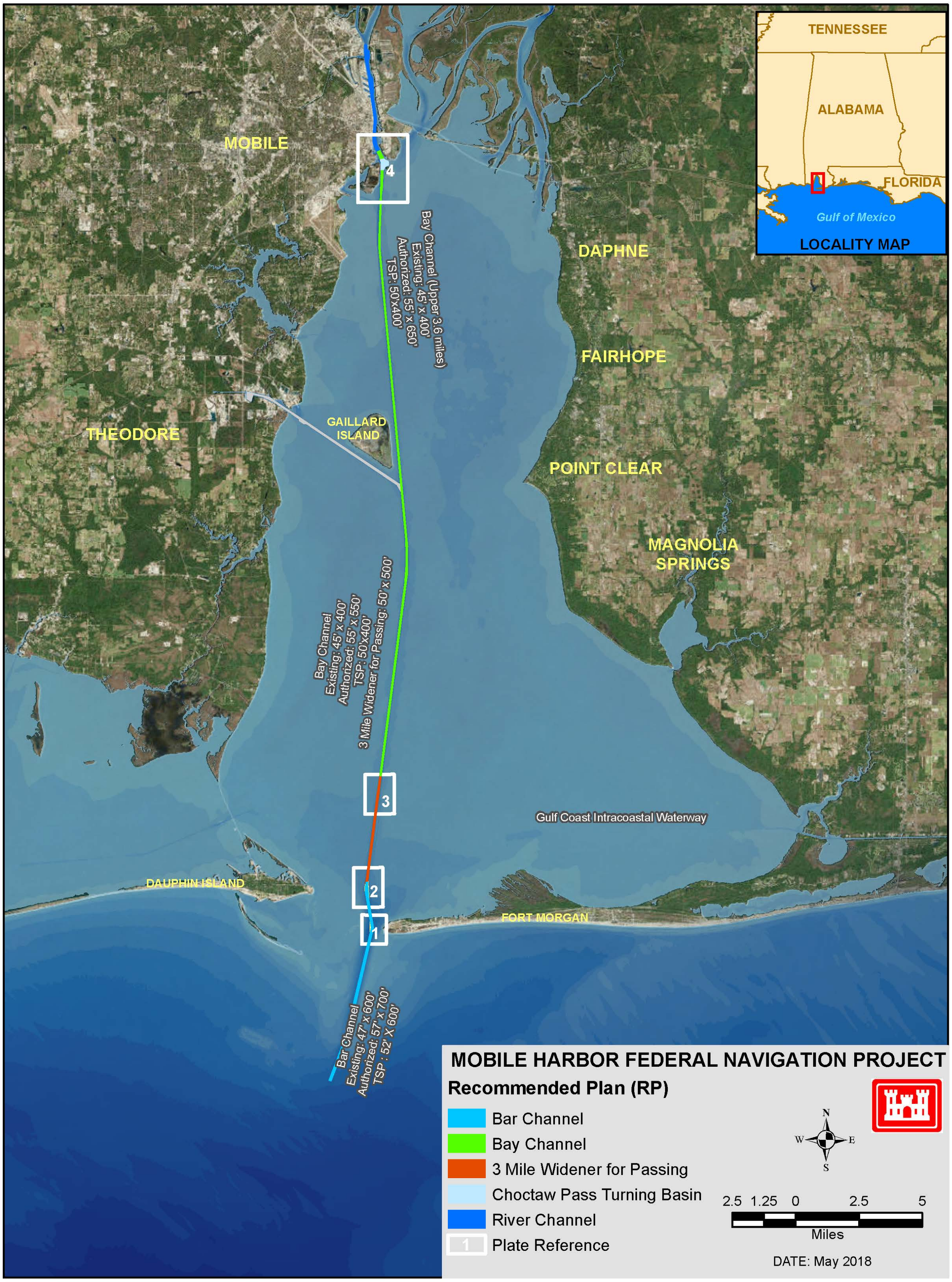


Figure 4-1. Recommended Plan (RP) for the Mobile Harbor Federal Navigation Project

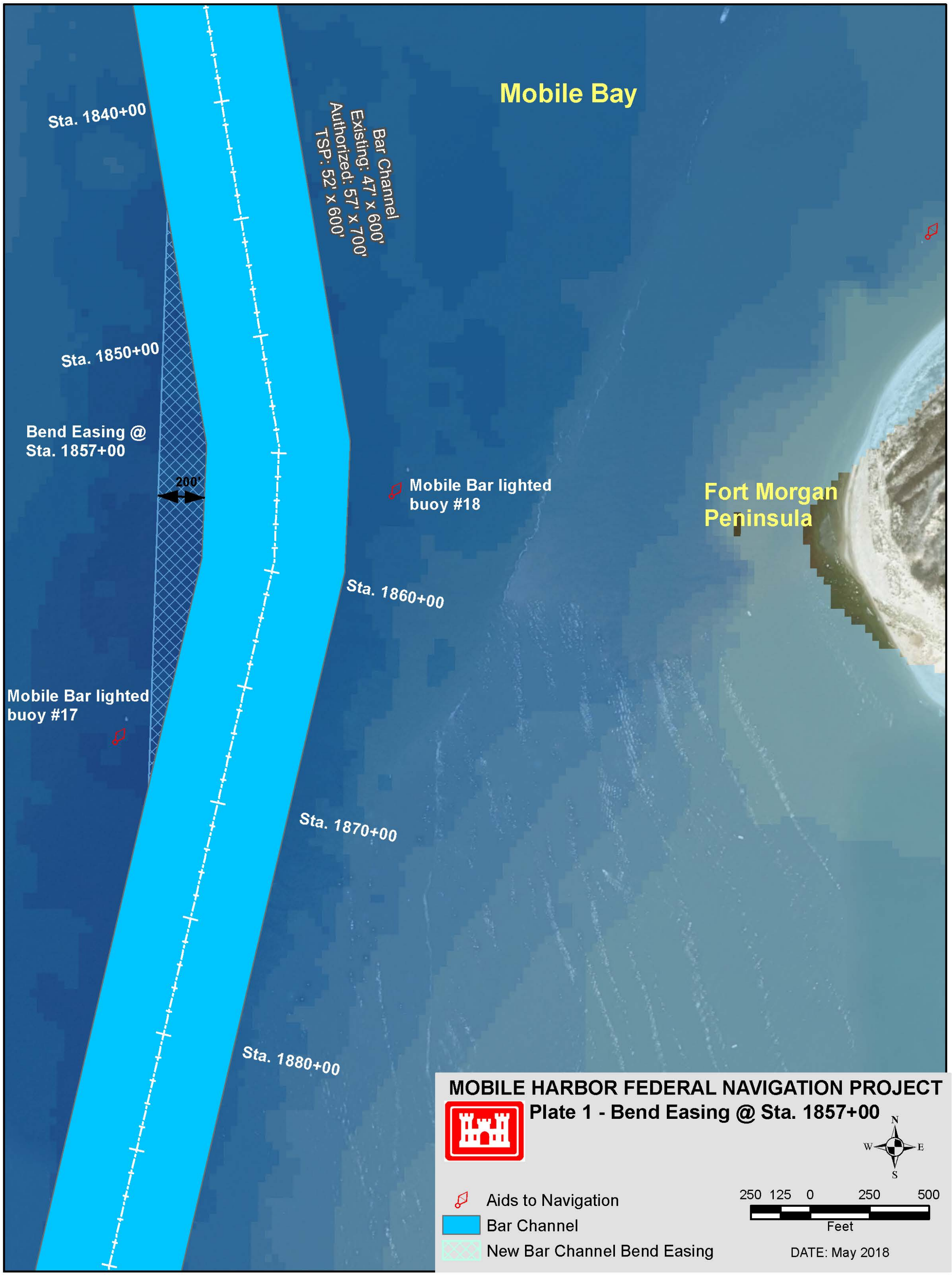


Figure 4-2. Bend Easing in Bar Channel at Station 1857+00

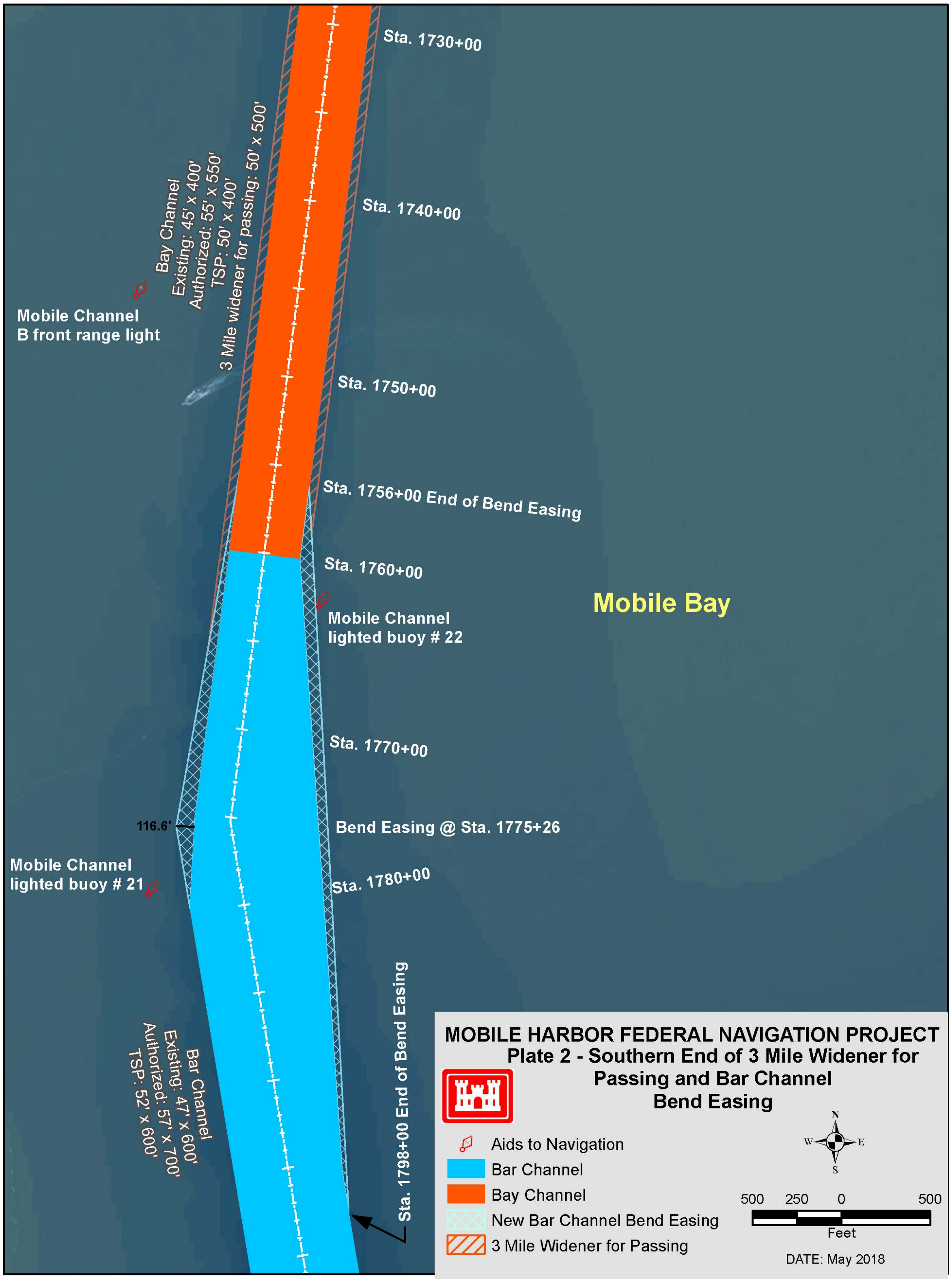


Figure 4-3. Bend Easing in Bar Channel at Station 1775+26 and Southern End of 3 Mile Channel Widener for Passing in Bay Channel

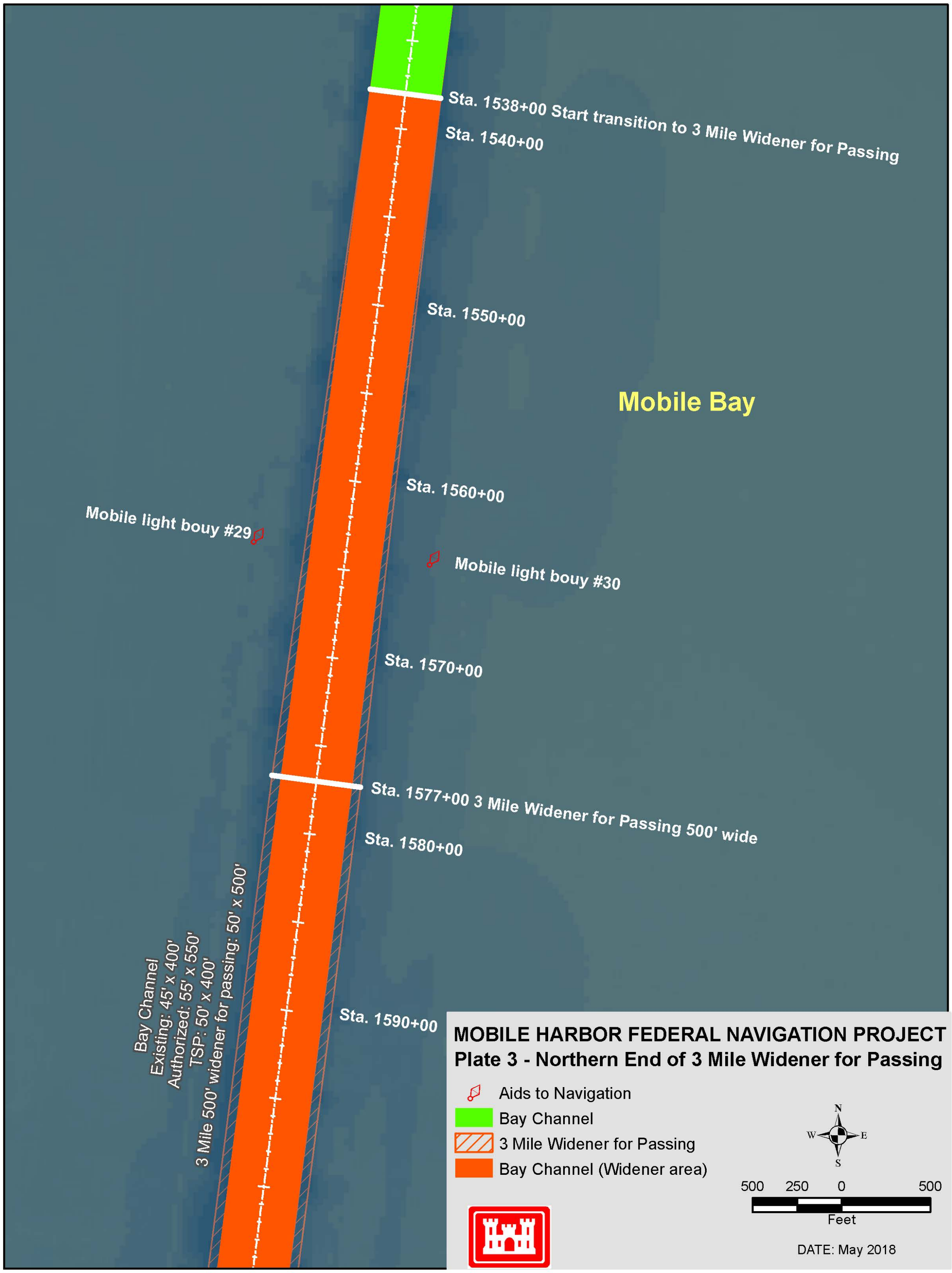


Figure 4-4. Northern End of 3 Mile Widener for Passing in Bay Channel

Figure 4-5. Choctaw Pass Turning Basin Expansion

4.3. Design Vessel

The design vessel is typically the largest ship(s) of the major commodity movers expected to use the project on a frequent and continuing basis. Because beam, length, or draft dimensions govern certain aspects of channel design, there may be more than one design vessel. Vessels governing the current design include the following: a 115,000 to 125,000 DWT, nominal 10,000 to 11,000 twenty-foot equivalent unit (TEU) container ship with an overall length, beam, and maximum draft of 1,100 feet, 158 feet, and 50.8 (44.5 feet static draft to account for underkeel clearance), respectively; and a 100,000 to 120,000 DWT tanker with an overall length, beam, and maximum draft of 851.5 feet, 141.2 feet, and 51.6 feet (44.5 feet static draft to account for underkeel clearance), respectively. Details concerning the selection of the design vessels can be found within Appendix B – Economics.

4.4. Channel Depths

In accordance with Engineering Manual (EM) 1110-2-1613 *Hydraulic Design of Deep Draft Navigation Projects,* care was taken to ensure the design channel depths developed from the economic analysis consider the loaded draft (summer, salt water) of the design ship, plus an allowance for the following factors: (1) ship squat; (2) ship lowering in fresh water; (3) extended periods of unpredictable low water levels; (4) vertical ship motion due to wave action; and (5) safety clearance.

Ship Squat: Total vertical ship motion resulting from sinkage and running trim (i.e., ship squat) in shallow water was calculated utilizing (Norrbin 1986, Rekonen 1980). Results of the calculated maximum squat relative to typical speeds known for vessels transiting the Mobile Harbor Navigation Channel are displayed in Figure 4-6.

As seen in Figure 4-6, the maximum squat varies depending on the vessel class and vessel speed between 1 to 4 feet for the selected design containership (1,100 feet and 158 feet) and 1 to 5.5 feet for the selected design tanker (851.5 feet and 141.2 feet,). Vessels transiting Mobile Bay have an average speed of around 10 knots. Based on this speed it is recommended that 3 feet of allowance for squat be incorporated into the underkeel esimates.

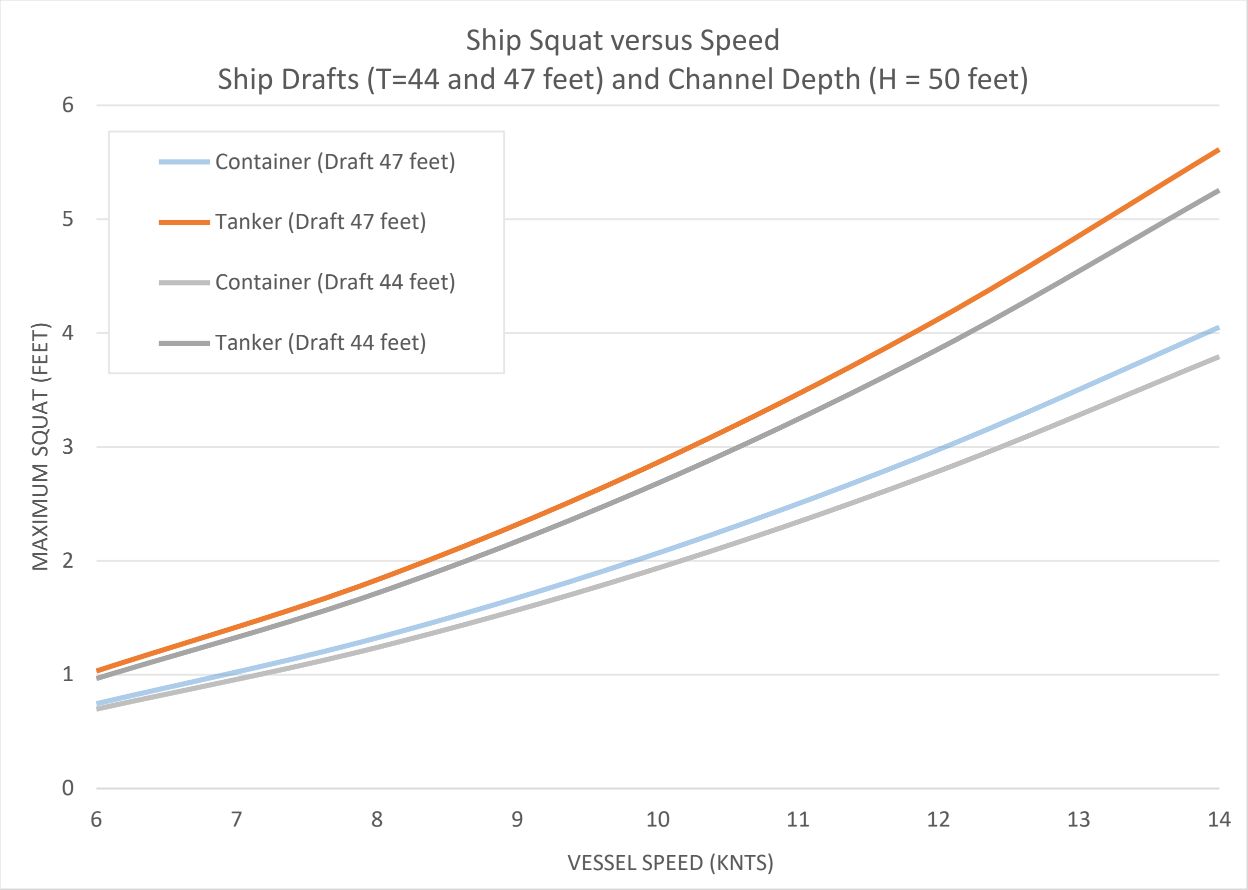


Figure 4-6. Maximum Ship Squat versus Speed

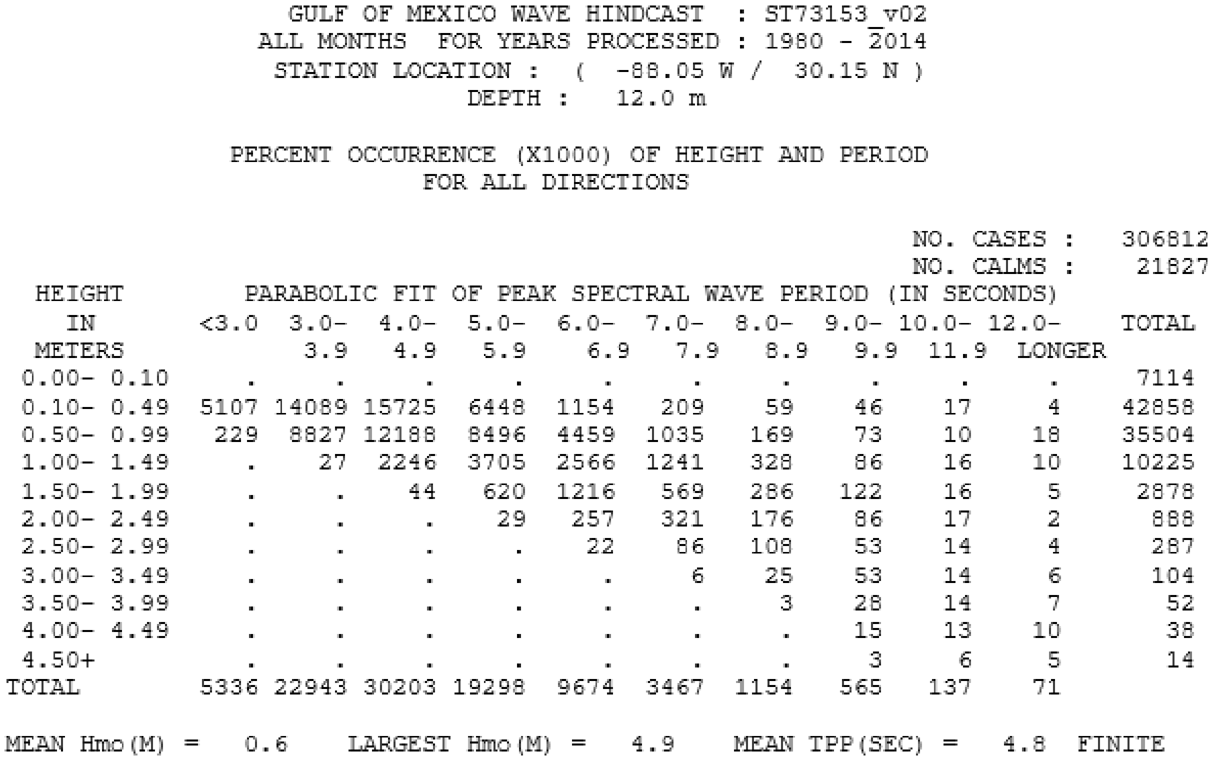
Lowering in Fresh Water: EM 110-2-1613 *Hydraulic Design of Deep Draft Navigation Projects* recommends 0.5 foot be utilized in brackish waters. Salinity conditions within the Mobile Harbor Navigation Channel would be considered salt water for the majority of the channel. Segments of the channel where brackish conditions would more frequently occur (i.e. north of Gaillard) are approaching the harbor, where vessel speeds and associated maximum squat are lessened. Based on this, a brackish water allowance is not recommended for estimates of the underkeel.

Tidal Conditions: As discussed in Section 2.4, the tidal range caused by astronomical forces is relatively small; however, winds, pressure gradients, and river discharge can induce larger variations. The daily mean water elevation averaged by month increases for half the year and then decreases over a range that is about the same amplitude as the diurnal range. As seen in Figure 2-4, water levels frequently fall within a range between 0.5 and 1.0 foot below MLLW during the fall, winter and spring months. This annual cycle level is more regular at Mobile than at most United States tidal stations (Hands, et. al 1990). Based on this assessment, it is recommended that 0.5 foot allowance be incorporate into the underkeel estimates.

Wave Action: As discussed in Section 2.5, fetch and depth limited wave conditions are found within the bay, with wave heights generally less than 1.5 feet and overall mean peak periods less than four seconds. These typical wave conditions would not be expected to generate significant commercial deep draft vessel response; therefore, no wave allowance is recommended for the Bay Channel segment.

In review of data from WIS 73153, wave intensity is low to moderate along the open coast. The common wave direction is out of the southeast between 112.5 and 180 degrees. The most common peak wave periods fall between a ranges of 4 to 5 seconds. Significant wave heights range from 0 to 16 feet, with an overall mean significant wave height of 2 feet. Unlike the bay, more frequent wave conditions (i.e. wave periods greater than six seconds), as shown in Table 4-1, occur out on the Bar Channel, which are capable of generating commercial deep draft vessel response; therefore, it is recommended that the current design criteria maintain a 2-foot allowance for waves and strong opposing tidal currents for the Bar Channel segment.

Table 4-1. Hindcast Percent Occurrence of Height and Period, WIS 73153



```
                    GULF OF MEXICO WAVE HINDCAST   : ST73153_v02
                  ALL MONTHS  FOR YEARS PROCESSED : 1980 - 2014
                   STATION LOCATION :   (  -88.05 W /  30.15 N )
                                DEPTH :   12.0 m

                PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD
                            FOR ALL DIRECTIONS

                                                           NO. CASES :   306812
                                                           NO. CALMS :    21827
  HEIGHT       PARABOLIC FIT OF PEAK SPECTRAL WAVE PERIOD (IN SECONDS)
    IN       <3.0  3.0-  4.0-  5.0-  6.0-  7.0-  8.0-  9.0- 10.0- 12.0-    TOTAL
  METERS            3.9   4.9   5.9    6.9   7.9   8.9   9.9  11.9  LONGER
 0.00- 0.10     .     .     .     .     .     .     .     .     .     .     7114
 0.10- 0.49  5107 14089 15725  6448  1154   209    59    46    17     4    42858
 0.50- 0.99   229  8827 12188  8496  4459  1035   169    73    10    18    35504
 1.00- 1.49     .    27  2246  3705  2566  1241   328    86    16    10    10225
 1.50- 1.99     .     .    44   620  1216   569   286   122    16     5     2878
 2.00- 2.49     .     .     .    29   257   321   176    86    17     2      888
 2.50- 2.99     .     .     .     .    22    86   108    53    14     4      287
 3.00- 3.49     .     .     .     .     .     6    25    53    14     6      104
 3.50- 3.99     .     .     .     .     .     .     3    28    14     7       52
 4.00- 4.49     .     .     .     .     .     .     .    15    13    10       38
 4.50+          .     .     .     .     .     .     .     3     6     5       14
TOTAL        5336 22943 30203 19298  9674  3467  1154   565   137    71

MEAN Hmo(M) =    0.6    LARGEST Hmo(M) =    4.9    MEAN TPP(SEC) =   4.8  FINITE
```

Source: WIS

Safety Clearance: In the interest of safety, a clearance of at least 2 ft (0.6 m) is recommended between the bottom of a ship and the design channel bottom to avoid damage to ship hull, propellers, and rudders from bottom irregularities and debris.

In summary, it is recommended that 3 feet be added below the static draft for squat, 0.5 foot for frequent prolonged periods of low water levels, with an additional 2 feet for a factor of safety within the Bay Channel segment. For the Bar Channel, an additional 2 feet is recommended to account for ship response associated with waves and strong tidal currents within the Bar Channel and Mobile Pass between Fort Morgan and Dauphin Island, Alabama. The final calculations of underkeel and thus design depth will be determined through considerations for days of accessibility utilizing Channel Analysis Design Evaluation Tool (CADET) to ensure the recommended allowances for waves and water levels balance the increased cost to maintain the associated depths. Below the recommended design depth, an additional 2 feet of advanced maintenance to account for the accumulation and storage of sediment and 2 feet of allowable overdepth to account for dredging tolerances within the navigation channel be incorporated into the RP.

In all, deeping associated with the RP includes the existing Bar, Bay (including the Choctaw Pass Turning Basin), and River Channels (below station 226+16) by 5 feet to project depths of 52, 50, and 50 feet, respectively, with an additional 2 feet for advanced maintenance plus 2 feet of allowable overdepth for dredging (total depths of 56, 54, and 54 feet, respectively).

4.5. Channel Widths

4.5.1. One-Way Channel Segments

In accordance ER 1110-2-1404 *Hydraulic Design of Deep Draft Navigation Projects*, the channel widths for the Bay, Bar, and Rivers Channels were evaluated to determine their adequacy for one-way traffic of the design vessel. Based on the feasibility level ship simulation results and Bar Pilot feedback, the current widths are suitable and recommended for the RP. However, additional ship simulations are recommended during the PED phase to confirm these dimensions using to the actual design vessel (see Section 6.5 for additional details on the ship simulation effort).

4.5.2. Two-Way Channel Segment

A two-way traffic area was also evaluated during the feasibility level ship simulations to determine the necessary length and width of a channel widener for passing in the southern portion of the Bay Channel (as shown in Figure 4-1). As generally described in Section 6.5 and detailed in Attachment A – 3, various vessel combinations were considered with Bar Pilot input to develop the passing rules for the Economic analysis described in Appendix B. For all simulations, the depth was increased from 45 feet (47 feet at entrance channel) to 51 feet (53 feet at entrance channel) and two different widths were screened for the passing area (500 feet and 550 feet). Each passing area spanned approximately 5 nautical miles. While testing was completed using a 5 nautical mile passing lane, it was determined the most likely length needed will fall between 3 and 5 miles. Additionally, it was found that bend easing increased safety and greatly influenced the ease in which passing could be completed. Results of the ship simulation led to recommendations to further soften the bends near buoy 21 on the west side of the channel and carry forward a 3-mile passing lane for the RP (see Figure 4-3 and Figure 4-4). Additional, ship simulations are recommended during the PED phase to confirm these design dimensions.

4.5.3. Bends

Existing channel bends were evaluated in accordance with design guidance found within EM 1110-2-1613 Hydraulic Design of Deep Draft Navigation Projects for the design vessel(s) identified in this GRR. As shown in Table 4-2 all bends meet current design standards with the exceptions of the bends near Buoys 18 (Sta. 1857+00) and 21 (1775+43) within the Bar Channel. The design guidance calls for cut off curves with widening on the inside of both curves. Based on the findings of the feasibility level ship simulations detailed in Section 6.5 and Attachment A – 3 widening on the outside of the curve near buoy 21 (1775+43), was recommended to allow adequate room for the swept path of inbound vessels that occurs with or without the Pilots setting up for passing. The recommended bend width increases are shown in Table 4-2. The cutoff curve at the bend near Buoy 18 (Sta. 1857+00) will require a total of 200 feet of widening on the inside. This area is naturally deep requiring little associated new work dredging. The cutoff curve at the bend near buoy 21 (1775+43) requires an increase to a total of 150 feet with approximately 50 feet on the inside and an additional 100 feet on the outside (see Figure 4-2 and Figure 4-3). As with the widening for one and two way traffic, additional ship simulations are recommended during the PED to optimize and confirm the design dimensions.

Based on the findings of the feasibility level ship simulations detailed in Section 6.5 and Attachment A – 3, the bends near Buoys 18 (Sta. 1857+00) and 21 (1775+43) were increased in accordance with design guidance found within EM 1110-2-1613 *Hydraulic Design of Deep Draft Navigation Projects* (see Figure 4-2 and Figure 4-3). Widening on the outside of the curve is recommended to allow adequate room for the swept path of inbound vessels that occurs with or without the vessels setting up for passing.

Table 4-2. Bend Width Increases

Bend Location	Deflection Angle deg	Turn Type	Existing Bend Width	Ship Length L (ft)	Ship Beam B (ft)	Radius R (ft)	R/L	Turn Width Increase Factor	Minimum Width for a Single Bend W (ft)	Minimum Bend Width Increase (ft)
Bend @ Sta. 244+66	28.7	Apex	170	1100	158	6,314	5.7	1.0	158	0
Bend @ Sta. 423+47	7.4	Angle	115	1100	158	N/A	N/A	0	0	0
Bend @ Sta. 1055+43	6.1	Angle	100	1100	158	N/A	N/A	0	0	0
Bend @ Sta. 1115+67	6.5	Angle	100	1100	158	N/A	N/A	0	0	0
Bend @ Sta. 1775+43	16.7	Cutoff	100	1100	158	4,279	3.89	1.56	245	150
Bend @ Sta. 1857+00	22.4	Cutoff	0	1100	158	3,575	4.68	1.16	183	200
Bend @ Sta. 2089+53.28	7.7	Angle	190	1100	158	N/A	N/A	0	0	0

4.6. Turning Basin

A feasibility level screening ship simulation was conducted on the Choctaw Pass Turning Basin, located at the northern most part of the Bay Channel, in 2017 to assess the turning basin dimensions as described in Section 6.5 and detailed in Attachment A – 3. During the study, the bar pilots had indicated concern about the turning basin configuration and suggested improvements such as extending the turning basin to the south to accommodate the turning of larger vessels, with lengths of approximately 1,000 feet or greater. Vessels of these dimensions are currently turned on an infrequent basis (approximately 3 per month). When turning they require tug assistance (using at least two tugs), slack tides, mild wind conditions and use of areas outside of the authorized channel. This was confirmed with automatic identification system (AIS) data and through ship simulations for the current design vessel (1,100 feet long).

As discussed in Section 6.5, feasibility level analysis confirmed that the turning basin should be elongated along the prevailing current to provide sufficient room for safe turning of the design vessel. Given time restrains simulations were limited to a 100-foot expansion along the southern boundary and were incorporated in to the simulations utilizing a flat bottom instead of actual bathymetry. While this extension greatly assisted in the safety of completing the turn with the Humber Bridge by allowing for more room for the falling bow, pilots still had to use more of the engine's power than they would typically be comfortable with; as such, further improvements beyond the 100 feet may be required.

For the GRR the extension of the turning basin was laid out with a minimum turning diameter of 1.5 times the design vessel of maximum length (i.e. 1,100 feet) in the direction of prevailing currents in accordance with EM 1110-2-1613 Hydraulic Design of Deep Draft Navigation Projects. This resulted in a recommended increase in the turning basin of 250 feet. As with the widening for one- and two-way traffic, additional ship simulations are recommended during the PED to optimize and confirm the design dimensions.

4.7. Navigation Aids

As a result of the channel improvement measures, some of the U.S. Coast Guard (USCG) aids to navigation (ATON) will be impacted and will require relocation. The USCG is providing relocation requirements for these structures. The quantities of each feature to be relocated are displayed in Table 4-3 and further details of the costs associated with the relocations are provided in Section 7.4.1.

Table 4-3. ATON Relocations

Feature	Deepening (-50 feet MLLW)	Widening for Passing at -50 feet (3 nautical miles)	Bend Easing	Turning Basin Expansion (250 feet)
Ranges	0	0	0	0
Buoys	5	0	0	0
Beacons	13	0	0	0

4.8. Utility Crossings

A search of design files, permit records, and state and Federal databases indicate several utility crossings are located within the project footprint. The locations of these have been identified with details provided in Table 4-4. While most crossing have been verified with as-built drawings, uncertainty associated with utilities remain and cross-referencing of files with permit records are ongoing. The associated risk has been accounted for in the abbreviated risk analysis (ARA) and the cost and schedule risk analysis (CSRA), as generally described in Section 7.1.5, and reflected in the overall cost contingency. Surveys will be conducted during PED to validate the locations and depths of unverified pipeline crossings prior to commencement of any construction efforts. Locations of the pipelines within the project footprint are shown in Figure 4-7 and futher details of pipeline crossing coordination is provided in Appendix D – Real Estate.

Table 4-4. Utility Crossings

Type/Description of Utility	Elevation (feet)	Nearest Channel Stationing	Company	Relocation Requirement
Mobile Lower (ML) St. 1760+10 to 1055+43				
Exxon-Mobil AL-2001-00585 -8 5/8" PIP Gas Flowline, 3 1/2" diesel/dilution water pipeline, & 3 1/2" power cable	-74 feet MLLW at channel	1592+00	Exxon-Mobil Oil Exploration & Producing Southeast, Inc.	Permit Records indicate relocation unlikely Exxon states this is Bundle #14
Exxon-Mobil Hydrocarbon Bundle #22 8” Gas Flowline	-74 feet MLLW at channel	1599+00	Exxon-Mobil Oil Exploration & Producing Southeast, Inc.	As-Builts confirmed no relocation
Exxon-Mobil Pipeline Bundle #14 4.5” & 8 5/8” PIP 3 1/2" diesel/dilution water pipeline, & 3 1/2" power cable	-74 feet MLLW at channel	1600+00	Exxon-Mobil Oil Exploration & Producing Southeast, Inc.	As-Builts confirmed no relocation
Exxon-Mobil Pipeline 6”, 8”, 10” and 12” Offshore Gathering System Pipeline Bundle #9	-74 feet MLLW at channel	1742+00	Exxon-Mobil Oil Exploration & Producing Southeast, Inc.	As-Builts confirmed no relocation
Mobile Bar (MB) Reach St.2189+59 to 1760+10 (i.e. offshore to Bay entrance)				
Submarine Telephone Cables AL-1942-00045	Unknown	1850+00 1860+00	Southern Bell and USCG	Permit Records indicate relocation unlikely
Tenneco AL-1993-02574 Hydrocarbon 20” pipeline	86 feet of coverage at channel	1957+00	Tenneco Gathering Partners	Permit Records indicate relocation unlikely
Exxon Mobil Bundle #15 4” H2O Produce Line	140 MLLW at channel	1975+00	Exxon-Mobil Oil Exploration & Producing Southeast, Inc.	As-Builts confirmed no relocation
Exxon Mobil Gas/Water Bundle #1: 4”, 4”, 4”, 6”, 16” Offshore Gathering System	74 feet MLLW at channel	2057+00	Exxon-Mobil Oil Exploration & Producing Southeast, Inc. (MOEPSI)	As-Builts confirmed no relocation
Fieldwood Energy: 2” Gas Supply Line and 8” Bulk Gas Pipeline	90 feet MLLW at channel	2085+00	Previously Devon Energy Production Co., LP ; Previously Shell Oil; Now owned by Fieldwood	As-Builts confirmed no relocation
PB Oil & Gas BP15362-64 20" Gas pipeline	Unknown	South of Project Limits	BP Oil & Gas	Permit Records indicate relocation unlikely
Note: Uilities are being verified against permit records.				

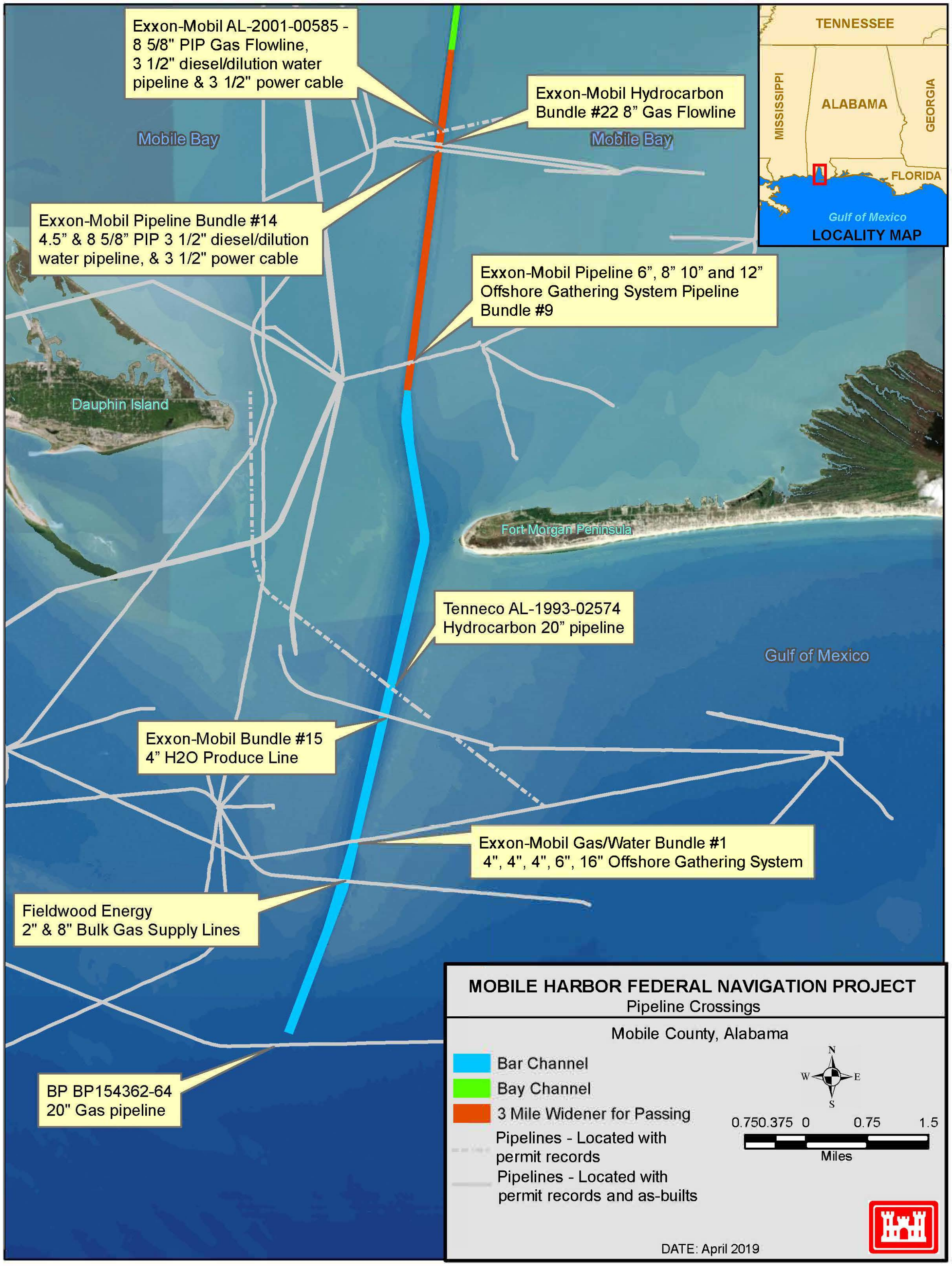


Figure 4-7. Pipeline Crossing Locations

4.9. New Work Dredged Material Quantity

New work quantities for the RP were computed for estimating dredged material placement needs and costs. All calculated dredge volumes were based on hydrographic surveys completed in 2016 following routine maintenance dredging of the channel. The surveys consisted of cross-sections at 100-foot centers along the existing channel. Average end area method calculations of in situ volume made with Microstation Inroads software are summarized in Table 4-5 (no degree of accuracy less than 1,000 cubic yards is implied).

Table 4-5. RP New Work Material Quantities

Channel Segment[1]	Quantity (cy)[2]
River (Sta. 226+16 to 244+66)	260,444
Bay (Sta. 244+66 to 1760+09.28)	15,331,506
Bar (Sta. 1760+09.28 to 2189+59)	5,327,942
3 Mile Widening for Passing (Sta. 1577+82 to 1760+10)	1,368,685
Bend Wideners (Sta.1775+43 and 1854+69)	155,259
Turning Basin (250 foot Expansion to the South)	1,688,864
Total New Work Volumes	**24,132,700**

Note: 1) Station is referenced to existing channel stationing.
2) Quantities include the proposed depths plus advanced maintenance and allowable overdepth.

As shown in Table 4-5, an estimated 24.1 million cubic yards (mcy) of total new work in situ material is contained within the design template for the RP, including depth of 2 feet in the channel and 4 feet within the Choctaw Pass Turning Basin for advance maintenance and 2 feet for allowable overdepth.

4.10. Maintenance Dredged Material Quantity

Approximately 5.9 million cubic yards of sediment are dredged annually as part of the routine maintenance of the Mobile Harbor Federal Navigation Project. Descriptions of the historic maintenance dredging rates and volumes by channel segment are provided in the following paragraphs. A discussion on anticipated changes in those rates and volumes due to a with project condition (e.g., implementation of the RP) is also provided.

4.10.1. Maintenance Dredged Material Quantities (Without-Project)

4.10.1.1. River Channel

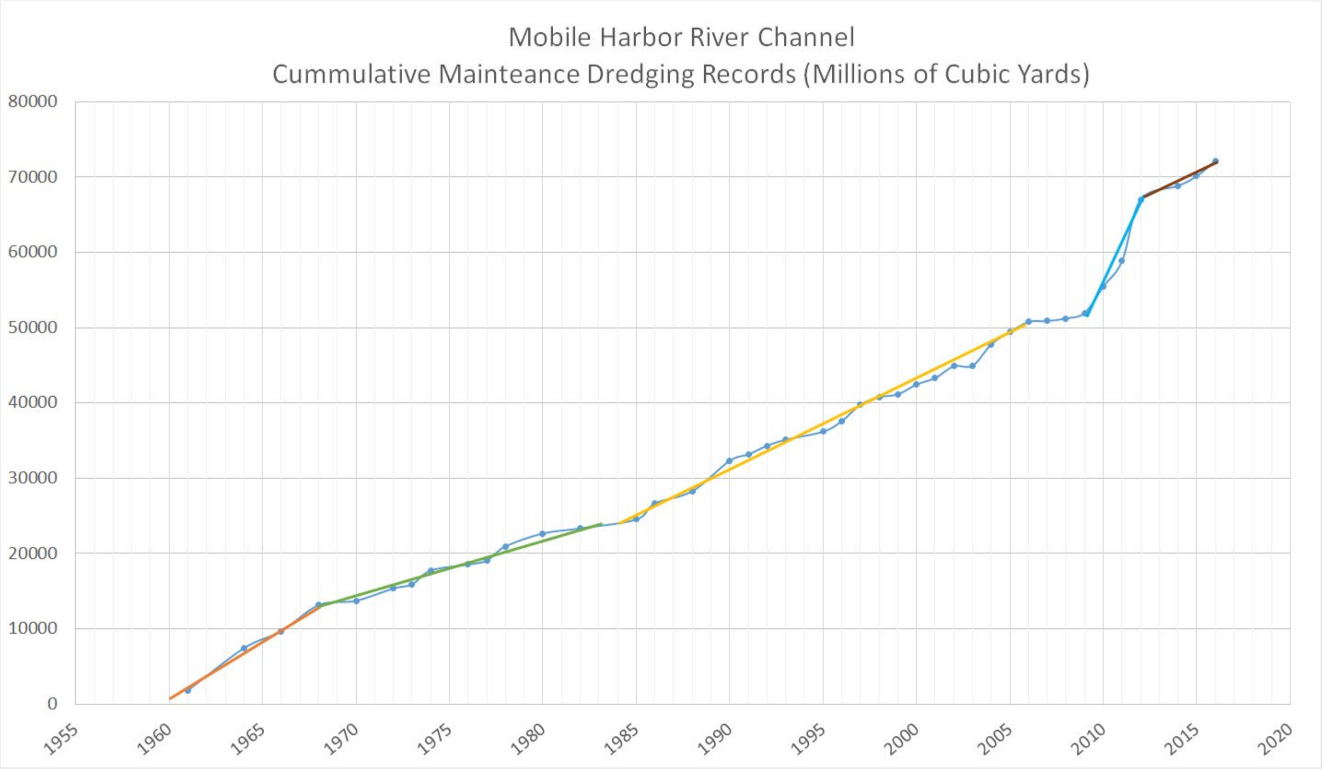
A summary of dredge history for the River Channel is provided in Table 4-6 and the cumulative maintenance dredge volumes are shown in Figure 4-8. The dredging history information was taken from Resource Management Group, Inc., 2010 "Guidelines for Sustainable Maintenance Dredging and Long-Term Dredge Material Management of the Mobile River Federal Management of the Mobile River Federal Navigation Project," and updated with USACE, Mobile District dredge records for the River Channel to 2016.

The figure of cumulative maintenance dredge volumes (Figure 4-8) shows fairly consistent rates through time with rates averaging approximately 1.3 million cubic yards per year since the 1960s, with the exception being a short period between 2009 and 2012. The reason for the increase in dredge rate in this time period is unclear but may be associated with the incorporation of some new work dredge volumes into maintenance dredge volume estimates, temporarily altered sediment transport patterns in the channel after completion of channel extensions and/or high river flows events, which occurred during this time period.

Table 4-6. River Channel Dredged Volumes 1961 – 2016

Dates	Maintenance Dredging (cy)	Maintenance Dredging (cy/yr)
1961-1970	15,809,904	1,057,754
1971-1980	9,519,787	1,231,870
1981-1990	11,086,834	1,167,886
1991-2000	10,510,970	1,081,540
2001-2010	9,733,857	1,481,238
2011-2016	13,331,146	2,666,229
1961-2016	72,179,400	1,312,353

Source: Modified from Resource Management Group, Inc., 2010 with records to 2016



Source: Modified from Resource Management Group, Inc., 2010 with records to 2016

Figure 4-8. River Channel Cumulative Maintenance Dredged Volumes (1961 – 2016)

4.10.1.2. Bay Channel

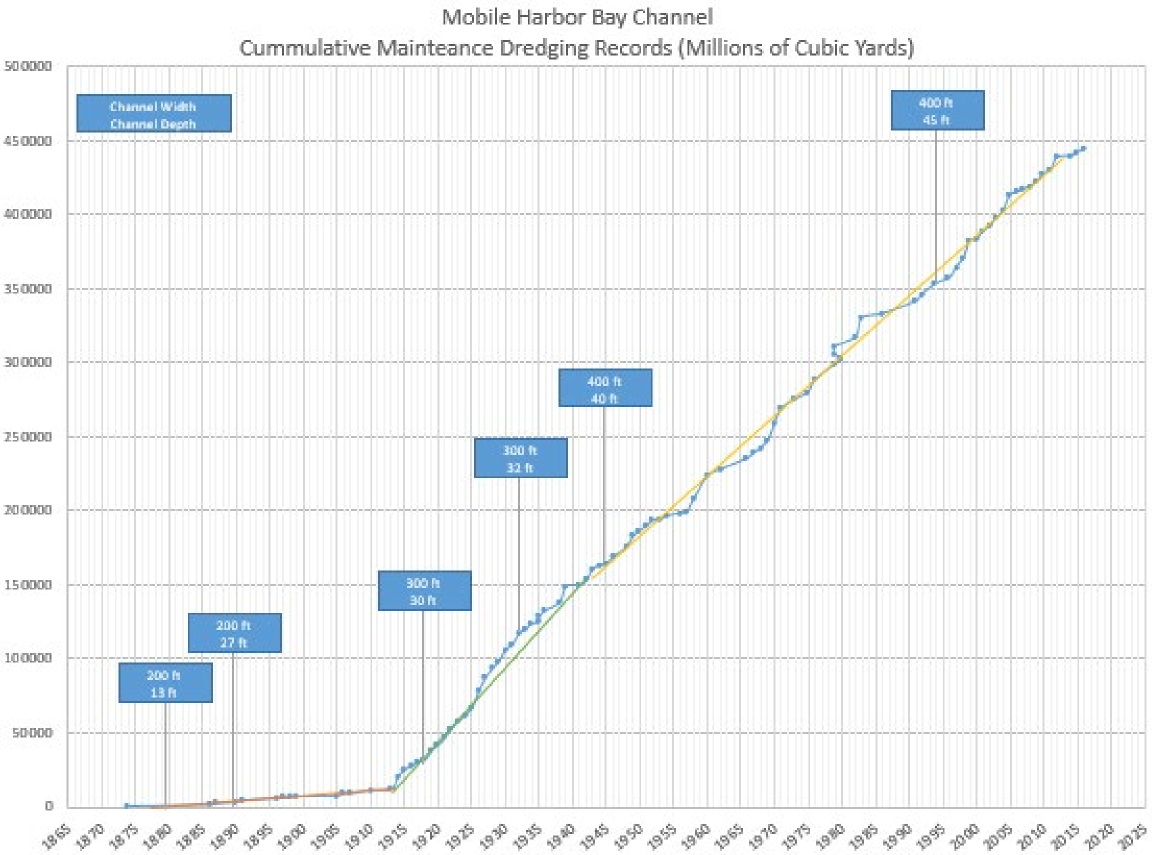
A summary of the dredge history for the Bay Channel is provided in Table 4-7 and the cumulative maintenance dredge volumes are displayed in Figure 4-9. Dredging history was taken from Byrnes, et. al (2012) “Sediment Dynamics in Mobile Bay, Alabama: Development of an Operational Sediment Budget,” and updated with USACE, Mobile District dredging records to 2016.

The figure of cumulative maintenance dredge volumes (Figure 4-8) shows varying dredge rates through time, with rates averaging approximately four million cubic yards per year since the Bay Channel was deepened to -45 feet MLLW in 1988 to 1990. Of relevance is the fairly consistent dredge rate since 1964 despite increases in channel dimensions during the time period and changes in dredge material placement practices inside the bay.

Table 4-7. Summary of Dredging History for the Mobile Bay Channel (1870-2016)

Channel Dimensions (ft)	New Work Dredging Dates	New Work (cy)	Maintenance Dredging Dates	Maintenance (cy)
13 x 200	September 20, 1870 to September 1876	1,217,869	September 1876 June 30, 1885	0
17 x 200	February 19, 1881 to June 30, 1885	4,724,704	June 30, 1885 to October 3, 1895	3,236,420 (315,441 cy/yr)
23 x 280	October 1888 to October 3, 1895	20,428,577	October 3, 1895 to July 12, 1909	5,717,644 (415,225 cy/yr)
23 x 100	June 26, 1899 to July 12, 1909	17,673,578	July 12, 1909 to August 15, 1913	2,264,298 (557,709 cy/yr)
27 x 200	January 6, 1911 to August 15, 1913	14,231,311	August 15, 1913 to July 25, 1926	66,700,043 (5,150,582 cy/yr)
30 x 300	September 10, 1918 to July 25, 1926	14,712,024	July 25, 1926 to July 19, 1933	38,607,404 (5,531,147 cy/yr)
32 x 300	1932 to July 19, 1933	7,291,046	July 19, 1933 to November 10, 1964	106,628,266 (3,405,566 cy/yr)
40 x 400	January 27, 1956 to November 10, 1964	54,106,804	November 10, 1964 to July 3, 1989	108,945,745 4,419,706
45 x 400	October 24, 1987 to July 3, 1989		July 3, 1989 to October 3, 2016	109,911,136 (4,070,783 cy/yr)

Source: Modified from Byrnes, et. al., 2012



Source: Modified from Byrnes, et. al., 2012

Figure 4-9. Bay Channel Cumulative Maintenance Dredged Volumes (1904 – 2015)

4.10.1.3. Bar Channel

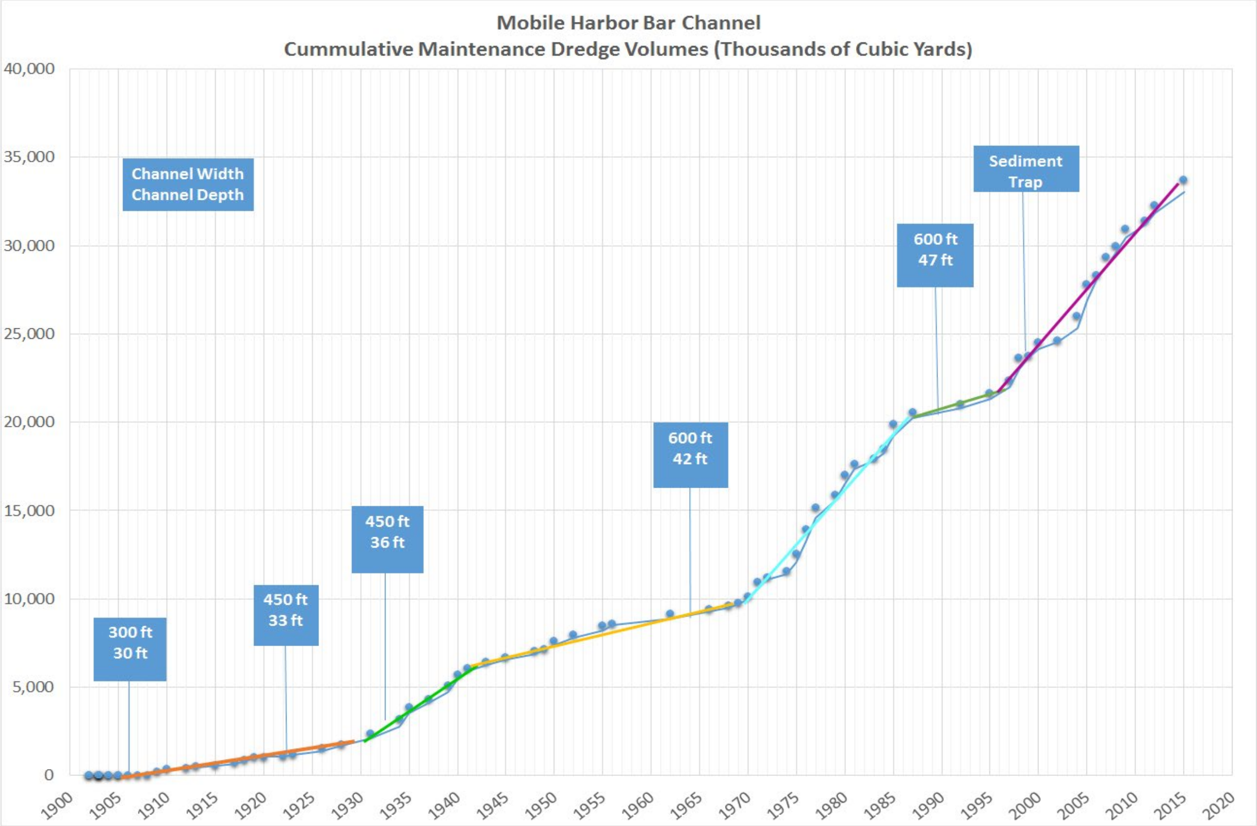
A summary of dredging history for the Bar Channel is provided in Table 4-8 and the cumulative maintenance dredge volumes are shown in Figure 4-10. The dredging history information was taken from Byrnes, et. al (2008) “Evaluation of Channel Dredging on Shoreline Response at and Adjacent to Mobile Pass, Alabama” and updated with USACE, Mobile District dredge records for the Bar Channel through 2015. No dredging has occurred on the Bar Channel since that time (i.e., 2015).

The figure of cumulative maintenance dredge volumes shows varying dredge rates through time, with rates averaging approximately 525,000 cubic yards/year since the Bar Channel was deepened to -47 feet MLLW in 1990. Since 1995, an increase in dredging rate to roughly 624,000 cubic yards per year is observed in the data. Of relevance to this later time period are the number of tropical storm events with significant water level response that impacted the area. This time period includes 7 of the top 10 hurricanes, which produced the highest water levels recorded at NOAA’s long-term Dauphin Island station 8735180 (see Figure 2-13).

Table 4-8. Summary of Dredging History for the Bar Channel (1904 – 2015)

Date (Authorized Dimensions)	New Work (cy)	Maintenance Dredging (cy)
May 1904 to October 1913 (30 ft deep, 300 ft wide)	787,304	529,727 (58,900 cy/yr)
October 1913 to June 1924 (33 ft deep, 450 ft wide)	1,078,426	651,236 (59,200 cy/yr)
June 1924 to August 1934 (36 ft deep, 450 ft wide)	685,171	2,012,611 (201,300 cy/yr)
August 1934 to July 1965 (42 ft deep, 600 ft wide)	3,510,878	5,944,787 (191,800 cy/yr)
July 1965 to April 1990 (47 ft deep, 600 ft wide)	6,755,352	11,422,278 (456,900 cy/yr)
April 1990 to September 1999 (47 ft deep, 600 ft wide)	3,061,598	3,204,170 (356,00 cy/yr)
September 1999 to 2015 (47 ft deep, 600 ft wide, sediment trap)	0	9,951,641 (622,000 cy/yr)

Source: Modified from Byrnes, et. al., 2008



Source: Modified from Byrnes, et. al., 2008

Figure 4-10. Bar Channel Cumulative Maintenance Dredge Volumes (1904 – 2015)

4.10.2. Maintenance Dredged Material Quantities (With-Project Conditions)

Existing, annual maintenance dredging of the Mobile River, Bay, and Bar Channels totals approximately 1.3, 4.1 and 0.5 million cubic yards, respectively. An analysis of future, with-project dredging requirements was performed for each measure detailed in Section 7 of this appendix.

Two methods for determining the quantity of future, with-project dredging sediments were considered: the perimeter method and the volume deficit method. The first method assumes that, over time, the average annual increase in dredging is directly proportional to the increased channel perimeter (Trawle, M.J., 1981). The volume deficit method (Rosati, J., 2005) uses an empirical equation developed by regression methods that predicts an increase in deposition based on the change from historically stable dimensions. The volume deficit method is most applicable to coastal inlets.

In recognition that sedimentation processes can be exceedingly complex and potentially influenced by a number of factors, the use of area and perimeter methods are not recommended by some authors (e.g., Trawle, M.J., 1981) but, lacking other methods, they are widely used in practice to generate preliminary with-project dredging estimates. Some shortcomings of these methods may be overcome by sub-dividing the channel to physically and geometrically similar sections, applying the equations to each, weighting the results by reach length, and summing the results, as was done here. Given that sedimentation in Mobile Bay is greatly influenced by riverine and estuarine processes, hydrodynamic and numerical sedimentation modeling studies were also employed for the present study. These exercises are discussed generally in Section 6.3 and further details are provided in Attachments A – 1 and A – 2 of this appendix. The final estimates of shoaling will incorporate the output from the sediment transport modeling efforts.

Given historic average annual dredging quantities detailed in Section 4.6.1, the ‘modified’ perimeter method and volume deficit methods were used to predict future maintenance requirements. Results for the RP are shown in Table 4-9 and agree reasonably well with the sediment transport modeling results, which predict 5 to 15 percent increases.

Table 4-9. Estimated Future Maintenance Dredging for the RP

Channel Segment	Existing O&M Quantity (cy/yr)	RP Future O&M Quantity (cy/yr)
River (Sta. 226+16 to 244+66)	99,000	104,000
Bay (Sta. 244+66 to 1760+09.28)	4,071,000	4,519,000
Bar (Sta. 1760+10 to 2189+59)	525,000	583,000
3 Mile Widening for Passing (Sta. 1577+82 to 1760+10)	82,000	94,300
Choctaw Turning Basin (250 foot Expansion to the South)	82,000	88,600
Total O&M Quantities	**4,859,000**	**5,388,900**

4.11. Dredged Material Management

As discussed in Section 4.9, approximately 24.1 million cubic yards of "new work" material will need to be dredged to construct the RP for the Mobile Harbor Federal Navigation Project. In addition, increases of 5 to 15% in maintenance dredging volumes are anticipated post-implementation. For reference of scale, approximately 5.9 million cubic yards of sediment are currently dredged annually as part of the routine maintenance of the project (see Section 4.10 for further information). The details of dredged material placement options for the new work construction and future maintenance operations are provided in the following paragraphs.

4.11.1. New Work Material Placement Options

Several sites were evaluated for potential placement of new work material for the RP. These included six locations in a relic shell mined area within the bay for the placement of mixed sands, silts, and clays dredged from the River and Bay Channels; the ODMDS, including an expansion of the site, for placement of mixed sand, silts, and clays within the River, Bay and Bar segments (see Figure 4-11); and the SIBUA, including a northwest extension, for any potential new work sand sources from the Bar Channel. Details of these areas are provided in the following paragraphs. The quantities and placement locations of new work dredged material described represent the least costly placement alternative that is consistent with sound engineering practices and meets all Federal environmental requirements (i.e., the Federal Standard).

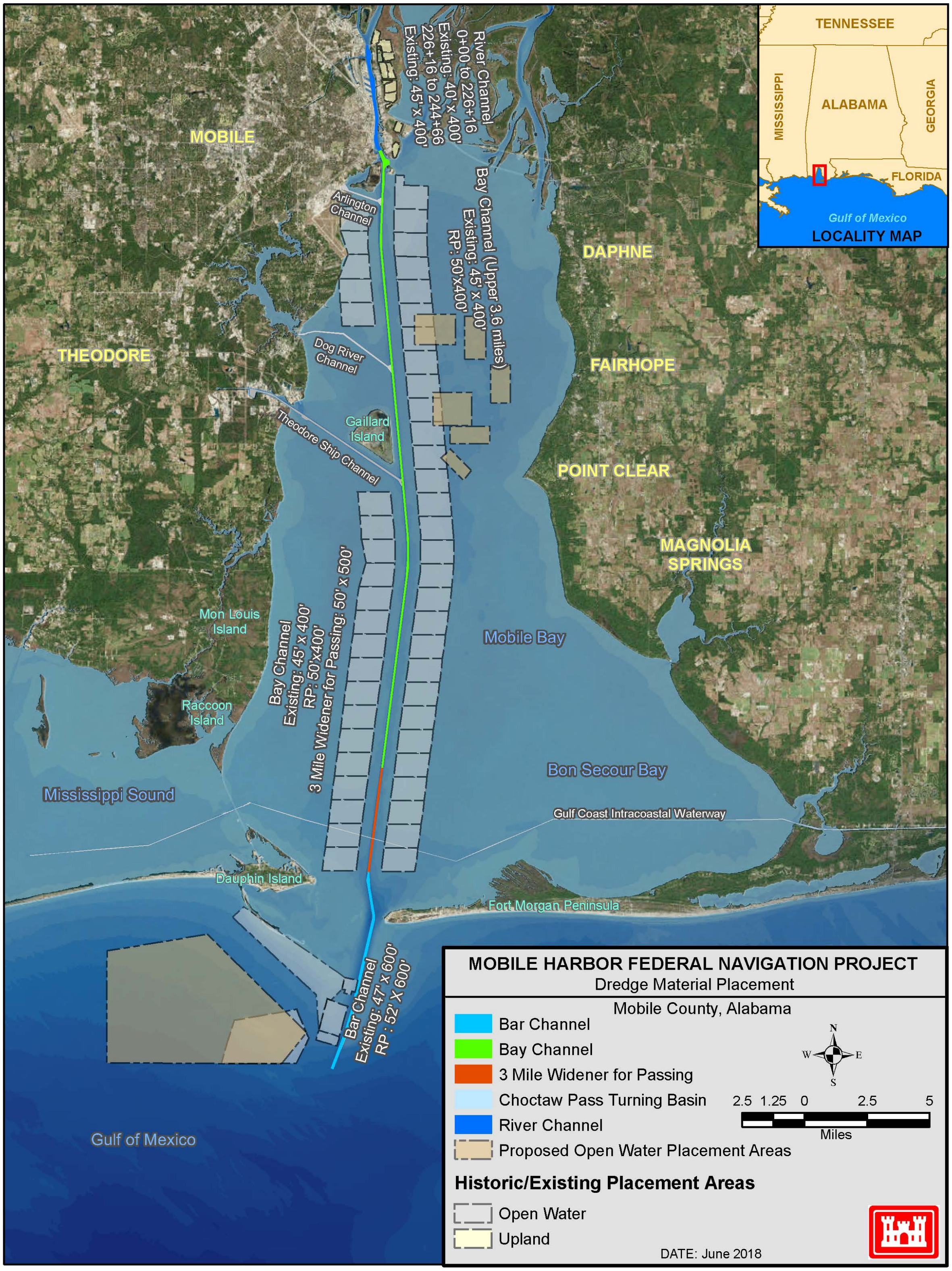


Figure 4-11. Dredge Material Placement Site Overview

4.11.1.1. Relic Shell Mined Area

The Relic Shell Mined Area is located to the northeast of Gaillard Island on the eastern side of the ship channel as shown in Figure 4-12. The proposed placement within this site is the result of beneficial use discussions with the cooperating agencies where it was suggested that the USACE, Mobile District conduct open bay placement of the dredged material in strategic areas of the bay in an effort to restore sediment to the system and improve bay bottom conditions.

Approximately 5.5 million cubic yards of new work material are anticipated to be placed in the Relic Shell Mined Area. Site selection and volume estimates for the six locations in the Relic Shell Mined Area (see Figure 4-12) were based on NOAA compiled surveys within the area between 1960 and 1961 and 1984 and 1987. The potential placement areas were laid out in sections where there were disturbances from historic mining of relic shell within the bay with 15-foot depths or greater based on the combined surveys from 1960/61 and 1984/87. These areas encompass approximately 4,100 acres and, assuming a layered placement in these areas, they have capacity to accommodate approximately 5.5 million cubic yards of new work material. Existing depths within these sites generally range from 10 to 14 feet.

Placement is anticipated to be accomplished with a maximum thickness of approximately three feet due to the characteristics of the new work material; however, the volume of material planned to be placed in the sites is based on an average material thickness of 1.5 feet over the sites. The quantity of material planned for placement in each area is shown in Table 4-10. Detailed hydrographic surveys of these sites will be collected during the PED phase.

Table 4-10. Relic Shell Mined Area

	Area (acres)	Placement Volume (cy) Placement Thickness assumed 1.5 foot[2]	Bulking Factor = 1.2 O&M, 1.8 New Work	Approximate Distance from Channel (ft) Center to Placement Center
A[1]			0	10,000
B	920	2,226,000	1,237,000	18,000
C	1306	3,161,000	1,756,000	12,000
D	770	1,863,000	1,035,000	22,000
E	702	1,699,000	944,000	16,000
F	403	975,000	542,000	12,000
Total	**4101**	**9,924,000**	**5,514,000**	

Notes:
1) Area A is located within the bounds of existing open water placement sites used for operation and maintenance material and was therefore not considered here for new work.
2) The volumes are computed based on a relative difference in surface area. These placement volumes do not reflect the available capacity based on the 3 foot tolerance.

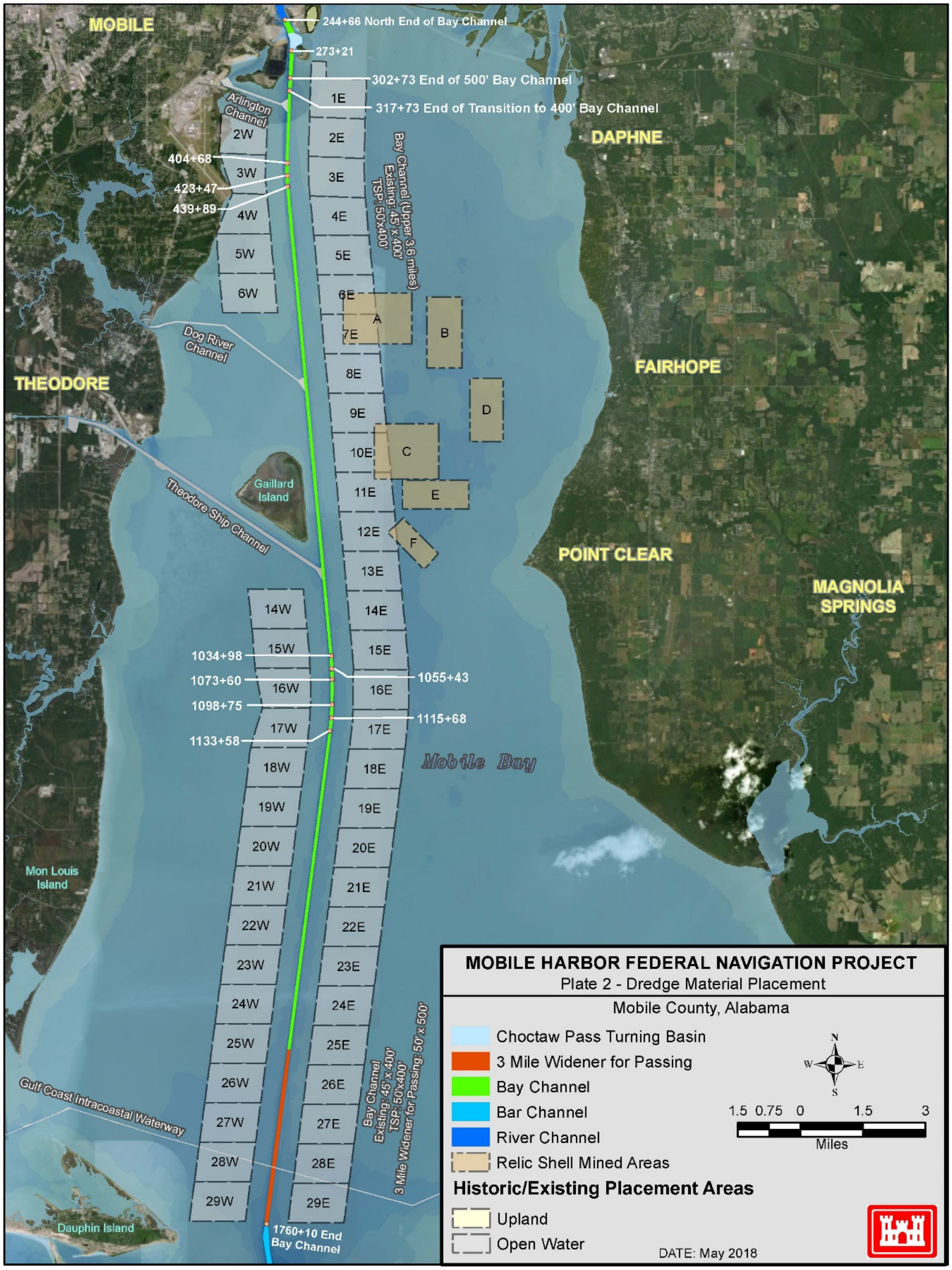


Figure 4-12. Relic Shell Mined Area

4.11.1.2. Expanded Ocean Dredged Material Disposal Site (ODMDS)

Approximately 18.6 million cubic yards of new work material (24.1 million total volume minus the 5.5 million cubic yards going in the Relic Shell Mined Area) are anticipated to be placed in the expanded ODMDS. The existing approximately 4,000 acre ODMDS was selected by the USACE, Mobile District, under Section 103 of the Marine Protection Research and Sanctuaries Act (MPRSA). The site is currently being expanded to accommodate future dredged material placement needs for the Mobile Harbor Federal Navigation Project and this effort is expected to be completed prior to release of the final Mobile Harbor GRR. Additional information and details regarding the status of the ongoing coordination is provided in Section 3.7.3 of Appendix C.

The capacities of the existing ODMDS and the proposed expansion were obtained from ongoing environmental coordination documents between the USACE, Mobile District, and the Environmental Protection Agency (EPA) and are provided in Table 4-11. As shown, an available/remaining capacity of approximately 52 million cubic yards is expected after 20 years of future placement of maintenance material in the site. This volume is more than adequate to handle the anticipated 18.6 million cubic yards of new work material that will be placed in the site during construction of the RP. The boundaries of the current and expanded area are shown in Figure 4-13. (Note: The approximately 1.7 million cubic yards of new work material to be dredged for the Choctaw Pass Turning Basin expansion, as shown in Table 4-5, are anticipated to be predominantly clean sands with some pockets of silty sands. For conservative cost and placement location planning purposes, this quantity is included in the 18.6 million cubic yards slated for the ODMDS; however, it could be considered for beneficial use at other locations, if deemed suitable. The suitability of this material will be investigated further during the Preconstruction Engineering and Design (PED) Phase of this project.)

Table 4-11. Placement Capacity within the Expanded ODMDS

Ocean Dredged Material Disposal Sites	Area (Acres)	Volume (CY)[1]
Current ODMDS	4,017	20,000,000
Expanded ODMDS	20,341	260,000,000
Total	**24,358**	**280,000,000**
20 year Capacity Need		228,000,000
Remaining Capacity after 20 Years		**52,000,000**

Note: Volume estimates including capacity needs were taken from ongoing environmental coordination documents with EPA.

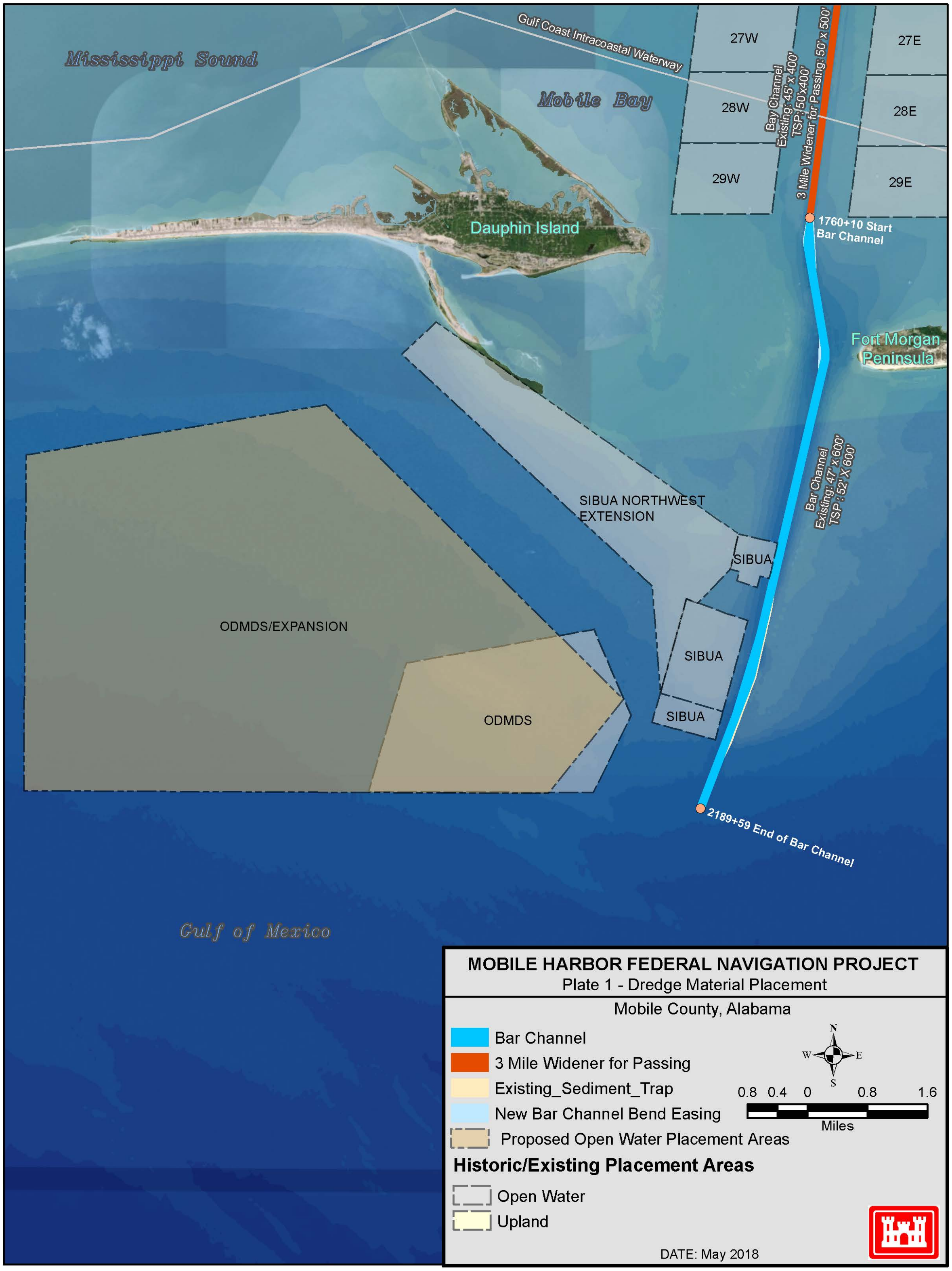


Figure 4-13. Expanded ODMDS Boundary

4.11.1.3. Sand Island Beneficial Use Area (SIBUA) and Northwest Extension for the Bar Channel

Currently, no new work material from the Bar Channel is anticipated to be placed in SIBUA or the Northwest Extension (see Figure 4-14) as part of the RP. The new work material in the Bar Channel is predominately clays and silts with some intermixed sands, and, per the geotechnical information obtained to-date, none of this material meets the suitability criteria for placement in SIBUA. Placement of new work material in SIBUA or the northwest extension will be considered in the future if sandy material is identified during additional geotechnical investigations of the Bar Channel.

4.11.2. Future Maintenance Material Placement Options

Material dredged as part of maintenance operations for the future with-project conditions will continue to be placed in a combination of upland sites adjacent to the River Channel; open water placement sites within the bay; the SIBUA on the ebb tidal shoal, including the northwestward extension of the site; and the ODMDS in both the current limits and a future expansion area. Details of these areas are provided in the following paragraphs. The quantities and placement locations of maintenance dredged material described represent the least costly placement alternative that is consistent with sound engineering practices and meets all Federal environmental requirements (i.e., the Federal Standard).

4.11.2.1. Upland Dredged Material Placement Sites for the River Channel

Material dredged as part of the routine maintenance of the River Channel (primarily fine-grained sediments) is placed in the upland dredged material placement sites located east of the River Channel, as shown in Figure 1-5. Existing capacity estimates for these sites were obtained from Resource Management Group, Inc., 2010 “Guidelines for Sustainable Maintenance Dredging and Long-Term Dredge Material Management of the Mobile River Federal Management of the Mobile River Federal Navigation Project,” and updated with USACE, Mobile District dredge records for the River Channel to 2016. Volume estimates were evaluated in an effort to determine if sufficient capacity exists to accommodate projected increases in routine maintenance material associated with the RP. These estimates are shown in Table 4-12. Per the estimates, adequate capacity exists to support the placement of maintenance material dredged from the River Channel over the next 20 years.

Table 4-12. Upland Dredged Material Placement Site Capacities

	Area (Acres)[1]	Projected Maximum Dike Elevation (ft)[1]	Total Idealized Volumetric Capacity (CY)[1,2]
North Blakeley	69	50	3,172,000
Mud Lake 6	70	46	3,388,000
Mud Lake 7	129	46	8,562,000
South Blakeley	196	65	12,087,000
North Pinto	48	47	3,434,000
Totals	**512**		**30,644,000**
20 year Project Capacity Needs of River Channel (1.3 mcy/year)			26,247,000
Remaining Capacity After 20 Years			4,396,000

1) Taken from Table 7 of Resource Management Group, Inc., 2010 updated with USACE dredge material placement records through 2016.
2) Idealized volumetric capacity includes interior capacity plus the volume to build projected maximum dike height cross-sections minus the volume in the spur dikes.

Source: *Modified from Resource Management Group, Inc., 2010.*

4.11.2.2. Open Water Dredged Material Placement Sites for the Bay Channel

A portion of the material dredged as part of the routine maintenance of the Bay Channel (primarily fine-grained sediments) is currently placed in the open water placement areas adjacent to the channel, as shown in Figure 1-3 and Figure 4-11 (the remaining material is placed in the ODMDS). The areas were evaluated in an effort to determine if capacity exists for future maintenance associated with the RP. Bathymetric surveys of these areas were obtained from the USACE, Mobile District Irvington Site Office and site capacities were calculated based on the most recent survey data available at the time of analysis (2012-2015) (see Table 4-13). The available survey data were limited to areas designated for placement in the survey year within the placement site, rather than over the entire site. Additional data for the sites were obtained from NOAA nautical charts. A minus four (-4) feet MLLW upper elevation limitation was applied over the sites before analyzing capacity. Per results of the analysis, adequate capacity using conservative estimates of capacity as detailed in Table 4-13 exists to support the placement of maintenance material dredged from the Bay Channel over the next 20 years.

Table 4-13. Open Water Dredged Material Placement Site Capacity

Open Water Placement Sites	Area (Acres)	Volume Capacity (CY)[1]
Placement Sites 1 - 29	21,560	140,974,000
20 Year Capacity Needs of the Bay Channel (4.5 mcy/year)		90,380,000
Capacity Remaining after 20 Years		**50,594,000**

Note: 1) Conservative estimate as no sediment transport from the sites were incorporated into the capacity estimates.
2) Conservative estimate as it assumes all material dredged from the bay will be placed in open water sites. In actual practice open water sites in the bay and the ODMDS are used.

4.11.2.3. Sand Island Beneficial Use Area (SIBUA) for the Bar Channel

Material dredged as part of the routine maintenance of the Bar Channel (primarily sandy sediments) is placed in SIBUA as a means of bypassing sand dredged from the Bar Channel to the downdrift littoral system. Sand Island Beneficial Use Area (SIBUA), located west of the channel on the ebb tidal shoal (see Figure 1-2), was evaluated to determine whether capacity exists to accommodate projected increases in maintenance dredged material associated with implementation of the RP. An additional level of analysis to evaluate transport rates leaving SIBUA as well as capacity available within depth constraints of dredging equipment were made in an effort to balance safe and efficient dredge material placement practices, while ensuring sandy material dredged from the Bar Channel is maintained within the littoral system.

A bathymetric change analysis was conducted on the ebb tidal shoal over a time period from 1987-1988 to 2018 using NOAA 1987-1988, NOAA 2014, USGS/USACE 2015, and USACE 2009-2018 survey datasets. Particular focus was placed on SIBUA and the sediment transport pathways feeding the Sand/Pelican Island complex. This analysis shows sand has been transported out of SIBUA at rate of approximately 260,000 cubic yards per year over the time period of 2009 to 2018. This material has primarily continued to move northwest to join in with the shallow platform associated with Sand and Pelican Islands (see Figure 4-14).

The main source of sedimentation within the Bar Channel is the dominate east to west sediment transport along Morgan Peninsula onto the offshore ebb shoal of the inlet complex forming the Dixie Bar. As discussed in Section 4.10.1.3, dredging of the Bar Channel since the last deepening has ranged from a longer-term average of 525,000 cubic yards to a recent shorter-term average of 624,000 cubic yards. The rate of dredged material placement has been higher than the rate of transport out of SIBUA, leading to decreased depths and restricted use of SIBUA for dredged material placement by a large hopper dredge to the southernmost extents of the site. An estimate using USACE 2018 surveys (see Table 4-14) and depth ranges appliciable to dredge equipment shows the majority of the site capacity is within the shallower depths, ultimately limiting the use of the existing SIBUA boundaries over the next 20 years to hydraulic cutter heads and smaller hopper dredge fleet. The volume in Table 4-14 for -25 foot depths and deeper represents the capacity available to the majority of the U.S. flagged fleet of hopper dredges. Depths between -20 feet and -25 feet represent usable bottom dump capacity for smaller hopper dredges. Placement in depths shallower then -20 feet represents capacity available for hopper pump-out or hydraulic cutterhead dredges.

In an effort to ensure adequate placement capacity for maintenance dredging of the Bar Channel, the USACE, Mobile District has recently completed modifications to extend the SIBUA beyond its existing boundaries to the northwest following the shoal and pathway of sediment transport towards Dauphin Island. A feasibility analyses based on the concept of “outer” and “inner” closure depth limits was conduted to assist in delineation of the SIBUA Northwest Extension. Using the Hellermier equation for inner and outer depths of closure and Wave Information Study (WIS) hindcast wave data from station 73153, the annual outer depth of closure ranged between 18 to 27 feet, for the available period of record from 1988 to 2016 as documented in CHENT-VI-45 Calculating *Depth of Closure Using WIS Hindcast Data.* During this same time period the inner depth of closure ranged between 15 to 26 feet, with a cumulative inner depth of closure around 24 feet. The SIBUA Northwest extension was laid out with these limits and the use of bathymetric change analysis on the ebb tidal shoal over a time period from 1987-1988 to 2018 using NOAA 1987-1988, NOAA 2014, USGS/USACE 2015, and USACE 2009-2018 survey datasets to ensure the site is located within the active region of the nearshore. The current depths targeted for placement within the proposed Northwest Extension are -15 to -27 feet mean lower low water (MLLW). As shown in Table 4-14 below, the majority of available capacity lies above the cumulative inner depth of closure.

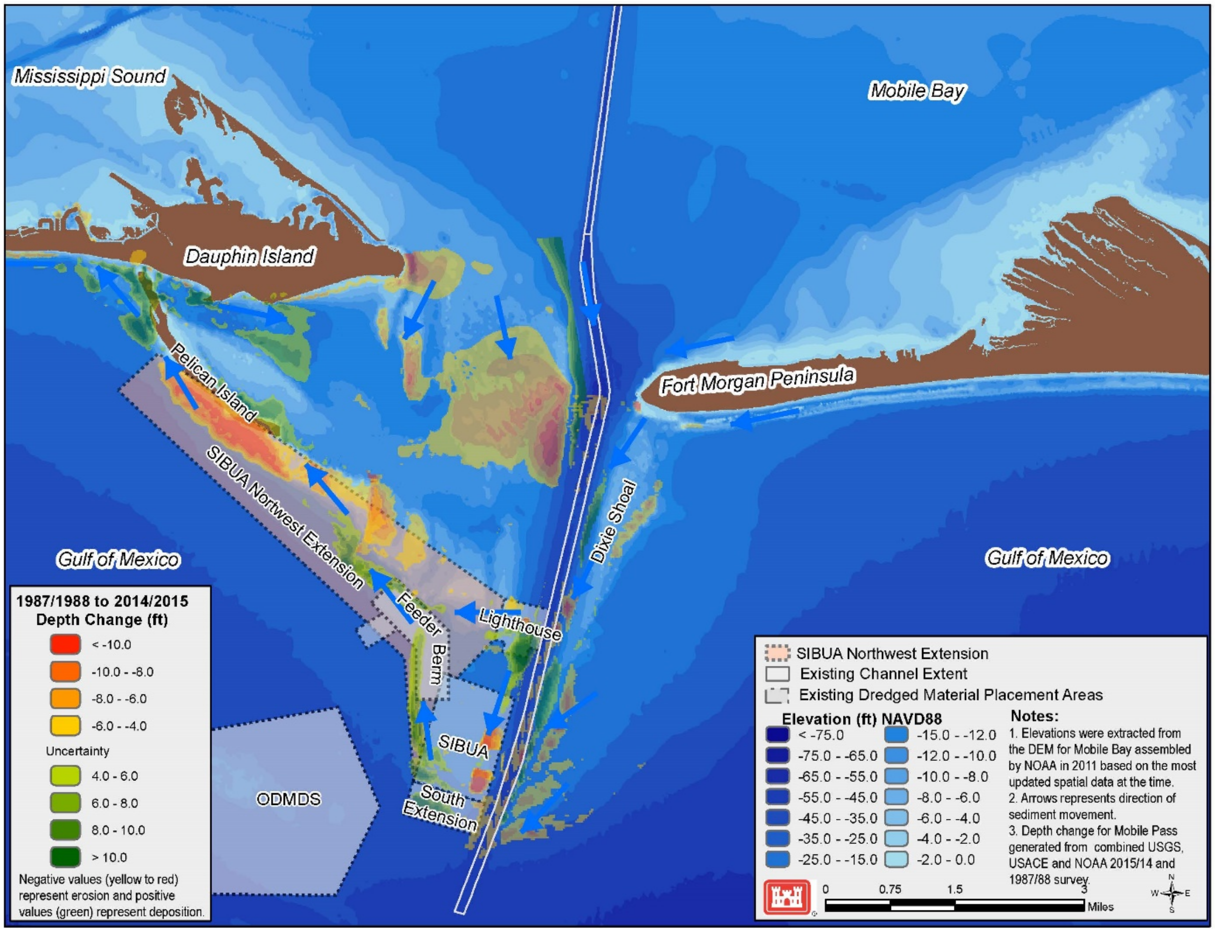
A water quality certification (WQC) and coastal zone consistency (CZC) determination was received from ADEM on November 15, 2018 for the SIBUA Northwest Extension. No adverse impacts to Dauphin Island resulting from the expansion are expected. Figure 4-14 and Table 4-14 provide the limits of the Northwest Extension as well as the estimated available capacity volumes. Per the estimates, adequate capacity exists to support the placement of maintenance material dredged from the Bar Channel over the next 20 years.

Table 4-14. Sand Island Beneficial Use Area Capacity

	2018 Volume (CY) Below -15' MLLW(5)	2018 Volume (CY) Below -20' MLLW(5)	2018 Volume (CY) Below -25' MLLW (5)
SIBUA	7,487,906	2,202,690	644,437
SIBUA South Extension	4,679,635	2,891,301	1,415,534
SIBUA Lighthouse(3)	1,320,708	682,208	309,517
Total 2018 Capacity	**13,488,249**	**5,776,199**	**2,369,488**
20 Year Net Erosion out of SIBUA (260,000 cy/yr)	5,200,000	5,200,000	5,200,000
20 Year Projected Capacity Needs (624,000 cy/yr + 15% increase) (4)	15,272,000	15,272,000	15,272,000
Remaining Capacity after 20 years	**3,416,249**	**-4,295,801**	**-7,702,512**
SIBUA Northwest Extension	9,294,614	6,241,179	1,014,424

NOTES:

(1) Capacity estimates displayed in this table do not account for uncertainty in volumetric change.
(2) Capacity estimates are rough order of magnitude assuming vertical side slopes. Final volume estimates will account for side slopes of the fill, which will likely result in reduced capacity.
(3) 2018 survey data did not cover the eastern section of SIBUA Lighthouse Site therefore volume estimates for this area are based on NOAA 2014 Survey Data
(4) Capacity needs are based on a conservate estimate using the higher end of dredging rates and percent increase.
(5) The volume associated with the -25' depth and deeper represents the capacity available to the majority of the U.S. flagged fleet of hopper dredges. Depths between -20' and -25' reprenent usable bottom dump capacity. Depths shallower then -20' represents capacity available for hopper pump-out or hydraulic cutterhead dredges.



Notes:
1. Elevations were extracted from the DEM for Mobile Bay assembled by NOAA in 2011 based on the most updated spatial data at the time.
2. Arrows represents direction of sediment movement.
3. Depth change for Mobile Pass generated from combined USGS, USACE and NOAA 2015/14 and 1987/88 survey.

Figure 4-14. SIBUA and Northwest Extension Limits

4.11.2.3.1. Future Mointoring and Management of SIBUA

The USACE, Mobile District, will budget for additional funds to place material in shallower areas within the existing SIBUA and the SIBUA Northwest Extension. The area will be proactively monitored and managed by performing semiannual hydrographic surveys to ensure material is placed in the best locations possible given the availability of funds and capabilities of the dredging industry. Hydrographic surveys of placement areas every 6 months, along with a comprehensive survey of the complex annually, will be conducted to gain a better understanding of future capacities and coastal processes that move sediment within the region. If additional funds are not available, the USACE, Mobile District will place material within the existing SIBUA and Northwest Extension, as necessary, to ensure reliability of the navigation channel.

4.11.2.4. Expanded ODMDS

The expanded ODMDS, which can be used for the placement of maintenance material in the future, is discussed in in Section 4.11.1.2 and shown in Figure 4-13. As shown in Table 4-13, adequate capacity will exist once the expansion is finalized.

SECTION 5. GEOTECHNICAL INVESTIGATIONS

The geotechnical and geologic information used for the feasibility-level analysis to support identification of the RP for the Mobile Harbor GRR was obtained from multiple subsurface investigations dating back to 1963 and from other existing data sources. Characterizations of the geologic and geotechnical conditions of the study area based on these data sets are presented in the following sections. No geotechnical investigations were conducted during the feasibility phase, however, additional investigations will be performed asa part of the PED phase.

5.1. Site Geology

Southern Mobile County and Mobile Bay are located in the Southern Pine Hills and Coastal Lowlands subdivision of the East Gulf Coastal Plain Section of the Coastal Plain Province. This region ranges in elevation from sea level to about 100 feet and is characterized by low, smooth hills developed on Pleistocene and Holocene terrace, alluvial, and beach deposits. These deposits overlie older Miocene and Pliocene beds which form the high ground that flanks Mobile to the east and west. Generally the Holocene alluvial deposits are less than 70 feet thick except in the Mobile River Basin where they are as much as 150 feet thick. Pleistocene and Holocene deposits consist of white, gray, orange, and brown sand strata with interbedded layers of clay and sandy clay. These are partly carbonaceous, very fine- to coarse-grained gravelly sands. Pleistocene sediments were deposited about 2.6 million to 11.7 thousand years ago. Holocene sediments were deposited after the end of the Pleistocene era from about 11.7 thousand years ago to the present.

5.2. Subsurface Investigations

Historical soil borings drilled within the River Channel, Bay Channel, Bar Channel, and Choctaw Pass Turning Basin were reviewed to characterize the soil conditions of the study area. They were collected over many different investigations, dating back to 1963. The USACE, Mobile District conducted geotechnical investigations in 1963-1964, 1972, and in 1982-1984 within the limits of the channel. Thompson Engineering conducted the initial geotechnical investigation in the vicinity of the Turning Basin in 1986 as part of an investigation for Mobile Naval Homeport Facilities. Additional investigations were conducted by USACE in the Turning Basin in 2006 and 2009 as part of the Turning Basin expansion in 2009. A study detailing the nature of fluid muds was also reviewed to understand the nature of the dredged maintenance material. The horizontal and vertical datum referenced on the boring logs vary. Boring logs were not changed to reflect a consistent datum; however, the datum were adjusted to NAD83 and MLLW to compare boring locations and elevations consistently across multiple drilling efforts. A material property description of all new work material, as interpretted from the boring logs, is detailed in the Subsurface Conditions section. Boring logs, location maps, and lab test data for all borings mentioned below are included in Attachment A-6 of this Appendix.

5.2.1. Subsurface Investigations of the Bay and Bar Channels

5.2.1.1. 1963 to 1964 Subsurface Investigation

The USACE, Mobile District collected 78 splitspoon borings as part of a subsurface investigation in 1963 to 1964. The borings were identified as SS-29 to SS-183, using odd numbers and skipping even numbers (SS-29, SS-31, SS-33, etc.). They were spaced at 2000-foot intervals along the channel alignment and sequentially staggered about the centerline, 275 feet left of the centerline, and 275 right of the centerline. The borings generally penetrated to approximately elevation -51 feet Mean Low Tide (MLT) or Mean Low Water (MLW). This translates to approximately -51.1 feet MLLW. SPT sampling was generally conducted on 5-foot centers unless sand was encountered, in which case, sampling was continuous. This is noticeable in the upper bay in borings SS-29 through SS-59.

Approximate locations for these borings were computed based on the recorded stations and offsets, considering the present channel alignment; however, this station conversion is inexact. It was derived from comparing stations on an overlay of scanned plan drawings with the current channel alignment at only a few comparable locations. The comparable locations were at channel bends, channel intersections, and the Middle Bay lighthouse. The plan and profile drawings showing these borings (USACE, 1980) were revised to include the current channel stationing, including the beginning and ending stations of this proposed project. This information is shown in Attachment A-6.

5.2.1.2. 1972 Subsurface Investigation

The USACE, Mobile District collected eight borings as part of a subsurface investigation in 1972. None of these borings are located within the limits of the project. However, seven borings (SS-3-70, SS-4-70, SS-5-70, CD-2-72, CD-3-72, CD-4-72, and CD-5-72) are within 200 to 500 feet of the edge of the channel. Borings CD-2-72 and CD-3-72 are in the upper bay, and borings CD-4-72 and CD-5-72 are in the lower bay. These borings were sampled using Shelby tubes, taken on 5-foot centers. Materials were classified in the field by observing the soil at each end of the Shelby tube before capping. It is assumed that the tubes were sampled for the purpose of lab testing; however, no lab test data could be found on these soil samples. Borings SS-3-70 through 5-70 were sampled on 5-foot centers by splitspoon, recording both field classification of soils and N-values. Boring elevations were referenced to Mean Sea Level (MSL) for the SS series borings, and while there is no vertical datum recorded for the CD series, it is assumed that the CD series is also referenced to MSL. Borings SS-3-70 through 5-70 and CD-2-72 through

CD-5-72 were advanced to the following elevations, respectively: -151.3 feet (MLLW), -151.0 feet (MLLW), -153.8 feet (MLLW), -49.7 feet (MLLW), -54.5 feet (MLLW), -51.0 feet (MLLW), and -51.0 feet (MLLW).

5.2.1.3. 1982 to 1984 Subsurface Investigation

One hundred seventy-six (176) borings were sampled by the USACE, Mobile District during the 1982 to 1984 subsurface investigation. The investigation explored soils within the channel as well as in possible areas for a new turning basin, anchorage, and a dredged material containment area located near Brookley Field. Of the borings sampled, 54 were within the current study limits to include the channel, the widener, and the bend easing. The borings were sampled via a combination of splitspoon and vibracore. Thirty-seven (37) borings were sampled in the bay (SS-203-84, SS-222-84, VC-1-84 through VC-24-84, VC-1A-84, VC-26-84 through VC-28-84, VC-32-84, VC-36-84, VC-38-84, VC-40-84, VC-42-84, SG-1-82, and SG-2-82), and 17 borings were sampled in the Bar Channel (SG-10-83 through SG-15-83, SG-17-83, SG-19-83 through SG-23-83, SG-30-83, SG-30A-83, and SG-35-83 through SG-37-83). Lab tests were run on various samples of both the vibracore and the splitspoon samples. Testing consisted of Unified Soil Classification System (USCS) lab classifications, gradation analyses, and Atterburg limits for clays and silts. The bottom-of-hole elevations ranged from -59.8 to -73.0 feet (MLLW) in the Bay Channel and -56.6 feet to -74.3 feet (MLLW) in the Bar Channel.

5.2.1.4. 1986 Subsurface Investigation

Thompson Engineering Testing Inc. (TET) completed seven marine soil borings in or near the limits of the Choctaw Pass Turning Basin in April of 1986. These borings were designated M-1 through M-5, MO-1 & MO-2 and penetrated to between 36 feet and 120 feet below the water surface. TET also completed 6 borings on Little Sand Island near the projected limits of the Turning Basin’s south side slope excavation. These are designated B-42 through B-47 and penetrated to elevations ranging between -33.04 and -44.84 feet MLLW. Elevations were referenced to NGVD 29 on the boring logs. All borings were advanced by splitspoon with varying sampling intervals. Borings M-1 through M-5 and B-47 were sampled on 5-foot centers. Borings MO-1 and MO-2 were sampled continuously. The upper 16 feet of borings B-42 through B-46 were sampled on 2.5-foot intervals, and samples were taken on 5-foot intervals thereafter.

5.2.1.5. 2006 and 2009 Subsurface Investigations

The USACE, Mobile District sampled 28 borings as part of a 2006 subsurface investigation to aid in the design of the Choctaw Pass Turning Basin. Twenty-two (22) of the borings were sampled using a splitspoon. These borings were designated as 1-D301-06, 2-D301-06, 5-D301-06, 7-D301-06, 9-D301-06 through 11-D301-06, 13-D301-06 through 15-D301-06, 17-D301-06, 18-D301-06, 22-D301-06, 23-D301-06, 25-D301-06, and 28-D301-106 through 30-D301-06. The borings were drilled to elevations ranging between -60.0 and -64.2 feet (MLLW). Six (6) of the borings were sampled for the purposes of chemical testing. The borings (CHEM-1-06 through CHEM-6-06) were sampled using 3-foot, plastic-lined spoons. These borings were drilled to elevations ranging between -52.4 and -53.8 feet (MLLW).

Eight (8) additional borings were drilled in 2009 within the turning basin as part of the same design and construction effort tied to the 2006 investigation. Borings MHTB-1-09 through MHTB-8-09 were sampled by splitspoon in the middle to eastern part of the turning basin. All borings were advanced to depths between elevation -50.0 and -51.0 feet MLLW.

5.2.2. 1976 Field Study

A field study was conducted in 1976 to study the nature of fluid mud in the dredging and disposal process. This investigation is documented in Nichols et al, 1978. The study looked at material that had been previously placed in a dredged material placement area within the bay, just west of the channel and approximately 3 miles south of Gaillard Island. The placement site is adjacent to channel stations 1150+00 to 1340+00 (see Figure 1-3 for a general reference to this location). Lab tests were run on samples taken from the site in both newly placed dredged material and consolidated material. Tests showed the materials were similar in nature. All samples of both old consolidated and new dredged material were classified as inorganic clays of high plasticity or fat clay (CH) in accordance with the Unified Soil Classification System. The average water content was 115% in 18 samples of old consolidated sediment and 165% in 5 samples in newly dredged material. The average plastic limit was 31 in 17 samples of old consolidated sediment and 39 in 5 samples of newly dredged material. The average liquid limit was 82 in 17 samples of old consolidated sediment and 117 in 5 samples of newly dredged material. The material had average silt to clay ratio of 30:70 and was described as cohesive silty clay in accordance with the Shepard system.

5.3. Subsurface Conditions

As previously mentioned, the material within the depths and horizontal extents of the tentatively selected plan are made up of two types of material: maintenance material and new work material. Maintenance material is composed of material that is deposited in the channel from rivers upstream, the near shore current, and resuspended sediment from other parts of the bay. New work material is the in-situ soil that is located at depths or horizontal extents (widening) that have not previously been excavated. The nature of the new work soils varies throughout the proposed areas of deepening and widening. Characterization of substrata encountered within the soil test boring investigative depths was based upon visual examination of soil samples, laboratory analysis of select samples representative of existing substrata, and standard penetration resistance values.

5.3.1. Turning Basin Sediments

The new work soil in the turning basin is predominantly clean sand (SP) with some pockets of silty sand (SM). Clean and silty sands are present from elevation -39 feet down to the extent of the proposed deepening at elevation -54 feet. Fat clays (CH) and silts (ML) were also sampled in historical borings, intermixed with sand above elevation -39 feet. Borings indicate that most of the clays and silts would have been removed during the construction of the turning basin. The areas that will be expanded horizontally on the north and south side of the turning basin have intermittent layers of silt and clay, though predominantly sand.

5.3.2. Bay Channel Sediments

Soils in the Bay Channel vary depending on location along the channel. A collection of soil types are present within the Bay Channel from stations 273+21 to approximately 740+00, or just north of Gaillard Island. Historical borings indicate four soil phases in this stretch, which include: 1) very soft to soft clays, silts, and clayey sands; 2) medium to very stiff clays, silts, and clayey sands; 3) medium to very dense coarse grained clean sands and clayey sands; and 4) organic deposits of silt and peat. These soils types occur in irregular layers or lenses. Generally, the soft, plastic clays and silts (CH, MH, and ML) tend to overlay the sands (SM and SP) and stiffer clays (CL). The top of the sand and stiffer clays generally starts between elevation -45 to -53. Vibracore borings taken in 1984 indicate that soils become sandier with depth, and a consistent layer of clean sand (SP) was noticed from elevation -53 to the termination of most borings. Pockets of organic silts (OH) and peat layers are present, however they are sparse, and they were predominantly found on the east side of the channel and within the top 10 feet of the borings.

Soils within the channel from approximately 740+00 to 1760+10 are almost entirely soft, plastic marine clays (CH) and silts (MH and ML). The majority of clays and silts in this stretch have an N value of zero. There is an isolated area of sand in the southern part of this reach, stretching from approximately one mile north of the Gulf Intracoastal Water Way down to the Morgan Peninsula. Borings in this area show lenses of clayey and silty sands (SC and SM) between elevations -45 to -51 feet. These sands can be found in small quantities, and are flanked by the marine clays and silts.

Soil boring have not been taken in the footprint of the passing lane widener. Adjacent borings at these stations, within in the channel, indicate the area is composed of predominantly soft fat clay. Additional borings are scheduled to be performed in this area during the PED phase of the project to better define material properties.

5.3.3. Bar Channel Sediments

Soils in the Bar Channel are intermixed and interbedded. These soils consist of silty sands (SM), poorly graded clean sands (SP), silts (ML), lean sandy clays (CL), clayey sands (SC), and inorganic plastic clays (CH). The coarse grained sandy soils are fairly dense, and the clays are generally stiffer than those that can be found within the bay. Most of the soils are greenish in color and contain small clam and oyster shells, shell fragments, and decomposed wood fragments.

5.4. Geotechnical Design

5.4.1. Channel Side Slopes and Slope Stability

The existing side slopes of the channel are approximately one vertical foot to every five horizontal feet of material (1V:5H) in the River and Bay Channels and 1V:7H in the Bar Channel. These side slopes were achieved by making a box cut to the overdepth excavation beyond the horizontal extents of the channel bottom. After the box cut is made, the material falls to its angle of repose which approximately creates side slopes to the configurations mentioned above. The slopes for the deepening and the widening will be cut in the same way. After reviewing the proposed alignment, there do not appear to be any structures close enough to the channel that would be impacted by a slope failure. No stability analyses were run during the feasibility phase as there was not sufficient strength data to perform the analyses. It is anticipated that the channel slopes will be roughly the same slope as they currently are, however, this will be confirmed during the PED phase. The potential for increased quantities of excavation due to flatter slopes is accounted for in the Cost and Schedule Risk Analysis.

Slope stability is a concern where the Choctaw Pass Turning Basin will be expanded. The turning basin was initially constructed by creating slopes on the north, east, and south sides of Choctaw Pass, between Pinto Island and Little Sand Island. Pinto Island flanks the basin on the north side, and Little Sand Island lies to the south. Slope stability analyses, performed as part of the Mobile Harbor Turning Basin GRR (2007), informed the decision to design the basin slopes at a 1V:4H. As part of the design effort, unconsolidated undrained tests (Q or UU tests) were performed on two samples from boring 5-D301-06. The first test was performed on a sample taken between elevations -19.7 and -22.7 ft. The second test was peformed on a sample taken between elevations -26.7 and -29.7 ft. The strength data from the tests was used in conjunction with SPT data to develop the soil profiles and strength parameters that were analyzed. The analyses of slopes cut to 1V:4H yielded a factor of safety of 1.15, which was considered adequate. Slopes of 1V:5H were also analyzed; however, it showed that flatter slopes would require excavation far enough back toward Pinto and/or Little Sand Island that it would in effect remove resisting material that supports near shore portions of the Pinto Island Upland Disposal Area. A factor of safety of 0.86 was computed from the analysis of slopes cut to 1V:5H. The same rationale was applied for the design of the east and south basin slopes, and a slope of 1V:4H was used for all basin slopes. The analyses performed as part of the 2007 GRR are attached in Attachment A – 6.

Further expansion of the turning basin will require additional excavation in either the north or south directions to accommodate longer ships. Since real estate is more developed and accounted for on Pinto Island, the majority of the expansion will be towards the southern side of the basin into Little Sand Island (see Figure 4-5 for reference). Though slopes were cut to a 1V:4H for the prior expansion to avoid cutting too close to the islands, the proposed expansion will cut into the island, regardless of whether the slopes are cut to a 1V:4H or 1V:5H. As such, slope stability analyses are necessary to account for the design of both submarine and upland slopes. The preliminary design accounts for slopes cut to 1V:5H, however, additional slope stability analyses will be performed during the PED Phase of this project to determine the slope. Flatter slopes will be considered at that time in a suite of slope stability analyses.

5.4.2. Impacts to Aquifers

Gillet et al. (2000) mentions two major aquifers in Mobile and Baldwin Counties in which recharge areas are located: the Miocene-Pliocene Aquifer and the Watercourse Aquifer. Chandler et al (1985) refers to these same two aquifers as A1 (the Watercourse Aquifer) and A2 (the Miocene-Pliocene Aquifer). The Watercourse Aquifer is located in the Pleistocene and Holocene alluvial deposits, and the Miocene-Pliocene Aquifer lies within the underlying series of the same name. Clay deposits are present in both of these series, especially in the Miocene and Pliocene. These clay layers act as aquitards within the Miocene and Pliocene, allowing for multiple aquifers which are hydraulically connected. The recharge areas for the Watercourse Aquifer are in close proximity to the bay, rivers, and other low-lying tributaries and waterways that are hydraulically connected to the bay. This aquifer is unconfined and also hydraulically connected to the Miocene-Pliocene Aquifer, making the two aquifers relatively subject to natural and manmade contaminants. Chandler et al. (1985) state that even though Aquifer A1 has a high yield, only a fraction of this groundwater can be used as there are many concerns with saltwater intrusion. Saltwater intrusion generally becomes more of a concern during periods of drought and low recharge. Additionally, the Watercourse Aquifer is susceptible to contaminants via land source, resulting in very few water supply wells that rely on the Watercourse Aquifer for potable water (Gillet et al. 2000).

There are communities within Mobile and Baldwin Counties which rely on the Miocene-Pliocene Aquifer for drinking water. Gillet et al. (2000) mentions 113 public groundwater wells within their well survey. Of these wells, 15 derive water from the Watercourse Aquifer, and the rest derive water from the Miocene-Pliocene Aquifer. If the new work dredging were to remove the confining layers between the Watercourse and Miocene-Pliocene aquifers within the channel's footprint, it is possible that brackish and salt water intrusion rates of the bay and bar areas could be affected, and in turn, affect the quality of water at the well locations.

The water wells on Dauphin Island are the most likely to be affected of all the wells mentioned in the survey. The Dauphin Island wells are closest to the new work dredging, located approximately 4.5 miles away from the shipping channel at its closest point. Additionally, the Dauphin Island wells are down gradient in the potentiometric surface of the Miocene-Pliocene Aquifer (Gillet et al 2000). The majority of the other wells are located more inland and more up gradient from the coast. Generally, the potentiometric surface falls as it approaches the coasts of the bay or gulf.

A report published by the USGS (1988) to assess the water supply potential of the Water Table Aquifer on Dauphin Island documents a 20-foot thick clay layer beneath the island that separates the Water Table and Miocene-Pliocene Aquifers. The top of the clay layer is around elevation -30 to -40 feet below sea level, and this layer is thought to provide a consistent confining layer underneath the island. Historical borings taken in the bay entrance, the bar channel, and between the bay entrance and Dauphin Island show a confining layer, though at lower depths than reported in the USGS report. Boring SG-4-82 (located approximately 800 feet east of the shipping channel) shows the top of the confining layer around elevation -46. The confining layer is present down to elevation -63, at which point the boring was terminated. Boring SG-3-83 (located approximately 3800 feet west of the shipping channel, between the channel and Dauphin Island) shows the top of the confining layer somewhere between -40 and -50. The layer is approximately 10 feet thick, which might suggest the confining layer present at the island is decreasing in thickness as it moves east. However, the borings are spaced very far apart and give an incomplete picture of the geology in the area of question.

In the northern part of the bay, historical borings indicate the presence of the sands which may be hydraulically linked to one of the aforementioned aquifers. Vibracore samples taken in 1984 show a sand layer with a top elevation around -44 to -48 feet. The sand layer extends down to termination of the borings, many of which extend down to -60 and below. When the channel was last deepened in 1991, these sands would have been exposed directly to the brackish waters of the bay, as the current channel configuration was dredged to elevation -49 feet (-45 feet plus 2 feet for advanced maintenance and 2 feet for over dredging). This would mean that the aquifer is hydraulically linked to the bay in the areas where new work deepening will occur. Since the last deepening, there have been no documented issues with increased groundwater salinity.

An analysis was initiated based on feedback from the initial release of this study report. The analysis was conducted to understand the possible implications that breaching the confining layer could have on known water sources. Given the close proximity of Dauphin Island to the shipping channel, the water sources at Dauphin Island were determined to present the most likely candidate to be affected, and the analyses were focused on modeling impacts to their 3 drinking water wells that draw from the Miocene-Pliocene Aquifer. The details of these analyses are discussed in section 6.6 of this report and Attachment A – 7.

SECTION 6. MODELING AND ANALYSES

The Geophysical Scale Transport Modeling System (GSMB) was utilized to quantify the relative changes in circulation, water quality, navigation, and sediment transport processes within Mobile Bay and lower Mobile-Tensaw River Delta resulting from the proposed modifications to the channel. The components of GSMB include the two-dimensional (2D) deep water wave model WAM (http://wis.usace.army.mil), STWAVE nearshore wave model (Smith *et al.* 1999) and the large scale unstructured 2D ADCIRC hydrodynamic model (http://www.adcirc.org). These components make up the Coastal Storm Modeling System, CSTORM-MS (Massey et al. 2015). In addition, the three-dimensional models CH3D-MB (Luong and Chapman 2009), which is the multi-block (MB) version of CH3D-WES (Chapman *et al*. 1996, Chapman *et al*. 2007), MB CH3D-SEDZLJ sediment transport model (Hayter *et al*. 2012 and 2015, Gailani et al. 2014), and CE-QUAL-ICM water quality model (Bunch *et al*. 2003, and Cerco and Cole 1994) were applied.

In an effort to quantify the relative changes in sediment pathways and the morphological response on the ebb tidal shoal and adjacent coastal areas, the Delft-3D (https://oss.deltares.nl/web/delft3d) integrated processed-based model composed of multiple modules was utilized. The components include the 2D FLOW module and SWAN spectral model, which coupled accounts for the effects of water level variations and current-induced frequency shifting, wave radiation stresses and gradients that drive nearshore circulation and sediment transport.

In an effort to quantify the relative changes in vessel generated ship wake the USACE, Mobile District performed site specific field data collection, processing and assessment of vessel generated wave energy (VGWE) through data trending, forecasted vessel calls for years 2025 and 2035 and a model published by Schoellhamer (1996).

A summary of the data collection, modeling and analyses is provided in the following paragraphs. In addition, details of this work can be found in the technical reports contained in Attachments A – 1 through A – 5 of this appendix.

6.1. Hydrodynamic Modeling

Hydrodynamic modeling was conducted by ERDC to characterize the existing conditions (e.g., flows, circulation, waves, etc.) of the study area and determine the relative changes in those conditions due to proposed navigation channel modifications. A summary of the overall approach and results of these analyses are described in the following paragraphs.

6.1.1. CSTORM Modeling

The parallel versions of ADCIRC and STWAVE coupled via the CSTORM-MS framework (Massey *et al,* 2011) were utilized to provide the offshore water surface elevation tidal boundary, wave height, period, direction, and radiation stress gradient forcing to the GSMB hydrodynamic (MB-CH3D-WES) and sediment transport (MB-SEDZLJ) modules. The time period selected for GSMB hydrodynamic, sediment transport, and water quality modeling of Mobile Bay was January through December of 2010. This time period represented an average hydrologic year, as seen in Figure 6-1, and the annual mean flow for year 2010 also roughly falls into average condition; however, January and February are closer to high flow conditions, whereas July through December are within low flow conditions. The combination of this data results in a year (i.e., 2010) that covers the range of hydrological conditions (i.e., low, average, and high). The bars in Figure 6-1 represent monthly mean discharge in 2010 whereas dotted line shows 30 minute record. The error bars represent USGS published monthly mean and maximum and minimum discharges from long term statistics.

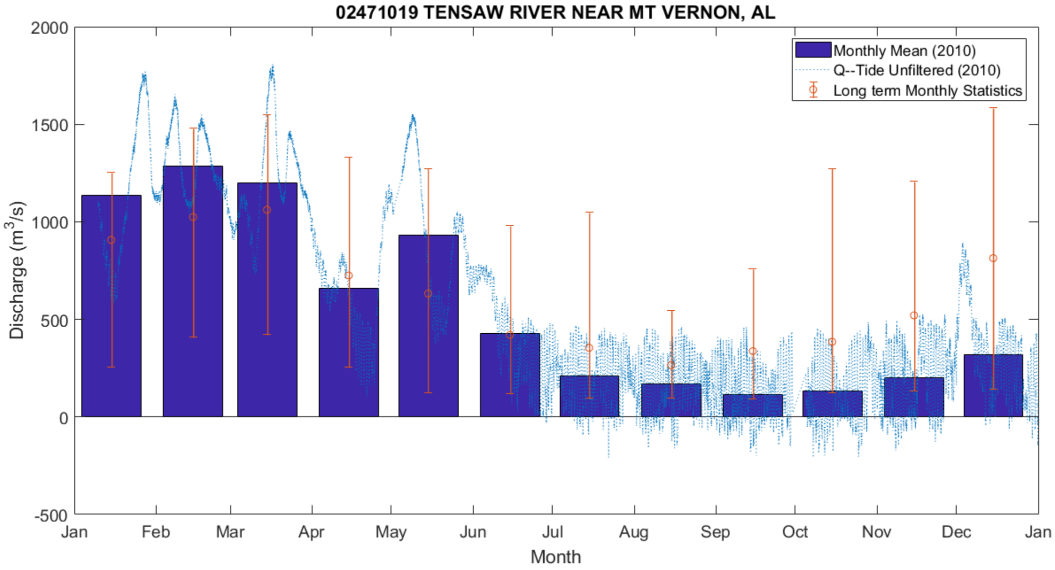


Figure 6-1. Discharge record from USGS Gage 02471019, Tensaw River near Mt. Vernon, AL

In addition to the 2010 time period, CSTORM was used to provide a screening level comparison of storm tide levels in Mobile Bay between existing conditions and with project conditions for two historical hurricanes, Hurricane Katrina 2005 and Hurricane Ike 2008. These two hurricanes were selected as they produced some of the highest water levels on record (see Figure 2-13) in the area.

The model results indicate that deepening the project to depths of 50 feet in the Bay Channel with an additional 2 feet for advanced maintenance and 2 feet for allowable overdepth dredging (total of 54 feet) and 52 feet in the Bar Channel with an additional 2 feet for advanced maintenance and 2 feet for allowable overdepth dredging (total of 56 feet) produces only slightly elevated peak water levels as compared with the baseline channel configuration and negligible changes in pre-storm tides. The largest simulated difference in maximum water surface elevation between the With- and Without-Project depths was 0.07 feet, which is well within the uncertainty of the model. Further details of this analysis are provided in Attachment A – 1 of this appendix.

6.1.2. GSMB Multi-Block Hydrodynamic Modeling

ERDC utilized the three-dimensional, baroclinic, multi-block hydrodynamic circulation model CH3D-MB to conduct hydrodynamic computations on a non-orthogonal curvilinear or boundary-fitted grid of the study area. The physical processes impacting circulation and vertical mixing that were modeled included tides, wind, wave radiation stress gradients, density effects (salinity and temperature), freshwater inflows, turbulence, and the effect of the earth's rotation. The boundary-fitted coordinate feature of the model provides grid resolution enhancement necessary to adequately represent the deep navigation channels (i.e. Bar, Bay, and River Channels) and irregular shoreline configurations of the flow system.

Localized refinement to provide greater resolution for existing conditions and modification measures for the Mobile Harbor Bar, Bay, and River Channels were implemented within the existing Mobile Bay multi-block CH3D grids. Model calibration and validation using the CSTORM boundary forcing were performed and the following scenarios/channel configurations were evaluated:

- Existing Condition: Depths in the Bar, Bay, and River (lower 1,850 feet) channels of 47, 45, and 45 feet, respectively, (as shown in Figure 1-1 through Figure 1-5) with an additional 2 feet for advanced maintenance and 2 feet of allowable overdepth dredging (total depths of 51, 49, and 49 feet, respectively).

- With-Project Condition: 1) Bar, Bay, and River (lower 1,850 feet) channels deepened 5 feet to depths of 56, 54, and 54 feet, respectively (see Figure 4-1 - Figure 4-4); 2) expand the Choctaw Pass Turning Basin located at the northernmost part of the upper Bay Channel 250 feet to the south (see Figure 4-5); 3) widen the channel from the mouth of the bay northward for 5 nautical miles from an existing width of 400 feet to 500 feet for passing; 4) incorporate minor bend easing at the double bends in the approach to the Bay Channel; and 5) incorporate dredge material placement of up to 3 feet in thickness in 6 open water sites within the Relic Shell Mined Area of the bay (see Figure 4-11). The With-Project presented above is the same as the RP, with the exception of a 5 mile long channel widener for passing in the Bay Channel evaluated in the modeling versus a 3 mile long widener for passing being considered in the RP.

- Future With- and Without-Project Conditions: Incorporated an increase in the mean sea level based on USACE intermediate rate curve of approximately 1.6 feet (0.5 meter) for both the Existing and With-Project Condition.

6.2. Water Quality Modeling

The focus of the water quality modeling effort was to understand the existing water quality conditions within Mobile Bay and quantify the relative changes in those conditions from the proposed Mobile Harbor Federal Navigation Channel modifications. A 3-D water quality model was utilized in concert with the combined wave and current numerical models (CSTORM and CH3D-WES MB). This model was determined necessary due to the existing deep-draft channel segments (i.e., Bar, Bay, and River Channels) and the vertical structure of salinity and temperature within the bay and adjoining waters.

Using the tidal and river flow boundary condition time series developed by the CH3D-MB model, CEQUAL-ICM was run for the chosen scenarios described in Section 6.1.2 for the time period of January 1 – December 30, 2010. The outputs from these scenario runs were analyzed to assess relative differences in dissolved oxygen, salinity, temperature, total suspended solids, nutrients, and chlorophyll-*a* (“Chl *a*”). Daily average values for all cells for all water quality constituents were saved during the model simulations and then retrieved for direct comparison of conditions between pairs of different model simulations.

The model results indicate the relative differences in water quality between the Existing and With-Project and future With- and Without-Project Conditions, were minimal over the year long duration of the simulation. Further details on the approach and results of this analysis are documented in Attachment A – 1 of this appendix.

6.3. Sediment Transport Modeling

6.3.1. Estuarine Sediment Transport

Channel modifications may change sedimentation rates and patterns, which directly impact maintenance dredging requirements. The purpose of the sediment transport modeling was to assess the relative changes in sedimentation rates within the navigation channel, dredged material placement sites, and surrounding areas as a result of channel modifications within the bay. This modeling work built upon previous multi-agency Regional Sediment Management data collection and modeling efforts conducted in 2012, which evaluated thin layer placement of dredged material in Mobile Bay. Field data collected in 2012 to parameterize cohesive sediment transport processes in the study area are documented in Gailani, J. Z. et al. (2014). The field experiments included Sedflume erosion and settling velocity measurements conducted using the Particle Imaging Camera System (PICS). Additional field studies were conducted in 2016 to more appropriately describe boundary conditions. These consisted of measured suspended sediment concentrations and discharges at the seven stations in the Mobile-Tensaw River Delta and upper bay (Ramirez et al. 2018). Cohesive sediment process descriptions were formulated from the data collection efforts and utilized in the development of the estuarine sediment transport model (GSMB-SEDZLJ).

GSMB-SEDZLJ is an advanced sediment bed model that represents the dynamic processes of erosion, bed load transport, bed sorting, armoring, consolidation of fine-grain sediment dominated beds, settling of flocculated cohesive sediment, settling of individual non-cohesive sediment particles, and deposition. GSMB-SEDZLJ is dynamically linked to CH3D-MB so that simulated changes in bed elevations at active grid cells due to erosion or deposition are utilized by CH3D-MB, which computes the transport of suspended material. The three-dimensional (3D) Mobile Bay grid has been developed and tested using GSMB-SEDZLJ to ensure that sediment mass is adequately conserved throughout the model simulation. The incorporation of a bed slope algorithm into GSMB-SEDZLJ has been completed, and the testing of this routine is also complete. This algorithm accounts for the effect of bottom slope in predicting bed load transport of the non-cohesive sediment size classes being used in the model as well as in the equation (developed from the analysis of the Sedflume data) used to predict the re-suspension of mixed grain sediments. Also added was the capability to simulate the formation of a fluff layer on top of an existing sediment bed. Being able to represent the resuspension of this layer during the early stages of the accelerating flow following slack water is essential to accurately simulating sediment transport, in particular in stratified estuaries such as Mobile Bay.

Using the tidal and river flow boundary condition time series developed by the CH3D-MB model, GSMB-SEDZLJ was ran for the chosen scenarios described in Section 6.1.2 for the period of January 1 – December 30, 2010. Results from STWAVE modeling (i.e., times series of wave heights, periods, and directions) over this same twelve month period was used in GSMB-SEDZLJ to calculate the current- and wave-induced bed shear stresses. The outputs from these scenario runs were analyzed to determine, among other factors, the difference in channel sedimentation rates for the different proposed channel configurations.

The simulated increases in annual shoaling vary from 5 to 15% along the channel with the largest increases projected at and south of the Theodore Ship Channel intersection (see Figure 6-2). These increases in sedimentation predicted by the modeling effort agree well with estimates developed using increased perimeter method documented in Technical Report H-78-5.

The results from the one year model simulation with the With-Project Condition (as described in Section 6.1.2) show a minimum difference range of no greater than 0.3 feet of erosion when compared to the Existing Condition. This in essence indicates no discernable net erosion or net deposition, as this is within the uncertainty of the sediment transport model. Similar results and conclusions were found for the future With- and Without-Project Conditions (i.e., accounting for mean sea level change). Additional details of the estuarine sediment transport modeling effort are provided in Attachment A – 1 of this appendix.

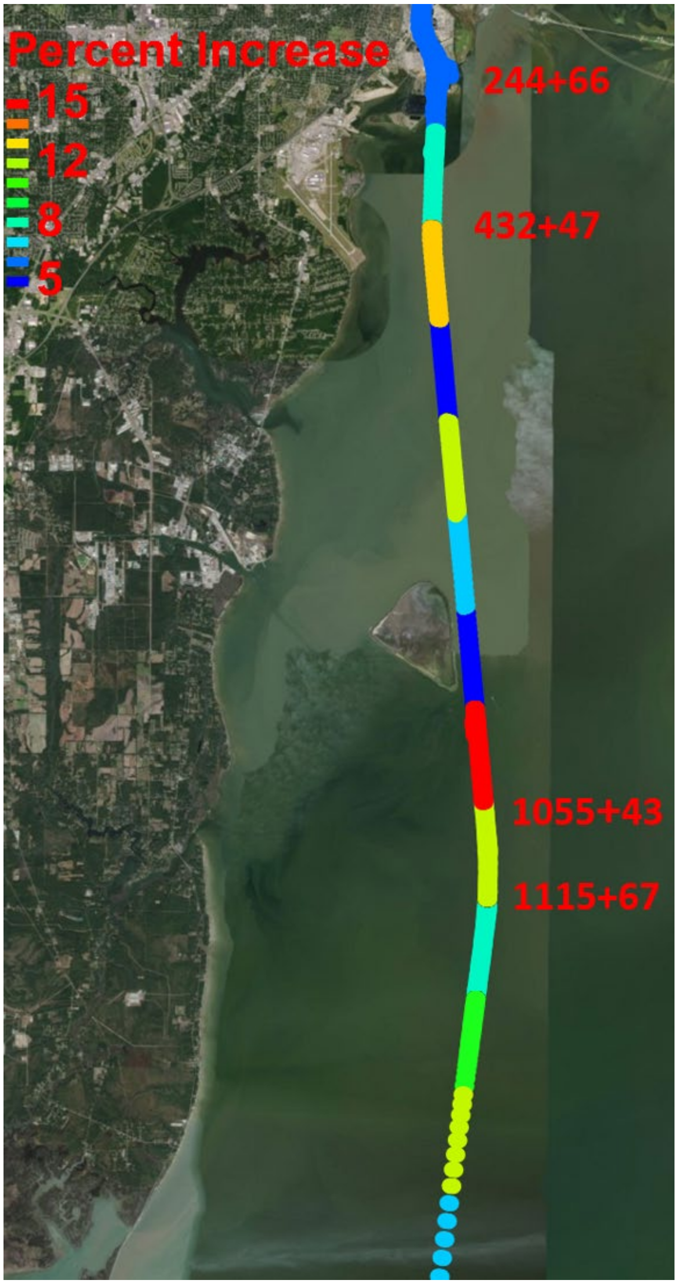


Figure 6-2. Simulated Increases in Annual Shoaling

6.3.2. Coastal Sediment Transport

The purpose of the coastal sediment transport modeling was to assess the relative changes in sediment pathways and morphological response on the ebb tidal shoal and adjacent coastal areas as a result of the proposed channel modifications to deepen the existing Bar Channel by five feet. This modeling work built upon the ongoing collaborative data collection and modeling efforts being conducted as part of the National Fish and Wildlife Foundation (NFWF) Alabama Barrier Island Restoration Assessment. Relevant field experiments conducted as part of the NFWF study included bathymetric, current, wave and sediment measurements. Details of these data collection efforts are contained within USACE and USGS (2017) *Alabama Barrier Island Restoration Assessment Interim Report*. Descriptions were formulated from these data sets and utilized in the development of the coastal sediment transport model (Delft-3D).

Delft-3D is an integrated processed-based model composed of multiple modules used to simulate hydrodynamics, short waves, sediment transport, and morphologic change. These components include the 2D FLOW module and SWAN spectral model, which account for the effects of water level variations and current-induced frequency shifting, wave radiation stresses, and gradients that drive nearshore circulation and sediment transport.

The model domain was expanded far enough to infer probable effects on shoreline changes due to proposed channel modifications (i.e., deepening and/or widening), with the minimum extents per USACE EM 1110-2-1613 guidance being 10 miles east and west of the channel. In addition, grid resolution was incorporated as to adequately represent the deep navigation channel, associated modifications, and irregular shoreline configurations of the flow system.

Simulation time periods included a 2010 wind/wave climatology as well as a 10-year longer term climatology derived from the European Centre for Medium-Range Weather Forecast (ECMWF) ERA-Interim reanalysis model over the Delft-3D hindcast period of 1988-2016. The Energy Flux Method of Benedet and others (2016) was then used to derive a binned (grouped) wave climatology where wave direction and height bin boundaries were defined such that all bins contained an equal amount of wave energy flux (Passeri et al., 2018). The wave climate was divided into nine wave classes (three directions and three heights) with mean direction, period and height used. Comparisons of model output from deterministic simulations were then compared with observed data of water levels and velocities and bed level changes to assess model performace. This assessment indicated that the model was able to capture the hydrodynamics and sediment transport patterns with skill (Passeri et al., 2018).

Similar to the other modeling efforts, the scenarios outlined in Section 6.1.2 were evaluated for both wave climatologies, with the only difference being the With-Project Condition incorporated annual dredge material placement in the SIBUA (i.e., SIBUA as shown in Figure 1-2) as part of the 10-year simulations. The modeling results indicate minimal differences in morphologic change in the near shore areas of Dauphin Island and Pelican Island between the With-Project and Existing Conditions in the bay and on the ebb tidal shoal for the 2010 climatology as well as for the 10-year climatology. This suggests that sediment delivery away from the ebb tidal shoal to these areas is similar under the evaluated scenarios and that shoreline positions are unlikely to be impacted as a result of the modified channel. Although comparison of the two simulations shows some spatial shifting of sand offshore of the Morgan Peninsula, the patterns of erosion/deposition in the two simulations are quite similar. Based on these results, it also appears unlikely that these changes would alter sediment delivery to the peninsula and only minor impacts to the terminal end of the peninsula closest to the channel could occur. Similar results and conclusions were found for the future With- and Without-Project Conditions (i.e., accounting for mean sea level change). Additional details of the coastal sediment transport modeling effort are provided in Attachment A – 2 of this appendix.

6.4. Vessel Generated Wave Energy Assessment

A vessel generated wave energy (VGWE) assessment was conducted to quantify the relative changes in wave energy due to future vessels calling the port. The investigation included field data collection using a suite of 5 pressure sensors located north of Gaillard Island and a validation deployment using similar techniques in the southern part of the bay. A unique and efficient method of data processing was employed using a continuous wavelet transformation (CWT) to extract the vessel generated disturbances from a continuous time series by utilizing frequency modulation or “chirp” signal produced and shown to be valid within the context of large data sets where random errors can be averaged. VGWE was computed on the extracted time series using a fast Fourier transformation which is widely accepted and used for describing energy of a time series. The method proved successful for this study with the exception of cases with higher background energy or weak VGWE signals. VGWE computed using field data compared well with expected results based on theoretical values and dependencies. Overall, the field data collection collected for this study proved to be valid when used for general trending.

VGWE was also estimated using the model described by Schoellhamer (1996) and compared to the collected data described in previous paragraph. The results were found to underestimate at all measured stations for Froude numbers greater than 0.5. For Froude numbers less than 0.5 the model tends to overestimate at the far field stations and underestimate for near measurement stations. As a result of this analysis, it is recommend the Schoellhamer (1996) should only be applied to Mobile Bay for low precision prediction of far field VGWE at Froude numbers greater than 0.5 with the understanding values could be slightly underestimated.

Potential impacts of VGWE were evaluated at two locations in the bay by comparing the relative difference of With- and Without-Project conditions using forecasted vessel calls for years 2025 and 2035 as described in detail in Appendix B - Economics. Vessel speed was obtained from a statistical summary of 2016 Automatic Identification System (AIS) data categorized by vessel length. Cumulative VGWE was computed using the model published by Schoellhamer (1996).

No increase in VGWE was determined as a result of the proposed project. The confidence of this finding was tested with respect to the assumption of vessel speed which determined for realistic potential increases in vessel speed as a result of the project the relative difference in VGWE does not become impactful. Details of the data collection of VGWE in Mobile Bay and the assessment of relative impacts as a result of the project are detailed in Attachment A – 4 of this appendix.

6.5. Ship Simulations

A feasibility level ship simulation was performed in accordance with ER 1110-2-1403 to evaluate channel navigability with a particular focus on testing varying widths for a two-way traffic area in the lower Bay Channel, bend easings in the Bar Channel, and expansion of the Choctaw Pass Turning Basin. A site visit was performed to observe navigation conditions and take photographs for the model's visual scenes. Following discussions with the Mobile Bar Pilots, current fields were generated from the hydrodynamic model described in Section 6.1 using a combination of a constant wind speed of 20 knots; wind directions of northeast, southeast and west; maximum spring tide (flood and ebb) combined with low flow conditions of approximately 5,000 cubic feet per second; and high flows of approximately 60,000 cubic feet per second for testing some of the tougher conditions Pilots have experienced in the past.

The ship simulations were conducted in Vicksburg, Mississippi at the ERDC laboratory where two Bar Pilots experienced in navigating the Mobile Harbor Federal Navigation Project participated the effort. In order to best manage their time on the simulator, the entire length of the channel was not piloted for all scenarios. The pilots' discretion was used to define the limits of the channel to run during the simulations, based on the features being evaluated (e.g., the two-way traffic area in the lower Bay Channel, bend easing in the Bar Channel, and Choctaw Pass Turning Basin).

For all simulations, the Bay Channel was deepened from 45 feet to 51 feet and the Bar Channel was deepened from 47 feet to 53 feet. Two different widths were screened for the two-way traffic area (500 feet and 550 feet) and each area spanned approximately 5 nautical miles. All proposed testing of the two-way traffic area included bend easing on the inside at buoys 18 and 21, with width increases at the bends of approximately 185 feet and 50 feet. The Choctaw Pass Turning Basin was deepened to from 45 feet to 51 feet for proposed testing.

Vessels readily available in the ERDC library were chosen for the feasibility level testing. The MSC Daniella 2 (1200 feet x 159 feet x 50 feet) was chosen to closely match the design vessel's beam (i.e., 158 feet), which is vital to passing. The Humber Bridge (1102 feet x 150 feet x 46 feet) was chosen to match the length of the design vessel (i.e., 1100 feet), which is essential to turning. Additional vessels used for validation and passing scenarios based on discussions with the Mobile Bar Pilots are shown in Table 6-1. A description on the design vessel is provided in Section 4.3.

Table 6-1. Ships used in Simulations

Model Name	Vessel Name	LOA (ft)	Beam (ft)	Draft (ft)	Area Tested
CNTNR28L	Sovereign Maersk	1138.5	140.4	47.6	Passing, bends, and validation of turning basin
CNTNR40	MSC Daniella 2	1201.1	158.8	49.9	Passing, bends, and turning basin
CNTNR20L	KMSS Dainty	964.9	105.7	41.0	Validation only, replaced by Zim Piraeus for testing of passing
CNTNR44	Zim Piraeus	964.9	105.6	43.0	Passing and bends
CNTNR33L	Humber Bridge	1102.4	150.3	46.2	Passing, bends, and turning basin
VLCC15L	MT Brittania	859.6	137.8	49.2	Passing and bends
TANK10L	MT Danita II	750.0	105.8	45.9	Used only as docked vessel near turning basin

Validation runs (i.e., simulations to validate the performance of the existing fleet and the visual and navigational feel of the ship simulation model) were performed by two Mobile Bar Pilots. It became evident during those runs that adjustments to the flow conditions were needed for the turning maneuver simulations in the Choctaw Pass Turning Basin due to a misrepresentation of actual conditions experienced by the pilots. For instance, while performing the turning maneuver, the pilots position large vessels such that they block most of the channel, which conveys the flow of the Mobile River, causing the currents and forces on the vessel to greatly intensify (see Figure 6-4). The simulations, however, were not producing similar forces; therefore, new ebb currents with increased flows were used to produce forces on the vessels that were more representative of actual conditions. Real-time recalculation of currents to account for the blockage was not conducted because it is beyond the ability of present day simulation modeling.

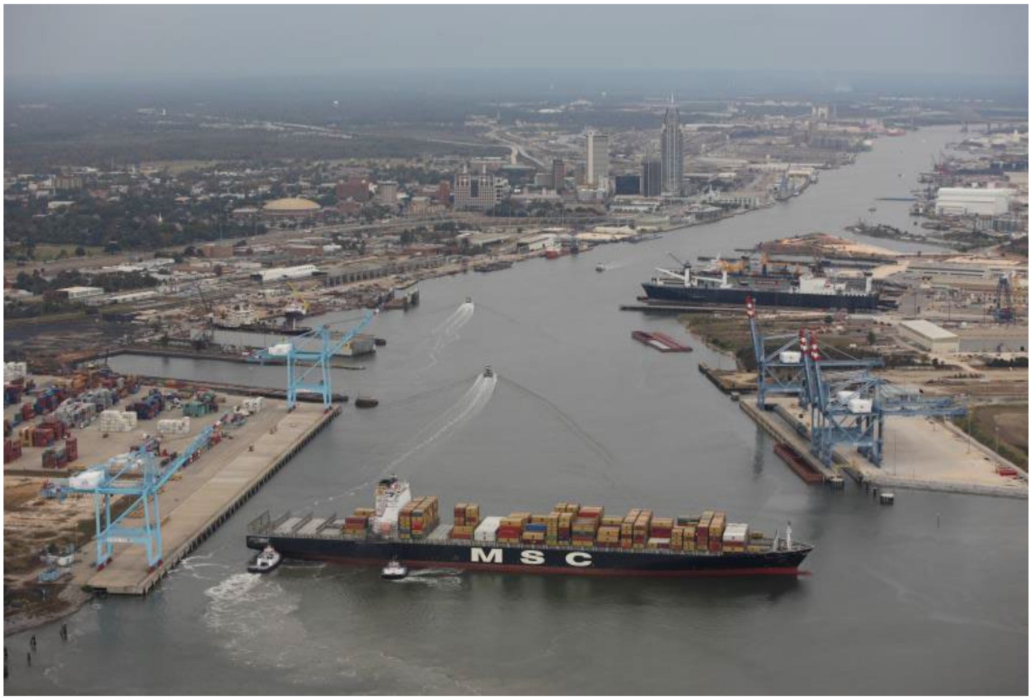


Figure 6-3. Turning of a MSC Container Ship at the Mouth of the Mobile River at Choctaw Terminal

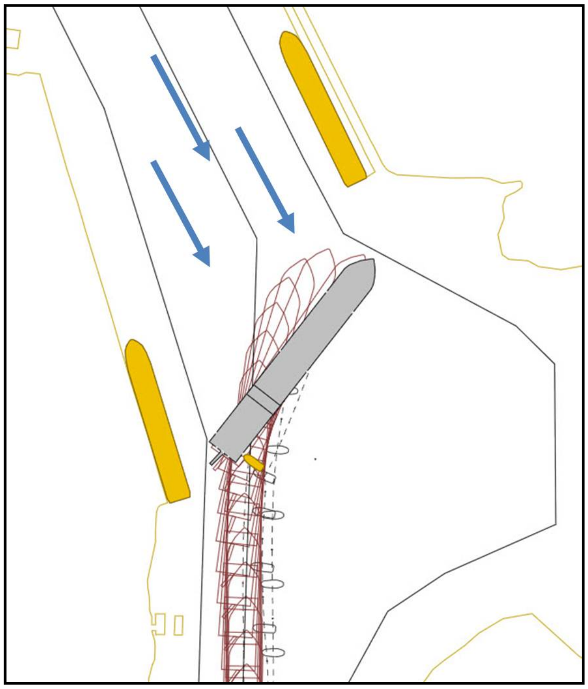


Figure 6-4. Turning Vessel Blocking Majority of the Mobile River Flow

Table 6-2 shows the bend easing and passing lane simulations conducted. Based on the simulations and pilot feedback, it was determined that vessels equal to or less than two Zim Piraeus (965 feet x 106 feet) and a Zim Piraeus (965 feet x 106 feet) and MT Brittania (860 feet x 138 feet) could successfully pass in a 500-foot wide channel with restrictions on tankers. For a 550-foot wide channel, it was determined two Sovereign Maersk (1140 feet x 140 feet); a Sovereign Maersk (1140 feet x 140 feet) and a Zim Piraeus (965 feet x 106 feet); a Daniella 2 (1200 feet x 159 feet) and a Sovereign Maersk (1140 feet x 140 feet); and a Daniella 2 (1200 feet x 159 feet) and a MT Brittania (860 feet x 138 feet) could successfully pass with restrictions on tankers.

While testing was conducted on a 5 nautical mile two-way traffic area (a.k.a. channel widener for passing or passing lane), it was determined the most likely length needed will fall between 3 and 5 nautical miles. Additionally, it was found that bend easing increased safety and greatly influenced the ease in which passing could be completed. Results of the ship simulation led to recommendations to further soften the bends near buoy 21 on the west side of the channel. Additional ship simulations during the PED Phase will be necessary to confirm these design dimensions.

Table 6-2. Ship Simulation Passing Lane Testing Array

Run #	Passing Lane Width (ft)	Inbound Ship (ft)	Outbound Ship (ft)	Combined Dimensions (ft)	Current	Wind
1	550	MSC Daniella 2 (1200 x 159)	Zim Piraeus (965 x 106)	2165 x 266	Alt Flood	20 SE
3	500	MSC Daniella 2 (1200 x 159)	Zim Piraeus (965 x 106)	2165 x 266	Alt Flood	20 SE
4	500	MT Brittania (860 x 138)	Zim Piraeus (965 x 106)	1825 x 244	Alt Flood	20 SE
5	500	MT Brittania (860 x 138)	Zim Piraeus (965 x 106)	1825 x 244	Alt Flood	20 SE
6	500	Humber Bridge (1102 x 150)	Zim Piraeus (965 x 106)	2067 x 256	Alt Flood	20 SE
7	500	Humber Bridge (1102 x 150)	Zim Piraeus (965 x 106)	2067 x 256	Alt Ebb	20 N
8	500	MSC Daniella 2 (1200 x 159)	MT Brittania (860 x 138)	2060 x 297	Alt Ebb	20 N
9	500	Sovereign Maersk (1140 x 140)	Sovereign Maersk (1140 x 140)	2280 x 280	Alt Ebb	20 N
10	500	MSC Daniella 2 (1200 x 159)	Sovereign Maersk (1140 x 140)	2340 x 299	Existing Flood	20 E
23	550	MT Brittania (860 x 138)	MSC Daniella 2 (1200 x 159)	2060 x 297	Alt Flood	20 SE
24	550	MSC Daniella 2 (1200 x 159)	Sovereign Maersk (1140 x 140)	2340 x 299	Alt Flood	20 SE
29	500	Sovereign Maersk (1140 x 140)	Sovereign Maersk (1140 x 140)	2280 x 280	Alt Flood	20 SE

Table 6-3 shows the turning basin simulations conducted. Based on the simulations and Bar Pilot feedback, a modification to the Choctaw Pass Turning Basin was deemed necessary. Currently, to turn an inbound vessel during an ebb tide, pilots position the stern of the ship as close to the APM Terminal dock (or docked vessel at the APM Terminal) as possible. This maneuver often requires the vessel to go outside of the Federal channel and relies on use of the APM Terminal berthing area. Once the vessel is perpendicular with the ebb current, two tugs are positioned on the stern. These tugs attempt to hold the stern in place while the bow of the vessel falls to the south due to the strong ebb current. In simulations with a docked vessel at the southern berth of the terminal, pilots had to go further east into the turning basin which, they currently avoid in practice because the further east the vessel commits into the turning basin, the greater the risk of the bow of the vessel clipping the southern edge of the turning basin in the vicinity of Little Sand Island. A more easterly approach also forces the pilot to rely on engines working full astern to pull out of the turning basin. With engines pulling full astern and tugs working at full power, there is no room for error or engine failure. Due to this added risk, pilots were uncomfortable with the maneuver necessary to turn this larger vessel with a docked vessel at the terminal. While simulations with a 100-foot expansion along the southern boundary greatly assisted in the safety of completing the turn with the Humber Bridge by allowing for more room for the falling bow, pilots still had to use more of the engine's power than they would typically be comfortable with; as such, further improvements may be required. As discussed in Section 4.6 for the GRR extension of the turning basin was laid out with a minimum turning diameter of 1.5 times the design vessel of maximum length (i.e. 1,100 feet, 158 feet, and 50.8) in the direction of prevailing currents in accordance with EM 1110-2-1613 *Hydraulic Design of Deep Draft Navigation Projects.* This resulted in a recommended increase in the turning basin of 250 feet. Additional ship simulations are recommended during the PED to optimize and confirm the design dimensions.

Further details of the feasibility level ship simulation study are provided in Attachment A – 3 of this appendix.

Table 6-3. Ship Simulation Choctaw Turning Basin Testing Array

Run #	Plan	Vessel (ft)	To dock/ Off dock	Docked Vessel (south berth, Pinto terminal)	Tugs (tons)
13	P1	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50 and 60
14	P1	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50 and 60
15	P1	Humber Bridge (1102 x 150)	Off dock	Tank10L, Tank10L	50 and 60
16	P1	Humber Bridge (1102 x 150)	Off dock	Tank10L, Tank10L	50 and 60
17	P1	MSC Daniella 2 (1200 x 159)	To dock	Tank10L, Tank10L	50, 60, and 60
18	P1	MSC Daniella 2 (1200 x 159)	To dock	Tank10L, Tank10L	50, 60, and 60
19	P1	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50, 60, and 60
20	P1	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50, 60, and 60
21	P2	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50, 60, and 60
22	P2	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50, 60, and 60
25	P2	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50, 60, and 60
26	P2	Humber Bridge (1102 x 150)	Off dock	Tank10L, Tank10L	50, 60, and 60
27	P2	Humber Bridge (1102 x 150)	To dock	None, Tank10L	50, 60, and 60
28	P2	Humber Bridge (1102 x 150)	Off dock	None, Tank10L	50, 60, and 60
30	P2	Humber Bridge (1102 x 150)	To dock	Tank10L, Tank10L	50, 60, and 60
31	P2	Humber Bridge (1102 x 150)	To dock	Tank10L, MSC Daniella 2	50, 60, and 60
32	P2	Humber Bridge (1102 x 150)	Off dock	Tank10L, Tank10L	50, 60, and 60

*All runs used the increased river flow ebb current for the deepened alternative and a 20 knot northern wind

**P1 is a deepened only turning basin (51-ft) , P2 is deepened using a flat bottom depth of 51-ft

6.6. Groundwater Modeling and Analysis

The USACE, Philadelphia District (NAP) developed a three dimensional (3-D) groundwater model to understand the impact that new work dredging may have on the drinking water supply wells at Dauphin Island. The model explains how the change in the shipping channel, due to new work dredging, may affect the water supply to the Dauphin Island water wells. Additionally, the model seeks to quantify changes in travel time of groundwater from the channel to the island. A detailed report discussing the model development, calibration, and findings is in Attachment A – 7.

The analyses incorporated regional geologic data and current water well withdrawal rates for the town of Dauphin Island into a series of steady state models. Particle tracks were then run in the models to assess the flow of water under certain variables (i.e. channel deepening, varying hydraulic conductivity, sea level rise, and increased withdrawal). Models were compared by looking at the particle tracks around the well capture zones, mainly within a 1,000-year timeframe. An “existing condition” model was run assuming that the confining layer, present within the many of the borings, was present and uniform through out the channel. This model was compared with models showing partial and full exposure of the underlying aquifer. Results show that the new work dredging may have a minor influence on the drinking water source at Dauphin Island. However, variables such as drought, sea-level rise, or increased demand have considerably more effect on increases in salinity. Additionally, the model shows that the minor effects of salinity change caused by the new work dredging may not be realized for thousands of years. The models show minor differences in the 1,000-year capture zone for the existing conditions versus the cut through the channel condition. Based on the modeling results, the new work dredging minimally impacts the groundwater source to the Dauphin Island water wells and any negative effect could take thousands of years to be realized.

SECTION 7. COST ENGINEERING

This section presents the cost analyses conducted to evaluate navigation improvement alternatives for the Mobile Harbor Federal Navigation Project. Two levels of analyses were completed. The goal of the initial cost analyses was to provide a basis equal in development for comparing alternatives with the purpose of determining the Tentatively Selected Plan (TSP). Further cost refinements were conducted to develop a Recommended Plan (RP), intended to provide reliable cost data that supports the definition of the Government's and the NFS's financial obligations.

The feasibility study followed the SMART (Specific, Measurable, Attainable, Risk Informed, & Timely) Planning process which is a shortened, yet appropriate level of analysis to determine the RP for a USACE feasibility study. The cost cycle used during the feasibility study is shown in Figure 7-1. The cost estimates and products were evaluated by the USACE Cost Engineering Mandatory Center of Expertise (MCX) and found to be compliant with requirements and acceptable for the alternatives, TSP, and RP.

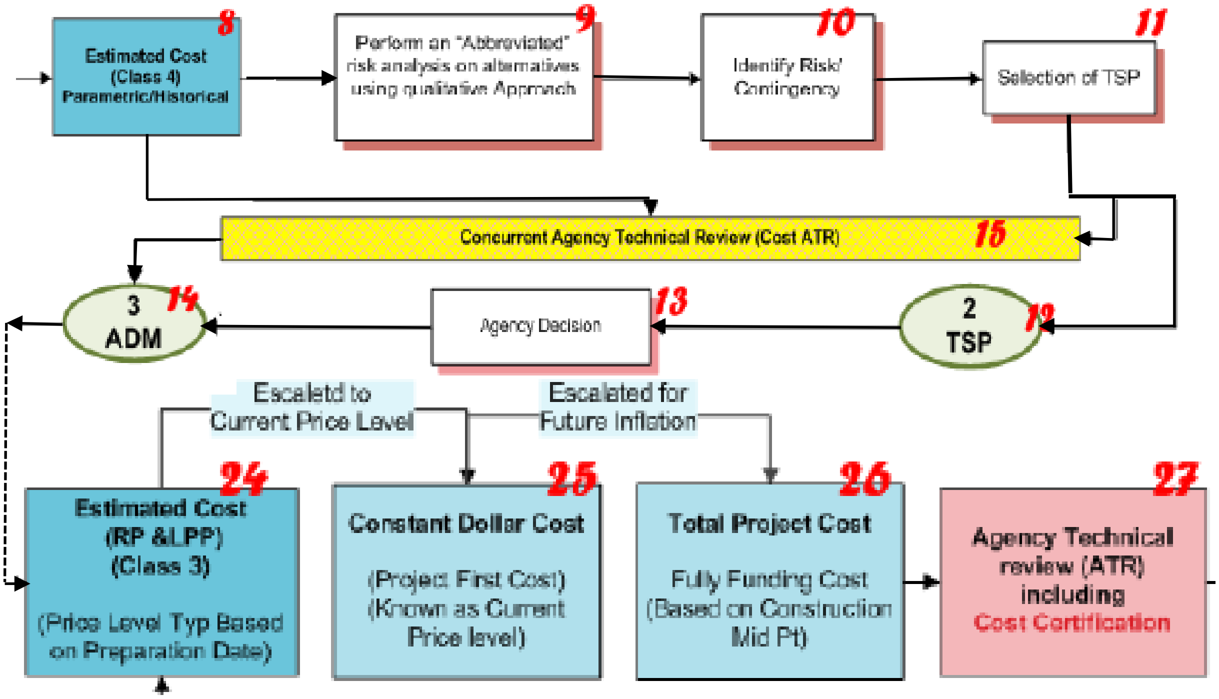


Figure 7-1. Project Cost Management Life Cycle

7.1. Format and Basis

Costs were developed in accordance to the requirements of ER 1110-2-1302 with the support of the Project Delivery Team (PDT) as provided per ER 5-1-11.

The cost estimate supporting the RP was prepared using USACE required Cost Engineering Dredge Estimating Program (CEDEP) and implemented into Micro-Computer Aided Cost Estimating System (MCACES/MII) with the Civil Works Work Breakdown Structure (CWWBS) sub-feature level. The RP contingency was calculated as a result of the Cost and Schedule Risk Analysis (CSRA). Resulting cost products, TPCS, and Cost Certification can be found in Attachment A – 8.

7.1.1. Cost Classification

The cost estimating effort for the study yielded a series of class 4 alternative cost estimates and class 3 TSP cost estimate for plan formulation decision making. The estimates are supported by technical information such as scope, design, acquisition, construction methods and uncertainties associated with each major cost item. The class of estimates are explained in detail in ER1110-2-1302 and ASTM E2516.

The class 3 cost estimate for the RP is developed further for the purposes of budgeting and funding authorization. The refined cost estimate (i.e., the Total Project Cost Summary) including supporting cost products (i.e., the Cost Engineering Dredge Estimating Program and the Cost and Schedule Risk Analysis) undergo technical reviews resulting in a Cost Certification.

7.1.2. Civil Works Work Breakdown Structure (CWWBS)

USACE Civil Works cost estimates are summarized by feature code levels. The feature code for a navigation project is based on a weighted composite of marine equipment cost, diesel fuel cost, operating labor cost, and facilities capital cost of money, while other CWWBS codes are based on historical estimates. The CWWBS feature codes applied are identified below and found in EM 1110-2-1304 and ER 1110-2-1302. The 01, 02, 12, 30 and 31 accounts include respectively real estate actions; aids to navigation; dredging activities; preconstruction planning, engineering, design and post design monitoring; and management and engineering during construction.

- 01 Lands, Easements, Rights of Way, Relocations, and Dredged Material Placement Areas
- 02 Relocation
- 12 Navigation Ports & Harbors

- 30 Planning, Engineering, and Design

  31 Construction Management

7.1.3. Cost Engineering Dredge Estimating Program (CEDEP)

CEDEP is the required proprietary software program used throughout USACE for preparation of dredging costs, including costs associated with mobilization and demobilization of equipment. Early in the study for purposes of comparing alternatives, all measures were developed using CEDEP with input from the PDT and included in an excel based cost summaries. The dredging costs developed from CEDEP for the RP are implemented in MCACES/MII.

7.1.4. Microcomputer Aided Cost Engineering System (MCACES)

MCACES is the USACE approved estimating software for the preparation of the cost estimate for the RP. Measures for alternative selection do not require the use of an approved estimating software; therefore, MCACES was only used for the cost estimate of the RP. Design details, information, and assumptions are provided in the notes of the MCACES/MII estimate. The MII estimate is to be treated as For Official Use Only (FOUO) because disclosure of cost data may easily compromise the integrity of the bidding processes.

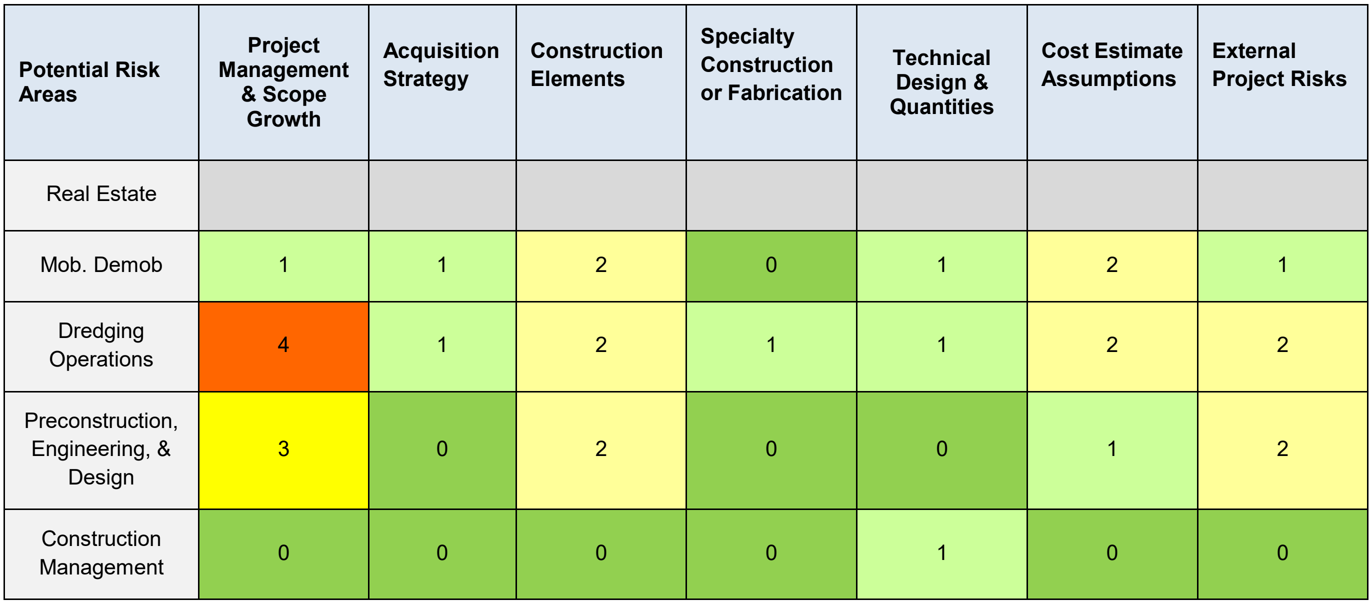
7.1.5. Risk Analysis

The risk-based contingencies throughout the study greatly influenced the total costs. During the evaluation of alternatives and TSP, an abbreviated risk analysis (ARA) was performed as a qualitative risk-based assessment whereas a Cost and Schedule Risk Analysis (CSRA) was performed as a quantitative risk assessment of cost and schedule uncertainties. As reported in this section, scope growth due to the possibility of mitigation was carried until the engineering and environmental modeling conclusions were finalized. The main report describes the conclusions of minimal impacts, concluding little to no mitgation is required. The contingency based from the CSRA and used for the RP decreased significantly, contributing to lower overall costs.

7.1.5.1. Abbreviated Risk Analysis

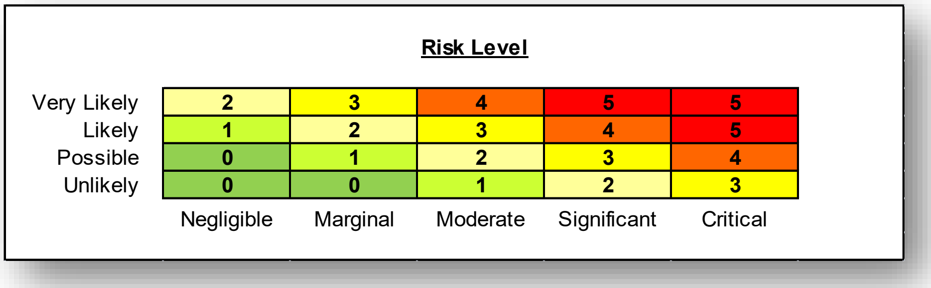
As a way to evaluate the alternatives and TSP, an abbreviated risk analysis (ARA) was performed to qualitatively assess risk elements that may cause a variance to cost, schedule, or both. Four abbreviated risk analyses (ARAs) were performed as a joint effort between the cost engineer and PDT for deepening, widening, Choctaw Pass Turning Basin modification, and routine maintenance work. The results were used to identify areas of high uncertainty and to apply single contingency values to the cost estimates.

The ARA contingencies range from 24% to 44%. The matrix developed from the ARAs identifies the risk levels of the most typical risk factors for civil works projects, including: scope growth, acquisition strategy, construction elements, specialty construction, design and quantities, cost assumptions and external project risks. Figure 7-2 is an example of the risk matrix.



Potential Risk Areas	**Project Management & Scope Growth**	**Acquisition Strategy**	**Construction Elements**	**Specialty Construction or Fabrication**	**Technical Design & Quantities**	**Cost Estimate Assumptions**	**External Project Risks**
Real Estate							
Mob. Demob	1	1	2	0	1	2	1
Dredging Operations	4	1	2	1	1	2	2
Preconstruction, Engineering, & Design	3	0	2	0	0	1	2
Construction Management	0	0	0	0	1	0	0

Figure 7-2. Risk Matrix



Risk Level

	Negligible	Marginal	Moderate	Significant	Critical
Very Likely	2	3	4	5	5
Likely	1	2	3	4	5
Possible	0	1	2	3	4
Unlikely	0	0	1	2	3

7.1.5.1.1. Initial Identified Risks

The initial key cost risk driver for the alternatives and TSP identified through the ARAs is scope growth. Concerns of mitigation, pipeline crossings, cultural resources, and impacts to hydraulically linked aquifers contributed to uncertainties in scope growth.

Aquatic resources, sediment transport, ship wake, hydrodynamic, and water quality initial assessments determined minimal impacts. Although the results of those analyses indicated minimal impacts and no mitigation was necessary, the risk remained significant due to observations in other USACE deep draft navigation improvement projects.

Additionally, shoreline erosion and impacts to aquatic resources caused by the ship wake of larger vessels transiting the channel was a noted public concern. As a result of the ARAs and team assessments, to increase certainty and decrease the risk levels, additional modeling and efforts have been conducted, including completion of cultural Phase I survey, oyster distribution modeling, aquifer analysis, and a vessel generated wave energy assessment.

When developing the ARAs, it was not anticipated that the deepening of the channel would result in adverse effects to the surrounding aquifers or groundwater used by the surrounding communities (see Section 6.6); however, the impact was unknown and assumed by the PDT to be significant. This risk was captured within the ARA scope growth. Furthermore, an aquifer analysis was initiated as a outcome. The result from the analysis as captured in the follow-up risk analysis discussed below lowered due to the additional investigations.

Mobile Harbor provides an environment that is rich in prehistoric and historic human activity. Within the widener, concerns from the PDT include efforts to document and or preserve any cultural resources legally protected such as shipwrecks. The Choctaw Pass Turning Basin, the Bar, Bay, and River Channels have been previously surveyed. Phase I surveys were conducted in the summer of 2018. Although the risk was included in the ARA scope growth, professional cultural judgement indicates a reduced risk.

The Mobile Harbor Federal Navigation Channel traverses an area where pipelines exist. All known pipelines have been identified; however, uncertainty associated with the pipeline locations (or unknown pipelines that may exist) was accounted for in the abbreviated risk analysis. The risk of unidentified pipeline locations is also captured in the CSRA of the RP. Furthermore, surveys will be conducted during preconstruction activities to validate any unconfirmed locations and depths.

In addition to the scope risks, the lack of geotechnical data within the widener was identified to increase cost uncertainties with the potential of differing site condition than what is currently assumed.

7.1.5.2. Cost and Schedule Risk Analysis (CSRA)

For projects where the total project cost is $40 million or greater, a CSRA using Crystal Ball, a statistically based Monte Carlo simulation software, is required in accordance with current USACE guidance ER 1110-2-1302. The CSRA is to be treated as For Official Use Only (FOUO) because disclosure of cost data may easily compromise the integrity of the bidding processes.

A CSRA was performed for the RP and quantitatively addresses project uncertainties, including schedule and cost impacts. The conclusions from the additional investigations and modeling conducted as a result of the ARAs are included in the CSRA, including pipeline research, cultural Phase I survey, oyster distribution modeling, aquifer analysis, and a vessel generated wave energy assessment.

7.1.5.2.1. Schedule Risk

A construction schedule was developed by the project manager with input from the project delivery team. From the developed schedule, several risks were identified as part of the CSRA exercise including funding stream, locating pipelines, additional ship simulation modeling, public concerns, and cultural mitigation delays. The result of the schedule risk at the 80% confidence level is likely exceeding the construction schedule by 37 months.

The key schedule risk drivers for the RP identified through the CSRA are shown in Figure 7-3 which include analyses concerns, identification of pipelines, quantities, and number of contracts.

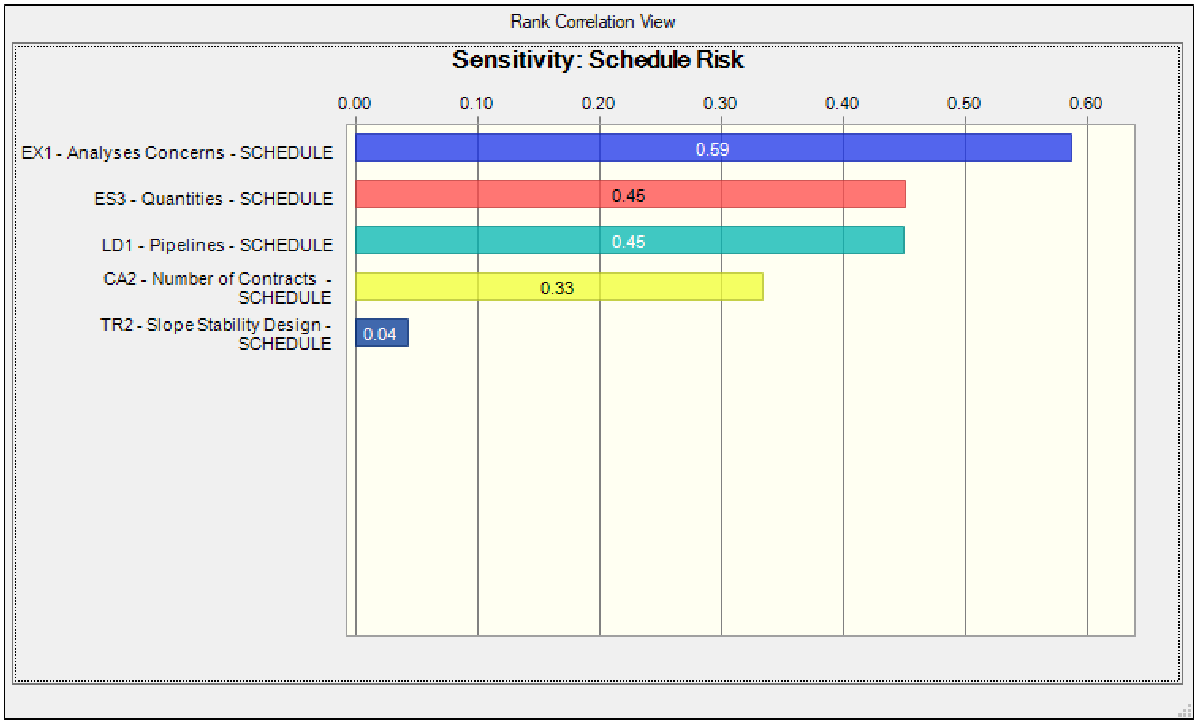


Figure 7-3. Schedule Risk Sensitivity Chart

7.1.5.2.1.1. Public Concern

The Mobile Harbor Navigation Project has received an immense amount of public participation throughout the feasibility study regarding modeling and maintenance dredging practices. Although future maintenance dredging practices will likely satisfy much of the concerns, there may be additional concerns that will need to be addressed. The PDT has mitigated this risk by including additional modeling for oyster larval distribution, vessel generated wave energy, and aquifer analyses. The high uncertainty of the public concerns regarding the analyses could have a large impact of the schedule.

7.1.5.2.1.2. Identification of Pipelines

A search of design files, permit records, and state and Federal databases indicate several pipeline crossings are located within the project footprint. The locations of these have been identified with details and provided in Table 4-4. While most pipelines have been verified with as-built drawings, uncertainty associated with pipelines remain and cross-referencing of files with permit records are ongoing. Surveys will be conducted to validate the locations and depths of unverified pipeline crossings prior to commencement of any construction efforts. If unlikely relocation is necessary, the process may be lengthy. Since the unidentified pipeline crossings are in the lower Bay Channel and Bar Channel, the order of work may be strategically phased to mitigate the risk to the schedule. Futher details of pipeline crossing coordination is provided in Appendix D – Real Estate.

7.1.5.2.1.3. Number of contracts

The structure of the RP estimate is phased from FY 2020 to FY 2023. Each phase includes an appropriate number of contracts for a strong funding stream. Table 7-1 includes the assumptions made for each phase.

Table 7-1. Construction Phasing

Schedule	Phase Desciption	Number of Contracts
FY2020	Phase I: Widening	One
FY 2021	Phase II: Deepening Bar Channel & Widener	One
FY 2022	Phase III: Deepening Lower Bay Channel	One
FY 2023	Phase IV: Deepening Upper Bay Channel and Turning Basin	Two

Based on assumptions, five contracts will be utilized. It is possible that additional contracts will be necessary based on the progress of design and the funding stream. The

PDT is developing an acquisition strategy considering that the work may be broken into more contracts than optimistically developed in preparation of the foreseeable risk.

7.1.5.2.2. Cost Risks

The construction cost was developed by the cost engineer with input from the project delivery team. From the developed cost, several risks were identified as part of the CSRA exercise including locating pipelines and cultural resources, sea level rise, site conditions, modeling efforts regarding ship simulation, aquifers, and ship wake, and estimating assumptions such as bidding competition and quantities. The result of the cost risk at the 80% confidence level is likely to exceed the estimated construction cost by 26%.

Many of the cost risks were identified as unlikely to occur or minimal impacts. For example, Mobile Harbor provides an environment that is rich in prehistoric and historic human activity. Within the widener, concerns from the PDT include efforts to document and or preserve anomalies identified as a result of the 2018 Phase I survey. Phase II surveys will be conducted; however, the cost impact of a possible Phase III survey is identified as minimal. As an additional example, aquifer impacts due to dredging may not occur for thousands of years and the current treatment is determined sufficient using brackish water membranes. The analysis for the vessel generated wave energy assessment determined that the likelihood is low. No quantifiable impacts were identified in the evaluation for exposure and vulnerability to sea level rise. Reference Section 2.10.4 for more information. Finally, although ship simulation is a likely impact, the cost increase is isn't considered significant.

The key cost risk drivers for the RP identified in Figure 7-4 Cost Risk Sensitivity Chart through the CSRA are cost estimating assumptions, slope stability design, and quantities.

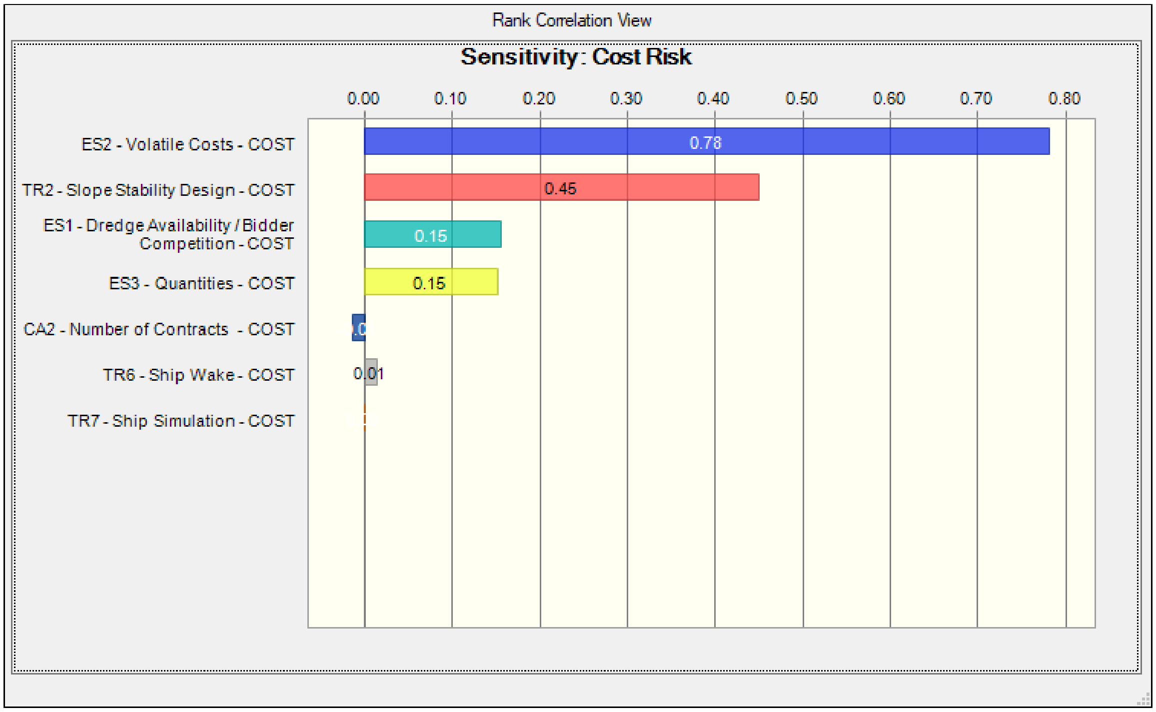


Figure 7-4. Cost Risk Sensitivity Chart

7.1.5.2.2.1. Cost Estimating Assumptions

Many assumptions included in estimating costs lead to uncertainties; however, volatile costs and bidder competition include some of the highest uncertainties in the cost estimate. Volatile costs include escalation and fuel fluctuations. Bidder competition is based on the availability of dredging equipment and the amount of work available at the time of the project. The cost risk is mitigated through conservative assumptions and application of a quantitative based contingency.

7.1.5.2.2.2. Slope Stability

It is anticipated that the channel slopes will be roughly the same slope as they currently are designed; however, the slopes will be confirmed during the PED phase through slope stability analyses using strength data. Although not expected to impact the design assumption, the increase in quantities was determined a key cost risk. Reference Sectoin 5.4.1 for more information.

7.1.5.2.2.3. Quantities

The new work quantities are thought to be conservatively developed. Several unknowns such as shoaling, overdepth, and non-pay quantities are factored into the costs. Since the estimate was developed conservatively, an opportunity for cost savings was identified, making the quantities included in the estimate a cost opportunity, positively affecting the cost contingency.

7.1.6. Total Project Cost Summary (TPCS)

During the evaluation of alternatives, a TPCS was not required; however, per ER 1110-2-1302, it is required for the Federally RP which reflects all applicable project feature costs, contingencies, escalation, and inflation to project completion. The RP TPCS includes a project first cost of $338,548,000 and and fully funded project cost of $365,732,000. The project first cost is at fiscal year 2019 price level whereas the fully funded project cost includes inflation to the midpoint of construction. The fully funded cost is used for budget purposes. The TPCS may be referenced in Attachment A – 8.

7.1.7. Value Engineering (VE) Study

Implementation guidance for Section 1004 of the Water Resources Reform and Development Act of 2014 removes the duplicative analysis of a Value Engineering (VE) study during a USACE feasibility study; therefore, no VE study will be conducted for purposes of this GRR. During the PED phase, Value Engineering remains a requirement under 41 U.S.C. 1711 and OMB Cir. A-131 and, therefore, will be applied per ER 11-1-321.

7.1.8. District Quality Control Review

The District Quality Control (DQC) review, which is a technical review of the cost products by a senior cost engineer at the USACE district level, is complete in accordance with ER 1110-2-1150. The DQC review was completed in The Design Review and Checking System (DrChecks) in June 2018 for the Draft Mobile Harbor Intergrated GRR with Supplemental EIS and February 2019 for the final Mobile Harbor Intergrated GRR with Supplemental EIS. All cost DQC review comments are to be treated as For Official Use Only (FOUO) because disclosure of cost data may compromise the integrity of the bidding processes.

7.1.9. Cost Mandatory Center of Expertise (MCX) TPCS Certification

The cost certification is the determination by the Civil Works Cost Engineering and Agency Technical Review Mandatory Center of Expertise (MCX) that the cost products meet current cost regulations and standards. Per ER 1110-2-1302, the review for obtaining the cost certification was conducted for the RP during the ATR March 2019 and documented in Attachment A – 8.

7.2. New Work Costs

Details about the quantities and costs of the measures and RP are provided in the following paragraphs.

An array of structural measures was identified to include modifications to a portion of the River Channel and the Bay and Bar Channels, bend easing, and modifying the Choctaw Pass Turning Basin. The initial alternatives include:

- depths ranging from 46 to 55 ft with an additional 2 ft of depth in the Bar Channel
- widths of 500 and 550 ft for up to 15 nautical miles in length
- easing of the two sharpest bends in the Bar Channel
- design modifications to the turning basin including proposed design depth

The initial alternatives were screened based on study ojectives, criteria, models and needs. The focus array of alternatives were then screened based on economics. Table 7-2 includes a summary of the costs of the final array of alternatives.

Table 7-2. Final Array of Alternatives

Combined Measures Preliminary Project Cost ($M) Deepening, 3-NMile Widener, Bend Easing, Turning Basin				
	Alternative (River and Bay Channel Depth/ Bar Channel Depth)			
	47’/49’	48’/50’	49’/51’	50’/52’
Cost*	$179.09	$249.53	$315.41	$387.76

Note: FY 2018 Price Level, Includes Associated Costs, Excludes O&M

Based on screening analysis, the PDT was able to identify an alternative that appeared to satisfy the project objectives and be considered as the TSP; that plan is the 50-foot River and Bay Channels and 52-foot Bar Channel alternative; Table 7-3 is a summary of the TSP project first costs used for early economic analysis.

Table 7-3. Tentatively Selected Plan First Cost

Description of Cost Component	Project First Costs (K)
General Navigation Features (GNF)	
Dredging: Deepening including Bend Easing and Turning Basin	$350,372
Dredging: 100’ Widening of 3 Nautical Mile Lane	$12,773
Preconstruction, Engineering & Design	$8,542
Construction Management	$4,029
Subtotal	$375,756
Lands Easements Rights of Way and Relocation (LERR)	$40
Total Project First Costs	$375,796
	Economic Costs (K)
Local Service Facilities: Berthing (ASPA)	$11,397
Associated Costs: Aids to Navigations (U.S. Coast Guard)	$609
OMRR&R: Annual Deepening, Bend Easing, Widening, Turning Basin	$2,358

Note: FY 18 Price Level

The TSP was then approved as the RP which includes a 3 nautical mile widener of 100-ft, 50-ft deep Bay Channel and 52-foot Bar Channel with bend easing and a modified turning basin.

The costs were updated to include the conclusions of modeling which are summarized in the main report and final cost assumptions as discussed in Section 7.1.5.2. Table 7-4 is a summary of the project first costs used for economic analysis. The total first cost of the RP is estimated to be $338,548,000.

Table 7-4. Recommended Plan First Costs

Description	Total First Costs[2] (K)
General Navigaton Features (GNF)	$327,571
Preconstruction, Engineering & Design	$5,550
Construction Management	$5,368
Lands Easements Rights of Way and Relocation (LERR)	$59
Total Project First Costs	$338,548
	Other Economic Costs [2] (K)
Local Service Facilities: Berthing (ASPA)	$11,488
Associated: Aids to Navigations[3]	$614
Estimated Economic Costs	[1]$350,650
Average Incremental Annual OMRR&R Cost[4]	$2,537

[1]The reported estimated economic cost excludes Interest During Construction; however included in BCR calculation.
[2]FY19 Price Level
[3]U.S. Coast Guard cost
[4]Average Incremental Annual OMRR&R (Operation, Maintenance, Repair Replacement, and Rehabilitation) over 50 year period at FY 19 Price Level

7.2.1. Dredging

The scope of work will be refined during PED and the exact construction methodology would be determined by the contractor selected through the contracting process; however, assumptions regarding various possible construction techniques were made for planning and estimating purposes and described in this section. Quantity development (see 7.2.1.1), placement areas (see Section 4.11.1) and dredge material characteristics (see 5.3) are important factors in estimating. Note that no costs are associated with expanding existing placement areas.

7.2.1.1. Placement Areas

Several potential placement areas are considered for cost assumptions within the RP, including the Relic Shell Mined Area and the ODMDS. The assumed placement locations of new work dredged material represent the least costly placement alternative that is consistent with sound engineering practices and meets all Federal environmental requirements (i.e., the Federal Standard).

The Federal Government has placed considerable emphasis on using dredged material in a beneficial manner. Several areas were considered and discussed in more detail in the main report Section 4.2.3. Four of the possible beneficial placement areas include: Denton Reef, Bayfront Park southward to Jemison's Fish Camp, Dauphin Island Causeway from the Heron Bay cutoff southward to Cedar Point and Dauphin Island direct placement. Although recognized as possible beneficial placement areas, these were not considered in the RP cost assumptions due to the requirement to use the least cost placement area. The costs are approximations and depend on designs, equipment selection, and material type and quantity. As design of beneficial use designs are refined and assumption are modified, the costs may differ from the costs reported.

Any additional beneficial uses of dredged material would be implemented at the option of the USACE and any associated cost differences would likely be paid by a NFS requesting the use of the material. The identified least cost placement areas and incremental costs are included in Table 7-5. See Section 4.2.3.4 in the Main report for more details.

Table 7-5. Beneficial Use Incremental Costs

Borrow Reach	Possible Beneficial Use (BU) Placement Sites	Estimated Placement Volume for BU (CY)	Default Placement Area	Least Cost Placement Area	Incremental Cost for BU Placement
Bar Channel	Dauphin Island Beaches*(2)	TBD	SIBUA	SIBUA	$8.00
Lower Bay Channel	Bayfront Park Marsh Restoration	450,000	ODMDS	ODMDS	$4.00(4)
Lower Bay Channel	Dauphin Island Causeway Marsh Restoration	1,500,000	ODMDS	ODMDS	$4.00(4)
Upper Bay Channel	Relic Shell Mined Area	5,000,000	ODMDS	Relic Shell Mined Area	$0
River Channel	None known	NA	ODMDS	ODMDS	NA
Turning Basin	Denton Reef Restoration(3)	500,000	ODMDS	ODMDS	$3.00

NOTES:

(1) **The costs are approximate and depend on design, equipment selection, and material type and quantity. As beneficial use designs are refined and assumptions are modified, the costs may differ from the costs reported.**

(2) **Based on existing borings, there is not sufficient quantities of suitable material within the new work dredged material for direct beach placement.**

(3) **In the case of using material dredged from the turning basin for restoration of Denton Reef, this may fall under the authority of Section 302 of WRDA 1996 and allow for the adjustment of the Federal Standard.**

(4) **The incremental cost for BU placement for the Bayfront Park and Dauphin Island Causeway marsh restoration represents placement at an upland site adjacent to the Theodore Industrial Canal. Additional effort will be required by the project proponent to place the material at the project site.**

7.2.1.2. Quantity Development

The quantities are an important aspect of cost estimate development and serve as a critical basis of estimate data. The project scope is largely based on the quantity take-offs and calculations of sediment to be dredged for each alternative. The quantities for alternatives and the RP were developed in CADD software (InRoads) using existing 2016 surveys, current design templates, and future design templates. The quantity ranges based from the 2016 surveys for the alternatives are shown inTable Table 7-6.

Table 7-6. Quantity Ranges for Focus Array of Alternatives

Channel Segment	Quantity (cy)[1]
River Channel, Bay Channel, and Bar Channel	9,100,000 to 22,200,000
Turning Basin	1,200,000 to 1,700,000
Bend Easing	113,000 to 155,000

Note[1]: -47 feet to -50 MLLW River Channel, Bay Channel, Turning Basin /-49 to -52 feet to MLLW Bar Channel and Bend Easing, Based on 2016 survey to include proposed depths, 2' advanced maintenance and 2' allowable overdepth

The alternatives considered include the River Channel at stations 226+16 to 244+66, Bay Channel at stations 244+66 to 1760+10, and Bar Channel at stations 1760+10 to 2189+59, Bend Easings at stations 1775+43 and Station 1854+ 69, and a 250 foot expansion of Choctaw Pass Turning Basin.

Also based on 2016 surveys are the quantities for the RP which are listed in Table 7-7.

Table 7-7. Quantities for RP

Channel Segment	Volume (cy)[1]
River Channel (Sta. 226+16 to 244+66)	260,444
Bay Channel (Sta. 244+66 to 1760+10)	15,331,506
Bar Channel (Sta. 1760+10 to 2189+59)	5,327,942
3 Mile Widening for Passing (Sta. 1577+82 to 1760+10)	1,368,685
Bend Easing (Sta.1775+43 and 1854+69)	155,259
Choctaw Pass Turning Basin (250 foot Expansion to the South)	1,688,864
Total New Work Volume	**24,132,700**

[1] Quantities include the proposed depths plus advanced maintenance and allowable overdepth.

Costs for the RP and the focus array of alternatives were based on dredging quantities calculated for the design template plus 2 feet of advanced maintenance and 2 feet of allowable overdepth throughout the Bay and Bar Channels. For example, the quantity for a design depth of -49 feet includes an additional 4 feet of material (to -53 feet) to account for the required advanced maintenance and the maximum amount of allowable overdepth as illustrated in Figure 7-5. The quantities resulting from extending the Choctaw Pass Turning Basin south 250 feet from stations 244+65 to 273 +21 and deepening to -50 MLLW include a 4 foot overdepth and 2 feet of advanced maintenance.

Additionally material that is dredged outside of the paid template would not receive payment, but is anticipated. Consequentially, some material outside the paid template is accounted within the estimate. Furthermore , a portion of maintenance overdepth material is included in the project cost estimates to account for material that will likely be in the channel at the time construction.

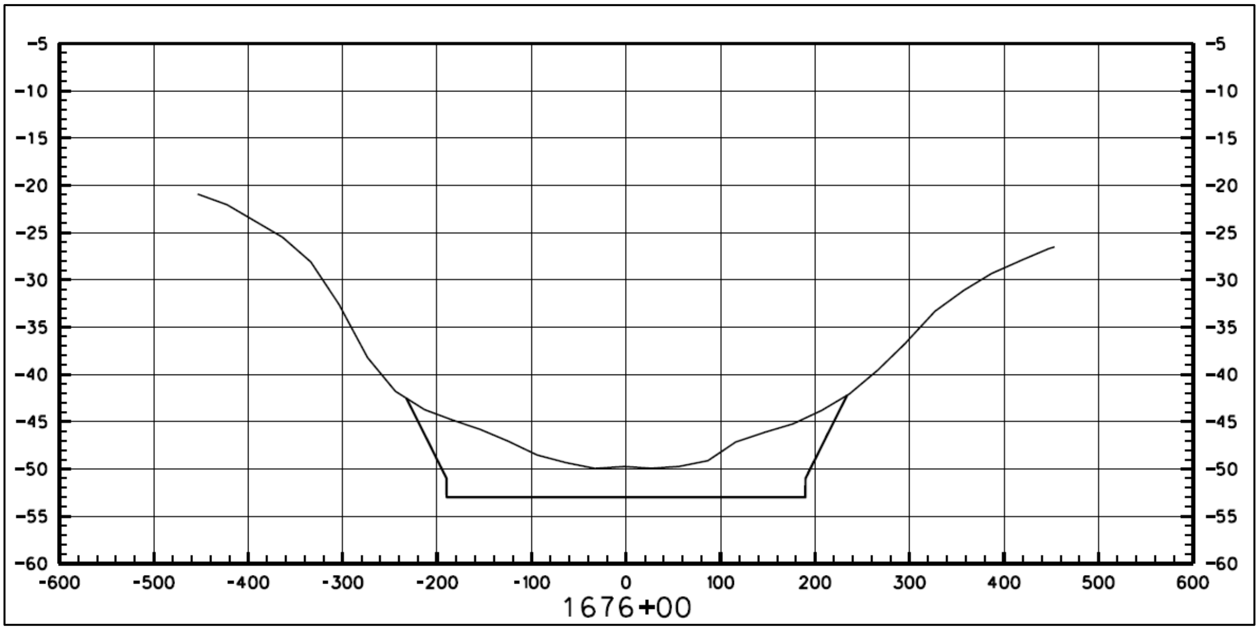


Figure 7-5. -49 feet MLLW Deepening Design Template for Station 1676+00

7.2.2. Preconstruction Engineering & Design (PED) Costs

Costs for the RP PED phase are funded prior to General Construction for the preparation and award of contract plans and specifications (P&S). PED costs were provided by the project manager with input from the PDT. For the RP, a cultural Phase II survey, additional ship simulation study, geotechnical investigation, and a VE study are required to support the final design and completion of P&S. In addition, further environmental agency and real estate coordination is necessary. The PED costs also include monitoring, as well as the additional costs for preparing advertisement packages for multiple construction contracts due to a phased construction approach.

7.2.3. Construction Management Costs

Construction Management costs are for the supervision and administration of the contracts required to perform the various aspects of construction for this project. They include project management, construction quality assurance, engineering and environmental compliance during construction, and contract administration costs. These costs were provided by the project manager with input from the project delivery team based on the anticipated duration of the multiple construction phases of the project.

7.2.4. Real Estate Costs

Lands, Easements, Rights of Way, and Relocations (LERR) is a project cost component factored into the economic analysis and also cost-shared by the NFS. The USACE, Mobile District Real Estate Division determined the LERR costs, which include the breakout of related administrative efforts and appraised land associated with the modifications of Choctaw Pass Turning Basin. Schedule impacts due to real estate are considered negligible and very unlikely, respectively, owing to the fact that no acquisition is required.

As a result of the modification along the southern portion of the Choctaw Pass Turning Basin as described, a portion along the northwestern shoreline of Little Sand Island (approximately 1 acre) will be impacted. The NFS currently holds the fee simple title to Little Sand Island per the Statutory Warranty Deed dated November 10, 2009. Since the potentially impacted land is above the ordinary high water line, the NFS is required to provide this portion of Little Sand Island for the benefit of the project in advance of construction of the project. The NFS will be entitled to credit against their share of project costs for the appraised value of the land being provided. The appraised land value prepared by USACE, Mobile District Real Estate Division does not require additional contingencies in accordance with ER 405-1-4.

Federal and non-Federal administrative costs have also been included in the Baseline Cost Estimate for Real Estate (BCERE) to account for project coordination, crediting, and miscellaneous expenses that may occur during the implementation of the proposed project. USACE, Mobile District Real Estate Division includes a 25% contingency based on a low real estate risk level for the non-Federal administrative expenses as detailed in the (BCERE) of the Real Estate Appendix D.

7.3. Maintenance Costs

Additional maintenance dredging resulting from channel modifications falls under the Operation, Maintenance, Repair, Replacement, and Rehabilitation (OMRR&R) responsibilities of the Federal Government, and the resulting costs were considered as part of the economic screening of alternatives. The cost impacts of the measures were estimated based on current practices and historical data.

Currently, the Bay Channel is dredged to a depth of 45 feet plus 2 feet of advanced maintenance and 2 feet of allowable overdepth. The Bay Channel, including the Choctaw Pass Turning Basin, typically requires removal of approximately four million cubic yards of sediment annually. Maintenance of the Bay Channel and Choctaw Pass Turning Basin is typically completed by a hopper and/or hydraulic pipeline dredge. The placement areas for the Bay Channel are the approved open water placement sites in Mobile Bay and the ODMDS (see Figure 1-2 and Figure 1-3). A hopper dredge is required for placement in the ODMDS, a hydraulic pipeline dredge can be used for placement of material in the open water sites in Mobile Bay using thin layer placement techniques.

The Bar Channel is currently dredged to a depth of 47 feet plus 2 feet of advanced maintenance and 2 feet of allowable overdepth. See Section 4.10.1.3 for the average annual quantity of sediment removed from this channel segment. The sediment is typically removed by a hopper dredge every 2 to 3 years and placed in the SIBUA; however the ODMDS may be utilized under certain circumstances. To ensure adequate disposal capacity for future dredging cycles, the SIBUA will be expanded to the northwest, along the ebb-tidal shoal and pathway of sediment transport towards Dauphin Island (see Section 4.11.2.3 for further details on the SIBUA extension).

The future annual incremental maintenance costs were determined using future shoaling rate estimates and historical dredging data. This information was provided by Engineering and Operations Division staff from the USACE, Mobile District, and reflect the estimated annual incremental quantities for all deepening and widening measures considered. The details of how shoaling rates were calculated for the Bay and Bar Channels are provided in Section 4.6. Rates for the lower Bay Channel and Choctaw Pass Turning Basin are still being evaluated; subsequently, the costs will be refined upon completion of those evaluations. The Fiscal Year (FY) 17, FY18, and FY19 unit costs for maintenance dredging were determined using historical costs and escalation calculated from the maintenance contracts ranging from 1997 to 2017. Construction management costs were provided by the USACE, Mobile District Operations Division based on historical monthly rates. It’s assumed that PED and mobilization costs will not increase; therefore, they were excluded from the incremental maintenance costs.

The Bay Channel dredging contracts used in the analysis include: W91278-16-D-0041, W91278-15-D-0051, W91278-14-D-0024, W91278-14-D-0041, W91278-13-D-0005, W91278-13-D-0024, W91278-12-D-0023, W91278-11-D-0023, W91278-10-D-0021, W91278-10-D-0038, W91278-10-D-0051, W91278-10-D-0099, W91278-09-D-0014, W91278-09-D-0014, W91278-09-D-0026, W91278-09-D-0027, W91278-09-D-0054, W91278-08-D-0004, W91278-08-D-0029, W91278-08-D-0051, W91278-07-D-0001, W91278-07-D-0087, W91278-07-D-0068, W91278-06-D-0001, W91278-06-D-0001, W91278-05-D-0044, W91278-05-C-0008, W91278-05-C-0003, W91278-05-D-0046, W91278- 04-C-0022, W91278-04-C-0045, W91278-03-C-0004, W91278-03-C-0026, W91278-03-D-0032, W91278-02-C-0015, W91278-01-C-0003, W91278-01-C-0019, W91278-00-C-0023, W91278-00-C-0023, W91278-00-C-0012, W91278-99-C-0020, W91278-99-C-0020, W91278-99-C-0020, W91278-99-C-0027, W91278-99-C-0046, W91278-98-C-0003, W91278-98-C-0023, W91278-98-C-0067, and W91278-97-C-0003.

The Bar Channel contracts used in the analysis include: W91278-14-D-0087, W91278-11-D-0006, W91278-09-D-0014, W91278-08-D-0026, W91278-07-D-0087, W91278-05-D-0005, W91278-04-C-0049, W91278-04-C-0005, W91278-01-C-0019, W91278-00-C-0012, W91278-99-C-0028, and W91278-98-C-0023.

The Choctaw Pass Turning Basin contracts used in the analysis include: W91278-14-D-0024 and W91278-15-D-0051.

The annual incremental OMRR&R costs for the widening and deepening measures were initially derived in FY17 price level as shown in Table 7-8. The widening measures include a 3 nautical mile and 5 nautical mile length of a 500-foot and 550-foot wide lane for passing. The initial maintenance costs for the widening measures range from $154,600 to $463,200. The initial deepening measures include -47 feet MLLW to -52 feet MLLW for the Bar, Bay and River Channels, and the costs range from $850,000 to $2.973 million.

Table 7-8. Annual Incremental OMRR&R Costs-Initial Measures

Bay/Bar Depth (ft.)	Deepening*	Widening*			
		500'/5 Nmiles	550'/5 Nmiles	500' /3 Nmiles	550' /3 Nmiles
47/49	$850,000	$309,600	$463,200	$154,600	$234,995
48/50	$1,272,000	$309,600	$463,200	$154,600	$234,995
49/51	$1,700,000	$309,600	$463,200	$154,600	$234,995
50/52	$2,123,000	$309,600	$463,200	$154,600	$234,995
51/53	$2,545,000	$309,600	$463,200	$154,600	$234,995
52/54	$2,973,000	$309,600	$463,200	$154,600	$234,995

*The extension of the Choctaw Pass Turning Basin was not included in the initial alternatives./
*FY17 Price Level

The final array of alternatives include channel deepening measures from -47 feet MLLW to -50 feet MLLW and a 3 nautical mile long by 500-foot widener. Two areas of bend easing and a modification to the Choctaw Pass Turning Basin were included in the final deepening measures. The costs for the final array were updated to FY 18 price level as shown in Table 7-9.

Table 7-9. Annual Incremental OMRR&R Costs-Final Array Measures

Bay/Bar Depth (ft.)	Deepening*		Widening*
	Channels	Turning Basin	500'/3 Nmiles
47/49	$877,000	$24,000	$161,420
48/50	$1,307,000	$24,000	$161,420
49/51	$1,743,800	$24,000	$161,420
50/52	$2,173,000	$24,000	$161,420

*Price Level FY18/ TSP highlighted at 50 foot River and Bay Channel,52 foot Bar Channel

The average annual incremental OMRR&R cost was updated to FY19 price level then calculated for a 50 year period for the RP. The incremental average annual OMRR&R cost for the study is determined to be $2.537 million.

7.4. Associated Cost

Costs analyses for USACE deep draft navigation projects include associated costs which are not components of the direct construction costs of the recommended Federal project, but are a necessary non-Federal responsibility or U.S. Coast Guard (USCG) responsibility due to the channel modifications. These costs are not typically cost-shared. Associated costs include items like Aids to Navigation (ATONs), required improvements to docking or berthing areas, and sometimes mitigation efforts.

No cultural mitigation efforts are currently included in the associated costs for this study, but they are included in the risk-based contingency for construction elements.

7.4.1. Aids to Navigation

The USCG is the responsible agency of nautical navigation markers and aids. They were consulted in early 2017 and again in spring 2018 to confirm the required relocation or replacement of ATONs as a result of the channel modifications. ATONs include relocation of channel lights and lighted buoys. The USCG also provided and confirmed the costs for relocating the ATONS by means of USCG keeper class cutters and inland construction tenders. In addition to the costs provided by the USCG, a contingency was added for cost or scope growth.

ATON costs were evaluated for deepening and widening measures from -47 feet MLLW to -52 feet MLLW. In total, 6 to 24 navigational aids were identified to be relocated.

Currently no navigational aids are in place for the turning basin; therefore the USCG has confirmed that no additional nautical navigational aids are required within the proposed turning basin. The costs provided by the USCG for the relocation of the identified ATONs exclude contingencies and range from approximately $110,000 to $451,000. The cost for relocation of ATONs for the RP is estimated to be $614,000 which includes a contingency for cost growth.

The TSP includes the following ATONs:

- Mobile Channel Light 78
- Mobile Channel Light 73
- Mobile Channel Light 67
- Mobile Channel Light 55
- Mobile Channel Light 51
- Mobile Channel Light 52
- Mobile Channel Light 50
- Mobile Channel Lighted Buoy 28
- Mobile Channel Lighted Buoy 26
- Mobile Channel Lighted Buoy 25
- Mobile Channel Lighted Buoy 24
- Mobile Channel Lighted Buoy 23
- Mobile Bar Lighted Buoy 14
- Mobile Bar Lighted Buoy 12
- Mobile Bar Lighted Buoy 10
- Mobile Bar Lighted Buoy 8
- Mobile Bar Lighted Buoy 7
- Mobile Bar Lighted Buoy 6

7.4.2. Berthing Area

Although the USACE does not factor cost sharing for berth modifications due to the proposed channel modifications, the cost to adjust berths to the matching depth is factored in the economic analysis as an associated cost to the project. McDuffie, APM Terminals, and APM Terminals extension berths are expected to need berth modifications. Pinto berth is not included since the customer to Pinto advises they will never need depth beyond -45 foot draft.

The ASPA provided their rates and volumes for the berths that would require deepening. The rates are confirmed to be at 2019 price level. The volumes are based on 3:1 side slopes for each berth while using a hydraulic dredge with minor dewatering of material and removal of material from associated placement areas. The costs for -47-foot MLLW to -52-foot MLLW deepening measures range from $3,467,000 to $12,765,000 without contingencies. A contingency is included in the analyzed costs for uncertainties. The cost for the berthing area at -50 MLLW included in the RP is estimated to be approximately $111,488,000 at FY 19 price level.

7.5. Schedule

Based on reasonable estimated productivities, the construction duration is estimated to be 48 months, FY20-FY23. The overall schedule and durations may change depending on the time required to obtain congressional appropriations. Other areas of schedule uncertainty include the availability of dredging equipment to complete the work and to comply with environmental requirements and delays due to unexpected severe weather conditions. Table 7-10 summarizes the PED and construction activities.

Table 7-10. PED and Construction Duration

Description	Duration in Months	Cumulative Months
Division Engineer's Transmittal (S= PED Start)	0	S
Plans and Specifications	12	S+12
Advertise (Contingent upon funding) Contract	3	S+15
Award Phase I Contract	3	S+18
Construction Start (C=Construction Start)	0	C
Award Phase II	12	C+12
Award Phase III	12	C+24
Award Phase IV	12	C+36
Construction Complete	12	C+48

7.6. Recommended Plan Cost Summary

The estimated project first cost is $338.548 million, which includes the cost of constructing the general navigation features, PED, construction management (CM), and the value of lands, easements, rights of-way and relocations. Details are provided in Table 7-11. The allocation of costs between the Federal Government and NFS can be found in the executive summary of the main report.

Table 7-11. Recommended Plan Costs

Description	Constant Dollar Costs[2] (K)	Fully Funded Costs (K)
General Navigation Features (GNF)	$327,571	$353,532
Preconstruction, Engineering & Design	$5,550	$6,019
Construction Management	$5,368	$6,180
Lands Easements Rights of Way and Relocation (LERR)	$59	-
Project First Cost	$338,548	-
Project First Cost Allocation		
Fully Funded Total Project Costs[5]		$365,732
	Other Economic Costs[2] (K)	
Local Service Facilities: Berthing (ASPA)	$11,488	-
Associated: Aids to Navigations[3]	$614	-
Estimated Economic Costs[1]	$350,650	-
Average Incremental Annual OMRR&R Cost[4]	$2,537	-

[1] The reported estimated economic costs exclude Interest During Construction; however IDC is included in BCR calculation, [2] FY19 Price Level [3] U.S. Coast Guard cost, [4] Average Incremental Annual OMRR&R (Operation, Maintenance, Repair Replacement, and Rehabilitation) over 50-year period at FY19 Price Level, [5] Slight difference in sum due to rounding

SECTION 8. RESIDUAL RISK AND FUTURE STUDY ACTIVITIES

There were several high risk study items identified upon initiation of this study. Those were primarily associated with the uncertainty in potential impacts from deepening and widening the channel, and the outcome that could have on the decision making process and project costs. Since that time, extensive evaluations, modeling, and analyses were completed, as documented in this appendix, and there are no high risk engineering related items remaining. There are some analyses that will be conducted during the PED phase of the project (i.e., geotechnical investigation and an additional ship simulation study to further evaluate the length of the two-way traffic area, bend easings, and turning basin using the actual design vessel(s)). Residual uncertainty associated with these items were accounted for in the the final CSRA and TPCS.

SECTION 9.SUMMARY AND CONCLUSIONS

The engineering team was charged with supporting the development and evaluation of navigation improvement alternatives for the Bar Channel, Bay Channel, Choctaw Pass Turning Basin, and a portion of the River Channel (i.e., south of station 226+16) of the Mobile Harbor Federal Navigation Project in Mobile, Alabama. The Mobile Harbor Federal Navigation Project is an approximately 41 mile deep draft channel through Mobile Pass and Bay that connects the Alabama, Tombigbee, and Mobile Rivers to the Gulf of Mexico (see Figure 1-1). Currently, the Bar, Bay, and River (lower 1,850 feet below station 226+16) Channels are 47, 45, and 45 feet deep, respectively, with an additional 2 feet for advanced maintenance plus 2 feet of allowable overdepth for dredging (total depths of 51, 49, and 49 feet, respectively). Those same channel segments are currently 600, 400, and 600 feet wide, respectively. The Choctaw Pass Turning Basin, located at the northern limit of the Bay Channel, is 45 feet deep by approximately 1,570 feet long (including the 400-foot width of the existing Bay Channel) by 715 feet wide at its easternmost extent and contains a 100-foot widener/transition section about 3,500 feet in length along the eastern edge of the existing Bay Channel immediately south of the basin.

Modifications to these channel features, as recommended by the RP, are as follows:

- Deepen the existing Bar, Bay (including the Choctaw Pass Turning Basin), and River Channels (below station 226+16) by 5 feet to project depths of 52, 50, and 50 feet, respectively, with an additional 2 feet for advanced maintenance plus 2 feet of allowable overdepth for dredging (total depths of 56, 54, and 54 feet, respectively).
- Incorporate minor bend easing at the double bends (at stations 1857+00 and 1775+26) in the Bar Channel approach to the Bay Channel.
- Widen the Bar Channel by 100 feet to project width of 500 feet from the mouth of Mobile Bay northward for 3 nautical miles to provide a two-way traffic area for passing.
- Expand the Choctaw Pass Turning Basin 250 feet to the south (at a depth of 50 feet) to better accommodate safe turning of the design vessel and other large vessels.

Specific tasks completed by the engineering team to help identify and evaluate the RP include the following: (1) a geotechnical investigation to characterize the subsurface conditions; (2) hydrodynamic, water quality, sediment transport, and groundwater modeling to characterize the physical conditions and processes of the study area and determine the relative changes due to widening and deepening the navigation channel; (3) a vessel generated wave energy assessment to quantify the relative changes in wave energy due to vessels calling the port in the future, with and without the proposed navigation channel modifications; (4) a feasibility level ship simulation study to evaluate channel width for turning basin dimensions, bend easing widths, and lengths and widths for a portion of the channel for two-way traffic; and (5) and cost estimating to identify the total project costs for all alternatives considered. The summaries and conclusions of these efforts are provided below.

Geotechnical Investigation: Historical soil borings from the River Channel, Bay Channel, Bar Channel, and Choctaw Pass Turning Basin were reviewed to characterize the soil conditions of the study area. They were collected over many different investigations, dating back to 1963. The USACE conducted geotechnical investigations in 1963-1964, 1972, 1982-1984 within the limits of the channel. Thompson Engineering conducted the initial geotechnical investigation in the vicinity of the Turning Basin in 1986 as part of an investigation for Mobile Naval Homeport Facilities. Additional investigations were conducted by the USACE, Mobile District in the Turning Basin in 2006 and 2009 as part of the Turning Basin expansion in 2009.

The nature of the soil varies throughout the proposed channel modification areas. Soil within the proposed channel deepening and widening areas is predominately comprised of very soft, fat clay (CH). The in situ soil in the Choctaw Pass Turning Basin is predominantly clean sand (SP) with some pockets of silty sand (SM) and intermittent layers of clay. Borings have not been taken in the footprint of the two-way traffic area / channel widener for passing. Adjacent borings at these stations, within the channel, indicate the area is predominantly soft fat clay. Additional borings are scheduled to be sampled during the PED phase to determine material properties. Details of this investigation are provided in Section 5 and Attachment A – 6 of this appendix.

Hydrodynamic, Water Quality, and Sediment Transport Modeling: The Geophysical Scale Transport Modeling System (GSMB) was utilized to quantify the relative changes in circulation, water quality, and sediment transport processes within Mobile Bay and lower Mobile-Tensaw River Delta resulting from the proposed modifications to the channel. Components of GSMB include the two-dimensional (2D) deep water wave model WAM (http://wis.usace.army.mil), STWAVE nearshore wave model (Smith *et al.* 1999), and the large scale unstructured 2D ADCIRC hydrodynamic model (http://www.adcirc.org). These components make up the Coastal Storm Modeling System, CSTORM-MS (Massey et al. 2015). In addition, the three-dimensional models CH3D-MB (Luong and Chapman 2009), which is the multi-block (MB) version of CH3D-WES (Chapman *et al*. 1996, Chapman *et al*. 2007), CE-QUAL-ICM water quality model (Bunch *et al*. 2003, and Cerco and Cole 1994), and MB CH3D-SEDZLJ sediment transport model (Hayter *et al*. 2012 and 2015, Gailani et al. 2014) were applied to evaluate relative changes in water quality and estuarine sediment transport (i.e., fine-grained sediment transport in Mobile Bay) for the existing and future With- and Without-Project conditions. The simulation time period for the models was the year 2010 and results indicate minimal changes in water quality and sediment transport between the With- and Without-Project scenarios. Details of the hydrodynamic, water quality, and estuarine sediment transport models are provided in Sections 6.1, 6.2, and 6.3.1 as well as Attachment A – 1 of this appendix.

Additionally, in an effort to quantify the relative changes in sediment pathways and the morphological response on the ebb tidal shoal and adjacent coastal areas, the Delft-3D (https://oss.deltares.nl/web/delft3d) model was utilized. Delft-3D is an integrated processed-based model composed of multiple modules used to simulate hydrodynamics, short waves, sediment transport, and morphologic change. These components include the 2D FLOW module and SWAN spectral model, which account for the effects of water level variations and current-induced frequency shifting, wave radiation stresses, and gradients that drive nearshore circulation and sediment transport. The Delft-3D model simulation time periods included a 2010 wind/wave climatology as well as a 10-year longer term climatology derived from the European Centre for Medium-Range Weather Forecast (ECMWF) ERA-Interim reanalysis model over the Delft-3D hindcast period of 1988-2016. The modeling results indicate minimal differences in morphologic change in the near shore areas of Dauphin Island and Pelican Island as a result of the channel modifications. This suggests that sediment delivery away from the ebb tidal shoal to these areas is similar under these two scenarios and that shoreline positions are unlikely to be impacted as a result of the modified channel. Although comparison of the two simulations shows some spatial shifting of sand offshore of the Morgan Peninsula, the patterns of erosion/deposition in the two simulations are quite similar. Based on these results, it also appears unlikely that these changes would alter sediment delivery to the peninsula and only minor impacts to the terminal end of the peninsula closest to the channel could occur. Details of the coastal sediment transport analysis are provided in Section 6.3.2 and Attachment A – 2 of this appendix.

Groundwater Modeling: The USACE, Philadelphia District (NAP) developed a three dimensional (3-D) groundwater model to understand the impact that new work dredging may have on the drinking water supply wells at Dauphin Island. The model explains how the change in the shipping channel, due to new work dredging, may affect the water supply to the Dauphin Island water wells. Results show that the new work dredging may have a minor influence on the drinking water source at Dauphin Island. However, variables such as drought, sea-level rise, or increased demand have considerably more effect on increases in salinity. Additionally, the model shows that the minor effects of salinity change caused by the new work dredging may not be realized for thousands of years. The models show minor differences in the 1,000-year capture zone for the existing conditions versus the cut through the channel condition. Based on the modeling results, the new work dredging minimally impacts the groundwater source to the Dauphin Island water wells and any negative effect could take thousands of years to be realized. A detailed report discussing the model development, calibration, and findings is in Attachment A – 7.

Vessel Generated Wave Energy Assessment: A vessel generated wave energy (VGWE) assessment was conducted to quantify the relative changes in wave energy due to future vessels calling the port for the with and without project conditions. The investigation included field data collection to measure VGWE using a suite of five pressure sensors located north of Gaillard Island as well as an estimation of VGWE for an area in the southern bay where no data was collected or available using the model described by Schoellhamer (1996). Impacts were evaluated at the two locations using forecasted vessel calls for the years 2025 and 2035. Results of this analysis indicate no increase in wave energy is expected between the future with and without scenarios. Details of this analysis are provided in Section 6.4 and Attachment A – 4 of this appendix.

Ship Simulation Study: A feasibility level ship simulation study was performed in accordance with ER 1110-2-1403 to evaluate channel navigability with a particular focus on testing varying widths for a two-way traffic are in the lower Bay Channel, bend easings in the Bar Channel, and expansion of the Choctaw Pass Turning Basin. For all simulations, the Bay Channel was deepened from 45 feet to 51 feet and the Bar Channel was deepened from 47 feet to 53 feet. Two different widths were screened for the two-way traffic area (500 feet and 550 feet) and each area spanned approximately 5 nautical miles. All proposed testing of the two-way traffic area included bend easing on the inside at buoys 18 and 21, with width increases at the bends of approximately 185 feet and 50 feet. The Choctaw Pass Turning Basin was deepened to from 45 feet to 51 feet for the proposed testing.

Per the results of the simulations and feedback from the Bar Pilots, vessels equal to or less than two Zim Piraeus (965 feet x 106 feet) and a Zim Piraeus (965 feet x 106 feet) and MT Brittania (860 feet x 138 feet) could successfully pass in a 500-foot wide channel with restrictions on tankers. In addition, two Sovereign Maersk (1140 feet x 140 feet); a Sovereign Maersk (1140 feet x 140 feet) and a Zim Piraeus (965 feet x 106 feet); a Daniella 2 (1200 feet x 159 feet) and a Sovereign Maersk (1140 feet x 140 feet); and a Daniella 2 (1200 feet x 159 feet) and a MT Brittania (860 feet x 138 feet) could successfully pass in a 550-foot wide channel with restrictions on tankers. While testing for the two-way traffic area was conducted on a 5 nautical mile segment in the southern bay, it was determined the most likely length needed will fall between 3 and 5 nautical miles. Additionally, it was found that bend easing increased safety and greatly influenced the ease in which passing could be completed.

Finally, a modification to the Choctaw Pass Turning Basin was deemed necessary to accommodate the safe turning of large vessels during a strong ebb current, particularly when a vessel is docked on the southern berth at APM Terminals. Simulations were conducted with a 100-foot expansion of the basin to the south, which greatly assisted in the safety of completing the turn; however, the pilots still had to use more of the engine's power than they would typically be comfortable with and, as such, further improvements may be required (Note: the RP recommends a 250-foot expansion to the south to account for additional modifications that may be needed beyond the simulated 100-foot expansion).

Additional ship simulations during the PED Phase will be necessary to confirm all recommended channel dimensions since the actual design vessels were not readily available in the ERDC vessel library for the feasibility level testing. Ones that most closely matched the design vessels were utilized but confirmation using the actual design vessels will be necessary prior to construction. Further details of the feasibility level ship simulation are provided in Section 6.5 and Attachment A – 3 of this appendix.

Cost Estimating: Cost analyses were conducted to evaluate a range of navigation improvement alternatives for the Mobile Harbor Federal Navigation Project. Channel modification costs for alternative comparison purposes, the TSP, and the RP were developed using the Cost Engineering Dredge Estimating Program (CEDEP). During the evaluation of alternatives and the TSP, an abbreviated risk analysis (ARA) was performed as a qualitative risk-based assessment whereas a Cost and Schedule Risk Analysis (CSRA) was performed for the RP as a quantitative risk assessment of cost and schedule uncertainties. The key cost risk drivers identified from the CSRA for the RP are cost volatility and assumptions of slope stability analysis. The key schedule risk driver is public concerns to the project. The estimated total project first cost of the RP, including contingency, is approximately $338,548,000 and the total fully funded project cost is $365,732,000. The estimated increase in annual cost to maintain the channel post implementation of the RP is approximately $2,537,000 at a FY 2019 price level assuming a 50 year analysis.

Further details of the cost analyses are provided in Section 7 of the appendix. The Cost Certification and supporting TPCS of the RP are shown in Attachment A – 8.

SECTION 10. GUIDANCE

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ATTACHMENT A-1

ERDC MODELING REPORT

ATTACHMENT A-2

USGS MODELING REPORT

ATTACHMENT A – 3

SHIP SIMULATION REPORT

ATTACHMENT A – 4

VESSEL GENERATED WAVE ENGERGY REPORT

ATTACHMENT A – 5

DATA COLLECTION REPORT

ATTACHMENT A – 6

BORING LOGS AND LAB DATA

ATTACHMENT A – 7

GROUNDWATER ANALYSIS REPORT

ATTACHMENT A – 8

COST ESTIMATE