APPENDIX E – PLAN FORMULATION

Galveston Intercoastal Waterways Coastal Resilience Study, Texas

January 2022

US Army Corps of Engineers ®
Galveston District

Texas Department of Transportation

<This page intentionally left blank>

Contents

1.0 Introduction 5
1.1 STEP 1 – PROBLEMS, OPPORTUNITIES, OBJECTIVES, CONSTRAINTS 5
1.2 Study Area 6
1.3 STEP 2 – EXISTING CONDITIONS 8
1.4 Future Without Project (FWOP) Condition Assumptions 8
2.0 STEP 3 – PLAN FORMULATION STRATEGY 10
3.0 Management Measures and Screening of Measures 10
4.0 Formulation of Initial Array of Alternatives 22
5.0 STEP 4 - INITIAL EVALUATION AND SCREENING 26
5.1 Final Array of Alternatives 30
6.0 Evaluation 30
6.1 Hydrology & Hydraulics Engineering Methodology 43
6.2 Geotechnical Engineering Methodology 44
6.3 Cost Engineering Methodology 46
6.4 Environmental Cost Estimating Methodology 46
6.5 Real Estate Cost Estimating Methodology 47
6.6 HTRW Considerations 47
6.7 Cultural Resources Considerations 48
6.8 Economic Considerations 48
7.0 STEP 5 – COMPARE AND EVALUATE FINAL ARRAY OF ALTERNATIVES 48
7.1 Planning Model 49
7.2 Further Screening of Increments 49
7.3 Incremental Comparison 50
8.0 EVALUATION CRITERIA 58
9.0 STEP 6 - RECOMMENDED TSP 58
9.1 Zone 12 for safety reduction: 60
9.2 Zone 13 for resilience: 61
9.3 Estimated ecological lift for zone 13 of the GIWW-CRS: 62

FIGURES:

Figure 1: GIWW Project Zone Map 7
Figure 2: Study Area Map (also Figure 2 in the main report)..... 26
Figure 3: Zone 12 Alternative 3 Increment Maps 37
Figure 4: Zone 13 Alternatives 3 & 6 Maps 38
Figure 5: Zone 14 Alternatives 3 & 6 Maps 39
Figure 6: Zone 16 Alternatives 3 & 6 Maps 40
Figure 7: Zone 18 Alternative 3 Increment Maps 41
Figure 8: Zone 18 Alternative 6 Increment Maps 42

TABLES:

Table 1: Estimated Relative Sea Level Rise (feet) at Galveston Pier 21 (Region 1)..... 9
Table 2: Estimated Relative Sea Level Rise (feet) at Rockport (Regions 2 and 3) 10
Table 3: Measures..... 11
Table 4: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 1and Zone 2)..... 12
Table 5: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 3 and Zone 4)..... 13
Table 6: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 5 and Zone 6)..... 14
Table 7: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 7 and Zone 8)..... 15
Table 8: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 9, Zone 10 and Zone 11)..... 16
Table 9: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 12 and Zone 13)..... 17
Table 10: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 14 and Zone 15)..... 18
Table 11: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 16 and Zone 17)..... 19
Table 12: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 18 and Zone 19)..... 20
Table 13: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 20) 21
Table 14: Initial Array of Alternatives..... 25
Table 15: Relative Qualitative Assessment of Alternatives 29
Table 16: Initial Increments within zones and Alternatives 3 and 6 34
Table 17: Incremental Comparison of Addressing Study Problems 54
Table 18: Evaluation and Comparison of final array of alternatives 56
Table 19: Comparison of Plans Against Evaluation Criteria 59
Table 20: Comparison of Plans Against Study Objectives..... 60
Table 21: Estimate of ecological lift for zone 13 62

1.0 Introduction

This appendix summarizes the plan formulation process. Plan Formulation is the process of formulating management measures and building plans that meet planning objectives and develop alternatives within the planning constraints.

Alternative plans are a set of one or more management measures functioning together to address one or more planning objectives. Measures include construction and restoration of protective channel features that would reduce shoaling, improve transportation efficiency, and reduce operations and management (O&M) costs; creation and restoration of existing dredge material placement areas; and measures that use dredge spoil as beneficially as possible.

Plan formulation for this study was conducted in accordance with the six-step planning process described in *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (*1983) and the P*lanning Guidance Notebook* (ER 1105-2-100, dated April 2000). The six-step iterative process is:

Step 1 - Specify the water and related land resource problems and opportunities for the project area;
Step 2 - Inventory and forecast existing and future without conditions;
Step 3 - Formulate alternative plans;
Step 4 - Evaluate alternative plans;
Step 5 - Compare alternative plans; and
Step 6 - Select the recommended plan.

1.1 STEP 1 – PROBLEMS, OPPORTUNITIES, OBJECTIVES, AND CONSTRAINTS

This study addresses three main issues within the navigation channel: 1) the chronic erosion and episodic coastal storms eroding the shorelines and barrier islands that have historically protected vessels on the GIWW; 2) sea level rise and continued hurricane and tropical storm risk that will likely exacerbate the loss of barriers around the channel; and 3) erosion of shorelines and sediment carried by coastal storms exacerbate shoaling in the channel leading to light-loading and unintentional groundings of vessels resulting in navigation safety risks.

Barrier islands provide the navigation channel with a buffer against disruptive episodic storm events, as well as the chronic effects of high wind and wave conditions in the study area that affect navigation efficiency, channel operations and maintenance. According to testimonies from local barge pilots, representatives of the Gulf Intracoastal Canal Association (GICA), and the non-federal sponsor the Texas Department of

Transportation (TXDOT), disruptions to the navigation channel have become more frequent in this stretch of the GIWW. In the study area, chronic shoaling and forces of winds and waves occur regularly throughout the year, causing shipping companies to change their schedules to match the tide and weather conditions. USACE personnel in Operations Branch and local industry have reported these situations already occurring, and out of cycle dredging is often required to remove shoals that cause draft restrictions to navigation. In future conditions, as the barrier islands continue to erode and expose the navigation channel to the bay, conditions are expected to become much worse for transiting vessels, exposing them to transit hazards or excessive delays from channel conditions.

1.2 STUDY AREA

The PDT conducted a scoping charette with the vertical team comprised of USACE Southwestern Division and Headquarters staff in June of 2020 where the team discussed problems, opportunities, objectives and constraints. The team also discussed existing conditions and next steps in the study. After completing the initial scoping charette, the PDT held weekly plan formulation meetings, and determined that breaking the project area for Brazoria and Matagorda county into 20 distinct geographical zones would ensure that the PDT captured all problems in the 80-mile study area. (See Figure 1). Those 20 distinct geographical zones are as follows:

- Zone 1: Brazoria County Line to Chocolate Bayou - Station 433+500 to 454+000
- Zone 2: Chocolate Bayou - Station 454+000 to 472+500
- Zone 3: Chocolate Bayou to Freeport Wiggles - Station 472+500 to 538+500
- Zone 4: Freeport Wiggles - Station 538+500 to 556+500
- Zone 5: Freeport Harbor - Station 556+500 to 567+000
- Zone 6: Freeport Harbor to Brazos Floodgates - Station 567+000 to 583+500
- Zone 7: Brazos Floodgates - Station 583+500 to 599+000
- Zone 8: Brazos Floodgates to San Bernard River - Station 599+000 to 610+500
- Zone 9: San Bernard River - Station 610+500 to 618+500
- Zone 10: San Bernard River to Cedar Cut - Station 618+500 to 654+000
- Zone 11: Cedar Cut to Caney Creek - Station 654+000 to 691+500
- Zone 12: Caney Creek - Station 691+500 to 704+000
- Zone 13: Caney Creek to Live Oak Bay - Station 704+000 to 723+000
- Zone 14: Live Oak Bay - Station 723+000 to 739+500
- Zone 15: Live Oak Bay to Big Boggy Creek - Station 739+500 to 757+500
- Zone 16: Big Boggy Creek to Colorado River Locks - Station 757+500 to 797+000
- Zone 17: Colorado River Locks - Station 797+000 to 825+000
- Zone 18: Colorado River Locks to Oyster Lake - Station 825+000 to 883+000
- Zone 19: Oyster Lake to Matagorda Bay Mile 460 Turn - Station 883+000 to 902+500
- Zone 20: Matagorda Bay Mile 460 Turn to Matagorda County Line - Station 902+500 to 955+000

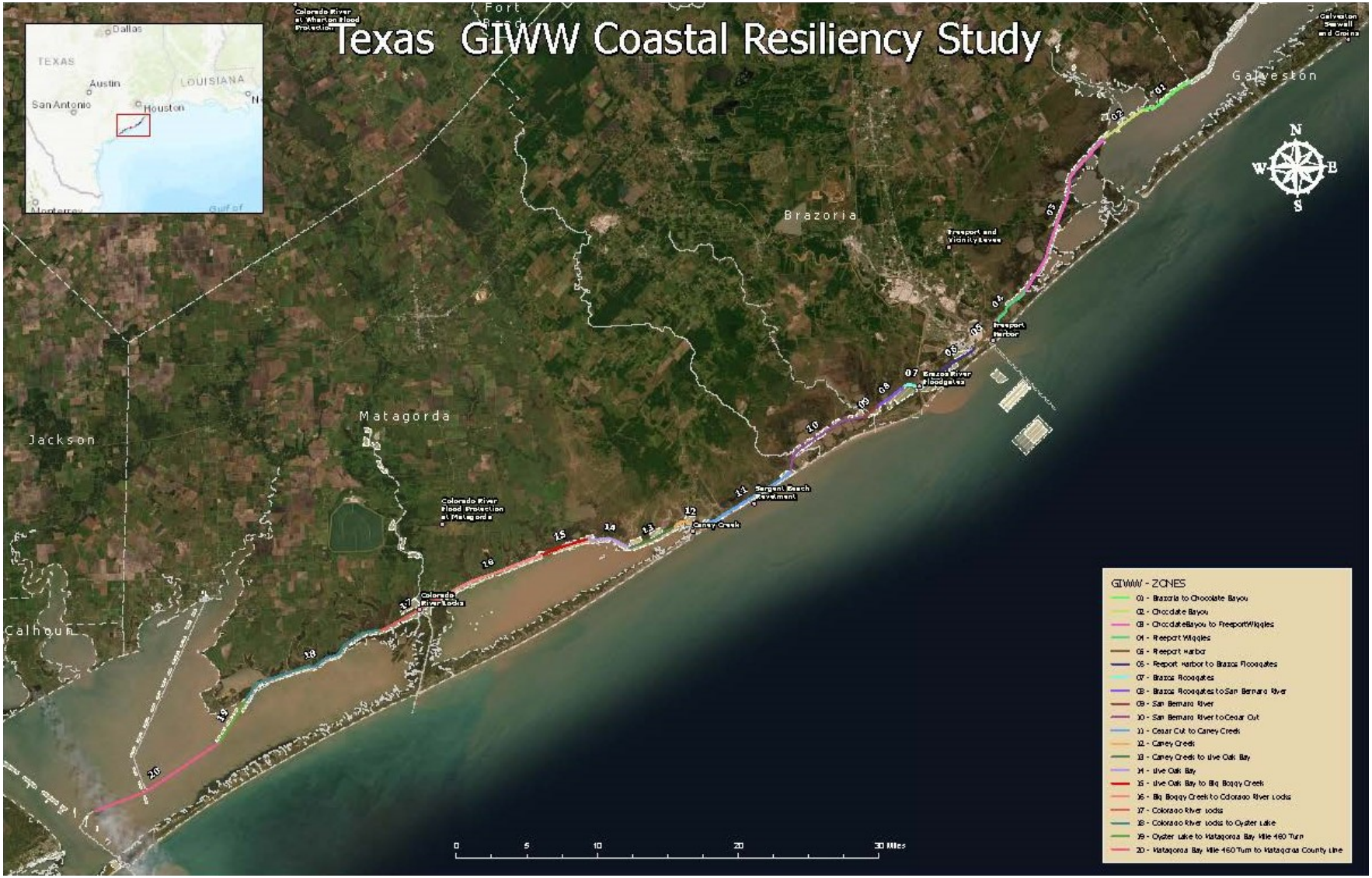

Figure 1: GIWW Project Zone Map

1.3 STEP 2 – EXISTING CONDITIONS

The existing conditions in the coastal region include a dynamic economic environment that combines populations and investments in an area that is exposed to coastal forces. Coastal storms have the potential to damage property and infrastructure and pose life safety risk to residents and workers. The continuing exposure to less intense coastal forces erode sediment along the GIWW and result in habitat loss and safety concerns for navigation. Development in the region is dense and expected to continue over time.

More than one-quarter of the Texas population has lived within the coastal counties with over 6.4 million residents in the study area, and over 80 percent of those residing along the upper Texas coast (Wilson and Fischetti, 2010, U.S. Census Bureau, 2018). Within the study area, numerous coastal communities are at risk from storm surge, where approximately 673,346 structures are located. Over 3,500 critical infrastructures, including electricity, gas distribution, water supply, transportation, education, and community services (e.g., police, fire department, etc.) are at risk. Severe storm surge events threaten the health and safety of residents living within the study area. Loss of life, injury, and post flood health hazards may occur in the event of catastrophic flooding. There are 140 medical care facilities, 364 police stations/sheriff's offices, and 672 fire stations (parish and volunteer) located within the study area (NOAA, 2018). Within the study area, 14.8 percent of the population fell below the poverty level, much of those populations are found in the lower coastal counties. Minority residents make up 16 percent of the population in the study area. Recreation and tourism play a large role in the study area, with over 50 NWRs, WMAs, State Parks, preserves, etc.; outstanding fishing, birding, and waterfowl hunting opportunities; and nature tourism opportunities.

1.4 Future Without Project (FWOP) Condition Assumptions

The PDT evaluated existing information and preliminary data to determine the future without project (FWOP) condition assumptions. Those assumptions are as follows:

a. *Projects Not Yet Authorized.* For the period of analysis (2030 to 2080), the PDT's assumption is that the future without project (FWOP) condition will have approved and constructed projects by Texas General Land Office (GLO) and USACE including the Coastal Texas and GIWW BRFG-CRL selected plans.

b. *Economic Trends.* Traffic levels and commodity tonnage are expected to continue as indicated in regional forecast prepared for the recently completed GIWW-BRFG/CRL feasibility study.

c. *Navigation Channel Operations*. The navigation channel will be increasingly exposed to winds and waves as barrier islands erode. According to Gulf Intracoastal Canal Association (GICA), vessels stop normal operations in areas of the channel exposed to the bay when winds exceed 35 mph.

d. *Hazardous Toxic and Radioactive Waste*. Based on the findings of the HTRW survey, the probability of encountering contaminated sites or toxic substances without project construction is considered low. Information compiled by this assessment indicates additional investigations are not warranted at this time.

e. *Real Estate*. It is expected that much of the privately-owned land in the scope of this study will have eroded by the beginning of the period of analysis (2030). Therefore, these lands are considered to fall under federal navigational servitude.

f. *Climate Stressors.* The impacts of erosion and coastal storms are expected to be exacerbated by changing sea level conditions. To evaluate the impacts of Relative Sea Level Rise (RSLR) on future conditions, the following reference years are used:
    - Reference year 2030: Assume construction is complete and project is operating, economic benefits begin
    - Reference year 2080: End of quantitative period of analysis for economics

    Tables 1 and 2 show the RSLR in feet for the Local Mean Sea Levels (LMSL) at Galveston Pier 21 and Rockport, respectively. The RSLR numbers are starting from reference year 2030 and ending at reference year 2080. The USACE Sea Level Change Curve Calculator version 2021.12 and USACE 2013 projection curves were used to determine the RSLR values below.

Table 1: Estimated Relative Sea Level Rise (feet) at Galveston Pier 21 (Region 1)

	USACE		
Year	Low	Intermediate	High
2030	**0.80**	**0.93**	**1.33**
2080	**1.85**	**2.53**	**4.72**

Table 2: Estimated Relative Sea Level Rise (feet) at Rockport (Regions 2 and 3)

	USACE		
Year	Low	Intermediate	High
2030	**0.44**	**0.56**	**0.92**
2080	**1.29**	**1.96**	**4.10**

The USACE 2013 Intermediate curve was assumed to be the most likely scenario for FWOP conditions, and a sensitivity analysis was performed to ensure this assumption would not significantly impact the performance of the alternatives.

2.0 Step 3 – PLAN FORMULATION STRATEGY

Plan formulation is an iterative process that develops and compares solutions to the water resources problems identified within the study area. The process consists of incremental development of measures, strategic combination of those measures into alternatives, and screening with increasing details in phases that support risk informed decision making. The plan formulation process for this study was completed in phases that can be briefly characterized as follows:

1st Plan Formulation Iteration:

1) Formulated measures to address problems within Zones 1 – 20 (See Section 3);
2) Combined measures into conceptual initial array of alternatives for Zones 1 - 20 (See Section 4.0);
3) Screened zones within the study area based on FWOP assumptions; (See Section 5.0);
4) Compared and qualitatively screened initial alternatives (including Zones 12, 13, 14, 16 and 18) (See Section 6.0);

2nd Plan Formulation Iteration:

5) Evaluated final array of alternatives (Alternative 1, 3, and 6) by evaluating the zone individually and incrementally adding measures for Alternative 3 and 6 within each zone based on performance with traditional NED criteria and resilience metrics measured as navigation cost savings by reduced interruptions in future navigation use (See Tables 16-18 and Figures 3-8);
6) Compared Alternative 6 - NED Plan and Alternative 6 - Resilience Plan (Tables 19 – 20 below); and
7) Next steps, PDT will refine TSP to maximize performance and achieve most cost-effective approach for the period of analysis (Next steps to be performed after concurrent reviews prior to ADM and final report).

3.0 Management Measures and Screening of Measures

A management measure is a structural or non-structural feature for a specific geographic site that addresses one or more planning objectives. Measures were formulated based on problems within each of the 20 zones (Figure 1 above); and a system resiliency analysis.

Next, the measures were grouped into five categories (Table 3 below) and assigned codes for formulation.

1. Hard Stabilization features
2. Natural Stabilization features
3. Channel Modifications
4. Sediment Placement
5. Aids to Navigation

Table 3: Measures

MEASURE [1]	CODE
Non-Structural Measures:	
Light Loading	NS1
Operational Scheduling	NS2
Speed Restrictions	NS3
New Current Meters	NS4
Structural Measures:	
Hard Stabilization Features:	
Breakwaters / Wavebreaks	HF1
Jetties	HF2
Revetments / Shoreline stabilization	HF3
Natural Stabilization Features:	
Living Shoreline	NF1
Earthen Levee/Dikes	NF2
Windbreak / Dune Fence	NF3
Barrier Island	NF4
Coastal Dune Strengthening	NF5

MEASURE [1]	CODE
Channel Modification:	
Bend Easing / Minor realignments	CM1
Widen Channel / Straightaways for Meeting	CM2
Bedload Collector	CM3
Sediment Traps	CM4
Deepening – dredging	CM5
Additional Moorings / Fleeting	CM6
Sediment and Placement:	
Offshore Placement	SP1
Create new PA	SP2
Sidecast Dredging	SP3
Sediment Bypass	SP4
Beneficial Use (BU): Thin layer Placement, Nearshore unconfined placement, Amend material for BU	SP5
Aids to Navigation (ATONS)[2]:	
Buoys / markers	AT1

[1] *Highlighted text indicates measures screened from further evaluation.*
[2] *ATONS are another Federal cost (U.S. Coast Guard).*

Tables 4 through 13 indicate how the list of measures were analyzed for each zone to address the problems in that area. Red highlighting indicates measures that were screened out. Yellow highlighting indicates measures that are in the Coastal Texas Protection and Restoration Study Recommended Plan to provide area context for FWOP Condition.

Table 4: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 1and Zone 2)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 1																										
Light Shoaling	X																		X							
Barrier Loss			X		X		X				X		X								X				X	
Exposed Upland PAs to Wind Waves due Barrier Loss					X		X	X			X		X	X							X				X	
Moderate Shoreline Erosion on Upland Side			X		X		X	X			X		X	X							X				X	
Exposed Channel to Wind Waves due to Barrier Loss					X						X		X								X				X	
ZONE 2																										
Moderate Shoaling	X																		X							
Upland Island Loss			X				X				X		X								X				X	
Submerged PAs exposed to currents and waves with SLR					X		X				X		X								X				X	
Exposed Channel to Wind Waves					X						X		X								X				X	
Issue with turn at wye?		X	X														X									

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition)

Table 5: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 3 and Zone 4)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 3																										
Moderate Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X			X			X								X				X	
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X												X	
Barrier Loss at Bastrop Bayou (Additional Breaches)			X		X		X	X			X			X								X				X	
Barrier Loss at Oyster Lake (Breach Imminent)			X		X		X	X			X		X	X								X				X	
Barrier End Loss at Chocolate Bayou			X		X	X	X	X			X		X									X				X	
ZONE 4																										
Moderate Shoaling at Swan Lake Inlet	X				X		X	X			X			X								X				X	
Difficult negotiation of curves and passing issues		X	X													X	X									

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition).

Table 6: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 5 and Zone 6)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 5																										
Moderate Shoaling - current dredging every 1 1/2 year	X																		X							
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X											X	
Moderate shoreline erosion – upland			X		X		X	X						X											X	
No adjacent placement areas																					X	X			X	
ZONE 6																										
High Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X											X	
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X											X	

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition).

Table 7: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 7 and Zone 8)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 7																										
High Shoaling (Mostly Episodic)	X																	X	X				X	X		
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X												
Channel exposed to cross currents (tidal and riverine)		X		X																						
High number of accidents due to gates and crossing		X	X	X													X									
Dwindling PA Capacity																					X	X				
Traffic Jams due to wait time and not enough Moorings		X																		X						
ZONE 8																										
Moderate Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X						X						

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition).

Table 8: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 9, Zone 10 and Zone 11)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 9																										
High Shoaling	X																	X	X				X	X		
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X												
Channel exposed to cross currents (tidal and riverine)		X		X																						
PA 2 at risk due to channel erosion			X		X		X	X						X												
ZONE 10																										
Moderate Episodic Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X						X						
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X						X						
ZONE 11																										
Light Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X																		
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X																		
High Shoreline Erosion on Barrier Gulf Side (PA Loss)					X		X	X			X	X	X		X							X			X	
Channel too narrow for at-speed passing			X														X									

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition)

Table 9: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 12 and Zone 13)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 12																										
High Shoaling	X																	X	X				X	X		
Channel exposed to high cross currents (tidal and riverine)		X		X													X									
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X												
Moderate Shoreline Erosion on Barrier Channel Side			X		X		X	X						X												
Moderate Shoreline Erosion on Barrier Gulf Side					X		X				X	X	X		X							X				X	
Channel too narrow for at-speed passing			X														X									
ZONE 13																										
Moderate Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X			X			X								X			X	
Upland PAs Exposed to Wind Waves					X		X	X			X		X	X								X			X	
Barrier Island Loss (PA Loss)					X		X	X			X		X	X								X			X	
Gulf-Side PAs exposed					X		X	X			X		X	X								X			X	
Channel exposed to Wind Waves					X						X		X									X			X	

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition)

Table 10: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 14 and Zone 15)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 14																										
Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X			X			X								X			X	
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X												
High Shoreline Erosion on Barrier Gulf Side (PA Loss)					X		X	X			X		X	X								X			X	
ZONE 15																										
Moderate Shoaling	X																		X							
Moderate Shoreline Erosion on Upland Side (Light at PAs)			X		X		X	X			X			X								X			X	
Upland PAs Exposed to Wind Waves					X		X	X			X			X								X			X	
Barrier Island Loss (PA Loss)					X		X	X			X		X	X								X			X	
Gulf-Side PAs exposed					X		X	X			X		X	X								X			X	
Channel exposed to Wind Waves					X			X			X		X	X								X			X	

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition)

Table 11: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 16 and Zone 17)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 16																										
Light Shoaling at Mile 435	X										X								X			X			X	
Moderate Shoaling at East End	X																		X							
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X												
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X												
High Shoreline Erosion on Barrier Gulf Side (PA Loss)					X		X	X			X		X	X								X			X	
ZONE 17																										
High Shoaling	X																	X	X				X	X		
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X												
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X												
Channel exposed to cross currents (tidal and riverine)		X		X																						

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition)

Table 12: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 18 and Zone 19)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 18																										
High Shoaling at Oyster Lake	X																	X	X							
High Shoaling at Mad Island	X																	X	X							
Light Shoreline Erosion on Barrier Channel Side			X		X		X	X						X												
Moderate Shoreline Erosion on Upland Side			X		X		X	X						X												
High Shoreline Erosion on Barrier Gulf Side (PA Loss)					X	X	X	X			X		X	X								X				X	
ZONE 19																										
Moderate Shoaling at West End	X																		X							
High Shoaling at Oyster Lake	X																		X							
Open Bay - Channel exposed to Wind Waves					X						X		X													X	
Adjacent Submerged PAs exposed to currents and waves with SLR							X															X					

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition)

Table 13: Measures Combined to Formulate Initial Array of Alternative Plans (Zone 20)

Measures with Measure Code	Non-Structural Measures				Hard Stabilization			Natural Stabilization								Channel Modifications					Sediment and Placement					Aids
	Light loading NS1	Operational Scheduling NS2	Speed restrictions/ recreation NS3	Additional Meters NS4	Breakwaters / Wavebreaks HF1	Jetties HF2	Revetment / Shoreline Stabilization HF3	Living shoreline NF1	Levee/Dikes NF2	Windbreaks NF3	Barrier Island / Restore Breaches NF4	Coastal Dune Strengthening NF5	Oyster Reefs / Wave Breaks NF6	Coastal Marsh creation/restoration NF7	Beach/Berm/Dune Creation/restoration NF8	Bend Easing / Minor Realignments CM1	Widen Channel / Straightaways for Meeting CM2	Sediment Traps CM3	Deepening CM4	Additional Moorings / Fleetings CM5	Offshore placement SP1	New Confined PA SP2	Bed load collector SP3	Sediment bypass SP4	Beneficial Use SP5	Buoys / Markers AT1
ZONE 20																										
Moderate Shoaling West of Mile 465 Turn	X																		X							
Open Bay - Channel exposed to Wind Waves					X						X		X												X	
No adjacent placement areas																					X	X			X	

Notes: Red highlighting indicates measure screened; yellow highlighting indicates Coastal TX measure (FWOP condition)

4.0 Formulation of Initial Array of Alternatives

Preliminary plans were formulated by combining management measures using an additive approach formulation strategy. Using data and best professional judgment about the problems in the defined zones, the PDT identified potential measures that could be employed to solve these problems, and combined similar measures into a suite of actions to solve related problems across the applicable zones. These combined measures were identified as stand-alone alternatives where logical, and then further combined into hybrid alternatives aimed at a more comprehensive solution to address multiple different, but related, problems.

The PDT developed distinctively different plans using the 5 categories of management measures in various combinations as well alternatives required by policy (No-action and non-structural). Table 15 provides the initial array of alternatives followed by a description of each alternative.

Alternative 1 (No Action) is the baseline to which all other alternatives are compared Alternative 1 does not meet study objectives; and although there are no additional capital or O&M costs, or environmental impacts associated with Alternative 1; it would not provide additional benefits or increase resiliency of the system. A key assumption for the No Action or Future without Project Condition (FWOP) is that recommended plans from the Texas Coastal and GIWW Brazos River Floodgates and Colorado River Locks (BRFG-CRL) are in place and operational.

Alternative 2 (Non-structural) would use non-structural measures in zones 1 through 20 to allow continued vessel transit to the greatest possible extent; however, some are already practiced and would alleviate existing navigation inefficiencies. Non-structural measures include light-loading, current meters, operational scheduling, and speed restrictions.

Alternative 3 (Shoreline Stabilization) would address shoaling problems by reducing sediment input from eroding shorelines and upland placement areas and barriers caused by vessel wake and wind driven waves. Alternative 3 would employ hard stabilization features (breakwaters, jetties, groins and revetments); and natural stabilization features (oyster reefs, marshes, plantings, coastal barriers, and coastal dunes and beaches).

Potential benefits include balancing structural stability and natural functions (living shorelines) to directly address erosion and help the navigation channel withstand erosional effects over time. Potential concerns include financial costs and whether the alternative is economically justified based on traditional NED metrics. Navigation projects are usually justified based on NED; however, the GIWW-CRS also focuses on system resiliency that will require additional or non-traditional metrics for plan evaluation. The PDT will develop non-traditional metrics as the study progresses.

Zones 1, 3, 13, and 14 have some stabilization features in place or underway that address erosion on the upland side of the channel (inclusive of upland placement areas exposed to wind and waves); however, there is still erosion and sedimentation on barrier islands and Gulf side placement areas that are not addressed in the FWOP. The PDT evaluated measures to address remaining problems in zones 1, 3, 13 and 14. Other zones (2, 11, 12, and 16 through 20) share common problems associated with shoaling, erosion, barrier island losses, and placement areas exposed to cross-currents.

Alternative 4 (Alternative 2 Combined with Sediment and Placement) builds upon Alternative 2 (non-structural measures) by addressing sedimentation in zone 4, 5, 7, 8, 9, 12, 17, 19 and 20 and will assess how the Corps manages dredged material within minimal federal standards, which may be more expensive than current methods, and analyze options to improve system resiliency. As the study progresses, the PDT reevaluated the study area to identify additional zones where non-structural or sediment placement measures are applicable. With respect to resiliency of navigation and ecosystems, placement options would supplement plans identified in the Corps' Coastal Texas Protection & Restoration Feasibility Study (Galveston District and Texas Land Office), which is expected to complete in 2021, and potentially constructed in phases beginning in 2042.

Alternative 5 (Alternative 4 Combined with Channel Modification) builds on measures for Alternative 4 and also includes potential channel modifications such as deepening[1] in zone 1 through 20 with the exception of zone 4 (Freeport Wiggles). Measures including bend easing and minor realignments, channel widening, bed-load collectors, and sediment traps would be considered for zones 2, 4, 5, 7, 9, 11, 12, 17 and 18. Alternative 5 would use dredged material to enhance or create living placement areas and increase the resiliency of the navigation system by allowing the channel to maintain flexibility by creating spaces (sediment banks) where sediment would accumulate outside of the channel. Sediment would then be dredged and placed in a manner that benefits navigation and provides ancillary environmental benefits.

Alternative 6 (Alternative 4 Combined with Alternative 3) builds on combined measures in Alternative 4 by incorporating shoreline stabilization measures from Alternative 3. Alternative 6 would employ the most effective combination of hard and natural stabilization measures to satisfy resiliency metrics in zones 1 through 4, 9, and 11 through 20. Placement of dredged material would not necessarily be based on the least cost option (base plan) per federal standards but would consider resiliency metrics as well. The PDT will reevaluate the study area to identify additional zones where non-structural and sediment placement measures may be applicable.

As is the case with Alternative 3, potential benefits include balancing structural stability and natural functions (living shorelines) to directly address erosion and help the navigation channel withstand erosional effects over time. Concerns include financial costs

[1] Deepening in this study is not defined as increasing the authorized depth of the channel. The intent of "deepening" is to identify measures that improve the reliability of the authorized channel to increase economic efficiencies while enhancing resilience to disturbances.

and whether the alternative is economically justified based on traditional NED metrics. Navigation projects are usually justified based on NED; however, the GIWW-CRS also focuses on system resiliency that will require additional or non-traditional metrics for plan evaluation. The PDT will develop non-traditional metrics as the study progresses.

Alternative 7 (Alternative 5 Combined with Alternative 3) builds on the combination of measures included in Alternative 5 by incorporating shoreline stabilization measures from Alternative 3. The primary difference between Alternative 6 and 7 is that Alternative 6 includes potential channel modifications. Alternative 7 would combine both hard and natural stabilization measure to satisfy resiliency metrics in zones 1 through 4, 5, 9, and 11 through 20. In addition, appropriate channel modifications would address site specific issues in zones 1 through 20. Placement of dredged material would not necessarily be based on the least cost option (base plan) of the federal standard but would consider resiliency metrics as well. Potential benefits and concerns of Alternative are the same as Alternatives 3 and 6.

Table 14: Initial Array of Alternatives

		Non-Structural Measures				Hard Stabilization			Natural Stabilization						Channel Modifications					Sediment and Placement				
	Description	Light loading	Operational Scheduling	Speed restrictions/ recreation	Additional Meters	Breakwaters / Wavebreaks	Jetties	Revetment / Shoreline Stabilization	Living shoreline	Barrier Island / Restore Breaches	Coastal Dune Strengthening	Oyster Reefs / Wave Breaks	Coastal Marsh creation/restoration	Beach/Berm/Dune Creation/restoration	Bend Easing / Minor Realignments	Widen Channel / Straightaways for Meeting	Sediment Traps	Deepening	Additional Morrings/Fleetings	Offshore placement	New Confined PA	Bed load collector	Sediment bypass	Beneficial Use
Alt 1	No Action																							
Alt 2	Non-structural	A	2,4,7,9, 12,17	1-18	7,9, 12, 17																			
Alt 3	Shoreline Stabilization					1-3, 5, 11-20	3,18	1-3, 5, 11-14, 16-18	1, 3, 5, 9, 11-14, 16-18	2-4, 11-14, 16-20	11,12	2,3, 11-14, 16, 18-20	1, 5, 9, 12-14, 16-18	11,12										
Alt 4	Alt 2 + Sediment Placement		2,4,7,9, 12, 17	1-18	7,9, 12, 17															5, 7, 20	1-5, 7, 11-16, 18-20	7,9, 12, 17	7,9, 12, 17	1-6, 11-16, 18-20
Alt 5	Alt 4 + Channel Modifications		2,4,7,9, 12, 17	1-18	7,9, 12, 17										4	2,4,7, 11,12	7,9, 12,17, 18	1-3, 5-20	7-8, 10	5, 7, 20	1-5, 7, 11-16, 18-20	7,9, 12, 17	7,9, 12, 17	1-6, 11-16, 18-20
Alt 6	Alt 3 + Alt 4		2,4,7,9, 12, 17	1-18	7,9, 12, 17	1-3, 5, 11-20	3,18	1-3, 5, 11-14, 16-18	1, 3, 5, 9, 11-14, 16-18	2-4, 11-14, 16-20	11,12	2,3, 11-14, 16, 18-20	1, 5, 9, 12-14, 16-18	11,12						5, 7, 20	1-5, 7, 11-16, 18-20	7,9, 12, 17	7,9, 12, 17	1-6, 11-16, 18-20
Alt 7	Alt 3 + Alt 5		2,4,7,9, 12, 17	1-18	7,9, 12, 17	1-3, 5, 11-20	3,18	1-3, 5, 11-14, 16-18	1, 3, 5, 9, 11-14, 16-18	2-4, 11-14, 16-20	11,12	2,3, 11-14, 16, 18-20	1, 9, 5, 12-14, 16-18	11,12	4	2,4,7, 11,12	7,9, 12,17, 18	1-3, 5-20	7-8, 10	5, 7, 20	1-5, 7, 11-16, 18-20	7,9, 12, 17	7,9, 12, 17	1-6, 11-16, 18-20

Numbers indicate Zones where measures would be employed. "A" indicates all zones (1-20).

[1] Deepening in this study is not defined as increasing the authorized depth of the channel. The intent of "deepening" is not to go below the authorized depth, but to find ways to make the channel more resilient in maintaining that depth reliably through time and chronic and episodic events.

5.0 STEP 4 - INITIAL EVALUATION AND SCREENING

As the PDT developed Future Without Project (FWOP) conditions, it was determined that the Coastal Texas and GIWW Brazos River Flood Gates and Colorado River Locks (GIWW BRFG-CRL) Feasibility Studies would collectively address zones 1 through 10, which cover all zones in Brazoria County, and also zones 15 and 17 in Matagorda County. The PDT also determined that zone 11 would be addressed through the maintenance of an existing USACE revetment structure and a Texas General Land Office (GLO) project. Additionally, the PDT eliminated zones 19 and 20 because they are open water areas in Matagorda Bay that do not impact the navigation channel. Details on the engineering evaluation and screening of Zones 1 – 11; 15, 17, and 19-20 are found in the Engineering Appendix D.

As a result of eliminating the above-mentioned zones, the updated study area carried forward for further evaluation included zones 12, 13, 14, 16, and 18 which covers approximately 30 miles of the GIWW channel in Matagorda County (Figure 2).

Figure 2: Study Area Map (also Figure 2 in the main report)

Alternative 1 (No Action) is the baseline to which all other alternatives are compared. There are no additional capital or O&M costs, or benefits provided by this alternative.

Alternative 2 (Non-structural) was screened out as a stand-alone alternative because non-structural measures are already being practiced or implemented to the greatest extent possible. However, non-structural alternatives will be added to any alternative to address any residual risks associated with the recommended plan.

Alternative 3 (Shoreline Stabilization) was evaluated as having the most effective hard stabilization structural measures which were predicted to provide the most economic benefits by focusing on protecting the navigation channel. Economic benefits are comprised of transportation cost savings and O&M cost savings. This alternative was carried forward for further evaluation.

Alternative 4 (Alternative 2 Combined with Sediment and Placement) was screened out because placing sediment without providing hard stabilization to reduce exposure to wave action would cause the sediment to erode rapidly and was not considered to be as resilient as a stand-alone alternative.

Alternative 5 (Alternative 4 Combined with Channel Modifications) was screened out for the same reason as alternative 4.

Alternative 6 (Alternative 4 Combined with Alternative 3) was evaluated as having the most effective combination of hard and natural stabilization measures which would provide resiliency benefits in addition to economic benefits. The establishment or restoration of barrier islands was identified as the most effective measure because it provides the navigation channel with the most robust protection from day-to-day wind and wave conditions as well as episodic hurricane and storm damage. Barrier islands are also an adaptable placement area that provide flexibility for placing dredged material. Therefore, protecting and restoring barrier islands was perceived as the highest effectiveness for providing resilience. Shoaling rates estimate the volumes of sediment accumulation in the waterway based on historic erosion and accumulation. The NED benefit estimates that capture reduced sedimentation impacts through transportation delays and O&M costs capture the benefits of reduced sedimentation impacts. Resilience benefits capture the reduced duration of navigation disruptions for future storm impacts, which are in addition to the continued historic rates of sedimentation. Climate considerations suggest that future storm events may have increased variability of impacts. Preparation and adaptation within the study area will decrease the recovery time following storm events, which is not captured in the navigation impact NED benefit calculation alone.

Alternative 7 (Alternative 5 Combined with Alternative 3) was screened out because the channel modifications were not needed for the majority of the study area. Channel modifications could be evaluated as optimization and refinement measures in problem areas and shoaling hotspots, but system-wide channel modifications were screened out for not meeting the study objectives.

Table 15 provides a relative qualitative assessment of the Initial Array of Alternatives. The PDT is developing the criteria for evaluation and comparison of the alternatives to determine the Tentatively Selected Plan.

Table 15: Relative Qualitative Assessment of Alternatives

Color Key	Alt #	Description	System Resilience	Initial Cost	Economic Benefits	Environmental Quality	Engineering Feasibility	Real Estate Requirements
No Change	1	No Action	NA - No Change from existing	NA - No Change from existing	NA - No Change from existing	NA - No Change from existing	NA - No Change from existing	NA - No Change from existing
Highest	2	Non-structural	Low: limited resilience	Lowest: Low cost NS measures	Low: low effective	High: Little environmental impact expected	High: Few engineering challenges	Lowest: Little to no real estate required
High	3	Shoreline Stabilization	Medium-High: Stabilization measures are the most likely measures to lead to resilience of navigation system	Medium-High: Construction of stabilization structures anticipated to be among most costly measures	Medium: May reduce O&M costs over time	Medium: Hard structures have the potential for Environmental Impacts but Natural features likely to benefit (may offset)	Medium: Some novel methods of natural stabilization may provide engineering challenges	Medium-High: Stabilization measures may require a significant amount of real estate
Medium - High	4	Alt 2 + Sediment Placement	Low-Medium: The incorporation of sediment placement would marginally increase resilience	Low-Medium: Sediment Placement is relatively inexpensive in comparison to other measures	Low-Medium: While this is likely to be an efficient method of disposal, unlikely to produce additional efficiencies	Medium-High Low impact from NS measures, Placement options vary in effects but no substantial negative effects anticipated	Medium-High: Some potential challenges with placement but relatively routine from an engineering perspective	Medium-High: Placement areas likely to require a significant amount of real estate
Medium	5	Alt 4 + Channel Modifications	Medium: Channel modifications would increase resilience over Alt 2, but may not significantly address resilience over time	Medium: Channel modifications are less numerous than stabilization measures and less expensive to implement	High: Channel Modifications are likely to perform best at increasing economic efficiency	Low-Medium Incorporation of channel modifications with Alt 4 likely to increase potential for Environmental Impacts	Medium: Some novel methods of channel modifications may provide engineering challenges	Medium-High: Same as Alt 4; In channel work not likely to increase real estate requirement
Low - Medium	6	Alt 3 + Alt 4	High: Incorporation of sediment and placement likely to expand resilience over Alt 3	High: Second most costly, includes most measures except channel modifications	Medium: May reduce O&M costs over time	Low-Medium Incorporation of sediment and placement with Alt 3 could lead to some additional Environmental impacts	Low-Medium Incorporation of sediment and placement with Alt 3 could lead to some additional Environmental impacts	High: Second largest footprint requiring real estate
Low	7	Alt 3 + Alt 5	Highest: Offers the most robust and resilient set of measures to address problems over time	Highest: Includes all measures, would be the most costly	High: Channel Modifications are likely to perform best at increasing economic efficiency	Low Includes the greatest footprint and potential for impacts, although some benefits may be off-setting	Low Presents the greatest potential suite of engineering challenges	Highest: Greatest footprint requiring real estate
Least								

Highest Preferred ↑ ↓ Least Preferred

5.1 Final Array of Alternatives

The PDT screened out four (4) of the initial alternatives resulting in the three (3) alternatives carried forward for further evaluation and described below:

Alternative 1 – No Action Plan – This alternative continues to implement scheduled and emergency dredging to maintain the navigation channel in the study area. The erosion, coastal storms, and shoaling and their impacts to navigation would continue to worsen.

Alternative 3 – Shoreline Stabilization – This alternative utilizes hard stabilization measures including breakwaters and reef balls. Breakwater crest elevation would be constructed from 3 to 7 feet above the NAVD88 sea level datum depending on location to sufficiently protect the navigation channel from wind waves and prevent further erosion of the existing barrier islands. These elevations also account for sea level rise through 2080.

Alternative 6 – Shoreline Stabilization and Sediment Placement – This alternative utilizes a combination of the hard stabilization described in alternative 3 and additional natural stabilization measures including: beneficial use of dredged material placement to create or replenish earthen berms; and marsh plantings to prevent rapid erosion of the sediment placement. All breakwater crest elevations for alternative 6 would be constructed at 3 feet above the NAVD88 sea level datum because the purpose is to contain the sediment placement and prevent erosion. The crest elevations of earthen berms would be 8 feet above the NAVD88 sea level datum to protect the navigation channel from higher wind and wave conditions, but the elevation could easily be adjusted with the sediment placement on the berm. These elevations also account for sea level rise through 2080.

Alternatives 3 and 6 aim to address the study problems and achieve the study objectives using different approaches. Alternative 3 intends to prevent the loss of existing barrier islands and protect the navigation channel by utilizing only hard stabilization measures such as breakwaters and reef balls. Alternative 3 was also intended to have lower project first costs than alternative 6. Alternative 6 intends to go beyond just preventing barrier island loss; in fact, it proposes to restore areas of barrier islands that are or will be lost in zones 13, 14, 16, and 18 by utilizing natural stabilization measures such as beneficial use of dredged material and marsh plantings.

6.0 Evaluation

Customarily, the assumption in a navigation study would be that adequate funding will be provided for O&M. In this study, the PDT will evaluate actual budget levels or the effect of actual budget levels on channel conditions. The PDT cannot solve the budget problems; however, the PDT will investigate more cost-effective maintenance of the channel in hopes that available funding can be leveraged most efficiently. This could include investing more on the construction side to result in less O&M burden and result in less impact on system performance.

Residual Risk: Authorization and scope of the project is limited to Brazoria and Matagorda counties:

- Risk Event: GIWW extends beyond these counties. Major problem areas (i.e., Port O'Connor) have been identified by GICA outside the authorized counties. There will be residual risk that still exists. District Counsel confirmed authorization is clear on county boundary; therefore, accept the risk.

The Corps Shoaling Analysis Tool (CSAT) was used to determine the annual shoaling rate from historical survey and dredging data. This shoaling rate was then used to develop the annual shoaling rate for the FWOP condition. This assumption produces realistic sedimentation estimates for Zones, 12, 14, 16, and 18 since the barrier islands for these areas are expected to be minimally intact through 2080. Since the barrier island in Zone 13 is expected to be essentially gone by the year 2030, the "closed system" sedimentation assumption is considered to underestimate sedimentation rates for this zone. An "open system" sedimentation assumption would provide a more realistic estimate of future shoaling since by the end of the project performance period (2080) there would be no barrier island in Zone 13. In an "open system" situation, the bottom sediments in exposed portions of Zone 13 would seek equilibrium and would silt-in to the depth of the surrounding bay, which is estimated at 3-8 foot in depth. This would restrict, if not impede the passage of vessels though any shallow portions. Given the underestimation of sedimentation in Zone 13, it is apparent that the benefits attributed to increments in this zone are underestimated. The PDT expects to be able to refine the sedimentation estimates for Zone 13 prior to the ADM.

Shoaling events caused by major storms result in additional restrictions such as light loading. In addition, significant erosion and sediment deposits coming from the mainland waterways are severe in the aftermath of major storms from the Gulf of Mexico, even if the storms do not directly make landfall in the study area. Examples of this were witnessed with Hurricane Harvey. In terms of storm risk, problems include storm-induced accelerated erosion of barrier islands and the resulting shoaling, as well as exposure of the navigational channel to an open bay environment. Absent additional protection, the risk associated with hurricane storm surge is anticipated to increase over time for multiple reasons including continued population growth and economic expansions within at-risk coastal areas, forecasted increases in storm intensity due to changes in climate patterns, and forecasted increases in relative sea level. USACE, August 2021, Coastal Texas Protection and Restoration Feasibility Study, Final Environmental Impact Statement, p.1-11.

The restoration of lost barrier islands could become cost-prohibitive in the future requiring major reconstruction efforts to reestablish them if steps are not taken to arrest continued erosion. Addressing loss of the barrier islands and exposure to the open bay now is substantially less than what it would cost in 2030 when barrier islands are

estimated to be essentially lost. The PDT did not fully develop costs for each zone or alternative in this situation.

Barrier islands prevent more harm to the navigation channel than breakwaters as evidenced by other USACE studies such as *GIWW High Island to Brazos River Section 216* and *Reducing Shoaling in the GIWW and Erosion of Barrier Islands Along West Galveston Bay*. Also, the loss of barrier islands could become irreversible if threatened and endangered species migrate into the gradually eroded areas and create a critical habitat. Therefore, barrier islands are more proactive at directly addressing the study problems to *prepare* for future conditions. Barrier islands also provide more robust protection of the navigation channel than breakwaters against episodic disturbances, such as major storm events, as well as the day-to-day navigation and erosion impacts from winds and waves. This is due to the larger footprint and the higher crest elevation of the barrier island and earthen berm which are able to *absorb* harsher conditions. By withstanding harsher conditions, barrier islands enable the GIWW to *recover* and resume normal operations more quickly after episodic disturbances. The use of barrier islands as placement areas also provides additional flexibility to use dredged material beneficially as needed and *adapt* to changing conditions. Therefore, alternative 6 offers more resilience as defined by the four principles: *prepare, absorb, recover, adapt*.

In February of 2021, the PDT held an In-Progress Review (IPR) meeting with the Vertical Team comprised of USACE Southwestern Division and Headquarters staff where a decision was made to deconstruct alternatives 3 and 6 into smaller increments. The PDT identified the measures that could be separately analyzed at each zone and created an initial list of 32 distinct increments (Figure 5). Each increment had varying extents of measures and were scrutinized for whether the measures appropriately addressed the unique issues at each zone. The broken-down measures include bayside breakwaters, channel bayside breakwaters, channel landside breakwaters, reef balls, berms, and sediment placement which includes marsh plantings. The PDT initially screened out the increments at zones 12, 13, and 14 with channel landside breakwaters because the Coastal Texas Feasibility Study is already proposing to construct them at these zones. The PDT also screened out increments at zone 16 that included channel bayside and channel landside breakwaters because the shoaling data did not justify constructing them at these locations.

In March of 2021, the PDT held a meeting with the U.S. Fish and Wildlife Services (USFWS) and presented the increments for alternatives 3 and 6 in all the zones. USFWS advised the PDT about the presence of critical habitat and the potential impacts to threatened and endangered species at zone 12. USFWS requested the PDT to consider

eliminating increments with sediment placement and increments where the breakwaters would completely enclose the barrier island at zone 12. As a result of the meeting with USFWS, the PDT decided to screen out all alternative 6 increments and the alternative 3 increments with breakwaters on both sides of the barrier island at zone 12. The PDT screened the alternative 6 increments at zone 12 due to the study's constraints to avoid or minimize impacts to critical habitat.

In April of 2021, the Galveston District Operations stakeholders requested that the PDT analyze channel widening and sediment traps as additional increments at zone 12 because of the higher number of delays and incidents reported at this location compared to other zones. Since channel modifications were screened out as alternative 5 from the AMM, the PDT decided it would be necessary to conduct initial Coastal Modeling System (CMS) analysis in order to determine the shoaling effects of these channel modifications before carrying them forward. Due to the lack of Hydrology & Hydraulics (H&H) resource availability at the Galveston District, the CMS modeling for channel modifications was done by another district in May of 2021. However, the results of the CMS modeling were inconclusive as to whether the channel modifications would provide a noticeable reduction in shoaling at zone 12 because only a one-month period was analyzed. The PDT determined that a longer duration of CMS modeling would be required to show usable shoaling data, but there was not enough time or resources to perform the additional analyses prior to the TSP milestone. Therefore, the zone 12 increments would require extended CMS modeling as refinement and optimization after the TSP milestone if approved as part of the TSP.

In June of 2021, the PDT presented the progress towards the TSP milestone to the Galveston District Board of Directors (BOD), and as a result of the meeting the BOD Operations stakeholders strongly advocated to include the channel widening increment at zone 12 in the TSP selection due to concerns of safety risk from unintentional groundings of vessels. The PDT reached out to other stakeholders including Gulf Intracoastal Canal Association (GICA) and a local Port Captain who corroborated the same safety concerns voiced by the BOD. Additionally, the PDT performed a sensitivity analysis and optimized construction costs for the increments after the BOD meeting.

Consequently, 14 increments (Table 16 – rows shaded) were carried forward for evaluation. Figures 3 through 8 below the Table show the maps and descriptions of the measures included in each evaluated increment and zone.

Table 16: Final Array of Alternatives – comparison within zones and scaling of measures
(Note: Shaded rows were carried forward)

Alternative	Zone	Increment	Measures	Notes
Alternative 3 – Zone 12				
3	12	12.3.0	Bayside Breakwater	Screened out after USFWS requested not to close off this area due to critical habitat.
3	12	12.3.1	Channel Bayside Breakwater	Only Channel Bayside Breakwater allowed due to section 7 critical habitat, see note above.
3	12	12.3.2	Channel Bayside Breakwater + widening of channel	Channel widening was requested to be included in the TSP evaluation by study sponsor and stakeholders.
3	12	12.3.3	Channel Bayside Breakwater + widening of channel + sediment traps	Sediment Traps may be evaluated further by the PDT after the TSP milestone.
3	12	12.3.4	Bayside Breakwater + Channel Landside Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.
3	12	12.3.5	Bayside Breakwater + Channel Bayside Breakwater + Channel Landside Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.
Alternative 3 – Zone 13				
3	13	13.3.0	Bayside Breakwater	Screened out. Bayside breakwater functions the same as the Channel Bayside Breakwater; Islands will be gone by 2030; Area of open water between two existing barriers would be too wide and would not fill in.
3	13	13.3.1	Channel Bayside Breakwater	Only Channel Bayside Breakwater needed; see notes in above row.
3	13	13.3.2	Bayside Breakwater + Channel Landside Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.
3	13	13.3.3	Bayside Breakwater + Channel Bayside Breakwater + Channel Landside Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.
3	14	13.3.4	Bayside Breakwater	Screened out. It doesn't make sense to only have Bayside Breakwater for these short distances.
Alternative 3 – Zone 14				
3	14	14.3.1	Bayside Breakwater + Channel Bayside Breakwater	The breakwaters here are C-shaped so Bayside Breakwaters and Channel Bayside Breakwaters are one measure since these are short distances.
3	14	14.3.2	Bayside Breakwater + Channel Landside Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.

Alternative	Zone	Increment	Measures	Notes
3	14	14.3.3	Bayside Breakwater + Channel Bayside Breakwater + Channel Landside Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.
Alternative 3 – Zone 16				
3	16	16.3.1	Bayside Breakwater	Keep as is.
3	16	16.3.2	Bayside Breakwater + Channel Bayside Breakwater	Screened out. The data does not show significant shoaling in the channel for this zone.
3	16	16.3.3	Bayside Breakwater + Channel Landside Breakwater	Screened out. The data does not show significant shoaling in the channel for this zone.
3	16	16.3.4	Bayside Breakwater + Channel Bayside Breakwater + Channel Landside Breakwater	Screened out. The data does not show significant shoaling in the channel for this zone.
Alternative 3 – Zone 18				
3	18	18.3.1	Bayside Breakwater	Keep as is.
3	18	18.3.2	Bayside Breakwater + Channel Bayside Breakwater	Keep as is.
3	18	18.3.3	Bayside Breakwater + Channel Bayside Breakwater + Channel Landside Breakwater + Reef balls	Channel Landside Breakwater include Reef balls.
3	18	18.3.4	Bayside Breakwater + Channel Landside Breakwater	Screened out. It doesn't make sense to have Channel Landside Breakwaters without Channel Bayside Breakwaters here. The prioritization should go to Channel Bayside Breakwaters.
Alternative 6 – Zone 12				
6	12	12.6.1	(Bayside Breakwater + Berm + Channel Bayside Breakwater)	Screened out after USFWS requested not to place material in this area due to critical habitat.
6	12	12.6.2	Bayside Breakwater + Berm + Channel Bayside Breakwater + Channel Landside Breakwater	Screened out after USFWS requested not to place material in this area due to critical habitat.

Alternative	Zone	Increment	Measures	Notes
Alternative 6 – Zone 13				
6	13	13.6.1	(Bayside Breakwater + Berm + Channel Bayside Breakwater) + Sediment Placement	Keep as is.
6	13	13.6.2	Bayside Breakwater + Berm + Channel Bayside Breakwater + Channel Landside Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.
Alternative 6 – Zone 14				
6	14	14.6.1	(Bayside Breakwater + Berm + Channel Bayside Breakwater) + Sediment Placement	Keep as is.
6	14	14.6.2	Bayside Breakwater + Berm Breakwater	Screened out. Coastal TX Study Scope will include the Channel Landside breakwaters.
Alternative 6 – Zone 16				
6	16	16.6.1	(Bayside Breakwater + Berm + Channel Bayside Breakwater) + Sediment Placement	Keep as is.
6	16	16.6.2	Bayside Breakwater + Berm + Channel Bayside Breakwater + Channel Landside Breakwater	Screened out. The data does not show significant shoaling in the channel for this zone.
Alternative 6 – Zone 18				
6	18	18.6.1	(Bayside Breakwater + Channel Bayside Breakwater) + Sediment Placement	No berm required due to barrier islands acting as berms.
6	18	18.6.2	(Bayside Breakwater + Channel Bayside Breakwater) + Channel Landside Breakwater + Sediment Placement + Reef balls	No berm required due to barrier islands acting as berms. Channel Landside Breakwater include Reef balls.

Note: shaded rows were carried forward

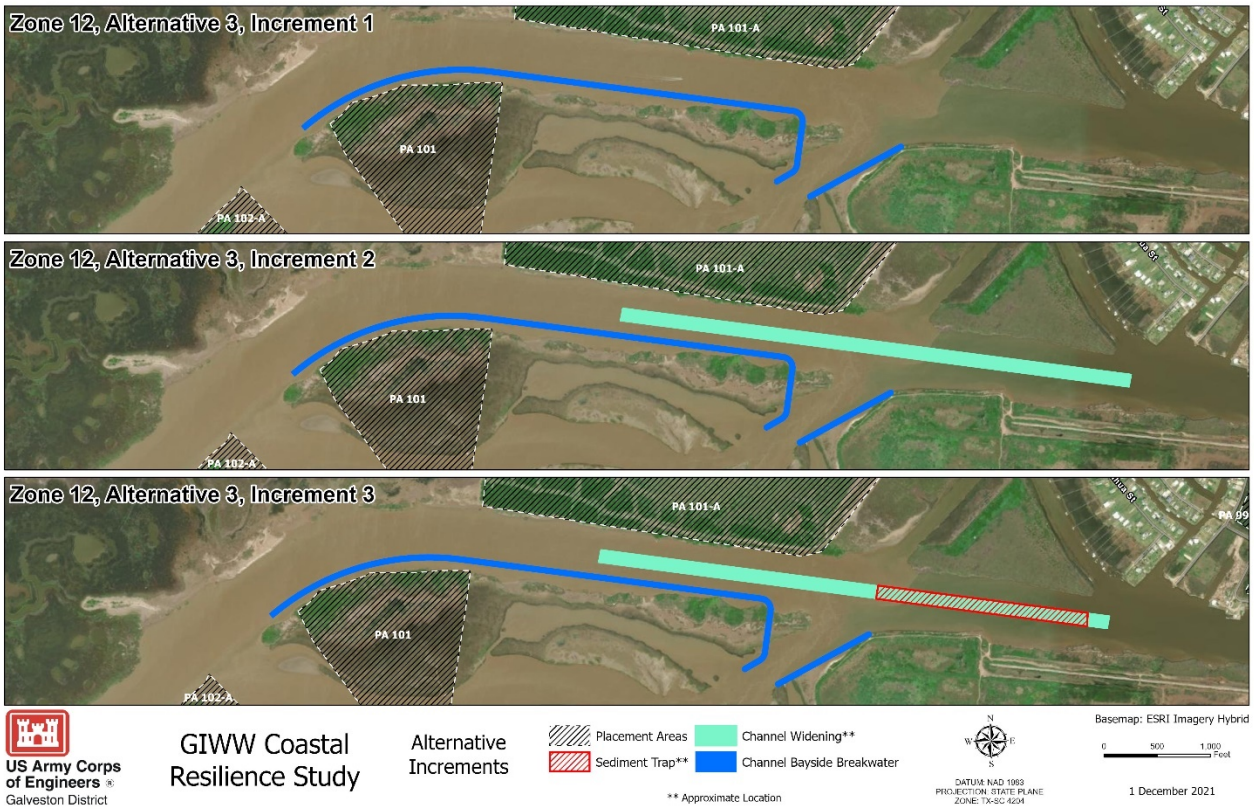

Figure 3: Zone 12 - Alternative 3 Increment Maps

Top Map - Zone 12 – Alternative 3- Increment 1 (12.3.1) - Breakwater Crests = 7 feet NAVD88

Middle Map – Zone 12 – Alternative 3 - Increment 2 (12.3.2)
Breakwater = 7 feet NAVD88 + channel widening

Bottom Map – Zone 12 – Alternative 3 - Increment 3 (12.3.3) Breakwater 7 feet Crests = 7 feet NAVD88 + Channel Widening + Sediment traps

Figure 3 shows increments 12.3.1, 12.3.2, and 12.3.3 which are the increments evaluated for Zone 12. Increment 12.3.1 proposes breakwaters to be constructed with crests at 7 feet above the North American Vertical Datum of 1988 (NAVD88) on the channel bayside of the GIWW. The breakwaters are designed to protect the vessels in the channel from waves and also protect the existing barrier islands from vessel wake which cause erosion. The breakwaters near the intersection at Caney Creek are also intended to reduce the effects of the strong crosscurrents reported by navigation vessels at this location.

Increment 12.3.2 proposes to add channel widening as an optimization measure to the breakwaters in 12.3.1. The channel widening is intended to provide vessels with more room to navigate in the portion of the channel which is identified as a shoaling hotspot. This location also poses a safety risk for vessels where 12 groundings were reported in the 2020 calendar year.

Increment 12.3.3 proposes to add a sediment trap as an optimization measure to the measures in 12.3.2. The sediment trap is intended to allow for more accumulation of sediment between scheduled dredging which would reduce or eliminate out-of-cycle dredging.

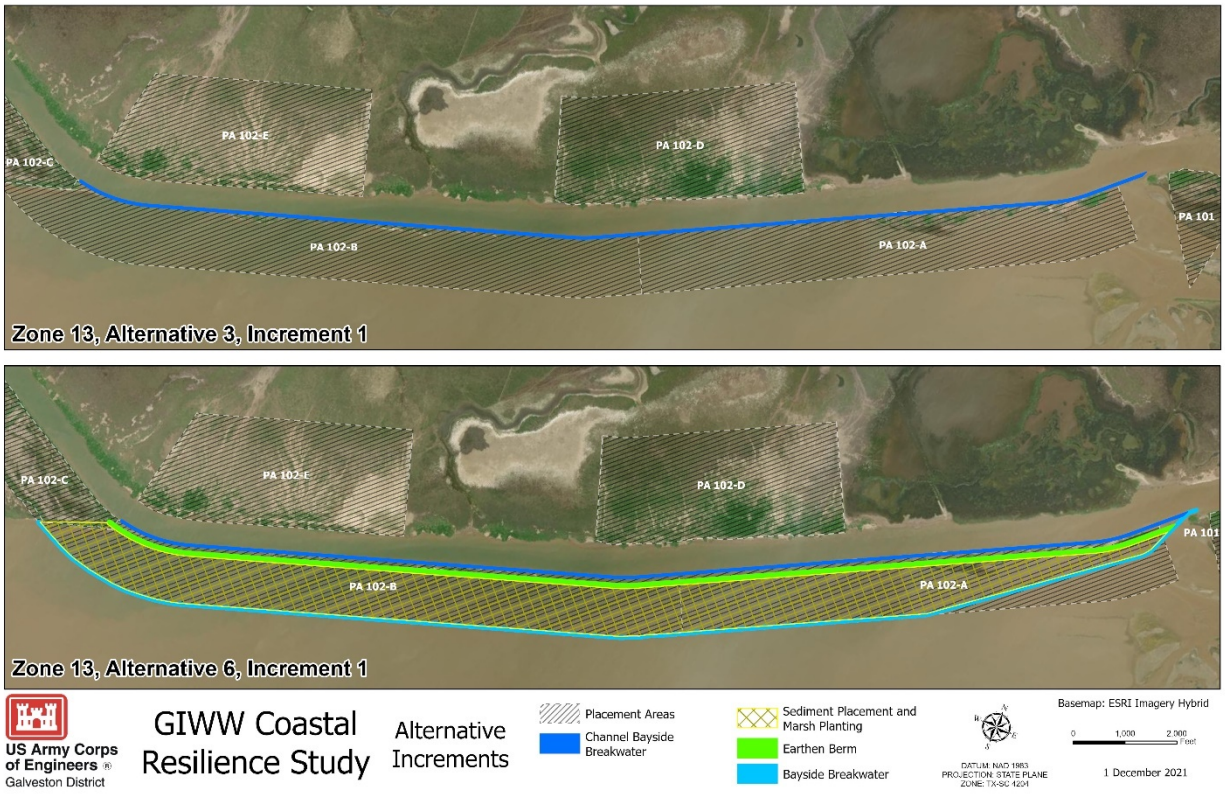

Figure 4: Zone 13 Alternatives 3 & 6 Maps

Top Map - Zone 13 – Alternative 3- Increment 1 (13.3.1)
Breakwater Crests = 7 feet NAVD88

Bottom Map = Zone 13 – Alternative 6 – Increment 1 (13.6.1)
Breakwater Crests = 3 feet NAVD88 + Berm Crest = 8 feet NAVD88
+ Barrier Restoration – Sediment Placement

Figure 4 shows increments 13.3.1 and 13.6.1 which are the increments evaluated for Zone 13. Increment 13.3.1 proposes breakwaters to be constructed with crests at 7 feet NAVD88 on the channel bayside of the GIWW. The breakwaters are designed to protect the vessels in the channel from waves and also protect the existing barrier islands from vessel wake which cause erosion.

Increment 13.6.1 proposes a combination of sediment placement, an earthen berm, marsh plantings, and breakwaters. The sediment placement is intended to restore the barrier islands which would nearly be completely lost by the end of the period of analysis in year 2080. Marsh plantings are intended to prevent rapid erosion from wind and wave exposure by stabilizing the sediment with vegetation. The earthen berm is proposed to be constructed with a crest elevation of 8 feet NAVD88 and is designed to attenuate the crosswinds that vessels in the channel would be exposed to. Breakwaters are proposed to be constructed with crests at 3 feet NAVD88 on the

channel bayside and bayside of the GIWW and are designed to contain the sediment in the placement area and prevent rapid erosion from wave exposure.

Figure 5 shows increments 14.3.1 and 14.6.1 which are the increments evaluated for Zone 14. Increment 14.3.1 proposes breakwaters to be constructed on the channel bayside and bayside of the GIWW with crests at 3 feet and 5 feet NAVD88, respectively. The breakwaters are designed to protect the vessels in the channel from waves and also protect the existing barrier islands from waves from the bay and vessel wake which cause erosion.

Increment 14.6.1 proposes a combination of sediment placement, earthen berms, marsh plantings, and breakwaters. The sediment placement is intended to restore the barrier islands, much of which would be lost by the end of the period of analysis in year 2080. Marsh plantings are intended to prevent rapid erosion from wind and wave exposure by stabilizing the sediment with vegetation. The earthen berm is proposed to be constructed with a crest elevation of 8 feet NAVD88 and is designed to attenuate the crosswinds that vessels in the channel would be exposed to. Breakwaters are proposed to be constructed with crests at 3 feet NAVD88 on the channel bayside and bayside of the GIWW and are designed to contain the sediment in the placement area and prevent rapid erosion from wave exposure.

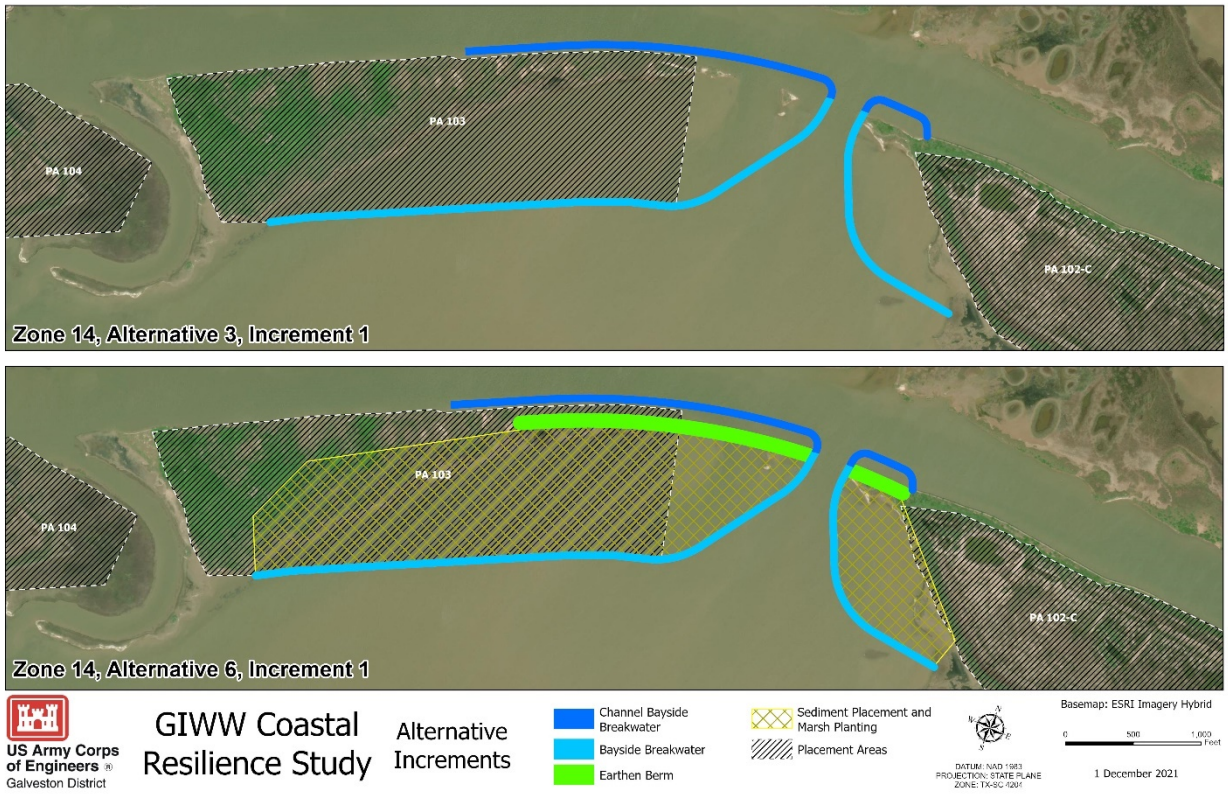

Figure 5: Zone 14 Alternatives 3 & 6 Maps

Top Map = Zone 14 - Alternative 3 – Increment 1 (14.3.1) Bayside Breakwater Crests = 5 feet NAVD88 + Channel Bayside Breakwater = 3 feet NAVD88

Bottom Map = Zone 14 – Alternative 6 – Increment 1 (14.6.1) Breakwater Crests = 3 feet NAVD88 + Berm Crest = 8 feet NAVD88 + Barrier Restoration – Sediment Placement

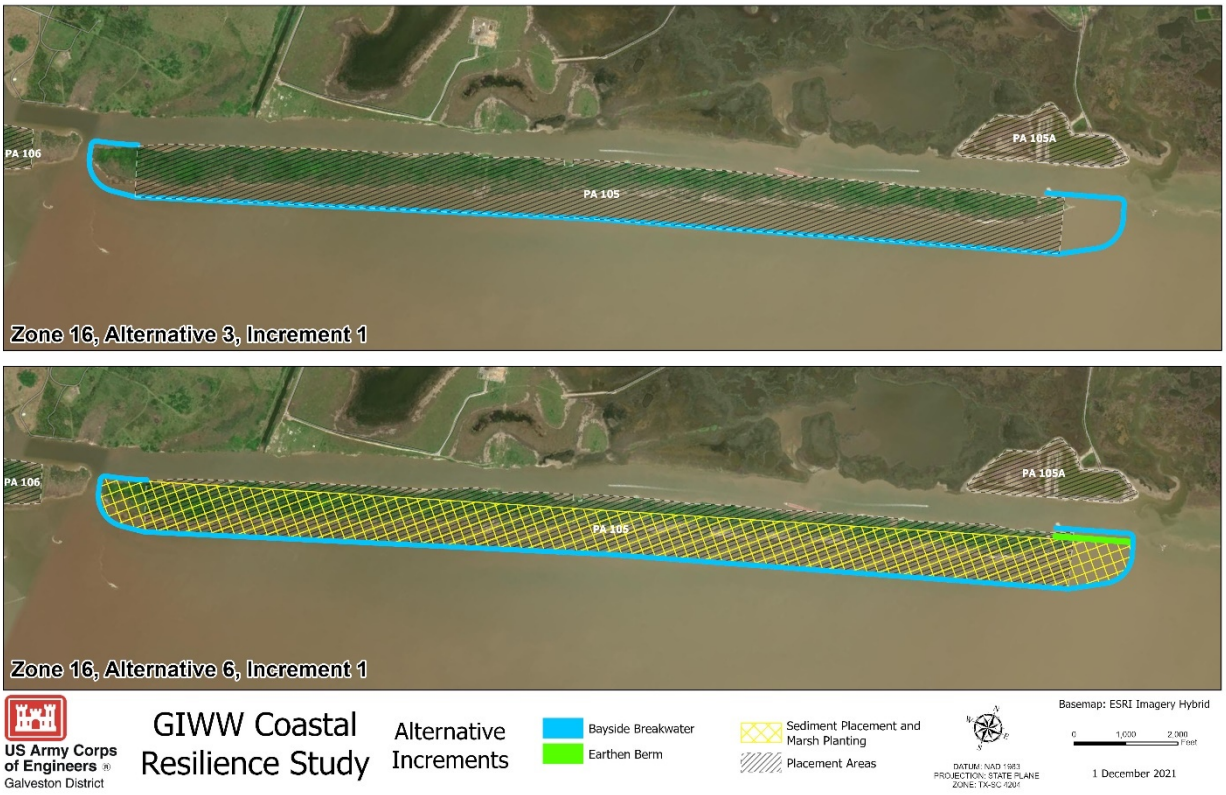

Figure 6: Zone 16 Alternatives 3 & 6 Maps

Top Map – Zone 16 – Alternative 3 – Increment 1 (16.3.1) Breakwater Crests = 5 feet NAVD88

Bottom Map – Zone 16 – Alternative 6 – Increment 1 (16.6.1) Breakwater Crests = 3 feet NAVD88 + Berm Crest = 8 feet NAVD88 + Barrier Restoration – Sediment Placement

Figure 6 shows increments 16.3.1 and 16.6.1 which are the increments evaluated for Zone 16. Increment 16.3.1 proposes breakwaters to be constructed on the bayside of the GIWW with crests at 5 feet NAVD88. The breakwaters are designed to protect the barrier islands from waves from the bay which cause erosion. The barrier islands protect the vessels in the channel from winds and waves.

Increment 16.6.1 proposes a combination of sediment placement, earthen berms, marsh plantings, and breakwaters. The sediment placement is intended to restore the barrier islands, much of which would be lost by the end of the period of analysis in year 2080. Marsh plantings are intended to prevent rapid erosion from wind and wave exposure by stabilizing the sediment with vegetation. The earthen berm is proposed to be constructed with a crest elevation of 8 feet NAVD88 and is designed to attenuate the crosswinds that vessels in the channel would be exposed to. Breakwaters are proposed to be constructed with crests at 3 feet NAVD88 on the channel bayside and bayside of the GIWW and are designed to contain the sediment in the placement area and prevent rapid erosion from wave exposure.

Figure 7 shows increments 18.3.1, 18.3.2, and 18.3.3 which are the alternative 3 increments evaluated for Zone 18. Increment 18.3.1 proposes breakwaters to be constructed with crests at 5 feet NAVD88 on the bayside of the GIWW and are designed to protect the barrier islands

from waves from the bay which cause erosion. The barrier islands protect the vessels in the channel from winds and waves.

Increment 18.3.2 proposes to add breakwaters on the channel bayside of the GIWW in addition to the breakwaters in 18.3.1. The breakwater crests on the channel bayside are proposed to be constructed to 3 feet NAVD88 and are designed to protect the barrier islands from vessel wake which cause erosion. The barrier islands protect the vessels in the channel from winds and waves.

Increment 18.3.3 proposes to add breakwaters and reef balls on the channel landside of the GIWW in addition to the breakwaters in 18.3.2. The breakwater crests on the channel landside are proposed to be constructed to 3 feet NAVD88 and are designed to protect the coastal lands from vessel wake which cause erosion. The reef balls are designed to attenuate waves while also allowing fish passage at the openings to Oyster Lake.

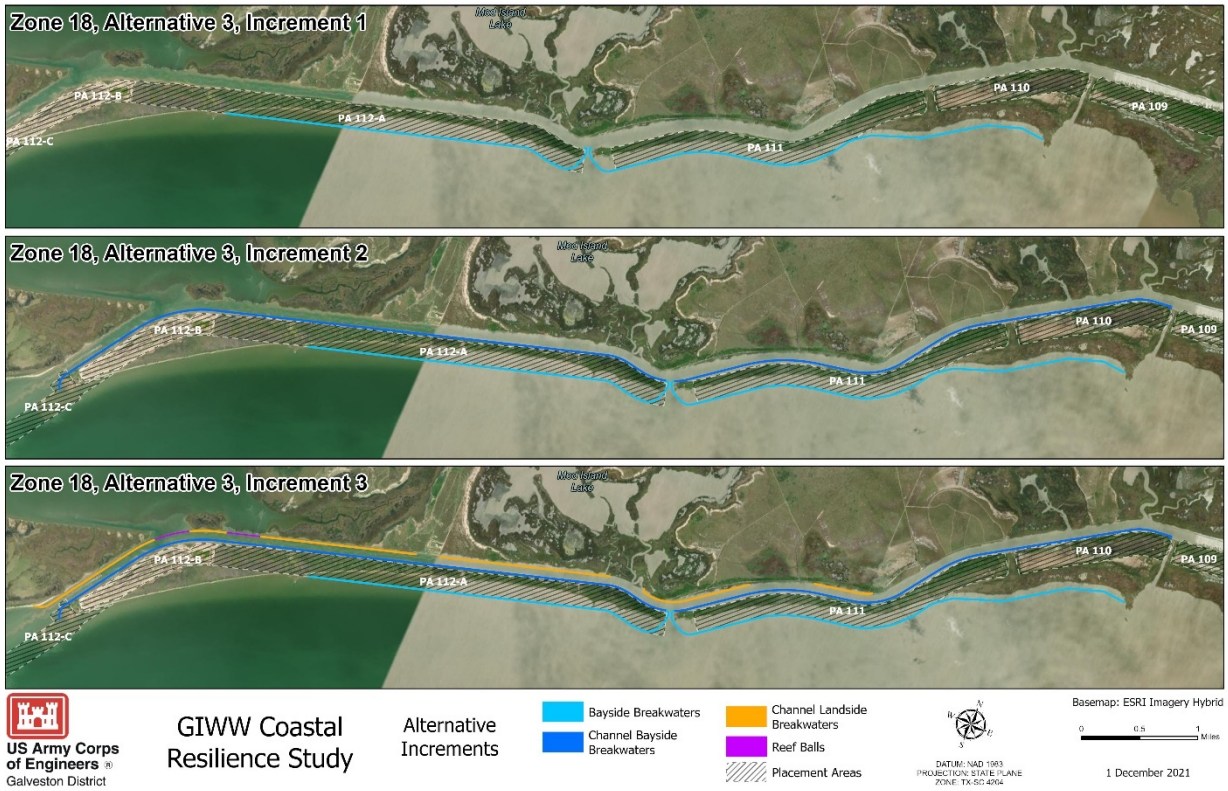

Figure 7: Zone 18 Alternative 3 Increment Maps

Top Map – Zone 18 – Alternative 3 - Increment 1 (18.3.1) – Bayside Breakwater Crests = 5 feet NAVD88

Middle Map – Zone 18 – Alternative 3 - Increment 2 (18.3.2), Bayside Breakwater Crests = 5 feet NAVD88 + Channel Bayside Breakwater Crests = 3 feet NAVD88

Bottom Map – Zone 18 – Alternative 3 – Increment 3 (18.3.3) Bayside Breakwater Crests = 5 feet NAVD88 + Channel Bayside Breakwater Crests = 3 feet NAVD88 + Channel Landside Breakwater Crests= 3 feet NAVD88

Figure 8 shows increments 18.6.1 and 18.6.2 which are the alternative 6 increments evaluated for Zone 18. Increment 18.6.1 proposes a combination of sediment placement, marsh

plantings, and breakwaters. The sediment placement is intended to restore the barrier islands, most of which would be lost by the end of the period of analysis in year 2080. Marsh plantings are intended to prevent rapid erosion from wind and wave exposure by stabilizing the sediment with vegetation. Breakwaters are proposed to be constructed with crests at 3 feet NAVD88 on the channel bayside and bayside of the GIWW and are designed to contain the sediment in the placement area and prevent rapid erosion from wave and vessel wake exposure.

Increment 18.6.2 proposes to add breakwaters and reef balls on the channel landside of the GIWW in addition to the sediment placement, marsh plantings, and breakwaters in 18.6.1. The breakwaters on the channel landside are designed to protect the coastal lands from vessel wake which cause erosion. The reef balls are designed to attenuate waves while also allowing fish passage at the openings to Oyster Lake.

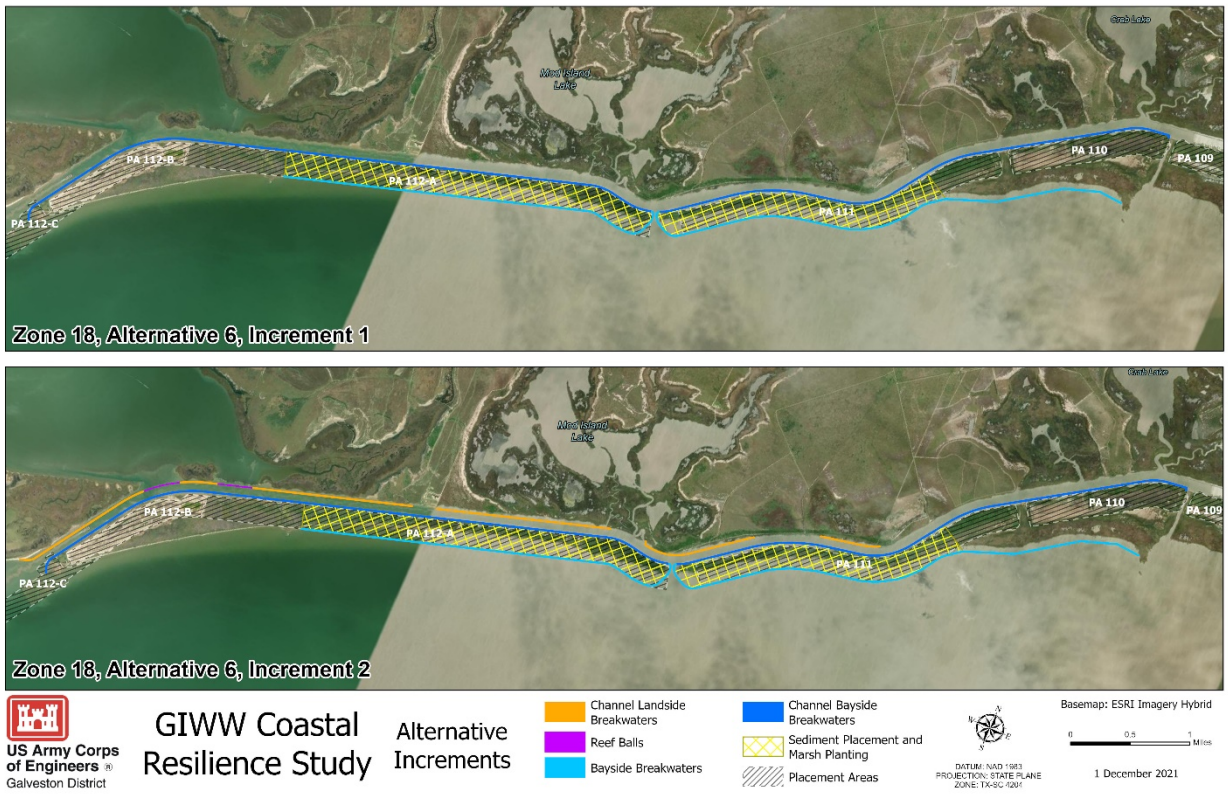

Figure 8: Zone 18 Alternative 6 Increment Maps

Top Map – Zone 18 – Alternative 6 - Increment 1 (18.6.1) Breakwater Crests = 3 feet NAVD88 + Barrier Restoration – Sediment Placement

Bottom Map – Zone 18 – Alternative 6 – Increment 2 (18.6.2) Breakwater Crests= 3 feet NAVD88 + Barrier Restoration – Sediment Placement + Reef balls

6.1 Hydrology & Hydraulics Engineering Methodology

To quantify the cost-savings generated by the various conceptual plans, a shoaling analysis was performed. The objective of the shoaling analysis was to develop an annual shoaling rate (ft) for each year of the project at 100-ft increments along the channel. This information would then be used to create Dredged Material Management Plans (DMMPs) for each potential plan and evaluate the costs of those plans in comparison to the Future Without Project (FWOP) DMMP.

CSAT was applied in this study to estimate annual shoaling rates along all National Channel Framework (NCF) reaches within Matagorda and Brazoria Counties using the eHydro data. NCF is a geodatabase of high-and medium-tonnage Congressionally authorized navigation channels maintained by the USACE. The NCF geodatabase and CSAT-generated high-resolution shoaling maps supported identification of areas with high rates of shoaling and erosion, or “hot spots”. CSAT shoaling estimates are developed by assessing channel dimensions, dredging events, and meteorological events and seasonal variations in rainfall that may influence sediment flux in the system. Results of the shoaling analysis are presented in two groupings, 2011-2015 & 2016-2020, because data was collected with different datum at one point in the period of record. Additional detail on the methodology and results of the CSAT analysis can be found in Annex 2 of the Engineering Appendix D.

Existing conditions and the considered alternatives were simulated using the Coastal Modeling System (CMS). The CMS is a depth-averaged hydrodynamic and wave model well suited for the project area. In addition to the flow and wave simulations, the CMS calculates sediment transport and morphologic change throughout the simulations. The CMS model covers the East Matagorda Bay. The CMS model was forced at the boundary using water surface elevation from nearest NOAA stations.

To project shoaling changes over time and by plan, the factors influencing the shoaling rate needed to be assessed. The three primary sedimentary inputs to the system are: 1) shoreline erosion, 2) watershed runoff, and 3) open-water circulation. Sediment that enters the navigation system: 1) shoals in the channel, 2) is deposited in the bay, 3) or is released out into the Gulf through inlets.

To estimate the shoreline erosion, a geospatial analysis was performed using aerial imagery from the years 1943, 1995, 2011, and 2018. Shoreline shapefiles were created for each year. The shoreline was categorized as: Channel Landward (CL), Channel Bayside (CB), or Barrier Bayside (BB). Shoreline erosion for each of these categorizations were computed from 2011 to 2018 and converted into an annual erosion rate. In addition, a weighted smoothing algorithm was performed +/- 500-ft along the channel. Lastly, shapefiles were created for any existing or planned armoring. Existing armoring included: revetments, breakwaters, and bulkheads, as well as the Sargent Beach revetment. Planned armoring included: Coastal Texas and the measures from this study, with all anticipated construction completion by the year 2030. In the analysis, whenever armoring was identified, the erosion rate was set to zero and the shoreline was set to the location of the armoring.

Using these shapefiles, a shoreline morphology was projected from the years 2018 to 2080. Erosion rates were assumed to be constant for each categorization, except in the case of armoring or if the barrier was eroded away, the BB rate would transfer to the CL. Each year, the location of the shoreline was tracked based on the erosion rate, and an erosion loss was tracked. The erosion loss was computed by multiplying the erosion rate by the height of the shoreline, which based on topo data was uniformly assigned to be 6-ft for the CL, and 10-ft for the CB and BB. This height includes the anticipated submerged land loss, which would be greater on the Bayside of the Channel. This erosion loss was then converted to shoaling rate by assuming a 1.0 bulking factor.

Based on an initial analysis of the overall Matagorda County from zone 7 to 18, shoreline erosion was estimated to represent 60% of the overall shoaling in the channel. Watershed runoff was estimated to be 17%, which means that at minimum 23% is either from bulking or open water. Considering open water only represents 13% of the channel length, the percentage contribution per channel foot could be relatively high. In addition, this assumes a 100% sediment budget; where it is likely that 20 to 50% of the system's sediment passes through the GIWW and is deposited in the Bay or Gulf, suggesting that this analysis is underestimating as much as 50% of the overall material movement and source of shoaling in the channel by not understanding the overall system circulation effects using a numerical model, which would better capture the deposition from watershed runoff, and the movement of wind-driven and tidally-driven circulation of sediment. Shoaling is assumed to be linearly additive. It is not influenced by SLR, because SLR is assumed to be inherently built into the shoreline analysis. Annual shoaling was also computed from 2018-2030 for FWOP and FWP Increments.

6.2 Geotechnical Engineering Methodology

The current dredged material placement plan requires approximately one-third of the O&M dredge material to be placed into existing upland confined placement areas (PAs) DA 99, DA 100, and PA 102-C. If the O&M dredge material is suitable for beach placement the dredge material will be pumped to PA 98 and PA 98-A to restore the eroding shoreline of Sargent Beach. Generally two-thirds of dredge material is suitable to be placed into Sargent Beach placement areas. Zone 12 experiences high rates of shoaling and requires frequent emergency dredging to remove areas of high shoaling O&M dredge material from the channel.

Future O&M shoaling rates remain relatively constant until 2030 when Texas Coastal Project has construction planned in this zone. Due to the construction of the Texas Coastal Project the annual shoaling quantities decrease immediately from approximately 110,600 CY per year to 104,400 CY per year in 2030. The shoaling rates are expected to increase gradually from approximately 104,400 CY per year in 2030 to 105,600 CY per year in 2080. The Texas Coastal Project will require 247,778 CY of dredge material to

be mined from the San Bernard to Colorado River reach and 1,195,299 CY to be mined from PA 102-C in 2030. Approximately one-third of the O&M dredge material will be placed into existing upland confined placement areas (PAs) DA 99, DA 100, and PA 102-C. PAs will be raised as necessary to contain the O&M dredge material. One raise is required in DA 99 and one raise in DA 100 to provide sufficient dredge material capacity until 2080. Approximately two-thirds of the O&M dredge material is suitable to be placed in the surf zone in PA 98 and PA 98-A to restore the eroding shoreline. The frequency of emergency dredging is expected to stay the same through 2080. For more information about the FWOP Placement plan for dredge material, see Sections 3.4 through 3.9 of the Engineering Appendix D.

6.3 Sediment Budget Analysis

The objective of the sediment budget analysis was to develop an annual shoaling rate (ft) for each year of the project at 100-ft increments along the channel. This information would then be used to evaluate the impacts to the Dredge Material Management Plan (DMMP) which will be developed in the future.

To develop the annual shoaling rate for the Future Without Project (FWOP) and Future With Project (FWP) conditions, a baseline first needed to be established, so the historical shoaling rate was estimated using the Corps Shoaling Analysis Tool (CSAT) based on historical survey and dredging history. Data was processed from 2011-2015 and 2016-2020 and then averaged. This was performed for both Brazoria and Matagorda Counties to establish a baseline historical shoaling rate in the channel.

To project shoaling changes over time and by plan, the factors influencing the shoaling rate needed to be assessed. The three primary sedimentary inputs to the system are shoreline erosion, watershed runoff, and open-water circulation. Sediment that enters the system either shoals in the channel or is deposited in the bay or is released out into the Gulf through inlets.

To estimate the shoreline erosion, a geospatial analysis was performed using aerial imagery from 2018, 2011, 1995, and 1943. Shoreline shapefiles were created for each year. The shoreline was categorized as either Channel Landward (CL), Channel Bayside (CB), or Barrier Bayside (BB). Shoreline erosion for each of these categorizations were computed from 2018 to 2011 and converted into an annual erosion rate. In addition a weighted smoothing algorithm was performed +/- 500-ft along the channel.

In addition, shapefiles were created for any existing or planned armoring. Existing armoring included existing revetments, breakwaters, and bulkheads, as well as the Sargent Beach revetment. Planned armoring included Coastal Texas and the GIWW-CR

measures, all anticipated for 2030. In the analysis, whenever armoring was identified, the erosion rate was set to zero and the shoreline was set to the location of the armoring.

From the shoaling analysis, the existing highest area of concern is Zone 12, but is followed closely by the transition between Zone 18 and Zone 19. It is interesting to see in the historical CSAT the changes between the 2011-2015 and 2016-2019 rates, particularly zone 13, where the rates have gone up as a result of the barrier being heavily breached. In terms of future shoaling changes, the area of greatest concern is zone 18, followed by zone 16 as these are two areas that will have barrier breached. For additional information about the sediment budget analysis, see the Engineering Appendix D.

6.4 Cost Engineering Methodology

The project first costs consist of construction costs, environmental costs, and real estate costs. For Alternative 3 increments, construction costs consist of the costs for engineering and design, mobilization, construction management, and materials for breakwaters and reef balls. For Alternative 6 increments, construction costs include the same costs described for Alternative 3 and also add the costs for building earthen berms including the dredging mobilization required. In June of 2021, the PDT conducted an Abbreviated Risk Analysis (ARA) and the resulting risks were used to develop the cost contingency of 35% which were applied to the project first costs for all increments.

Class 3 cost estimates were developed in MCACES (Micro-Computer Aided Cost Estimating System), also known as MII, for the final alternatives: Alternative 6 - NED and Alternative 6 - Resilience designed by the project delivery team (PDT).

Alternative 6 - NED plan is divided into two (2) contracts and Alternative 6 - Resilience plan is divided into three (3) contracts. Each contract is organized in accordance with a work breakdown structure. Midpoint dates for the construction contracts were developed in conjunction with the PM and the PDT for developing the fully funded costs. The estimates were prepared in accordance with ER 1110-2-1302 Civil Works Cost Engineering and EM 1110-2-1304 Civil Works Construction Cost Index System (CWCCIS), dated 30 September 2021.

6.5 Environmental Cost Estimating Methodology

Environmental costs estimates were generated by referencing the mitigation costs of other Corps projects in the region, and then multiplying them by the expected acres of effect for each section of the project. The acreages of impacts were determined using Arc Map Geospatial software. Using aerial imagery, polygons were drawn around visible environmental resources (Oyster reefs, sea grasses, wetlands) in GIS, and the areas calculated using the software. The costs of $236,500 per acre of oyster reef was used to determine estimated oyster reef mitigation costs. This figure was sourced from the Matagorda Ship Channel and Houston Ship Channel feasibility studies. These are local corps projects that had similar environmental impacts. The costs of $80,000 per acre of

seagrass was used to determine estimated seagrass mitigation costs. This figure was sourced from the Corpus Christi Ship Channel study. The *Spartina alterniflora* broadcast marsh planting costs were sourced from the GIWW Moorings Basin project. Plantings are expected to cost approximately $5,400 per acre. Coordination with local resource agencies will be needed to determine final planting plans, mobilization needs, planting duration, and if a monitoring plan will be needed after plantings are complete.

6.6 Real Estate Cost Estimating Methodology

The real estate evaluation for each of the proposed increments of the GIWW CRS Project was performed using data provided by engineering and geospatial PDT members, internal real estate data and public data. Using ArcGIS Pro, the engineering designs for each of the proposed increments was overlayed with county parcel data pulled from the Matagorda County Appraisal District, county pipeline data pulled from the Texas Railroad Commission website and internal USACE tract and PA layers to determine the real estate impacts of each of the proposed designs. Total acreage of the privately owned land to be impacted by each increment (lands not covered by USACE interests) was also calculated within ArcGIS Pro.

The real estate rough order of magnitude (ROM) costs was estimated using the data resulting from the evaluation described above. During discussions with the PDT, it was determined that it would be unlikely that any pipelines would require relocation for the construction of this project, so pipeline relocations were removed from the ROM estimation for each increment. Well relocations, residential, commercial, and industrial relocation and moving costs were excluded from the ROM as well, as they are not applicable to the project area. $2,000 was added to the estimate for each increment for PED phase reviews (DQC, ATR, and BCOES). This ROM was developed early on during feasibility, prior to the selection of a TSP, so a fairly high contingency of 35% was added to the estimated real estate cost of each increment. Typically, the cost of easements is estimated at about 90% of the fee value of the land for ROM estimations. However, it is estimated that much of the privately owned land that could be impacted by this project will have eroded by the time construction begins in 2030 and will, therefore, fall under navigational servitude. Due to this, the estimated cost of easements was decreased to 30%.

6.7 HTRW Considerations

In order to complete a feasibility level HTRW evaluation for the Gulf Intercoastal Waterway Coastal Resiliency Study (GIWW), a records search was conducted following the rules and guidance of ER 1165-2-132: *HTRW Guidance for Civil Works Projects*, and ASTM E1527-13: *Standard Practice for Environmental Site Assessment: Phase 1 Environmental Site Assessment Process*. In the records review, files, maps, and other documents that provide environmental information about the project area are obtained and reviewed. To complete the records review, USACE reviewed publicly available databases and sources, using the proposed footprint of the project, along with an approximate 1-mile search distance for each of the sources. The records search revealed

several HTRW sites in the vicinity of the project area, although none of these sites have the potential to affect the proposed project.

Based on the findings of the HTRW survey, the probability of encountering contaminated sites or toxic substances for the future without project condition is considered low. Information compiled by this assessment indicates additional investigations are not warranted at this time.

6.8 Cultural Resources Considerations

Federal agencies are required under Section 106 of the National Historic Preservation Act to "consider the effects of their undertakings on historic properties" and consider alternatives "to avoid, minimize or mitigate the undertaking's adverse effects on historic properties" [(36 CFR 800.1(a-c)] in consultation with the State Historic Preservation Officer (SHPO) and appropriate federally recognized Indian Tribes (Tribal Historic Preservation Officers - THPO) [(36 CFR 800.2(c)]. In accordance with this and other applicable regulations, including the National Environmental Policy Act of 1969 (NEPA), the Native American Graves Protection and Repatriation Act (NAGPRA), the Antiquities Code of Texas, and Engineer Regulation (ER) 1105-2-100, USACE has reviewed of the Texas Historical Commission (THC) ATLAS Database to better determine the existing conditions and potential risks of encountering cultural resources. A review of the Texas Historical Commission's ATLAS database revealed that twenty terrestrial cultural resource investigations have been performed within 1,000 meters of the project area. These investigations consist entirely of archeological investigations. Eighteen archeological sites and one shipwreck have been identified within 1,000 meters of the project area. Thus, the proposed project was considered to have a high probability for terrestrial and submerged cultural resources to occur. A Programmatic Agreement was developed with the Texas Historic Preservation Officer to determine the scope of any cultural resources investigations should the project proceed to the Preconstruction Engineering and Design Phase.

6.9 Economic Considerations

Historical traffic shows more than a 95 percent commonality of traffic between the BRFG and CRL, and that commonality is expected to continue into the future. The forecasted growth rates are presently flat for the TSP, but final numbers will show growth rates similar to the BRFG and CRL study. Average delays per vessel are expected to stay constant in the FWOP condition. Present speeds observed in Zone 14 were used as the baseline condition for FWP condition. Costs and benefits were annualized using a discount rate of 2.5% and are in fiscal year (FY) 2021 dollars. See Economic Appendix A for more details.

7.0 STEP 5 – COMPARE AND EVALUATE FINAL ARRAY OF ALTERNATIVES

After completing the incremental analysis, the PDT held another IPR in June of 2021 with the vertical team to present the progress towards the TSP milestone and determine the decision framework to further define resilience and its cost-effectiveness in order to develop the final array of alternatives and select the TSP. Due to the difficult and

subjective nature of quantifying resilience, some of the PDT and Vertical Team members subsequently held multiple focus-group meetings to further discuss the best approach for determining the decision framework. The result of discussions with the Vertical Team was that the decision framework for the TSP would be based on both economic and resilience metrics through a one-time-use Planning Model.

7.1 Planning Model

After completing the incremental analysis, the PDT held another IPR in June of 2021 with the vertical team to present the progress towards the TSP milestone and determine the decision framework to further define and capture resilience and its cost-effectiveness in order to develop the final array of alternatives and select the TSP. Due to the difficult and subjective nature of quantifying resilience, some of the PDT and Vertical Team members subsequently held multiple focus-group meetings to confirm the best approach to quantifying the additional contributions of resiliency within the decision framework. The result of discussions with the Vertical Team was that the decision framework for the TSP would be based on both economic and resilience metrics through a one-time-use Planning Model. The economic metrics include straightforward values such as project first costs, transportation costs, and O&M costs which are then used to calculate benefits in dollar cost savings. These economic metrics are similar to the ones used in a traditional inland navigation study's Economic Models. However, because this study also measures resilience benefits, a customized Planning Model was used which included resilience metrics that were decided in discussion between the PDT and the Vertical Team. Although less straightforward, the following resilience metrics were added to the Planning Model in order of importance: 1) acres of barrier island erosion protected or restored by 2080, 2) linear feet of channel exposure reduced by 2080, 3) cost per acre of barrier island in dollars, and 4) cost per linear foot in dollars. The resilience metrics 1 and 2 measure the amount of resilience provided by each increment, and metrics 3 and 4 measure the cost-effectiveness of the respective acre or linear feet of resilience provided by each increment.

7.2 Further Screening of Increments

The PDT used the economic and resilience metrics calculated in the Planning Model to further screen out the increments. Increments 14.3.1, 16.3.1, 18.3.1, 18.3.2, 18.3.3, and 18.6.2 were screened from further evaluation for less favorable values in both economic and resilience metrics compared to their counterparts within the same zones. Increment 12.3.2 had unusable shoaling data and hence inaccurate economic metrics, but it was still carried forward due to strong support from the sponsor and stakeholders related to addressing the particularly problematic navigation safety risk at zone 12. Further analysis would be required to develop usable shoaling data for increment 12.3.2 if it is accepted as part of the TSP, but the additional shoaling analysis would be done as a refinement after the TSP milestone. Increment 12.3.3 was screened out due to lack of usable shoaling data from the incremental analysis and the ability to include it as an optimization measure for 12.3.2 after the TSP. Increment 13.3.1 was screened out because it had similarly poor economic metrics and 435 acres less of barrier island when compared to increment 13.6.1.

7.3 Incremental Comparison

The final list of increments includes 12.3.1, 12.3.2, 13.6.1, 14.6.1, 16.6.1, and 18.6.1 from which different combinations could be developed for the final array of alternatives.

All zones in the study area had an alternative with positive net benefits except Zone 13. Zone 12 has two alternatives with positive net benefits. Two alternatives (12.3.1 and 12.3.2) in Zone 12 and two alternatives in Zone 13 (13.3.1 and 13.6.1) were carried forward for additional consideration using resiliency criteria. For the other zones, the alternative with the highest net benefits was carried forward without further screening.

Increment 12.3.1 includes:

- Zone 12
- Alternative 3 – shoreline stabilization
- Channel bayside breakwaters only to minimize impacts to critical habitatand endangered species
- Project first cost: $12M
- BCR 2.7

Increment 12.3.2 includes:

- Zone 12
- Alternative 3 – shoreline stabilization with widening measure
- Channel bayside breakwaters and widening of the channel for this zone
- Project first cost: $17.7M (widening adds $5.7M)
- BCR: 1.6

Increment 13.3.1 includes:

- Zone 13
- Alternative 3 – shoreline stabilization
- Bayside breakwaters and channel bayside breakwaters
- Project first cost: $ 39.1M
- BCR: 0.6

Increment 13.6.1 includes:

- Zone 13
- Alternative 6 – combination plan
- Bayside breakwater, channel bayside breakwater, berm, and sedimentplacement
- Project first cost: $ 61M
- BCR: 0.4

Increment 14.6.1 includes:

- Zone 14
- Alternative 6 – combination plan
- Bayside breakwater, channel bayside breakwater, berm, and sedimentplacement
- Project first cost: $15.8M
- BCR: 1.5

Increment 16.6.1 includes:

- Zone 16
- Alternative 6 – combination plan
- Bayside breakwater, channel bayside breakwater, berm, and sedimentplacement
- Project first cost: $ 32.3M
- BCR: 1.2

Increment 18.6.1 includes:

- Zone 18
- Alternative 6 – combination of shoreline stabilization and sedimentmanagement plan
- Bayside breakwater, channel bayside breakwater, and sedimentplacement
- Project first cost: $125M
- BCR: 1.1

The economic considerations in the evaluation of the final array were developed from vessel traffic data obtained from the U.S. Coast Guard's Automatic Identification System (AIS) data and historical traffic information which showed that more than a 95 percent commonality of traffic between the GIWW Brazos River Floodgates – Colorado River Locks (GIWW BRFG-CRL), and that commonality is expected to continue into the future. The forecasted growth rates are presently flat for the TSP, but final numbers will show growth rates similar to the GIWW BRFG-CRL recently authorized project. The average delays per vessel are expected to get worse as the barrier island continues to erode in the FWOP condition. Present speeds observed in Zone 14 were used as the baseline condition for future with-project condition. Cost and benefits were annualized using a discount rate of 2.5% and are in fiscal year (FY) 2021 dollars. The resilience metrics evaluated were barrier loss and linear feet of shoreline protected.

The PDT evaluated the final array using economic and resiliency considerations. The PDT estimated transportation costs savings, O&M cost savings, safety, and estimated benefits in terms of barrier loss and linear feet of shoreline protected. In all but one Zone, NED and resiliency coincide, i.e., the problems created by loss of the barrier islands are addressed with a resiliency plan that has positive net benefits. The following discussion supplies the rationale to recommend a plan beyond NED in Zone 12 and 13 for resiliency of the navigation system and is summarized in Table 1.

Increment 12.3.1 provides highest net benefits in Zone 12. Net benefits are similar ($139K difference) to increment 12.3.2 but has approximately $5.7 million in additional costs. ER 1105-2-100 Appendix G Exhibit G-1 states “Where two cost effective plans produce no significantly different levels of net benefits, the less costly plan is to be the NED plan, even though the level of outputs may be less.” Increment 12.3.2 provides an additional safety benefit, for these reasons the team is requesting increment 12.3.2 for the resiliency recommendation. The safety issue in Zone 12 is described as follows. Waterway users have identified areas of significant shoaling where the channel width is often draft-restricted. The area where the GIWW intersects Caney Creek (Zone 12) in particular, is a location of both high current velocities and shoaling due to the proximity to the Gulf of Mexico, as well as the typical chronic and episodic shoaling experienced in the channel. This creates navigation safety risks for barges traversing this intersection. Barge tows must often “crab-walk” across the currents at Caney Creek, and tows risk damage to their rudders and wheels during groundings on large sediment shoals exacerbated by erosion in the vicinity. These groundings pose a safety risk to life, property, and the environment. Additionally, the channel shoreline on the mainland side of the GIWW has also suffered significant erosion loss, increasing shoaling in the GIWW. This allows saltwater intrusion into ecologically important and diverse brackish and freshwater marsh habitats along the north side of the GIWW. Due to the compelling safety risks in Zone 12, an NED exception is proposed.

The PDT recommends action in Zone 13 to address further barrier island erosion and resiliency for the navigation system. Two alternatives considered in Zone 13 include the breakwater (13.3.1) and the breakwater and barrier island (13.6.1). As mentioned previously, shoaling conditions are expected to become much worse in the future, over what is currently captured in the shoaling model for the study. Similar to Zone 12, erosion of the channel shoreline on the mainland side of the GIWW introduces additional maintenance material into the GIWW and threatens brackish and freshwater marsh habitats on the mainland shoreline due to potential saltwater intrusion. The PDT will be conducting additional analysis in Zone 13 to reduce uncertainty and determine if the shoaling issues can be further characterized, and additional O&M benefits captured to account for worsening conditions. Additional refinements to the design assumptions will also explore potential reductions in costs. Until the work is complete, it is uncertain

whether an increment in Zone 13 will be economically justified, and which increment. In all other Zones except Zone 12, Alternative 6 offers the highest net benefits compared to Alternative 3.

An NED exception is proposed for Zone 13 for resiliency. Of the two alternatives considered for Zone 13, 13.3.1 (breakwater) and 13.6.1 (breakwater and barrier island), the PDT recommends the 13.6.1 increment for reasons described as follows. Increment 13.3.1 would address shoaling concerns in Zone 13 and costs less than 13.6.1. However, the PDT determined non-monetary rationale exists for selecting increment 13.6.1 that provides value to the navigation channel and the nation.

Barrier islands also provide more robust protection of the navigation channel than breakwaters against episodic disturbances, such as major storm events, as well as the day-to-day navigation and erosion impacts from winds and waves. This is due to the larger footprint and the higher crest elevation of the barrier island and earthen berm which are able to *absorb* harsher conditions. By withstanding harsher conditions, barrier islands enable the GIWW to *recover* and resume normal operations more quickly after episodic disturbances.

The use of barrier islands as placement areas also provides additional flexibility to use dredged material beneficially for resiliency as needed and *adapt* to changing conditions. Therefore, alternative 6 offers more resilience as defined by the four principles: *prepare, absorb, recover, adapt*.

The breakwater features protect the barrier islands, but the two measure complement each other and there is some interdependence. The barrier islands reinforce the breakwater toes from bed degradation. The natural process for barrier features is erosion and landward/lateral drift. They are naturally dynamic features, but the GIWW needs to be a reliable transportation corridor, so the barrier features need shoreline stabilization to ensure a more static condition. The breakwaters reduce shoreline erosion caused by wind-driven or vessel-induced waves. In addition, the breakwaters actually capture suspended sediment from wave overtopping, so they actually lead to a positive sediment budget.

Restoration and protection of the barrier islands reduces the likelihood of breaches and barrier island loss from erosion and storm events. Predicted erosion estimates show that much of the barrier islands in the study area will be lost in the next 10 to15 years if measures to combat that erosion are not put in place. Therefore, this study also evaluates the resiliency of using shoreline stabilization and dredged materialas a means to: recover and adapt from the episodic impacts from coastal storms, chronic wind and wave attack, and strong currents from the bay. This study considers the operations and maintenance life cycle costs to reduce project costs over time instead of a least cost option that may have fewer lasting benefits.

The barrier islands on the south side of the GIWW have long been a much-needed thin line of defense for the channel against strong currents and wave attack from East and West Matagorda Bay. Of the five zones included in the plan, Zone 18 is an excellent example of the problem experienced along the length of the channel within Matagorda County. Over the years, the barrier islands have experienced severe erosion which was expedited by the rough conditions of the bay. Although maintenance material has prolonged the protective service life of the barrier islands, there is continued erosive loss due to increased wind and current velocities associated with chronic and episodic storms and associated wave attacks from the bay.

Continued loss of these barrier islands will only result in increased velocities andwave attacks within the channel. In Zone 18, the barrier islands are predicted toerode 80% by year 2080 exposing more than 6 miles of the channel to the open bayIn Zone 13, a zone for which we are requesting the exception to NED, the barrier island will be essentially lost by the year 2030.

Table 17 below shows how each of the remaining increments address the study problems.

Table 17: Incremental Comparison of Addressing Study Problems

Increment	Problem 1: Erosion and Coastal Storms Eroding Shorelines and Barriers	Problem 2: Sea Level Rise and Storms Exacerbate Loss of Barriers	Problem 3: Shoaling in GIWW Leads to Light Loading
12.3.1	Prevents some erosion from vessel wake, but not from wind waves or coastal storms	Prevents some loss of barrier islands but does not prevent further exacerbation	Addresses shoaling hotspot by redirecting some of the flow of sediment out of GIWW
12.3.2	Prevents some erosion from vessel wake, but not from wind waves or coastal storms	Prevents some loss of barrier islands but does not prevent further exacerbation	Addresses shoaling hotspot as well as safety risk of vessel groundings with the channel widening
13.6.1	Creates a new barrier island fully protecting Zone 13 which would otherwise be exposed	Prevents further exacerbation of barrier island loss at Zone 13 by replenishing it with dredged material	Breakwaters contain the sediment placed on the barrier island which prevents it from entering the channel
14.6.1	Prevents further erosion of barriers at Zone 14 providing the most protection from coastal storms	Prevents further exacerbation of barrier island loss at Zone 14 by replenishing it with dredged material	Breakwaters contain the sediment placed on the barrier island which prevents it from entering the channel

Increment	Problem 1: Erosion and Coastal Storms Eroding Shorelines and Barriers	Problem 2: Sea Level Rise and Storms Exacerbate Loss of Barriers	Problem 3: Shoaling in GIWW Leads to Light Loading
16.6.1	Prevents further erosion of barriers at Zone 16 providing the most protection from coastal storms	Prevents further exacerbation of barrier island loss at Zone 16 by replenishing it with dredged material	Breakwaters contain the sediment placed on the barrier island which prevents it from entering the channel
18.6.1	Prevents further erosion of barriers at Zone 18 providing the most protection from coastal storms	Prevents further exacerbation of barrier island loss at Zone 18 by replenishing it with dredged material	Breakwaters contain the sediment placed on the barrier island which prevents it from entering the channel

Based on the values from the Planning Model and the incremental comparison shown in Table 17 above, the final array of alternatives and their trade-offs were developed as shown in Table 18 below.

Table 18: Evaluation and Comparison of final array of alternatives

		Economic Metrics					Resilience Metrics				Tradeoff Notes	
	Increment	**Total project First Cost**	**Average Annual Transportation Savings**	**Average Annual O&M Cost Savings**	**Average Annual net Benefits**	**BCR**	**Acres of Barrier Island Protected or Restored by 2080**	**Annualized Cost per acre**	**Linear Feet of channel exposure reduced by 2080**	**Annualized Cost per Linear foot of channel protected**	**Beneficial**	**Adverse**
Alternative 1 - No Action Alternative												
No Action	None	$ -	$ -	$ -	$ -	N/A	0	$ -	0	$ -	- No Cost	- 1,037 acres of existing barrier islands will be lost by 2080. - No transportation or O&M savings to be gained - Erosion
Alternative 3 – Shoreline Stabilization												
Most Efficient Increment	12.3.1	$ 12,023,356	$ 898,000	$ 260,714	$ 734,794	2.7	16	$ 27,297	951	$ 446	- Highest Efficiency (BCR) - Improves some problematic navigation conditions at Zone 12	- Does not fully address sponsor and stakeholder safety concerns at zone 12. - Least cost effective for resilience - Least resilience in acres and linear feet
Safety Reduction Increment	12.3.2	$ 17,703,372	$ 898,000	$ 120,865	$ 394,678	1.6	16	$ 40,192	951	$ 656	- Cost Efficient (BCR)\ - Additional improvement with shoaling and maneuvering room for cross-current at zone 12	- Additional cost - Portion of the barrier island will still be lost by 2080
Zone 13 Stabilization Increment	13.3.1	$ 39,124,868	$ 580,000	$ 191,391	$ (608,076)	0.6	3	$ 414,254	19,000	$ 73	- Improves some problematic navigation conditions at Zone 13	- High cost - Additional vulnerability to wind/waves from open bay with just breakwaters
Alternative 6 – Combination Alternative												
Zone 13 Barrier Island Restoration Increment	13.6.1	$ 60,907,295	$ 580,000	$ 212,408	$ (1,355,064)	0.4	438	$ 4,906	19,000	$ 113	- Additional 435 acres from increment 13.3.1 - Additional buffer protection from wind/waves from open bay with restoration of barrier island - Additional Placement Area (PA)	- High cost - Lower efficiency (BCR)
Most Cost-Effective Increment	18.6.1	$ 60,907,295	$ 580,000	$ 212,408	$ (1,355,064)	0.4	438	$ 4,906	19,000	$ 113	- Additional buffer protection from wind/waves from open bay with restoration of barrier island	- High cost - Lower efficiency (BCR)
NED	12.3.1, 14.6.1, 16.6.1, 18.6.1	$ 185,259,621	$ 2,424,000	$ 5,775,965	$ 1,668,070	1.26	1,666	$ 3,921	46,099	$ 142	- Highest Net Benefits - 2nd most effective plan for resilience	- Does not address the safety risk concern at Zone 12 voiced by sponsor and stakeholders and vessel operators - Additional vulnerability to wind/waves from open bay with just breakwater at Zone 13 - 2nd highest project first cost

		Economic Metrics					Resilience Metrics				Tradeoff Notes	
	Increment	**Total project First Cost**	**Average Annual Transportation Savings**	**Average Annual O&M Cost Savings**	**Average Annual net Benefits**	**BCR**	**Acres of Barrier Island Protected or Restored by 2080**	**Annualized Cost per acre**	**Linear Feet of channel exposure reduced by 2080**	**Annualized Cost per Linear foot of channel protected**	**Beneficial**	**Adverse**
Resilience	12.3.2, 13.6.1, 14.6.1, 16.6.1, 18.6.1	$ 251,846,932	$ 3,004,000	$ 5,758,958	$ (116,676)	0.98	2,104	$ 4,221	65,099	$ 136	- Most effective plan providing the most resilience in acres of barrier island restored and linear feet of channel protection - For an additional $5.7M above NED, addresses safety risk concern at Zone 12 voiced by sponsor, stakeholders and vessel operators. - For an additional $60.1M above NED, restores 435 barrier island and much needed PA at zone 13 while protecting an additional 19K linear feet of channel	- Highest project first cost - Negative Net Benefits - Lower Efficiency (BCR)
NED minus Zone 18	12.3.1, 14.6.1, 16.6.1,	$ 60,156,385	$ 1,680,000	$ 1,731,288	$ 1,290,291	1.6	505	$ 4,199	46,099	$ 163	- 2nd highest Net benefits - Cost $125M less than NED Plan	- Provides less than 30% of resilience of NED Plan - 1,161 fewer acres of erosion reduced and 33K fewer linear feet of shoreline protected - Provides less than 50% of resilience of Increment 18.6.1 by itself - 438 fewer acres of erosion reduced and 19K fewer linear feet of shoreline protected. - 664 acres of remaining barrier island will be lost by 2080
Resilience minus Zone 18	12.32, 13.6.1, 14.6.1, 16.6.1	$ 126,743,696	$ 2,260,000	$ 1,714,281	$ (494,456)	0.9	943	$ 4,740	31,984	$ 140	- 50% cost of Resilience Plan - Additional $60.1M restores 435-acre barrier island and much needed PA at zone 13 while protecting an additional 19k linear feet of channel	- Most Negative net benefits - Lowest efficiency (BCR) - 667 acres of remaining barrier island will be lost by 2080

8.0 EVALUATION CRITERIA

The final array of alternatives was evaluated and compared using the criteria specified in the Water Resources Council's Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (March 1983): complete, effective, efficient, and acceptable.

Complete:

- Addresses all the problems and objectives at each zone within the study area

Effective:

- Most Economic Benefits (measured in Annualized Cost Savings minus Project First Costs)
- Most Resilience Benefits (measured in Acres of Barrier Island Protected/Restored by 2080 and Linear Feet of Channel Exposure Reduced by 2080)
- Cost-effectiveness of resilience provided (measured in Dollars per Acre and Dollars per Linear Foot)
- Reduces Navigation Safety Risk

Efficient:

- Highest Benefit-Cost-Ratio (BCR)
- Efficient use of dredged material

Acceptable:

- Avoid environmental impacts
- Avoid cultural resources impacts
- Avoid HTRW areas
- Compatibility with agency lands

9.0 STEP 6 - RECOMMENDED TSP

Both Alternative 6 – NED Plan and Alternative 6 – Resilience Plan are complete and effective plans. However, for all the reasons stated below, the PDT is recommending the tentatively selected plan (TSP) as Alternative 6 - Resilience plan. This recommendation requires a NED Exception, which is still pending approval by the ASA(CW). Therefore, either plan could ultimately be selected at the Agency Decision Milestone in the late Spring of 2022.

The recommended Tentatively Selected Plan (TSP) is the Resilience Plan because it is the most effective at meeting the evaluation criteria, addressing the study problems, and achieving the study objectives. While the Resilience Plan is the costliest plan with a project first cost of $251.8 million, it also provides reasonable economic benefits and a BCR of 0.98. For an additional $66.6 million project first cost above the NED Plan, the

Resilience Plan prevents the complete exposure of Zone 13 and addresses the grounding safety risk at Zone 12.

Table 19 below shows how the NED Plan and Resilience Plan compared against the 1983 P&G evaluation criteria.

Table 19: Comparison of Plans Against Evaluation Criteria

Plans	Complete	Effective	Efficient	Acceptable
NED Plan	- This plan is complete and accounts for all actions to meet the estimated benefits.	- Highest Net Benefits (Total Cost $185M) - Most Cost-effective Combination per Acre	BCR = 1.26	Avoids impacts to ENV, CR, HTRW, or RE
Resilience Plan[2]	- This plan is complete and accounts for all actions to meet the estimated benefits.	- Highest Resilience (Total Cost: $251.8 M) - Zone 12 additional $5.7M for channel modification measure to address safety risk and resilience - Zone 13 additional $61M for resiliency of the barrier island to the bay - Most Cost-effective Combination per Linear Foot	BCR = 0.98 This is an efficient consideration for resiliency given the price tag is $50,345 per acre.	Avoids impacts to ENV, CR, HTRW, or RE

[2] This includes 12.3.2 as a total project first cost of $17.8M, which includes channel modification ($5.8M) and the stabilization increment (12.3.1) ($12M). Increment 12.3.1 is part of 12.3.2, so those measures for stabilization for $12M are part of both the NED and Resilience Plan as shown in the Table 1 above.

Table 20 below compares how the NED Plan and Resilience Plan meet the study objectives.

Table 20: Comparison of Plans Against Study Objectives

Plans	Objective 1: Improve Navigation Resiliency of GIWW	Objective 2: Improve Economic Efficiency of GIWW	Objective 3: Reduce Safety Risks in the GIWW
NED Plan	Provides 1,666 Acres of barrier island and 46,099 Linear Feet of channel protection	Provides $8.19M in total net benefits and a BCR of 1.26	Safety risk at Zone 12 not addressed, and Zone 13 left exposed and vulnerable to bay
Resilience Plan	Provides 2,104 (+21%) Acres of barrier island and 65,099 (+30%) Linear Feet of channel protection (compared to NED Plan)	Provides $8.76M (+6%) in total net benefits and a BCR of 0.98 (-22%) (compared to NED Plan)	Zone 12 safety risks addressed, and reducing safety risk at Zone 13

The PDT's conclusions from the comparisons are as follows:

- Both Plans are complete and equally acceptable;
- Resilience Plan provides more barrier creation and protection of the channel by 21% in additional Acres and 30% in Linear Feet of protection than the NED plan; and,

- Resilience Plan provides reduction in safety risk at Zone 12, a significant concernby the sponsor and stakeholders, and the entire length of Zone 13.

Based on the conclusions from the comparison of plans against the evaluation criteria and study objectives, the PDT recommends the Resilience Plan for the TSP. TSP includes increments: 12.3.2, 13.6.1, 14.6.1, 16.6.1, and 18.6.1. The TSP is the NED Plan plus additional measures for safety reduction in Zone 12 and resiliency in Zone 13.

9.1 Zone 12 for safety reduction:

Increment 12.3.2 at zone 12 has an additional project first cost of $5.7M for the channel modification measure to address unintentional groundings and significant sediment issues. These groundings pose a safety risk to life, property, and the environment.

U.S. Coast Guard data for unintentional groundings reported within Zone 12 at Caney Creek indicate that there were 13 reported groundings during the 2018 through 2020, three-year period requested. 12 out of the 13 where in the year 2020 and one in 2019.

Two emergency dredging contracts were executed between FY 18 and FY 20 for shoaling at Caney Creek. One additional emergency dredging contract was executed in early FY21 for shoaling at Caney Creek. Post Hurricane Harvey, USACE modified three contracts to

conduct emergency dredging at the Colorado River Locks and East Matagorda Bay. These two areas shutdown the GIWW completely for about two weeks, after which USACE was able to incrementally open channel in stages over an additional 2-3 weeks.

As stated, waterway users have identified areas of significant shoaling where the channel width is often draft-restricted. The area where the GIWW intersects Caney Creek (Zone 12) in particular, is a location of both high current velocities and shoaling due to the proximity to the Gulf of Mexico, as well as the typical chronic and episodic shoaling experienced in the channel. This creates navigation safety risks for barges traversing this intersection. Barge tows must often “crab-walk” across the currents at Caney Creek, and tows risk damage to their rudders and wheels during groundings on large sediment shoals exacerbated by erosion in the vicinity. These groundings pose a safety risk to life, property, and the environment. Additionally, the channel shoreline on the mainland side of the GIWW has also suffered significant erosion loss, increasing shoaling in the GIWW. This allows saltwater intrusion into ecologically important and diverse brackish and freshwater marsh habitats along the north side of the GIWW.

9.2 Zone 13 for resilience:

At Zone 13, there is an additional project first cost of $61M ($50,345 per acre) for restoration of the barrier to support navigation resilience. This barrier will be eroded by 2030, requiring substantial amounts of material to restore a buffer between the channel and the bay. This further illustrates that the longer these problems are not addressed, the more expensive the solution due to the extent of restoration requiredand the potential for mitigation costs. Navigation at this zone will become even more difficult due to strong winds as there will be no structure to attenuate the high wind and wave impacts without this resiliency increment.

Proposed measures at zone 13 promotes *PARA*. Breakwaters and restoration of the barrier island allow navigation to:

- *prepare* for storms by building more protection and stabilization;
- *absorb* and protect the channel from wind/waves and lessen shoaling;
- *recover* more quickly from the impacts due to the protection and decreased shoaling; and
- *adapt* by providing options for dredge material to be placed where it is most effective and offers maximum protection from the shoaling and storm impacts in the future.

If no action is taken is Zone 13, then zone 13 is the weakest link in the system. At over 3.8 miles long, it would also represent the only non-protected reach of the GIWW greater

than 500 ft between Galveston Bay and Matagorda Bay. Further, it would be the only section open to East Matagorda Bay and would be susceptible to all the Bay's tidal flushing through the GIWW, focalizing all that flow and sediment movement into that area, making it a hotspot for channel shoaling, higher cross-current velocities, and unmitigated wave action. It would be extremely susceptible to disruption during small and large events as compared to the standard for the rest of the GIWW within the project counties.

9.3 Estimated ecological lift for zone 13 of the GIWW-CRS:

The Coastal Texas Protection and Ecosystem Restoration Feasibility Study (Coastal Texas Study) included two measures which were located in Brazoria County and Matagorda Counties, Texas which similarly recommended barrier island creation and marsh restoration along the GIWW. The ecological modeling assumptions that were used in the Coastal Texas Study for these measures were applied to the recommendation in Zone 13 of the GIWW-CRS to generate an estimate of the ecological benefits expected from the action. The ecological modeling was preformed using Habitat Evaluation Procedure methodology which utilizes species specific habitat suitability indices to determine change in habitat value. The brown pelican habitat suitability index was used to model benefits from restoring barrier island (110 acres) and the brown shrimp habitat suitability index was used to model benefits from creating marsh habitat through the dredge material (328 acres). *See* Table 21 below.

The modeling assumptions were developed in collaboration with the resource agencies and incorporated affects assuming the use of the USACE intermediate sea level rise curve. Current salinity data was provided by the Texas Water Development Board and assumptions relating to future salinities were made in collaboration with the resource agencies. The ecological modeling in the Coastal Texas Study was reviewed during District Quality Control and is ATR certified. The modeling spreadsheets used to calculate the net Average Annual Habitat Units are certified for use by the Eco-PCX. USACE, Coastal Texas.

Table 21: Estimate of ecological lift for zone 13

	Acres of Marsh Creation	Brown Shrimp Net AAHUs	Acres of Barrier Island Restoration	Brown Pelican Net AAHUs	Total Acres Restored	Total AAHUs
Zone 13	328	223	110	65	438	288

The PDT will continue to refine Zones 12 and 13 measures to optimize costs and benefits. Additional modeling for Zones 12 & 13, which will expand the CMS model that was used

to evaluate qualitatively several structural alternatives in Zone 12. The model will be expanded to include and assess improvements in Zones 13 through 16, to understand the influence of open water sediment transport that contributes to shoaling in the GIWW. The model will also be expanded to assess channel widening/deepening improvements in Zone 12 and the overall simulations will be expanded from 1 month to 2-3 years to assess the long-term shoaling responses. This additional modeling will be approximately $50K and is estimated to take 3 to 4 months (completed by February 2022). Upon completion and analysis of this additional modeling, the PDT will evaluate the design and cost associated with Zone 12 and 13 for further refinement and optimization. The ADM is currently scheduled in March of 2022.

9.4 Post-TSP Analysis of Resilience Plan

The TSP for the draft report is recommended to be the "Resiliency Plan." Refinements to benefits and costs will require a revisiting economic justification of Zones 12 and 13 during concurrent reviews and prior to the Agency Decision Milestone (ADM) in late Spring 2022. The resilience plan will continue to be analyzed during the draft report review and prior to the ADM where additional comments can be gathered from peer review, industry, public and agencies. This allows additional flexibility for NEPA compliance and the final report to make recommendations for the NED versus the Resiliency Plan because the NED is a subset of the Resiliency Plan, but still leaves vulnerability to the open bay with wind/waves for Zone 13 of the GIWW navigation channel and does not address the increasing safety issue of unintentional groundings for Zone 12.

The PDT has scoped additional analysis to be performed during the concurrent reviews and prior to the Agency Decision Milestone in late Spring 2022. The study is preparing a scope for another district or ERDC to develop a hydrodynamic, salinity, and sediment transport model of the GIWW at Mitchell's Cut (Zone 12) and its associated system (including, but not limited to, Zone 13), and to evaluate the effects of the resilience plan measures for the GIWW Coastal Resiliency Study. In addition, the PDT is scoping a limited or scaled version of a ship simulation, as encouraged by the vertical team and ASA(CW) staff to analyze the channel modification measure within Zone 12.

The resilience recommendation is for measures including: channel modification and channel stabilization with the potential for the groin to be constructed by an outside party. Channel modifications include shallow water breakwaters near the shore and barrier island restoration in East Matagorda Bay. The focus of this additional analysis will be to evaluate the reasonableness and performance of the reliance plan at Zones 12 and 13.