GCCPRD

The Gulf Coast Community Protection and Recovery District

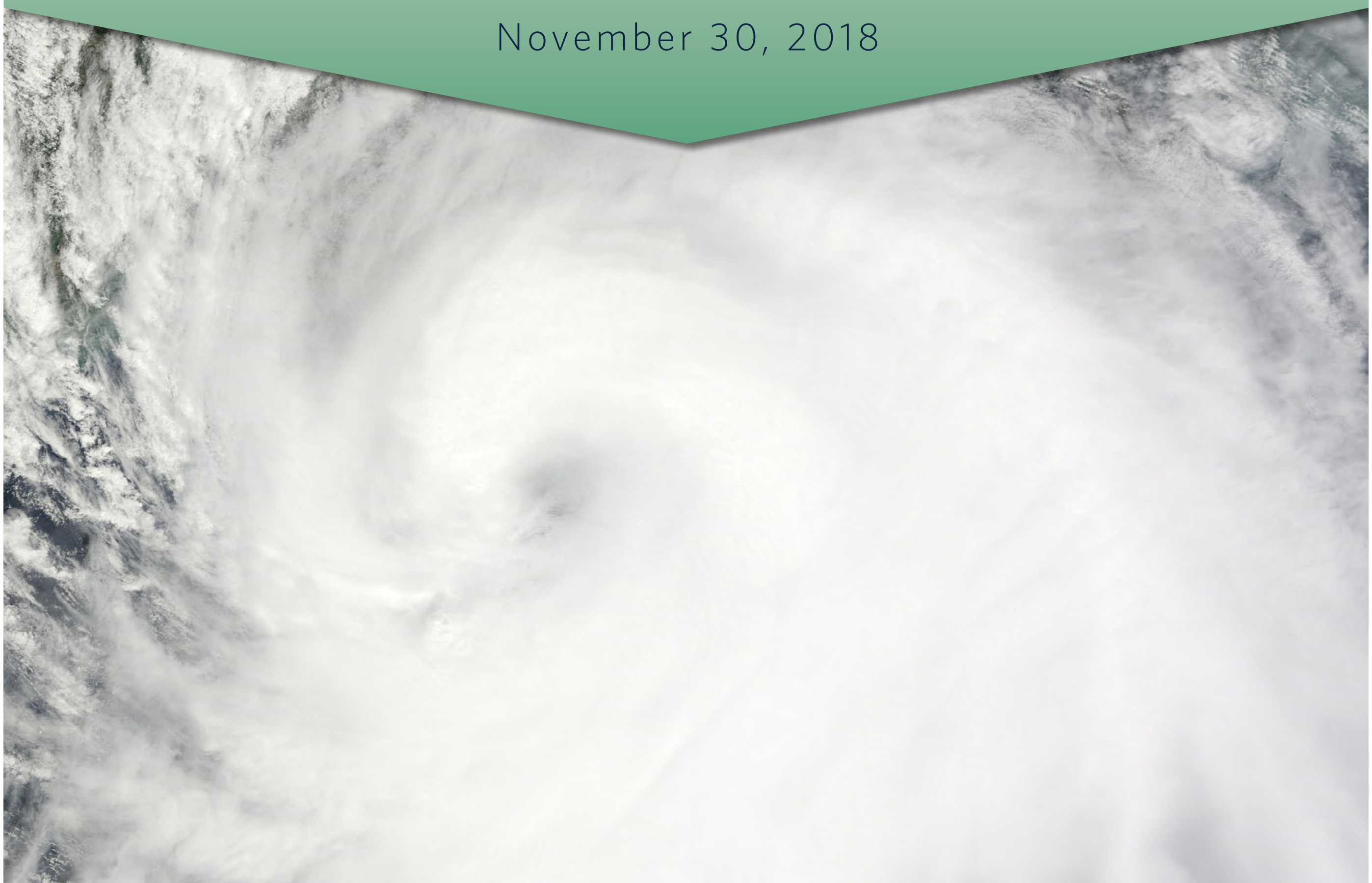
TEXAS GENERAL LAND OFFICE

ESTABLISHED 1836

STORM SURGE SUPPRESSION STUDY

PHASE 4 REPORT

November 30, 2018



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1. Executive Summary

In December 2013, The Gulf Coast Community Protection and Recovery District (GCCPRD) received a Community Development Block Grant (CDBG) from the Texas General Land Office (GLO) for the Upper Texas Coast Storm Surge Suppression Study. The purpose of the study is to investigate the feasibility of reducing the vulnerability of the upper Texas coast from storm surge and flood damages. The study evaluated numerous alternatives that could be implemented which would reduce the risk of storm surge flooding to life, health, and safety of the community and provide environmental and economic resilience within the study region. In June 2016, the GCCPRD published the Phase 3 report, which recommended a plan of action for the six-county area. The recommended plan identified the need to construct a new storm surge suppression system in Orange and Galveston Counties as well as the enhancement of existing systems in Jefferson, Galveston, and Brazoria Counties. The cost of the recommended plan was estimated at $13.6B with a regional benefit-cost-ratio (BCR) of 2.03.

In December 2016, the GCCPRD received funding to execute Phase 4 of the study. Phase 4 focused on optimizing the previously published recommended plan. Optimization measures included the following elements:

- Enhanced storm and wave modeling
- Optimization of the crest elevation for the Coastal Spine in the Central Region
- Economic impacts
- Environmental analysis
- Bolivar Roads barrier and gate design
- Wave overtopping and interior drainage analysis
- Cost review
- Geotechnical field investigations
- South Region alignment enhancements

1.1. Regional Summary

1.1.1. North Region Conclusions: Jefferson and Orange Counties

Phase 4 optimization did not change the recommended alignment or levee heights from the 2016 recommended plan. The construction costs were updated to reflect 2018 versus 2015 pricing, which increased the overall construction costs by 6 percent. The BCR in all of the elements within the North Region decreased. This can be attributed to the increase in construction cost and modifications that were made to the stage frequency and structure foundation height survey data that were provided to the study team by The U.S. Army Corps of Engineers (USACE).

1.1.2. Central Region: Chambers, Harris, and Galveston Counties

The crest elevation for the Coastal Spine did not change from the 17-foot elevation that was in the 2016 recommended plan. Lowering the elevation reduced the construction cost and increased net benefits, but only provided protection from the 50-year event. FEMA requires a 100-year level of protection for its Flood

Insurance Program, so this alternative was not feasible. Raising the elevation to 20 feet resulted in an increase in cost and a decrease in benefits. Seventeen feet was determined as the optimal height.

In the recommend plan, an 840-foot floating sector gate with 24, 100-foot vertical lift gates was recommended for the barrier crossing of the Houston Ship Channel at Bolivar Roads. Further environmental analysis and modeling determined that this structure should be 1,200 feet or larger in order to increase the tidal flow and reduce the potential environmental impacts to Galveston Bay. An alternate barrier design, the 1,200-foot floating sector with 15, 200-foot barge gates and 8 vertical lift gates was also analyzed. The barge gate increased the tidal flow and reduced the construction cost; however, it is much more complex to operate and maintain. The final configuration of the Bolivar Roads barrier will require further analysis and investigation to reduce the potential impacts to tidal flow to an acceptable level.

A more detailed analysis was also conducted to evaluate the effect of overtopping at the Galveston Seawall and its influence on the interior drainage and pumping requirements within the Galveston Ring Levee. The analysis showed that the pumping requirement within the ring levee increased from 7,400 cubic feet per second (cfs) to 117,000 cfs, which increased the cost of construction by $1.7B.

The overall cost of construction increased from $7.8B to $10.1B. This cost increase can be attributed to increasing the size of the floating sector gate from 840 feet to 1,200 feet, the increased pumping cost, and the 6 percent escalation that was used to update the construction cost to 2018 values. The increase cost combined with the updates to the stage frequency and structure foundation height survey data resulted in a final region BCR of 1.61.

1.1.3. South Region: Brazoria County

In the South Region, a new alignment for the Eastern Extension of the Freeport Hurricane-Flood Protection System (FHFPS) along FM 523 was adopted into the plan. In the 2016 plan, the alignment extended from the eastern terminus of the levee north toward the City of Angleton. The optimized plan extends the levee generally along FM 523 north to the City of Angleton. The new levee system will reduce the risk to 20,000 additional acres of land in the region where current and future residential and industrial development is expected to occur. The new alignment reduces the overall construction cost in the South Region by $100M; from $2.5B to $2.4B. The reduction in the construction cost is not enough to keep the overall BCR from dropping from 1.47 to 0.81. The decrease in the BCR is again attributed to the updates in the stage frequency and depth damage curves and the structure foundation height survey data.

Table 1 provides a consolidated summary of the economics analysis for each region. All benefits and costs are presented in thousands of dollars and reflect 2018 price levels.

Table 1: Consolidated Economic Analysis for the Six-County Region

	North Region	Central Region	South Region	Study Area Plan (North + Central + South)
Total length of the system (miles)	87	69	69	225
Pump stations required / total capacity (CFS)	22/29,650	4/127,900	5/10,925	31/168,475
Construction cost ($ thousands)	3,983,517	10,120,836	2,440,767	16,545,120
Annual Operations and Maintenance cost ($ thousands)	19,918	50,604	12,204	82,726
Total Annual Costs (TAC)	205,646	522,479	126,000	854,125
Total Annual Benefits (TAB)	126,431	842,287	102,097	1,070,815
Benefit - Cost Ratio (TAB/TAC) (2.875% Interest Rate)	0.61	1.61	0.81	1.25

Comparing the Phase 4 optimization to the 2016 recommend plan, construction costs for the entire region increased by $2.9B; from $13.6B to $16.5B. The increase is directly related to the increased cost for the 1,200-foot floating sector gate and the additional pumping capacity required for the Galveston Ring Levee. The overall BCR for the entire study region fell from 2.03 to 1.25.

2. Introduction

The upper Texas coast, stretching from Orange County to Brazoria County, has historically attracted people and industry to the region to take advantage of a multitude of economic opportunities and quality of life amenities. This six-county region is home to over 6 million people, the largest concentration of petrochemical complexes in North America, six of the top fifty ports in the United States, NASA's Johnson Space Center, and a highly productive coastal estuary system of national significance. The region is vitally important to the security of the national economy and the nation's energy sector. (Figure 1)

The study area is comprised of more than 4,300 square miles of land vulnerable to storm surge flooding associated with hurricanes and other tropical storm events. History has proven that Texas remains most vulnerable to large storms from June to October. The frequency of hurricanes along any 50-mile segment of the coast is about one storm event every nine years. Annual probabilities of a storm event range from 31 percent in the Sabine Pass Region to 41 percent in the Matagorda Region.

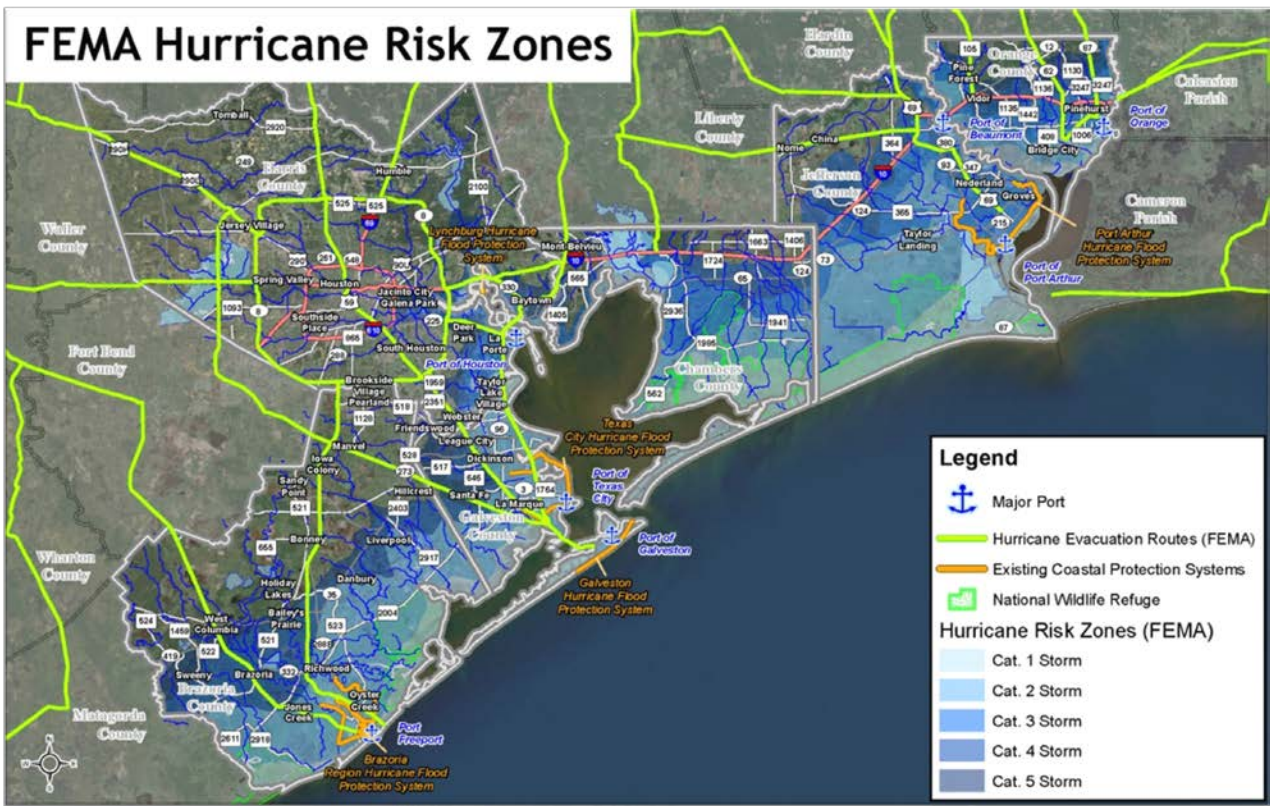


Figure 1: FEMA map illustrating coastal areas within the study area vulnerable to storm surge

In 2008, Hurricane Ike made landfall on the Texas coast in the vicinity of Galveston Island, causing 84 deaths and over $30 billion in damages. In 2017, Hurricane Harvey caused over $125 billion dollars in damages along the Texas Coast. These events clearly illustrate that additional flood risk mitigation measures are required throughout the region.

2.1. Gulf Coast Community Protection and Recovery District (GCCPRD)

The GCCPRD is a local government corporation that includes Brazoria, Chambers, Galveston, Harris, Jefferson, and Orange counties, which are the six counties included in this study area. The GCCPRD is governed by a board of directors comprised of the county judge of each participating county and three additional appointed members, each serving three-year terms. Board members include:

- Judge Ed Emmett – Harris County
- Judge Mark Henry – Galveston County
- Judge Matt Sebesta – Brazoria County
- Judge Jimmy Silva – Chambers County
- Judge Jeff Branick – Jefferson County
- Judge Dean Crooks– Orange County
- Lisa LaBean – At-large Member
- Jim Sutherlin – At-large Member
- Victor Pierson – At-large Member

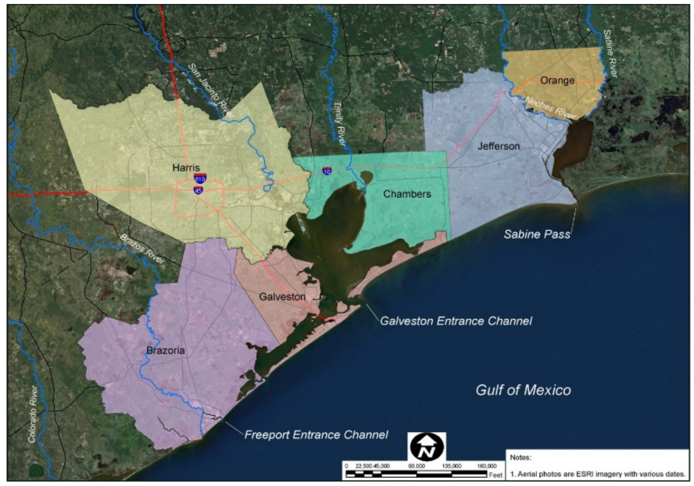


Figure 2: GCCPRD study area

Robert Eckels serves as President of the District and is appointed by the Board.

In September 2013, the GCCPRD received a $3.9 million grant funded by the Texas GLO through the Federal Housing and Urban Development (HUD) Community Development Block Grant (CDBG) Program to conduct the Storm Surge Suppression Study, which was completed in June 2016. In December 2016, an additional CDBG grant of $3.2 million was received to conduct additional analysis in order to optimize the recommended plan.

2.2. Study Purpose

The purpose of the Storm Surge Suppression Study is to investigate the feasibility of reducing the vulnerability of the upper Texas coast to storm surge and flood damages. The intent of this study is to develop a plan to protect the life, health, and safety of the community and provide environmental and economic resilience within the study region.

The goals of the study are to:

- Determine appropriate actions that may be taken to protect the life, health, and safety of the community and provide environmental and economic resilience within the study area.
- Develop a viable region-wide program that, once implemented, would better protect the region from future natural disasters associated with storm surge flooding events.

2.3. The Recommended Plan

In June 2016, the study team completed their initial study efforts and published the Storm Surge Suppression Study Phase 3 Report: Recommend Actions. The recommended actions identified specific structural solutions that should be implemented to reduce risk within the three geographic regions of the study area. The three regions are:

- North Region: Orange and Jefferson Counties
- Central Region: Galveston, Chambers, and Harris Counties
- South Region: Brazoria and remaining portion of Galveston Counties (vicinity of San Luis Pass)

Figure 3 graphically illustrates the proposed alignments for the new structural features included in the recommended plan. The recommended alignments were studied to develop the concept for the recommended and should not be considered as final. It is expected that during the preliminary engineer and design phase of the project that the alignments will be adjusted to resolve potential technical and social conflicts.

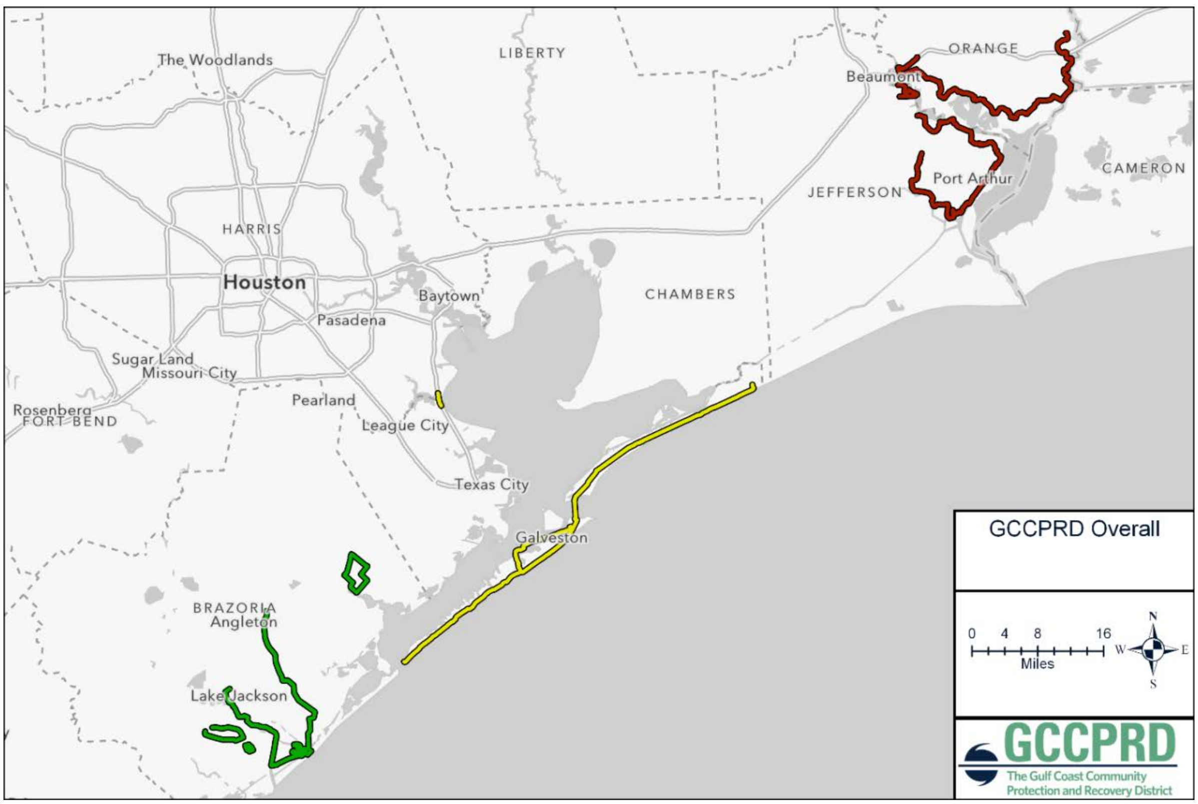


Figure 3: Alignments for Recommended Plan

The recommended plan includes the following elements:

- North Region – Enhancements to the existing Port Arthur Hurricane Protection System (PAHPS), Orange County Sabine River Levee, Orange County East bank of the Neches River Levee and Jefferson County West bank of the Neches River Levee
- Central Region – High Island to San Luis Pass Coastal Spine with a gate at Bolivar Roads (referred to as the “Coastal Spine”), the Galveston Ring Levee, and the Clear Lake Gate structure

- South Region – Enhancements to the existing Freeport Hurricane Protection System (FHFPS) and the Buffalo Camp Levee, Jones Creek Levee, Jones Creek Terminal Ring Levee, Chocolate Bayou Ring Levee, and the extension of the FHFPS along FM 523 to Angleton

The overall cost of the recommend plan was $11.6 billion and had a region-wide BCR of 2.03. The Phase 3 Report can be found at www.gccrd.com and is included as **Appendix A** to this report.

2.4. Phase 4 Optimization

The scope of work for Phase 4 focused on optimizing the recommended actions from the Phase 3 Report. Optimization included a more detailed environmental analysis, which enabled the study team to refine the recommended actions to reduce potential environmental impacts and cost and increase the project benefits. Optimization measures included:

- Enhanced storm and wave modeling
- Optimization of the structure's crest elevations
- Return frequency analysis
- Economic impacts
- Environmental analysis
- Bolivar Roads barrier and gate design
- Wave overtopping and interior drainage analysis
- Cost review
- Geotechnical field investigations
- South Region alignment enhancements

3. Phase 4 Optimization Measures

3.1. Storm Surge and Wave Modeling

During Phase 2 of the study, the study team executed extensive storm surge modeling for the years 2035 and 2085 to evaluate structural design elevations for each proposed alternative and to analyze storm surge related damages. The storm surge modeling provides the required data by evaluating flood hazards throughout the project region for hundreds of possible hurricanes and by accounting for potential future conditions including sea level rise in the model setup.

The coupled Advanced Circulation (ADCIRC) and Unstructured Simulating WAves in the Nearshore (UnSWAN) model system was improved and validated during these prior study phases. Model improvements included reduced friction dissipation in deep water and the Louisiana-Texas shelf, refined model resolution, and an integrated local instability smoother. The updated model was validated against high-water mark (HWM) data from Hurricane Ike, and the majority of differences between modeled and measured data were less than ±0.5 feet. Modeling scenarios were developed that analyzed the current conditions, the future without action (FWOA) in 2035 and 2085, and the future conditions with the alternatives (FWA) in place for 2035 and 2085.

For each scenario, 254 synthetic storms were simulated to determine maximum water surface elevations, maximum significant wave heights, and maximum wave periods in the study area. The suite of 254 storms included 152 high-intensity and 71 low-intensity storms from the Texas Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) storm suite (FEMA 2011), as well as 31 high-intensity storms from the Louisiana FEMA FIS storm suite (United States Army Corps of Engineers [USACE] 2008a and 2008b) with landfall locations near the Louisiana-Texas border. To simulate conditions for year 2035 and year 2085, the initial water level was increased by 0.94 feet and 2.44 feet, respectively, to reflect potential future relative sea level changes.

The FWOA configurations implemented existing storm risk management alignments and were used as a control to compare the effects of proposed alternatives during the FWA in place scenarios. This comparison process led to the selection of the recommended plan that was published in the GCCPRD Phase 3 Report in June 2016.

Appendix B provides a more detailed report for the storm surge modeling.

3.2. Optimization of Crest Elevations

In Phase 4, the validated ADCIRC and UnSWAN model was applied to two new FWA alternatives within the Central Region in order to optimize the crest elevations for the structures. Optimization of the crest elevations in the North and South Regions were not reevaluated based on a similar analysis conducted by USACE in their Sabine Pass to Galveston Study, which defined their optimal crest elevations.

The new FWA alternatives evaluated the costs and benefits associated with increasing and decreasing the levee height of the Coastal Spine elements and the Clear Lake Gate. The alignment for these systems based on the recommended plan was not changed.

The three FWA scenarios are referred to as FWA.a 2085, FWA.b 2085 and FWA.c 2085 and are described below:

- FWA.a 2085 – Crest elevation of the Coastal Spine and the Clear Lake system is maintained at 17 feet, based on the recommend plan.
- FWA.b 2085 – Crest elevation of the Coastal Spine is increased to 20 feet and Clear Lake system is reduced to 15 feet (new alternative)
- FWA.c 2085 – Crest elevation of the Coastal Spine is decreased to 15 feet and Clear Lake system is increased to 17 feet (new alternative)

Simulation results were reviewed and processed to create a dataset of individual storm surge peaks at all points of interest, which were used to estimate return interval stillwater levels.

3.3. Return Frequency Analysis

After completing the 254 storm simulations for each modeling scenario, the USACE Joint Probability Analysis (JPA) Model was used to combine the results of the storm simulations to calculate the 10-, 50-, 100-, and 500-year stillwater elevations for each of the modeling scenarios (FWOA 2035, FWOA 2085, and the three

FWA scenarios). Sensitivity tests, model optimization, and a thorough review of the results were completed to confirm the quality of the output statistics. The 10-, 50-, 100-, and 500-year stillwater elevations were also extrapolated to determine the 1-, 2-, 5-, and 10-year frequencies. By calculating the return stillwater elevations, the JPA Model allows the effects of each modeling scenario configuration to be compared and assessed. The following figures show the 100-year stillwater elevations throughout the region for multiple-model scenarios.

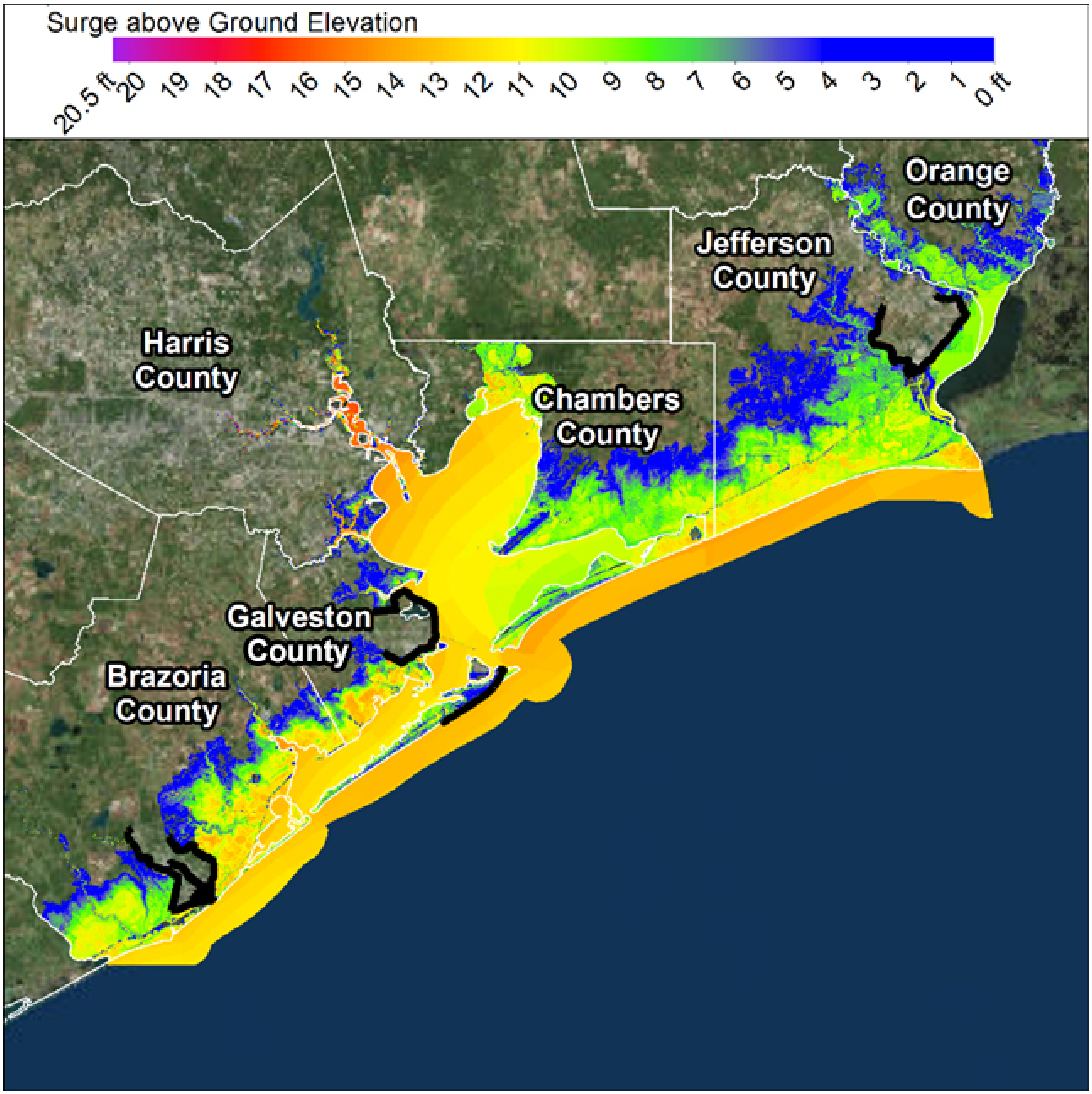


Figure 4: 100-year stillwater elevations for Current Conditions. Data referenced from FEMA 2008 FIS Map

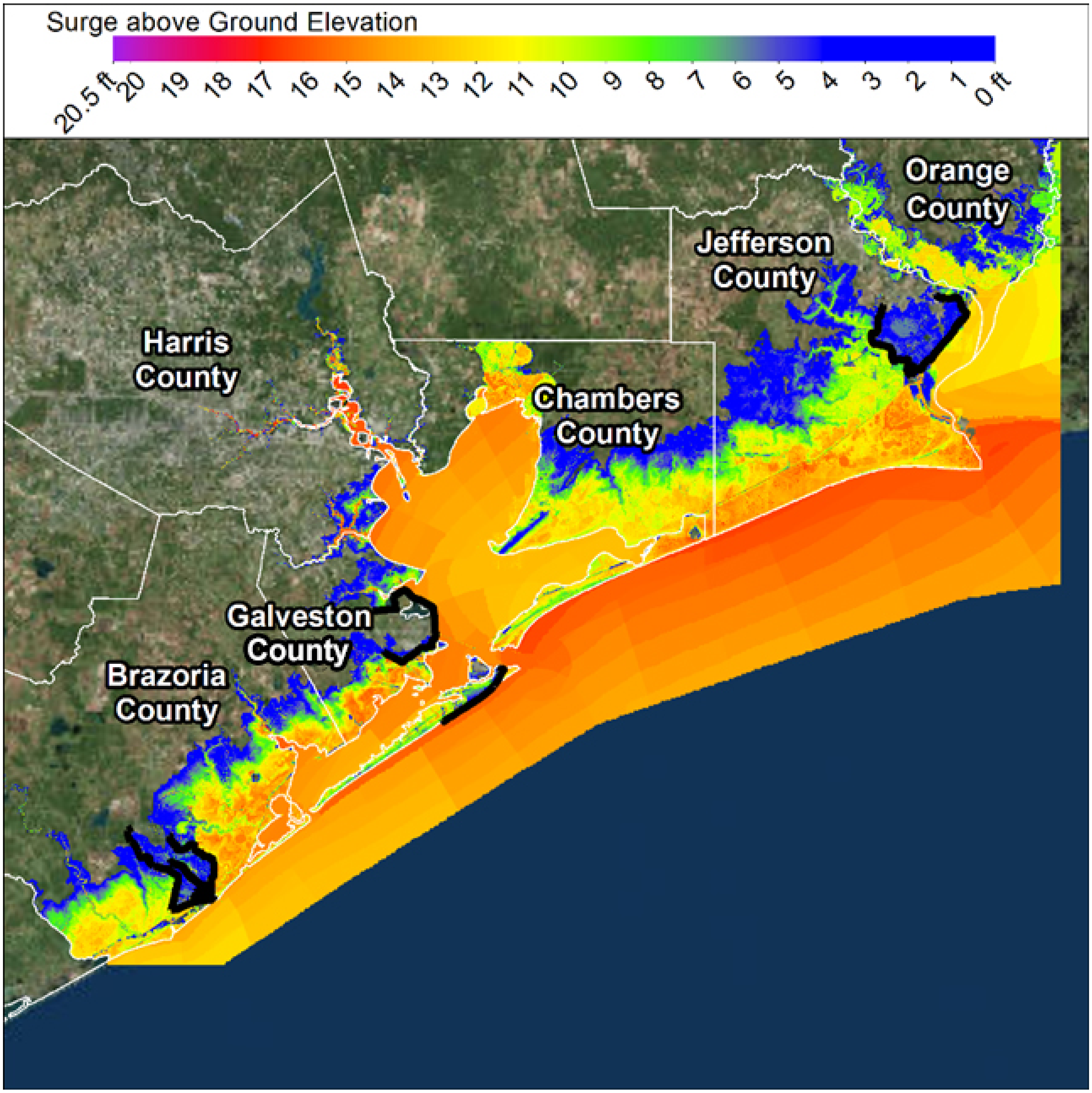


Figure 5: 100-year stillwater elevations for FWOA 2035 conditions. This model scenario includes 0.9 feet of Relative Sea level Rise

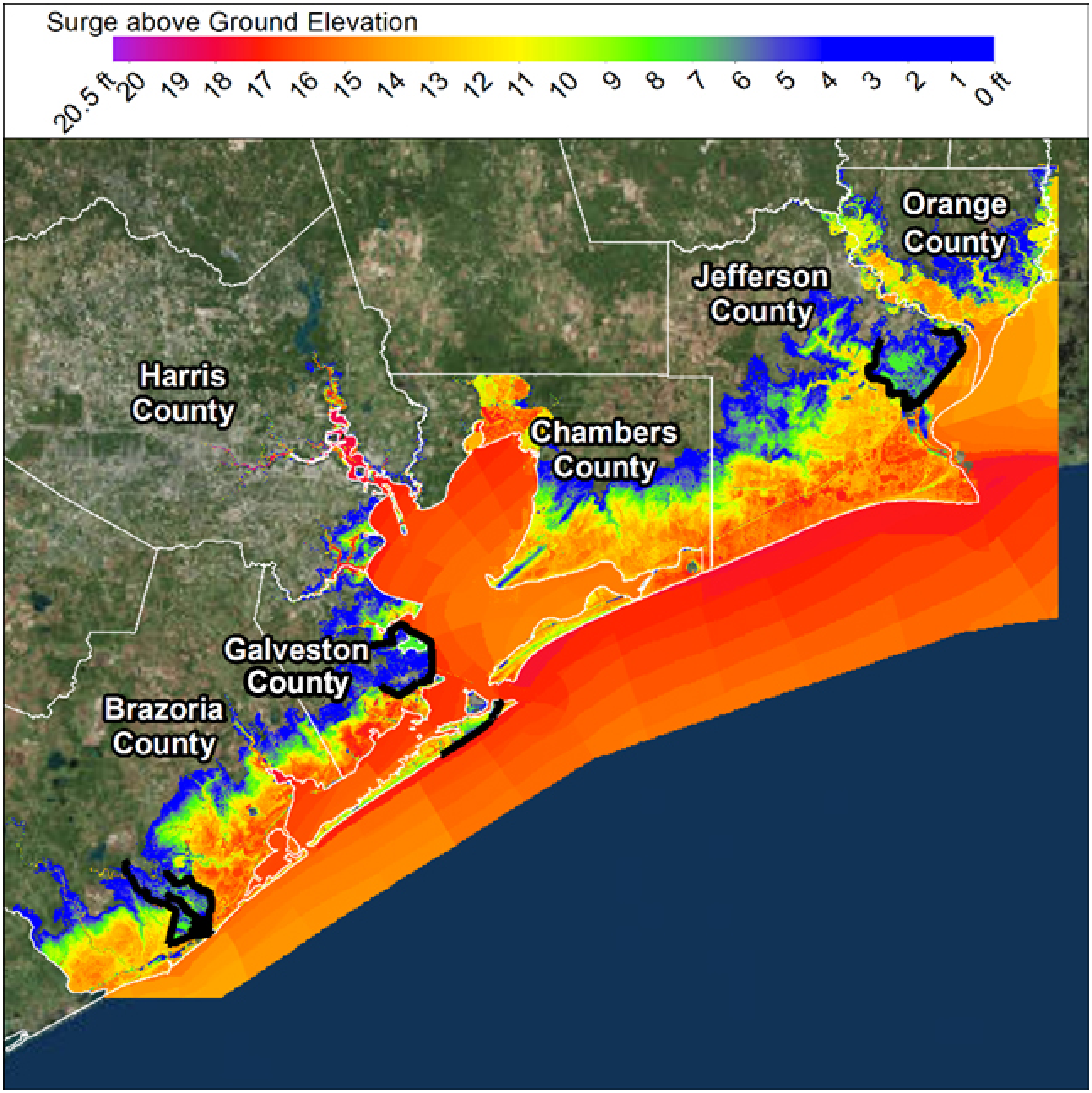


Figure 6: 100-year Stillwater elevations for FWOA 2085 conditions. This model scenario includes 2.4 feet of Relative Sea level Rise

The JPA model also allowed the study team to do additional analysis of interior flooding/ponding behind the levee systems. In order to understanding the flooding risk in an enclosed area, the overtopping rates for various return frequencies were estimated and input into the interior ponding analysis, which integrated the overtopping volume from the levee reaches and 25-year rainfall events. This analysis enabled the team to further refine and optimize interior drainage pumping requirements.

The estimated and stage frequency curves (including 1-, 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year frequency), after undergoing a quality assurance/quality control (QA/QC) check, were inputted into the USACE Hydrologic Engineering Center – Flood Damage Reduction Analysis (HEC-FDA) model for damage assessment and economics analysis.

3.4. Economics Optimization

The economic optimization measures incorporated during Phase 4 of the study build upon the work previously presented in the June 2016 GCCPRD Phase 3 Report and should be viewed as a supplement to that previous report. The additional analyses reported in this current phase focused on refinements and updates made to the previous analyses.

3.4.1. Damage Reach Designation

The review of the 2017 (HEC-FDA) model results revealed opportunities to streamline the modelling structure with minimal change to the required level of output detail. Streamlining took the form of damage reach consolidation. This consolidation reduced the original 41 damage reaches to 26. In addition to consolidation, the current analysis also added one damage reach to allow for incremental economic evaluation of a proposed project feature. The combined effect of these changes resulted in a total of 27 damage reaches for the current analysis, which is displayed in Figure 7.

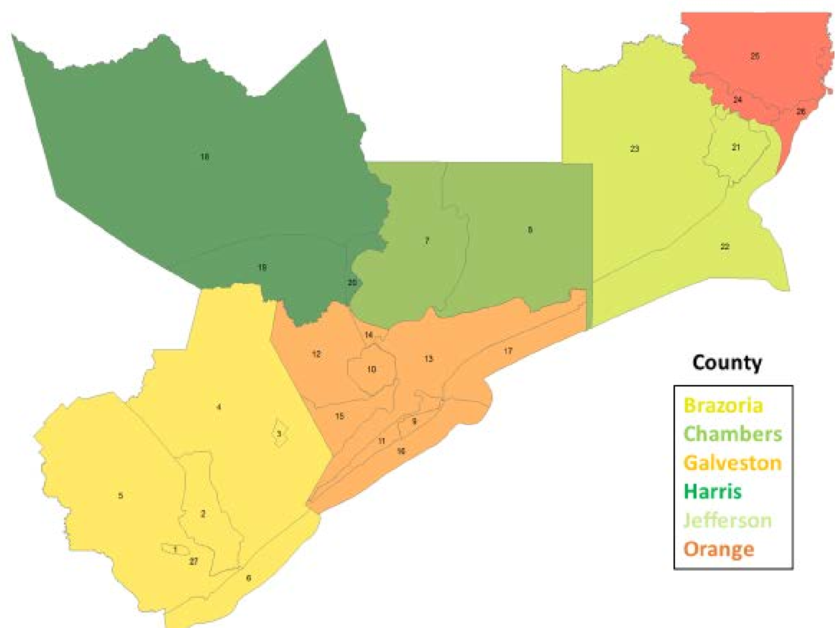


Figure 7: HEC-FDA Damage Reaches

The HEC-FDA model results were combined with project alternative cost information to perform benefit-cost analysis. Benefit-cost analysis was used to verify that the value of the benefits exceeded the value of the costs and ensured the resources would be allocated in the most efficient manner possible.

Benefit-cost analysis involves two mathematical comparisons:

- Net benefits are calculated by subtracting the total economic costs from the total economic benefits. Alternatives with positive net benefits contribute to economic efficiency. In an unconstrained budget situation, an alternative with higher net benefits is preferred over an alternative with lesser net benefits. This analysis can be used to help select and scale a recommended alternative from an array of alternatives.
- A benefit-cost ratio (BCR) is calculated by dividing the total economic benefits by the total economic cost. A BCR of 1.0 indicates that the total benefits equal the total costs. In other words, for every dollar spent, a dollar of benefits is produced. Because BCRs indicate which alternative produces the most benefits for every dollar of cost, it is useful for comparing or ranking alternatives when investment budgets are constrained.

Section 7 of the Phase 2: Technical Mitigation and **Appendix C** of this report provides additional details on the economic modeling approach and the methodology used.

3.5. Expanded Environmental Analysis

One of the key elements of Phase 4 of the study was to expand on the environmental analysis that was previously conducted to better quantify the potential environmental impacts that could occur with the implementation of the recommend plan. This analysis was conducted in two phases.

3.5.1. Phase 1: Enhanced Environmental Analysis of the Recommended Plan

Phase 1 was focused on the in-depth analysis of the potential environmental impacts that would occur with the construction of the recommended project alignments and structural features. A separate analysis was conducted for each region, and potential impacts were summarized on a regional basis. The analysis included the review and execution of the following National Environmental Protection Act (NEPA) elements:

- Clean Water Act Sections 303(d), 401, 402, and 404
- Rivers and Harbors Act 1899
- Floodplains, Wild and Scenic Rivers, and Coastal Barriers
- Socioeconomic impacts
- Cultural Resources
- Prime and Unique Farmlands
- Federal Water Project Recreation Act
- Biological resources- vegetation, marine and estuarine habitats
- Wildlife – invertebrate, migratory birds, fish, reptiles, terrestrial and marine mammal species
- Essential Fish Habitat
- Threatened and Endangered Species
- Air quality and greenhouse gas
- Hazardous waste
- Noise

This analysis included field inspections to verify habitat type and assess potential impacts. The study team used the Wetlands Value Assessment (WVA) model to determine mitigation requirements. Throughout this phase, the study team coordinated closely with USACE to ensure the latest models and baseline data were used for model setup. **Appendices D.1-D.3** contain the entire environmental report subdivided by region.

3.5.2. Phase 2: Environmental Modeling of Galveston Bay

Phase 4 also focused on defining the potential direct and indirect impacts of the proposed gate structure at Bolivar Roads on the Galveston Bay system. This modeling effort focused on the simulation of water levels, currents, and salinity due to astronomic tides, wind-driven water levels, and fresh water inflows throughout the bay. The selected models (Deltares D-Flow Flexible Mesh [D-Flow] and Advanced Circulation [ADCIRC]) demonstrate a high level of efficiency in simulating the physical dynamics of the bay while also being computationally efficient enough to simulate many different gate configurations.

This modeling effort was closely coordinated with USACE, Texas A&M University (TAMU)-Galveston, and the SSPEED Center at Rice University who were conducting similar modeling efforts. Each respective organization was using a different model for their analysis and by working together, the teams were able to gather and share the most up-to-date baseline data for the model setup. Using the same baseline data will allow all the teams to compare and a conduct a peer review of the results once all the efforts are complete. The outputs from this modeling effort defined and illustrated the following changes in conditions associated with the different gate configurations:

- Salinity
- Circulation, tidal and sediment impacts
- Discharge velocities
- Benthic habitat
- Marine and estuarine habitats
- Invertebrate species
- Fish and wildlife species

The data, the potential impacts, and the required mitigation costs were integrated into the cost of the overall plan. **Appendix E** contains the full report for the environmental modeling on Galveston Bay.

3.6. Bolivar Roads Barrier and Gate Optimization

Three alternative gate designs, which represent varying percentages of permanent cross-sectional blocking of the Houston Ship Channel, were evaluated for Bolivar Roads. The following sub-sections further discuss the details of structural gates within the barrier alternatives. Relative advantages and disadvantages of the barriers will be discussed along with constructability, operation and maintenance, and time required to close the gates. A discussion of the relative costs for all three alternatives will follow. The three alternatives for the Houston Ship Channel that will be discussed are:

1. GCCPRD840 – Features 54.8 percent permanent closure
2. GCCPRD1200 – Features 52.8 percent permanent closure
3. GCCPRD1200-Barge – Features 38.5 percent permanent closure

3.6.1. GCCPRD840

In the Phase 3 Report, an 840-foot floating sector gate was included in the recommended plan. This is the minimum width that is needed to span the ship channel in order to safely accommodate two-way traffic through the gate. This estimate was derived by reviewing the characteristics (draft, beam width, etc.) for the current and future fleet of vessels and assuming a potential future expansion of the Houston Ship Channel to a depth of 60 feet.

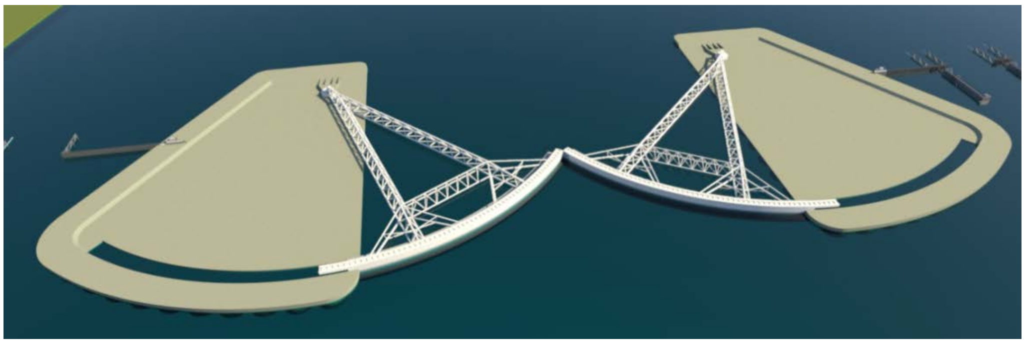


Figure 8: Floating Sector Gate and Artificial Island

As seen in Figure 8, the floating sector gate is comprised of two steel gate leaves and two artificial islands on either side. During regular channel operating conditions, the gate leaves rest on the island in their dry dock. During the time of closure, the dry docks are flooded and the gate leaves float up. These are then mechanically driven to position them in the middle of the 840-foot opening. Once in place, the gate chambers that act as flood barrier are filled with water and submerged to the bottom sill.

The flood barrier portions on either side of the artificial island of the floating sector gate consists of 24 vertical lift gates (VLG), Figure 9. The actual opening that is formed by a steel panel is 100 feet wide. This panel travels up and down mechanically as needed and is hosted on a concrete monolith and a tower on either side. The whole arrangement sits on a pile-supported concrete foundation slab. The concrete monoliths on both sides constitute 50 feet of permanent blockage of the waterway.

Figure 9: Bolivar Roads Floating Sector Gate with Vertical Lift Gates

Along the barrier, the space between adjacent VLG monoliths are permanently blocked using combi-wall sections. These are comprised of vertical and battered, concrete-filled steel pipe piles with a concrete cap on top that ties all of the piles.

The GCCPRD840 alternative blocked 54.8 percent of the channel cross-section permanently. This can have an extensive and long-lasting negative impact on growth and sustenance of aquatic life, vegetation, and geomorphology of the region.

3.6.2. GCCPRD1200

In order to further minimize the environmental impact a second alternative was developed: the GGCPRD1200 gate. This GCCPRD1200 widens the floating sector gate from 840 feet to 1,200 feet. The famous Maeslant Barrier in Rotterdam, Netherlands features a floating sector gate which is 1,200 feet wide. Because that gate has been in service for over 20 years, its width was considered as a natural choice for selecting a wider floating sector gate. The remainder of the closure structures for this alternative is comprised of 24 VLGs, similar to the GCCPRD840 alternative.

Since the sector gate leaves are larger and wider, there was a requirement to make the artificial islands broader to receive and fully protect the gate leaves. As such, even though the opening through the ship channel increased, longer lengths of the barrier were occupied by the islands on either side of the floating sector gate. Consequently, a minor increase in the amount of opening within the flood barrier was achieved, and a total of 52.8 percent of the waterway was still blocked.

3.6.3. GCCPRD1200-Barge

Analysis of the barrier alternatives previously discussed proved that the arrangement of the sector gate and combination of the VLGs was inadequate for lowering the permanent blockage of the tidal exchange through the ship channel to make it environmentally viable. One option to overcome this scenario could be to increase the number of VLGs throughout the barrier. However, that option would drive the cost of the entire barrier higher. It was imperative that a more economic closure structure be identified so that more openings through the barrier can be achieved at a lower cost. This resulted in the third option evaluated: the GCCPRD 1200-barge gate.

Information about the existing in-service barge gates in the United States was obtained and the feasibility of installing such gates within the barrier were investigated. The study team found that there are a number of these gates deployed in south Louisiana varying with a closure width of 100 feet to 270 feet. The largest barge gate installed is named Bubba Dove, located near Dulac, Louisiana, and boasts a total height of 43 feet. It should be noted that previous analysis confirmed that the VLGs need to span a vertical height from elevation (EL) -30.0 to EL +18.0; resulting in a total height of 48 feet. Thus, the Bubba Dove gate was considered a reasonable alternative for such application within Bolivar Roads.

The study team evaluated a barrier composed of the 1,200-foot wide floating sector gate, and fifteen (15) 200-foot-long barge gates and reduced the number of 100-foot VLGs to eight. Using the latest bathymetric profile of the channel cross-section through the proposed alignment, the deepest part of the channel (EL -60.0) will be blocked by the span of the 1,200-foot floating sector gate. The channel sill on either side of the artificial islands is located at an average elevation of EL -30.0, which is an ideal depth for the 48-foot-tall and 200-foot-long barge gates. On the north end of the barrier, the sill elevation depth is between EL -5.0 and EL -10.0, which is capability for the use of VLGs in these shallower depths. As before, the portions of the barrier between adjacent closure features will be blocked using combi-wall sections. Figure 10 below shows a three-dimensional (3-D) representation of this barrier option.

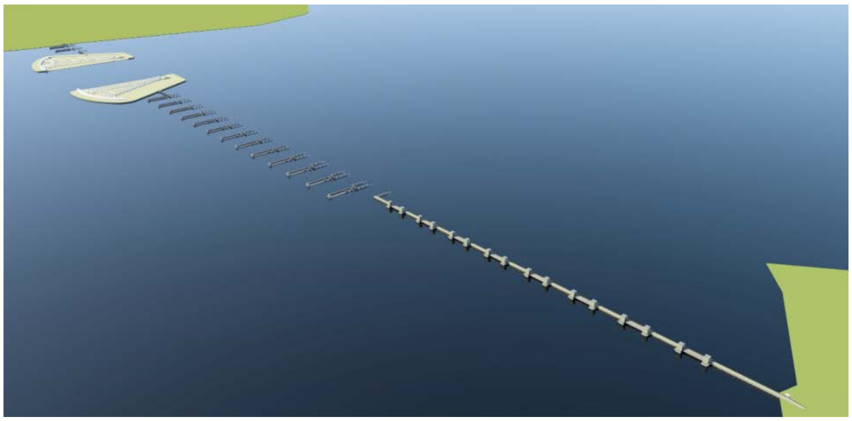


Figure 10: GCCPRD1200-Barge Alternative

The combination of the 1,200 ft. sector gate, barge gates and VLGs reduced the permanent blockage along the alignment to 38.5 percent.

3.6.4. Barge Gate Details

A series of barge gates are proposed in the GPPRD1200-Barge option. The reports from the previous phases described the structural details of floating sector gates, VLGs, and combi-wall segments. Since the barge gate is a newly introduced option, more details about this of type of closure structures are discussed below. Figure 11 illustrates the conceptual barge gate.

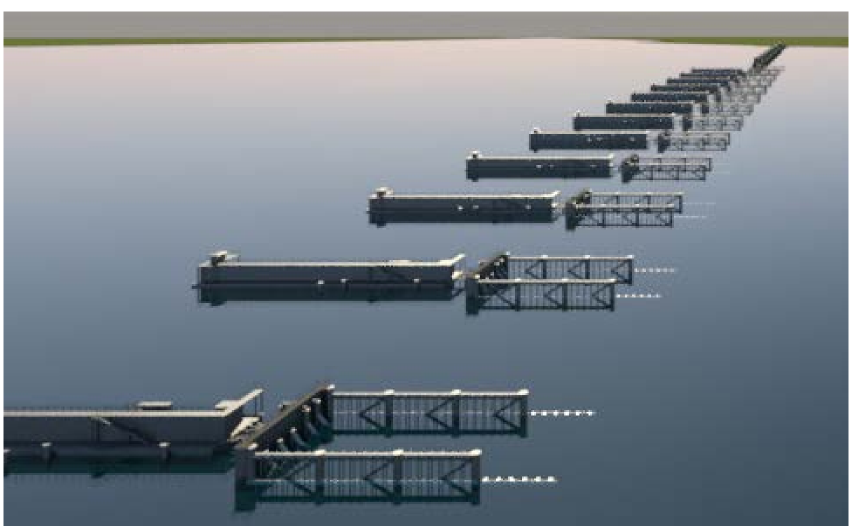


Figure 11: Series of Barge Gates

3.6.4.1. Structural Components

3.6.4.1.1. Chamber & Flood Wall

The barge gate is a steel structure which has two major components:

- A hollow steel rectangular chamber
- A 10- to 13-foot flood wall positioned on top of the chamber. The flood wall portion of the barge gate will constitute the top 10 to 13 feet of the barge gate height. The rest of the height is represented by the chamber itself.

The hollow chamber portion is equipped with an electro-mechanical pump system that can fill or drain the chamber within 1 to 2 hours. The chamber walls will be constructed with steel plates with additional bracing members in side. The chamber section is also equipped with a number of 6-foot diameter steel pipes that pass through the barge gate from the flood side to the protected side. These pipes will be fitted with mechanized sluice gates that will restrict flow of water through the gate.

The flood wall component on top of the barge gate chamber can be made from either concrete or steel. The walls may be fortified using stiffeners so that they can withstand the water pressure equal to their height. The flood wall portion provided space on the protected side of the barge gate on top of the chamber structure to house generators and other electro-mechanical controls. The flood walls are also somewhat offset from the flood side edge of the gate providing a platform on top of the chamber. This allows to have a platform on the flood side for personnel to perform periodic inspection and maintenance.

On top of the barge gate there will also be an operator's room which will house the winch mechanism that will close and open the gate. Figure 12 shows the details of a barge gate.

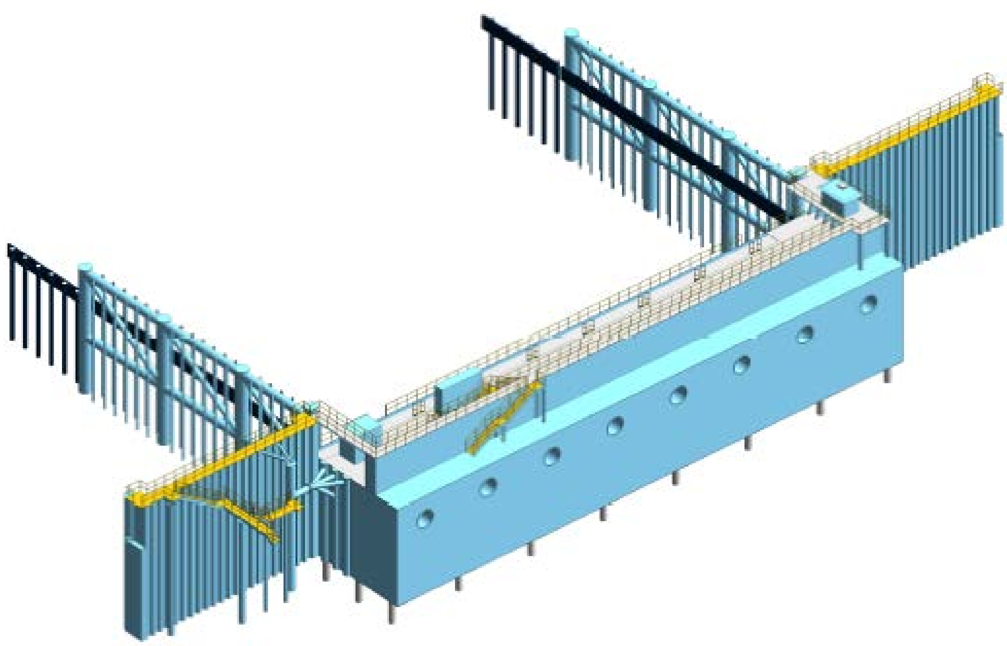


Figure 12: Barge Gate & its Components

3.6.4.1.2. Receiving Structure

In its deployed position, the barge gate needs to transfer the hydrostatic, hydrodynamic, and impact forces to a structure that can absorb the loads and safely transmit them to the ground. These structures are placed on either side of the barge gate and are referred to as “receiving structures.” Each receiving structure comprises of a frame-like structure made from steel pipe piles, often filled with sand or grout and capped with concrete. For this current span of 200 feet, a four-pile frame was envisioned with the first pile close to the gate having a diameter of almost 8 feet. The other piles within the receiving structure will be smaller. To make the system efficient to resist lateral loads, the piles will have diagonal bracings which are also tubular. All the pile head tops will be connected with a top chord. A similar member parallel to the top chord will be provided at mid height of the pile length that will be sticking out of the ground. Based on further analysis, these connectors and diagonals can be repeated several times to make the receiving structures stiffer.

3.6.4.1.3. Gate Pivot

At one end of the barge gate, along the length of the span, it will always be connected with a pipe pile that will act as the pivot point when the gate moves from open to close position and vice versa. Since the gate will always open toward the flood side, the pivot pile will also be placed on the flood side. The pivot will not be designed to sustain any loads when the gate is deployed. The pivot to gate connection will be done in a manner so that the two can be disconnected if there is a requirement to float the barge gate to a dry dock for repair.

3.6.4.1.4. Barge Gate Foundation

Each barge gate will require two foundations. When the gate is open, the barge itself will rest on a foundation that is laid out perpendicular to the alignment. This foundation is placed on the flood side since the gate opens toward that direction. The second foundation is required to sustain the weight of the gate once it is closed. This foundation will be placed parallel to the barrier alignment and is adjacent to the receiving structures.

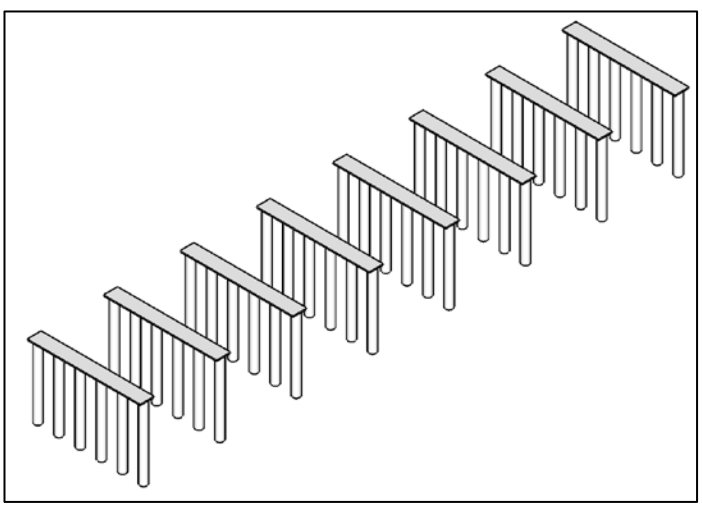


Figure 13: Barge Gate Foundation Pile Bents

As seen above in Figure 13, the foundation of the barge gate will be comprised of steel pipe piles. There is no need to install a concrete foundation slab. The gate sits on a series of pile bents that will be placed perpendicular to the span length of the barge. The number of pile bents is determined based on the total deployed weight of the gate. Each pile bent has a series of pipe piles that will be connected at the top using thick plates. The thickness of these plates is also determined from the distribution of weight of the barge gate. The top of the foundation will be placed near the existing sill elevation of the cross-section, so it is not necessary to perform a substantial amount of dredging. Riprap will be placed close to the pile bent tops for a distance before and after the bents. This will prevent scour at the pile bents. If needed, the minimal depth of riprap (2 to 3 feet) can be grout stabilized as well.

3.6.4.1.5. Tie-in Wall

A total of 15 barge gates is currently considered for the GCCPRD1200-Barge alternative. Adjacent barge gates will be placed 80 feet apart. The space between two barge gate structures will be closed using combi-wall segments. These will also be used to tie-in the barge gates at the periphery to the sector gate artificial island, VLGs, or adjacent land on higher grounds.

3.6.4.1.6. Barge Gate Operating Mechanism

When the flood barrier is not closed, each barge gate will rest on the foundation perpendicular to the alignment. This will allow tidal exchange through the 200-foot gate span. At this point the chamber within the barge gate will be full of water, producing enough ballast so that the gate will not be moved due to wave action. The gate will also be anchored to another a large pile that will be located on the flood side.

At the wake of a flood event an operator will start the pumps on the barge gate so that water will be drained out of the chamber and the gate will begin to lift due to buoyancy. At this point the barge will ride up along the vertical height of the pivot pile. Once the barge gate is buoyant enough, the winch rope will be tied to a pile close to the receiving structure. A boat will be required for this operation. Once the rope is fastened, the operator will start the mechanized winch, which will gradually pull the barge towards the receiving structure. Once in place, the pumps will be active again filling up the chamber with water. This will gradually ballast the gate and it will sit on top of the other foundation parallel to the alignment. Once the gate is sufficiently submerged, the pumps will stop and the gate will be fastened with the receiving structure. At this point the barge gate will be fully deployed and ready to take the loads from the storm surge. If required, the 6-foot diameter sluice gates within the gate can be opened remotely so that water can pass through from the protected side to the flood side.

Once the storm surge has subsided, the process will be repeated in reverse to stow the gates. The winch system is a critical system component to the operation of the gate, and in the event of a failure the gate can also be opened and closed using a tug boat.

3.7. Interior Drainage

Multiple areas within the region are protected by existing and proposed levee systems. Systems that are closed such as the FHFPS, the PAHPS, the proposed Galveston Ring Levee, and the Clear Lake Gate structure require pump stations to facilitate interior drainage and reduce the risk of interior flooding. During a tropical event, interior flooding is dominantly affected by the storm surge overtopping the levee system rather than the rainfall associated with the event.

Interior drainage for the existing and proposed levees included sizing pumps and mapping the floodplains for rainfall and storm surge scenarios of varying annual recurrence intervals for each proposed levee alignment established in Phase 3 of the study. The interior drainage pumping requirements associated with each levee alignment were sized to maintain internal flooding levels that result in minimal ponding and damage to properties and structures for a hurricane that simultaneously produces a 25-year internal rainfall event within the levee polder and a 100-year storm surge that overtops the designed levee. The pump sizing and requirement from this phase of the study are used to refine the cost and the overall BCR for the project through a comparison of the FWOA and the FWA 2085 scenarios.

3.8. Cost Analysis

During Phase 2 of the study, a data library of unit and lump sum costs was assembled from recently constructed hurricane protection projects from the Gulf Coast region. The library was standardized for all subgroups of the analysis team to employ, and then each subgroup applied the unit and lump sum cost library values to the alternatives under their charge. In some cases, such as calculating earthen levee fill costs, technology allowed for the quick calculation of actual quantities over a varying terrain surface and the application of a unit cost. In other cases of complex structures such as the medium and small navigation gates, a sufficient history of similar structure construction costs existed from which the study team was able to aggregate and simplify costs for such structures into a single lump sum unit cost that encompasses all aspects of construction and installation. Operations and Maintenance costs were estimated to be 0.5 percent of the total construction cost for each element.

For all costs in this report, a 25 percent contingency was added to account for the vast array of uncertainties and unforeseeable market changes which could occur in the near future and drive present-day costs up beyond the rate of inflation. Exceptions were made for the gate complex crossing the Houston Ship Channel at Bolivar Roads, where a 40 percent contingency was used due to the extreme complexity and the varying dynamics associated with this structure.

During Phase 4 of the study, costs were escalated from the original 2015 United States Army Corps of Engineers Civil Works Construction Cost Index System to reflect 2018 values.

Section 6.0 of the Phase 2 Report discuss in more detail the cost methodology. **Appendix G** details the Phase 4 costs associated with each respective element and alternative by region.

3.9. Geotechnical Investigations

During Phase 4, the GCCPRD performed geotechnical investigations in the six-county region along the three regional alignments that were in the Phase 3 recommend plan. This work included the integration of existing subsurface soil data to create a GIS soil model and collection of new geotechnical data, culminating in preliminary geotechnical recommendations. These recommendations are in the form of a preliminary geotechnical report (Fugro Report No. 04.10160148 dated October 18, 2017), summarized in the following sections and located in **Appendix H:**

- Geological Site Assessment
- Field Investigation
- General Site Conditions
- Surge Protection Systems
- Additional Geotechnical Considerations

3.9.1. Geological Site Assessment

The geological site assessment of the preliminary geotechnical report contains a review of regional geology, stratigraphy, surface faulting, subsidence, salt domes, and expansive soils along the Texas Gulf Coast. The regional geology portion includes a review of tectonic activities that led to the formation of Texas, identifying major rivers and land features, and providing surface elevation data along the Gulf Coast. In the stratigraphy portion, the historical and prehistoric periods of the formation of Texas are examined to support the identification of soils and sediments which make up the Texas Gulf Coast. Surface faulting and salt domes were examined along the Texas Gulf Coast to determine whether the three regional alignments are in proximity to known growth faults. Based on the preliminary report, the alignments are not in proximity to known growth faults; however, the alignments are in proximity to several salt domes. The State of Texas has groundwater management entities which control the rate of subsidence caused by withdrawal of water from underground reservoirs. The Harris-Galveston Subsidence District (HGSD) is an agency located in Groundwater Management Area 14 which lies within the six-county region. The preliminary geotechnical report provided subsidence observations monitored by HGSD. In addition, expansive soils are commonly found in the near-surface stratigraphy throughout the Texas Gulf Coast. These soils have high potential for swelling and shrinking with seasonal fluctuations and could impact the performance of the proposed structural alternatives for the storm surge suppression systems.

3.9.2. Field Investigation

The purpose of the field investigation was to identify the subsurface conditions (e.g., encountered soil and groundwater conditions) along the Central Recommended Alignment (Coastal Spine), and South Recommended Alignment. USACE performed their own investigation in the North Region as a part of their Sabine Pass-Galveston study. The data from that study were incorporated into the report. Field exploration activities included performing geotechnical soil borings and piezocone penetration tests (CPT's). Figure 14 shows the geotechnical soil borings and CPTs performed along the Central Recommended Alignment (Coastal Spine).

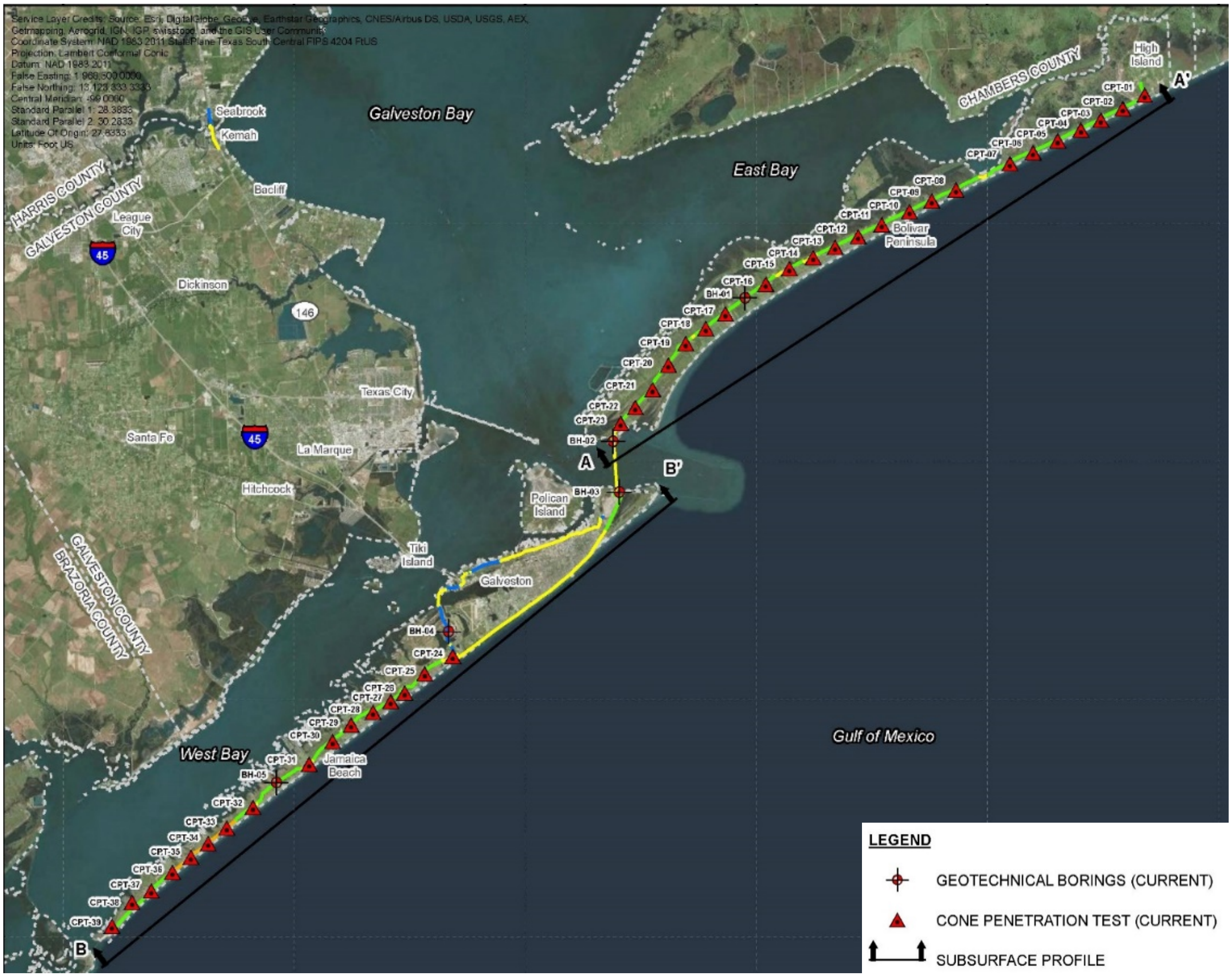


Figure 14: Plan of Explorations – Central Recommended Alignment (Coastal Spine)

3.9.3. Geotechnical Soil Borings.

The eight geotechnical soil boring operations were undertaken with a truck-mounted drilling equipment with a three-person crew. Six soil borings were explored below the ground surface to a depth of 50 feet, and two soil borings were explored below the ground surface to a depth of 400 feet. At each soil boring, the truck-mounted drilling equipment was used to drill soil borings and obtain soil samples at depth. The soil samples were transported to the laboratory for testing purposes.

<u>Piezocone Penetration Test (CPT's).</u> The 54 CPT's were conducted using our truck-mounted CPT equipment with a two-person crew. Each CPT was performed to a depth of about 60 feet below the ground surface. During CPT operation, no soil samples were collected. The CPT equipment utilizes a cone to advance into the ground to gather information on the soil stratigraphy.

3.9.4. Generalized Subsurface Conditions

The generalized subsurface conditions were developed based on reviewing geotechnical investigations performed by others and the current geotechnical data obtained by Fugro. Descriptions of the soil stratigraphy were provided for the Coastal Spine and the South Recommended Alignment only. No information was provided for the North Recommended Alignment because Fugro had limited access to obtain current geotechnical data along this alignment. In general, alternating layers of cohesive and granular soils were observed along areas of the Central Recommended Alignment (Coastal Spine) and the South Recommended Alignment. Figure 15 shows the Generalized Subsurface Profile Section A-A' along the Coastal Spine.

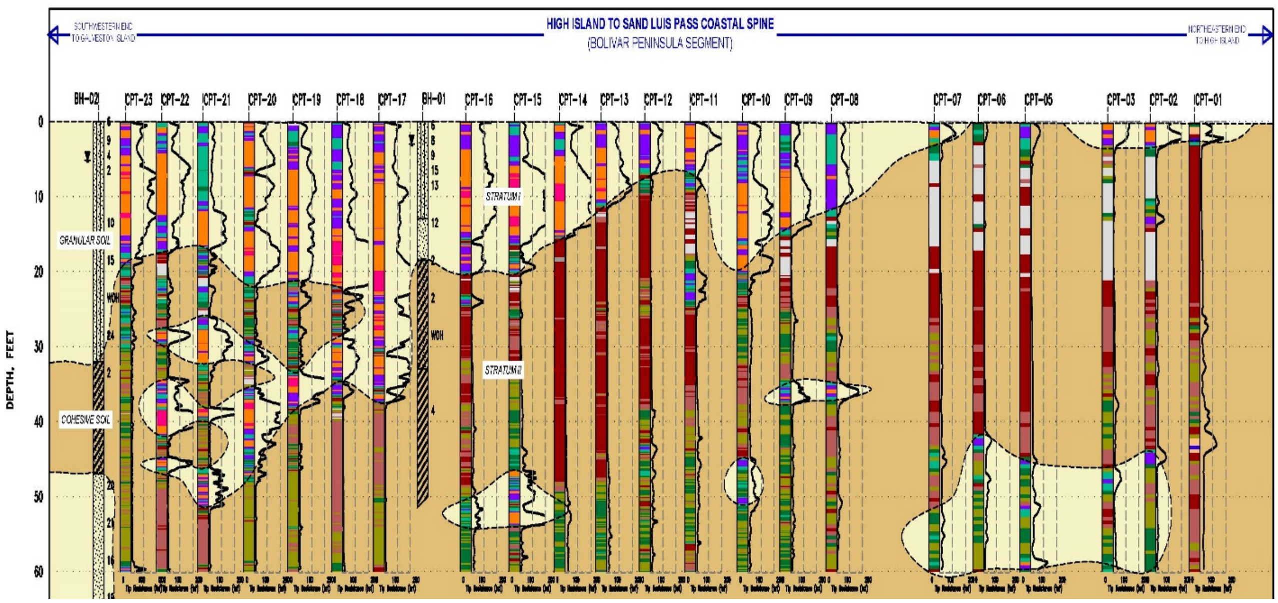


Figure 15: Subsurface Profile Section A-A': Central Recommended Alignment (Coastal Spine)

3.9.5. Additional Geotechnical Considerations

The geotechnical information collected during Phase 4 was used by the study team to identify areas along the alignment that may require additional structural stabilization. These factors were considered as we optimized the alignments and project costs.

The GCCPRD understands and recommends that a more detailed geotechnical study be performed prior to the design phase of the storm surge suppression system. The detailed geotechnical study should include performing additional land and marine borings/CPT's along all three alignments. The additional land and marine borings/CPT's should be performed where data gaps are present as well as at locations where the earth levees/T-walls and associated structures have a significant offset from the current soil borings/CPT's. These detailed geotechnical analyses should be performed for the earth levees, T-walls, the floating sector and barge gates, and the vertical lift gates once the updated information on these structures is available.

3.10. South Region Alignment Adjustments

During Phase 4, an alternate alignment for the extension of the FHFPS was evaluated. The modification involves realigning the recommended extension of the FHFPS east along SH 288 towards Angleton, to a new Freeport East Levee section along FM 523. The adjustment was made to provide additional protection to residential and commercial structures west of FM 523 by preventing storm surge from wrapping around the east side of the existing FHFPS alignment in 2085.

The new alignment along FM 523 protects approximately 20,000 additional acres over the previous alignment. Additional assets protected include south east Angleton, numerous residential neighborhoods, and the DOW Chemical Intermediates Plant.

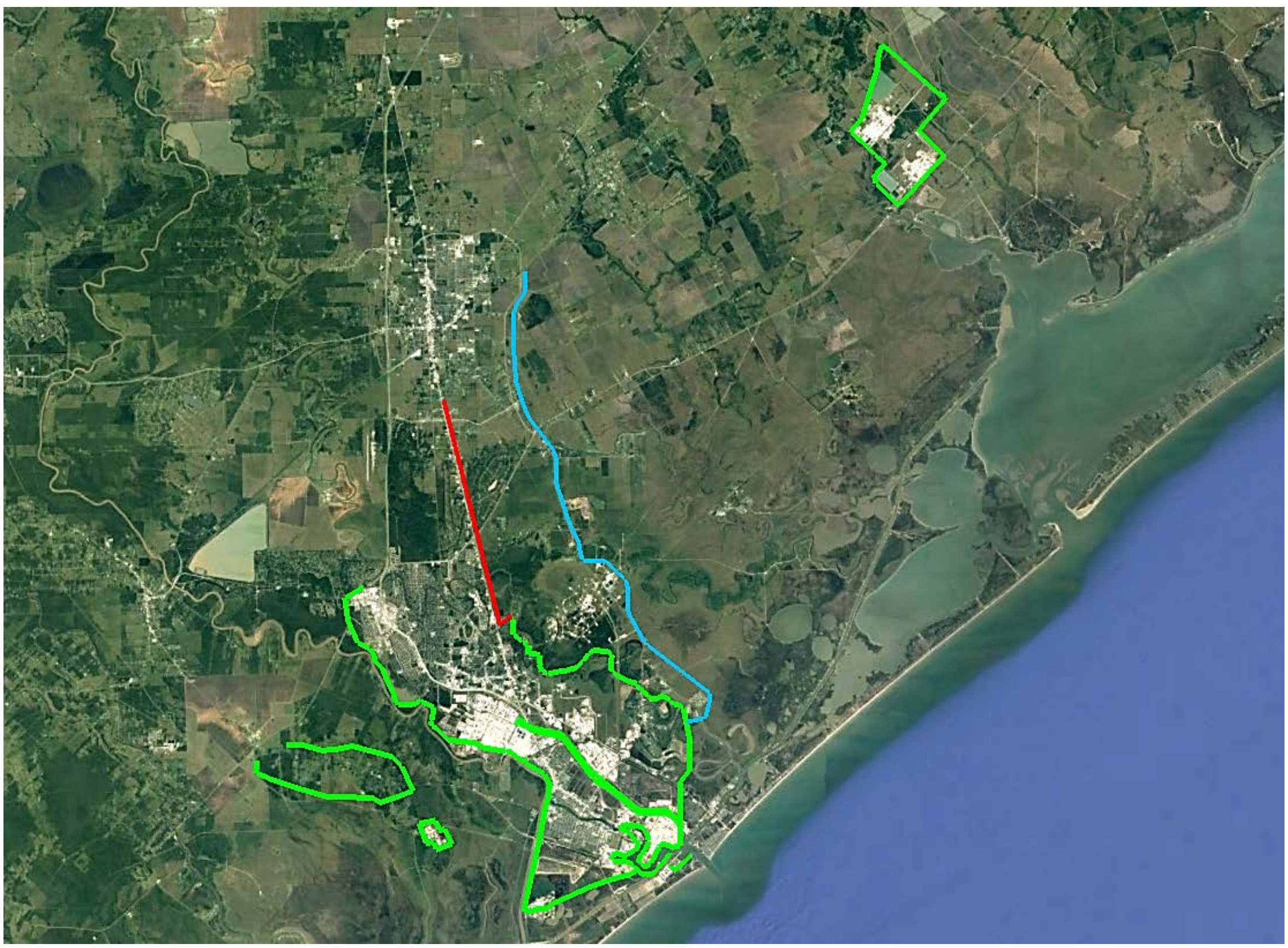


Figure 16: South Region Alignment (Green: Unchanged from the recommended plan, Red: Original alignment for the Freeport Levee Extension, Blue: New alignment for the extension evaluated in Phase 4 along FM 523)

4. North Region Optimization Results

4.1. General

The North Region of the GCCPRD jurisdiction consists of Orange and Jefferson Counties. The two counties are separated by the Neches River, which terminates into Sabine Lake, along with the Sabine River, which forms the eastern boundary of Orange County and the eastern boundary of the State of Texas. The southerly boundary of Orange County is Sabine Lake and the Sabine-Neches Canal. Jefferson County reaches to the Gulf of Mexico on the south and is bordered by Chambers and Liberty Counties on the West and Hardin County (Pine Island Bayou) to the north.

On September 13, 2008, the region was significantly affected by Hurricane Ike. In Orange County, the surge generated by Ike caused widespread flooding in industrial, commercial, and residential areas. The cities of Orange, Bridge City, West Orange, Pinehurst, Vidor, and Rose City, as well as unincorporated areas suffered extreme damages. Approximately one-third of the City of Orange was flooded, and primarily included the downtown and commercial districts of the city. Rose City also suffered major damages from the surge that traveled up the Neches River. Virtually 100 percent of Bridge City was flooded including most residential and commercial properties. It is estimated that only 15 of approximately 3,000 homes in the entire city were not flooded by Hurricane Ike's surge. The "chemical row" area of Orange County also received major damage. Total estimated damages including production losses exceeded $500 million.

In Jefferson County, Sabine Pass and rural areas south of the Cities of Beaumont and Port Arthur were similarly impacted by the surge generated by Ike. Except for low-lying areas along the Neches River, Beaumont was largely un-impacted, with the exception of the Exxon-Mobil plant facility situated on the western bank of the Neches River. Large parts of this facility were flooded with reported damage and production losses in the $1B range. The City of Port Arthur and the large petro-chemical complex in south Jefferson County were protected from surge impacts by the Port Arthur Hurricane Flood Protection System. This protection system, completed in the late 1970s, consists of earthen levees, floodwalls, gate structures and pump stations, and was largely constructed as a Federal Project by the USACE. The system performed as designed and prevented the damage seen in Orange County from occurring along the west bank of the Neches River in Jefferson County.

4.2. Phase 3: North Region Recommended Plan

The North Region recommended plan consists of four reaches that provide regional protection to Jefferson and Orange Counties.

Reach 1- Orange- Sabine River Levee – This reach consists of a line of protection that starts on the high ground along the Sabine River north of I-10 and the City of Orange. The system follows the Sabine River, crossing Adams and Cow Bayous and protecting the southeast side of Bridge City, to the east bank of the Neches River downstream of the Veterans Memorial Bridge on SH 87. The reach is composed of 125,579 feet of new levee, 16,842 feet of T-wall construction, six pump stations, 22 drainage structures, a 56-foot navigation gate on Adams Bayou, and a 30-foot navigation gate on Cow Bayou. The highway and roadway crossings are modified by grade elevations, and railroads will need to pass through gate structures. Elevations in this reach vary from 15.5 feet to 24.5 feet.

Reach 2 – East Bank of the Neches River- Reach 2 ties into Reach 1 south of Bridge City and follows an alignment along the east side of the Neches River to Interstate 10. This reach is composed of 125,278 feet of new levee, 10,433 feet of T-wall, 19 new drainage structures, 3 new pump stations, and 24 roadway gates. Elevations in this reach vary from 18 feet to 22.5 feet.

Reach 3 – Modernization of the Port Arthur Federal Levee System – This reach consists of upgrading the Port Arthur Federal Levee System for conditions reflected by the teams modeling in 2085. This reach is composed of 89,752 feet of levee to be raised, the replacement of 48,052 feet of I-wall with new T-wall, and modification or reconstruction of 10 railroad gates, 15 roadway gates, and 29 drainage structures. Elevations in this reach vary from 15 feet to 24.5 feet.

Reach 4 – West Bank of the Neches River- Reach 4 extends the existing Port Arthur Federal Levee System Northwest along the west bank of the Neches River. This reach consists of 55,311 feet of new levee, 32,645 feet of T-wall, 21 railroad gates, 5 new pump stations, and 16 drainage structures. Elevations in this reach vary from 20 feet to 17 feet. Figure 17 illustrates the recommended plan for the North Region and the system crest elevations.

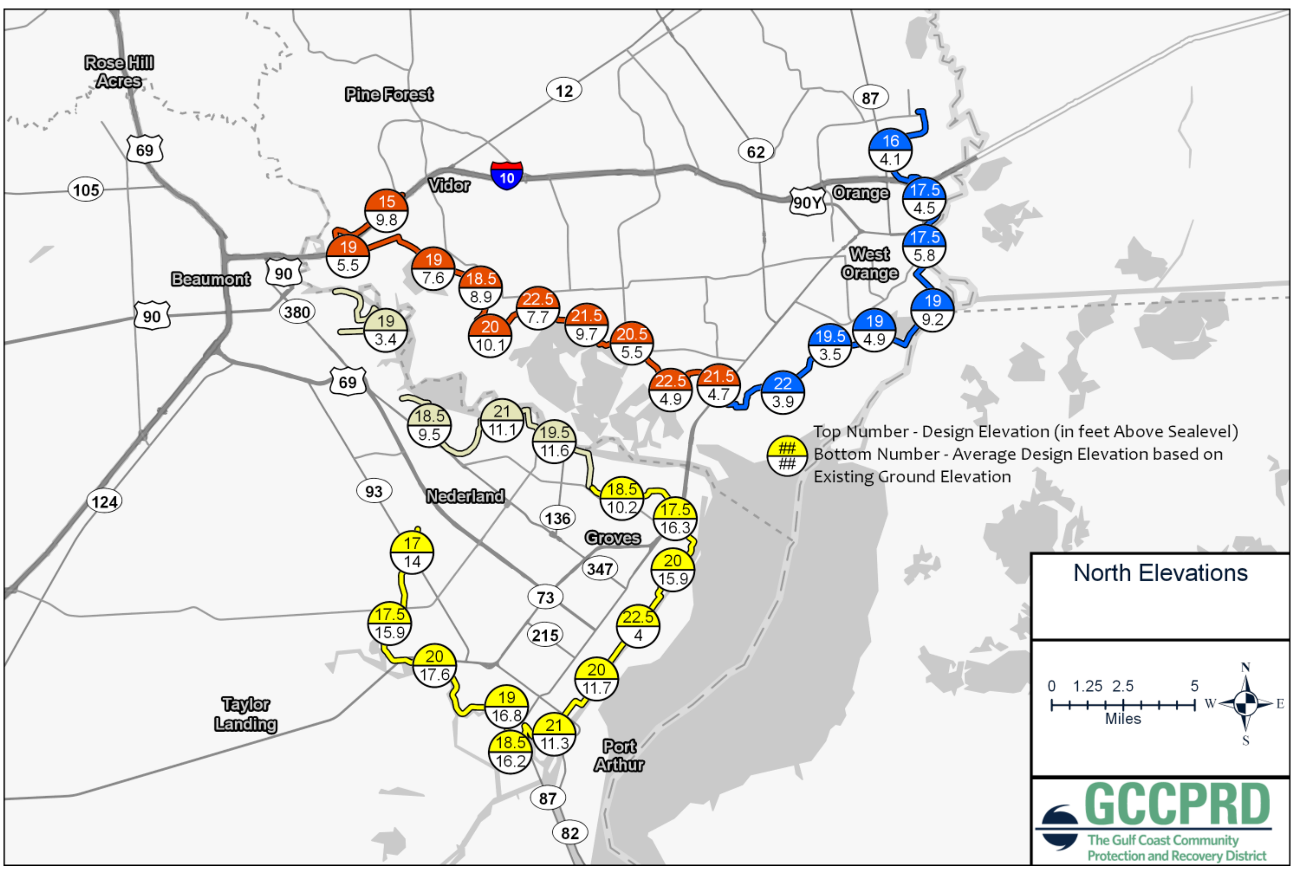


Figure 17: North Region Recommended Plan

4.3. Optimization Measures

The optimization process for the North Region consisted of the following steps:

- Comparison of alignments and lengths to USACE Sabine Pass to Galveston Study
- Separate examination and analysis of interior water levels for the Orange system and the Port Arthur system
- Enhanced Environmental analysis
- Revision of cost and economics based on the more detailed technical and environmental analysis

4.3.1. Comparison and Analysis of USACE Sabine Pass to Galveston Study

The USACE Sabine Pass to Galveston study (SP2G) recommended a protection system for Orange and Jefferson Counties that differs from the recommendation developed by the GCCPRD study team. In Orange County, the system along the east bank of the Neches River was truncated by the USACE due to economic factors. The GCCPRD study extends the system along the East bank of the Neches River to I-10 providing protection for the cities of Rose City and Vidor. Both cities experienced significant flooding during Hurricane Ike. Orange County officials requested this extension to ensure all citizens within the county received the same level of risk reduction. County officials also expressed concern that they would not be able to pass a future bond referendum for payment of their cost share if citizens within the county were excluded from the plan.

In Jefferson County, the USACE SP2G study includes a limited extension of the Port Arthur Hurricane Protection System along the west bank of the Neches River. The GCCPRD found that extending the system along the west bank of the Neches River would provide additional benefits and provide enhanced protection to the City of Beaumont and industry located along the river, especially the Exxon-Mobil facility. This facility sustained over $1B in damages and lost production associated with Hurricane Ike alone.

In February 2018, The Bipartisan Budget Act fully funded the recommendations in the USACE SP2G feasibility study. This is a positive step forward to providing and enhancing coastal storm surge protection for Jefferson and Orange Counties. The additional elements recommended by the GCCPRD study were not included in the overall budget. These elements remain viable and could be integrated into the system later by either local government authorities or the federal government.

4.3.2. Interior Water Levels and Drainage

4.3.2.1. Interior Drainage and Overtopping

The optimization process, as it relates to interior drainage and overtopping, consisted of development of overtopping models to predict flows and additional consideration of existing model information for interior drainage. This was necessary to account for a range of rainfall events as well as overtopping flows, which would occur in less frequent events.

Drainage system studies exist in Orange County and Jefferson County Drainage District No. 7 (DD7). For DD7, the existing studies consist of detailed hydrology and hydraulics models for every watershed and drainage facility within the district boundary. The modeling was developed for each separate watershed and utilized for identification and design of potential improvements within each of the watersheds, and they were utilized for Levee System Accreditation through FEMA.

In Orange County, broad, general models were developed as part of a study of a potential Hurricane Protection System in the aftermath of Hurricane Ike. Detailed models of Cow and Adams Bayous, which drain a majority of the east half of the county, were developed more recently and were utilized to develop a drainage improvement master plan for those two watersheds. The remainder of the county has not had detailed studies conducted.

To the extent possible, the existing studies were utilized to develop pumping requirements and gate and drainage structure sizes for the interior drainage of each system. For DD7, the levee and pump station systems already exist. For this study, it was determined that the older, less efficient pump stations would be replaced with new ones. The extensive system of gates and drainage structures were considered adequate in size, but each system is included for upgrade or replacement. Upgrades would include lengthening and/or the installation of positive closures.

For Orange County, no current storm surge protection system exists, and development of a levee system would necessitate a system of pump stations to drain the interior of the system during storm surge conditions. The previously mentioned studies in Orange County were utilized for development of pumping requirements and gate and drainage structure sizes in those watersheds. In un-modeled areas within the county, regional regression equations were used to develop runoff quantities for gate and structure sizing and pumping requirements.

For the purposes of optimization of the top elevation(s) and for consideration of additional pumping requirements of the systems in Orange and Jefferson Counties, the study team decided to utilize a broad, hydrologic modeling approach for each of the systems, which would not be as tedious as individual watershed models and would more efficiently deal with the analysis of potential overtopping of the proposed (and existing) protection systems. Overtopping of the levee systems would be expected when a storm event occurs in excess of the design event.

The following section describes the methodology used for the overtopping analysis.

4.3.2.2. Overtopping Methodology

The 2011 U.S. Geological Survey (USGS) National Elevation Dataset (NED) topographic information for the area was obtained from the Texas Natural Resources Information System (TNRIS) to develop drainage areas and stage volume relationships within the leveed areas. The study team determined that the best method to use for the determination of water surface elevations within the leveed areas during a storm surge event would be to model the areas using HEC-HMS.

The drainage area into each leveed area was determined based on the topographic information. For the Orange County area this was approximately 316 square miles with approximately 77 square miles draining into the Port Arthur area. The SCS Curve number loss method was used based on a curve number of 80 for both areas. The Clark Unit Hydrograph was used for the "transform method" for creation of the runoff hydrograph into the leveed areas.

Based on this methodology the precipitation excess for the Orange County basin was 9.49 inches for the 25-year, 96-hour event. For this event, the excess precipitation in the Port Arthur drainage area is 10.87 inches. This results in a total internal runoff of 160,069 acre-feet for the Orange County drainage area, and 44,496 acre-feet for the Port Arthur drainage area.

For the overflow rates for each frequency, the segment associated with each levee and the flows for each levee were determined by adding the flows for each segment associated with the levee. Because the overflows were based on cfs/ft for each segment, the flows for each segment were multiplied by the length of the segment in feet to obtain the total cfs for each segment at each time step. The flows for the segments were then summed at each time step to obtain the total inflow to the leveed area at each time step. The overflow rates for each levee for each frequency were input to the HEC-HMS model as discharge gage flows.

The HEC-HMS model had each basin connected to a reservoir. The storage-elevation data for each leveed area as determined from the topographic data was input for each of the reservoirs. A stage-discharge relationship for each leveed area reservoir was input based on the total pumping capacity of each leveed area. For the Port Arthur area, the existing total pumping capacity was used. For the Orange County area, it was assumed that nine pump stations with a total capacity of 16,000 cfs would be used.

The basins were connected to the reservoirs to simulate the inflow of the internal runoff. Sources were created using the overtopping discharge gage flows and connected to the reservoirs to simulate the inflow of the expected overtopping.

Based on the overtopping rates provided, there is essentially no overtopping for the 50- and 100-year events on either levee in the with-project condition. There are approximately 470 acre-feet (ac-ft) of overtopping volume for the 200-year event for the Orange County levee, and approximately 926 ac-ft for the Port Arthur levee. The 500-year overtopping volumes are approximately 17,175 ac-ft for the Orange County levee and 27,515 ac-ft for the Port Arthur levee.

Based on the HEC-HMS analysis, the Port Arthur system pumps approximately 28,240 ac-ft, and the Orange County system pumps approximately 157,667 ac-ft for the 200-year event. The peak storage for the Orange County system was 33,227 ac-ft, and the peak storage for the Port Arthur system was 33,281 ac-ft.

Table 2 illustrates the peak storage and the required pumping capacity for the overtopping associated with a 200-year surge event and a 25-year interior rainfall event.

Table 2: North Region Pumping Requirements

Location	Peak Storage Volume	Total Pumping Volume	Pump Stations Required
Jefferson County	926 Ac-Ft	6,100	16
Orange County	470 Ac-Ft	16,000	9

The peak storage values from the HEC-HMS model were used to determine the water surface elevation based on the stage-volume curves. These elevations were then mapped in GIS to determine the inundation areas.

4.3.3. Environmental Review

This section provides a summary of the potential environmental impacts associated the construction of the North Region system. The full North Region environmental report is located in **Appendices D.1-D1.2**.

During Phase 4, the study team conducted a more thorough review of the potential environmental impacts that would be associated with the construction of the four reaches in the North Region. In order to estimate potential impacts, the study team assumed that the proposed levee and T-wall system would have a 150-foot-wide footprint. This enhanced assessment included: field investigations conducted along publicly accessible rights-of-way, additional desktop analysis, coordination with USACE, and calculating future mitigation requirements using the WVA model. The costs associated with mitigation were incorporated into the overall project cost and considered in the BCR calculations.

Impacts to the following were minor and insubstantial:

- Prime and Unique Farmlands
- Socioeconomic Impacts
- Protection of Children from Environmental and Safety Risks
- Federal Water Project Recreation Act
- Executive Order 11990: Protection of Wetlands
- Section 303(d) of the Clean Water Act: Impaired Streams
- Section 402 of the Clean Water Act
- Wild and Scenic Rivers
- Coastal Barriers
- Vegetation
- Executive Order 13112 on Invasive Species
- Executive Memorandum on Environmentally and Economically Beneficial Landscaping
- Migratory Birds and the Migratory Bird Treaty Act
- Fish and Wildlife Coordination Act
- Bald Eagle Protection Act of 1940
- Air Quality
- Greenhouse Gas Impacts
- Noise

The primary potential impacts are described in the following sections.

4.3.3.1. Cultural Resources

A preliminary assessment of the cultural resources within the North Region Alternative was conducted using a combination of a desktop review of the Texas Historic Sites Atlas (THSA) and further confirmation of the mapped sites during a site visit. The Area of Potential Effect (APE) for the North Region Alternative would be the 150-foot buffer, 75-feet on either side of the proposed alternative for direct impacts on historic resources. There would be a 1,500-foot buffer for indirect impacts on standing structures or buildings.

A direct impact is determined if the site is within the 75-foot buffer that lies on either side of the proposed wall or levee. An indirect impact is determined if the site is within a 750-foot buffer that lies on either side of the proposed wall or levee.

There are three National Register Listings along the proposed North Region Alternative proposed vertical wall. The first is the Rose Hill National Register District, which was listed on October 31, 1979, and the official address is 100 Woodworth Boulevard, Port Arthur Texas. This is the address of the actual structure, though now it is part of Rose Hill Park. The property line for this parcel extends past the existing structure, according to the Jefferson County Appraisal District. The property itself could be indirectly impacted, depending on the level of ground disturbance. The structure on this property is called the Woodworth House.

The second National Register Listing is Eddingston Court and was listed on September 8, 2004. The official address is 3300 Procter Street. According to the Jefferson County Appraisal District, the parcel line for this historic site ends approximately 30 feet from the current existing seawall. The property could be directly impacted depending on modifications to the existing vertical wall and could be indirectly impacted depending on the level of ground disturbance.

The third National Register Listing is named Navy Park Historic District and was listed on November 18, 1999. This site would be considered an indirect impact because it is approximately 740 feet from the proposed alternative.

During the field visit, a potentially historic site was identified as the Arcadia House. This site was noted because the structure appeared to be eligible for the Historic Sites Atlas. If this site is deemed eligible, it would be considered an indirect impact since it is outside of the 150-foot direct impact APE, but is within the 1,500-foot indirect impact buffer.

Based on the current information for the proposed levee construction and improvements, 14 structures could be directly impacted, eight structures could be indirectly impacted, and one additional structure could be indirectly impacted if eligible for the Historic Site Atlas.

4.3.3.2. Texas Parks and Wildlife Code, Chapter 26

The proposed project would be located within the boundaries of Joe Hopkins Memorial Park, Ochiltree Inman Park, Oak Bluff Memorial Park, Port Neches Park, Rose Hill Park, and Lions Park as well as the Lower Neches Wildlife Management Area (WMA) Nelda Stark, Lower Neches WMA Old River, Adams Bayou WMA, and Tony Houseman WMA which are all Chapter 26 properties. A Public Hearing is required and would be held during the National Environmental Policy Act (NEPA) process in accordance with Chapter 26 requirements.

4.3.3.3. Section 404 of the Clean Water Act: Waters of the U.S.

Desktop surveys using U.S. Fish and Wildlife Services' (USFWS) National Wetland Inventory (NWI) maps, USGS 7.5-Minute Topographic Quadrangle maps, Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM), aerial photographs and limited site surveys were conducted. There are 513 individual NWI signatures that occur within the 150-foot-wide footprint of the levees, which would be impacted by the proposed project.

The amount of NWI wetlands within the 150-foot-wide levee footprint is as follows:

- Orange Levee: 318.88 acres
- Beaumont Levee: 37.25 acres
- Port Arthur Levee: 48.26 acres

Although some of the other present NWI signatures that occur within the footprint may qualify for a Nationwide Permit, it is anticipated that an Individual Permit (IP) would be required for the project, and mitigation would be required.

Table 3 shows estimated costs for two types of wetland mitigation: mitigation banks, and preservation, restoration, and creation. The total cost of mitigation through mitigation banks would be $103,459,626, and the total costs of preservation, restoration, and creation mitigation would be $29,086,381. These wetland mitigation costs were estimated using the acreage amounts above.

Table 3: North Region Estimated Wetland Mitigation Types and Cost

Segment	Mitigation Bank Cost	Preservation, Restoration, Creation Mitigation Cost
Orange	$81,733,750	$22,934,806
Jefferson		
Beaumont	$9,079,688	$2,679,132
Port Arthur	$12,641,313	$3,471,004
Total North Region Mitigation Cost	$103,459,626	$29,086,381

4.3.3.4. Section 401 of the Clean Water Act: Water Quality Certification

The project would impact more than 1,500 linear feet of stream and/or 3 acres of waters of the U.S. A USACE IP is anticipated. The Texas Commission on Environmental Quality (TCEQ) Tier II 401 Certification requirements for the IP would be met by implementing approved erosion controls, sediment controls, and post-construction Total Suspended Solids (TSS) controls.

4.3.3.5. Rivers and Harbors Act of 1899

Section 9 of Rivers and Harbors Act of 1899 (33 U.S.C. 403; Chapter 425) regulates the construction of any bridge, dam, dike, or causeway over or in navigable waterways of the U.S. Section 10 of the Rivers and Harbors Act of 1899 regulates any structures or work in navigable waters. The proposed project would place a gate across Cow Bayou and Adams Bayou, which are navigable waters of the U.S. Therefore, this project would require a Section 9 permit from the U.S. Coast Guard (USCG) and a Section 10 permit from USACE.

4.3.3.6. Floodplains

The acreage amount in the FEMA 100-year floodplain is listed in Table 4:

Table 4: Floodplains

Levee	Acreage Amount in 100-year Floodplain
Beaumont	182 acres
Port Arthur	155 acres
Orange	617 acres

The North Region Alternative must be located in a floodplain in order to reduce flood risk behind the flood suppression system. The North Region Alternative would adhere to the 8-step process as outlined under Executive Order 11988, Floodplain Management, including consideration of sea level rise.

4.3.3.7. Texas Coastal Management Program

For the proposed project, the Texas GLO would have to prepare a Consistency Determination that evaluates the proposed project for consistency with the Texas Coastal Management Program.

4.3.3.8. Wetland Value Assessment

A Wetland Value Assessment (WVA) was conducted for the North Region. The environmental period of analysis is a total of 50 years based on the following assumptions: The construction period is assumed to end in 2035. The period for which mitigation benefits are analyzed is 2036-2085.

The direct impacts assume no change in wetlands between the baseline and the future target year without the project and total loss of all wetlands within the footprint due to construction impacts. Table 5 provides a summary of the results of the WVA modeling of direct impacts. Total direct impacts would affect 530.55 acres of wetlands and result in the net loss of 50.07 Average Annual Habitat Units (AAHU's) over the period of analysis.

Table 5: Direct Impacts to the North Region Alternative

Levee System	Marsh Model Type	Acreage	Future w/o project AAHU	Future w/project AAHU	Net Impact
Jefferson Beaumont Port Arthur	Freshwater	36.6	12.15	8.77	3.38
	Freshwater/Intermediate	39.12	11.06	8.09	2.97
	Brackish	20.83	3.34	2.58	0.77
	Bottomland Hardwoods	20.28	6.70	4.62	2.08
Orange	Freshwater	99	30.18	21.93	8.25
	Brackish	81.263	31.01	22.02	8.98
	Bottomland Hardwoods	151.425	49.12	33.77	15.35
	Swamp	82.03	27.07	18.77	8.30
Total		**530.55**	**170.62**	**120.55**	**50.07**

The WVA modeling evaluated and quantified direct impacts of the North Region Alternative. The Beaumont levee would negatively impact 36.6 acres; the Port Arthur levee would impact 80.23 acres; and the Orange levee would impact 413.72 acres. Total impacts of the North Region Alternative would be 530.55 acres.

Total direct impacts would affect 530.55 acres of wetlands and result in the net loss of 50.07 AAHUs over the period of analysis. Mitigation would be required to compensate for a loss of 50.07 AAHUs from marshes.

4.3.3.9. Essential Fish Habitat

Tidally influenced waters occur within the project area, and Essential Fish Habitat for Red Drum, shrimp, and reef fish occurs within the project area. Coordination with National Marine Fisheries Service (NMFS) would be required.

4.3.3.10. Marine Mammal Protection Act of 1972

The North Region Alternative is within two counties that both have the West Indian Manatee (*Trichechus manatus*) listed on the USFWS Threatened and Endangered Species List; however, there is no suitable habitat for the West Indian Manatee. The alternative would include gate structures for Cow Bayou and Adams Bayou. Coordination with NMFS would be required.

4.3.3.11. Threatened and Endangered Species

Review of the USFWS Endangered Species List and Critical Habitat for Jefferson and Orange Counties (October 2017), Texas Parks and Wildlife Department (TPWD) Annotated County List of Rare Species for Jefferson and Orange Counties (October 2017), and a search of the Natural Diversity Database, in conjunction with GIS, was conducted to determine the potential occurrence of State and Federally listed threatened and endangered species and their habitat.

The proposed project may impact the habitat of 22 state-listed species but no federally listed species. Prior to construction, coordination with the TPWD would be initiated, and best management practices (BMPs) would be implemented to minimize habitat loss and impact to any state-listed species.

4.3.3.12. Hazardous Materials

A hazardous materials regulatory database search was conducted. There are approximately 654 sites that could pose a risk to the proposed project. More complete hazardous materials site investigations would be done during the NEPA phase of the proposed project.

4.3.3.13. Summary of Direct Impacts

The proposed project would involve the following impacts:

- The project may impact three historic resources listed as National Register Historic Districts and would require coordination with Texas Historical Commission (THC), would directly impact an additional 11 Historic Places or historical markers, and would indirectly impact eight places or historical markers.

- Six pubic parks and four WMAs would be impacted, and a Public Hearing per Chapter 26 requirements is required.
- 404.39 acres of potential wetlands would be impacted across the four regional reaches. Mitigation would be required and the total estimated cost of mitigation for the North Region would be $103,459,626 for Mitigation Banking and $29,086,381 for Preservation, Restoration, and Creation.
- The project would impact more than 1,500 linear feet of stream and more than 3 acres of waters of the U.S. and would therefore require Tier II Water Quality Certification from TCEQ.
- The project would involve construction of gates across two navigable waters of the U.S. and would therefore need a Section 9 Permit from the USCG and a Section 10 Permit from USACE.
- The North Region Alternative must be located in a floodplain in order to reduce flood risk behind the flood protection system. The North Region Alternative would adhere to the 8-step process as outlined under Executive Order 11988, Floodplain Management, including the consideration of sea level rise.
- The GLO would have to prepare a Consistency Determination that evaluates the proposed project for consistency with the TCMP.
- A wetland value assessment was performed. Total direct impacts would affect 530.55 acres of wetlands and result in the net loss of 50.07 AAHUs over the period of analysis. Mitigation would be needed to compensate for a loss of 50.07 AAHUs from freshwater, brackish, and saline marshes.
- EFH has been designated in Sabine Lake and Neches River for Red Drum, shrimp and reef fish. Coordination with NMFS would be required.
- The proposed project may impact the habitat of twenty-two state listed species but no federally listed species.
- There are approximately 654 hazardous material sites that could pose a risk to the proposed project.

4.3.4. Cost and Economic Review

The cost estimates presented in the Phase 3 Report were reviewed to assure consistency between the regions and to assure correctness. For the North Region, adjustments were made in real estate values, mitigation costs, and some item quantities.

For real estate costs, escalation factors were introduced based on USACE cost estimating guidelines. Environmental mitigation costs were revised based on completion of detailed analyses and estimates. Several adjustments were made to pump station sizes based on the final interior drainage and overtopping analyses. Finally, levee and floodwall lengths were checked with some adjustments made based on a re-analysis of mapping and alignment drawings. Table 6 provides an updated cost and economics summary for the North Region. All benefits and costs are presented in thousands of dollars and reflect 2018 price levels.

Table 6: Cost and Economics Summary for the North Region (in $Thousands)

North Region Summary	Jefferson County	Orange County	Total
Total length of the system (miles)	46 miles	41 miles	87 miles
Right of way required	428 acres	973 acres	1,401 acres
Pump stations required / total capacity (CFS)	13 / 9,270 CFS	9/ 20,230 CFS	22/ 29,650
Environmental mitigation required	85.51 acres	318.88 acres	404.39 acres
Construction cost	1,544,132	2,439,385	$3,983,517
Annual Operations and maintenance cost	7,721	12,197	19,918
Total Annual Costs (TAC)	79,715	125,931	205,646
Total Annual Benefits (TAB)	46,963	79,468	126,431
Benefit - Cost Ratio (TAB/TAC) (2.875 % Interest Rate)	0.60	0.63	0.61

4.3.5. North Region Conclusions

Phase 4 optimization did not change the recommended alignment or levee heights from the 2016 plan. The BCR in all the regions decreased, which can be attributed to the modifications that were made to the economics model in order to align with USACE assumptions and data, and the increase in construction and mitigation costs. The construction costs were updated to reflect 2018 versus 2015 pricing, which increased the overall constructions costs, by 6 percent. The enhanced environmental review enabled the study team to more accurately determine potential impacts and the costs associated with mitigation.

5. Central Region Optimization Results

5.1. General

The Central Region of the GCCPRD consists of Chambers, Galveston, and Harris Counties. The three counties all border Galveston Bay, which has a direct nexus to the Gulf of Mexico making them highly vulnerable to tropical storm related surge flooding.

The region has two existing hurricane protection systems. The Texas City Hurricane Protection System is a levee system that that provides storm surge protection to 36 square miles of the greater Texas City-La Marque-Hitchcock area from a 15-foot hurricane storm surge with associated wave run-up. The system was completed in 1987 and is currently being reevaluated by USACE to determine if it is sufficient to adequately protect the area from storm inundation in the future.

The second system is the Galveston Seawall, which provides protection to the City of Galveston from surge and surge-related flooding. Construction of the seawall began in 1902 and the initial segment was completed in 1904. From 1904 to 1963, the seawall was extended from 3.3 miles to over 10 miles. The elevation of the seawall is 17 feet, and it consists of a recurved front face to limit wave overtopping and related flooding.

During Hurricane Ike, the seawall and the Texas City Hurricane Protection system performed well. Nevertheless, the City of Galveston still experienced extensive flooding due to surge that originated from the unprotected backside of the island. All homes on the Bolivar Peninsula and many on the west end of Galveston Island outside the protection of the seawall were severely damaged by the surge. The west and east side of Galveston Bay in Chambers, Galveston, and Harris counties experienced a storm surge of 15 to 21 feet. Along the Houston Ship Channel, the surge was in the 18- to 21-foot range. Overall, the losses in Texas associated the Hurricane Ike exceeded $30B.

5.2. Phase 3: Central Region Recommended Plan

The Central Region recommended plan consists of three reaches that provide regional protection to Chambers, Galveston, and Harris Counties.

Reach 1- Coastal Spine – Reach 1 is a coastal levee system that starts at the high ground north of High Island running parallel to Hwy 87 along the Bolivar Peninsula, crossing Bolivar Roads and tying into the existing federal protection system at the Galveston Seawall. At the end of the seawall, the system continues along the length of the island, parallel to Hwy 3005, and terminates at San Luis Pass. The major elements include: 221,105 feet of new levee, 18,916 feet of new T-wall, 41,651 feet of Seawall enhancements, and a 1,200-foot-wide floating sector gate including 24 100-foot-wide vertical lift gates at the Bolivar Roads crossing, 78 drainage structures, 35 highway gates, and the reconstruction of 12 miles of two-lane highway. Elevations for this reach vary between 17 feet and 18 feet.

Reach 2-Galveston Ring Levee – Reach 2 consists of a ring levee that runs the entire length of the existing Seawall and includes a new levee extension that extends this line of protection west to Stewart Road. The levee then turns north, parallel to Stewart road and continues to Offatts Bayou, crosses Offatts Bayou and turns east along Teichman Road, crossing Interstate 45, and running parallel to the rear of the properties on the Southside of Harborside Drive. The system then crosses Harborside Drive and follows an alignment parallel to the Northside of Harborside Drive to Ferry Road. At Ferry Road, the system turns north parallel to Ferry Road and then crosses Ferry Road at Fort Point Road to tie into the high ground at the San Jacinto federal dredge material placement area. Elevations for this reach vary between 17.5 feet and 26 feet. The major elements of this reach include: 26,303 feet of new levee, 70,488 feet of T-wall, 46 two-lane highway gates, five four-lane highway gates, four railway gates, three new pump stations, and one navigation gate at Offatts Bayou. Elevations for this reach vary between 18 feet and 21 feet.

Reach 3- Clear Lake Protection System – Reach 3 consists of a protection system that starts at the intersection of FM 518 and SH 146 extending northward to NASA Road 1. The major elements of the system include: 1,260 feet of levee systems, 7,575 feet of T-wall, a navigation gate at the Clear Lake channel, improvements to the existing Harris County Flood Control District second drainage outlet, two roadway crossings, and one new pump station. Elevations for this reach are at 17 feet.

Figure 18 illustrates the Central Region recommended plan.

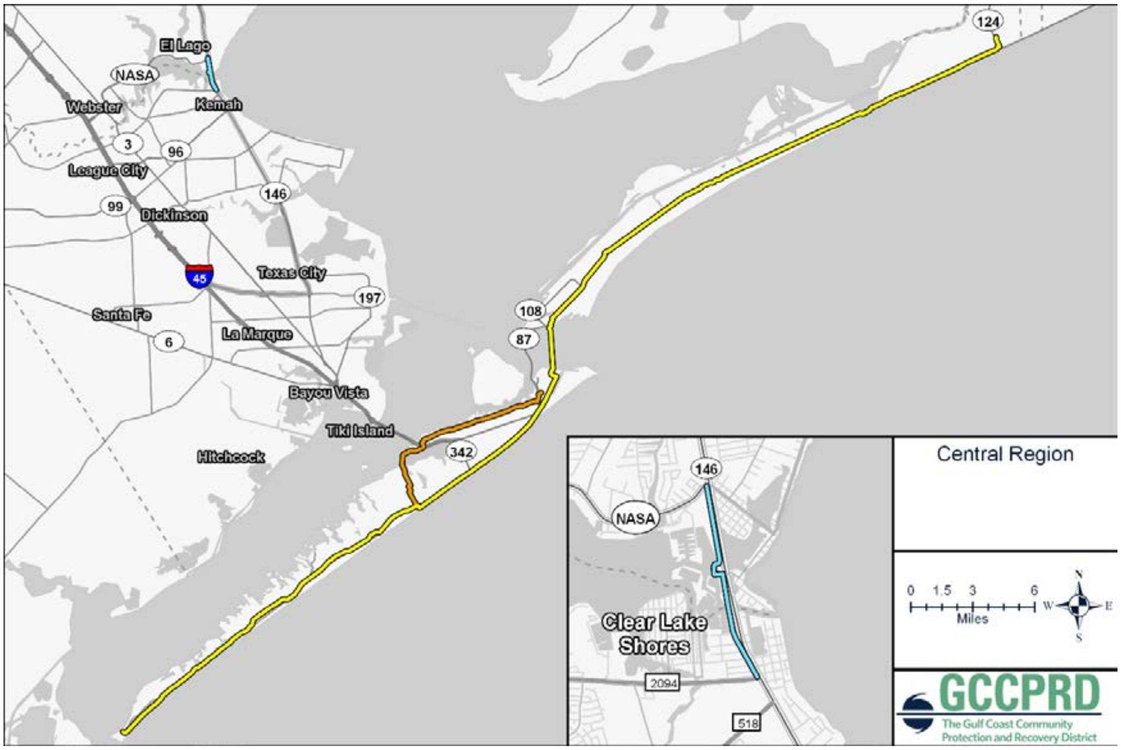


Figure 18: Central Region Recommended Plan

5.3. Optimization Measures

The optimization process for the Central Region consisted of the following steps:

- Analysis of final crest elevations for the Costal Spine to optimize the BCR
- Analysis of interior water levels and pumping requirements for the proposed Galveston Ring Levee and Clear Lake Gate system.
- Review of different alternatives for the Bolivar Gate structure
- Consideration of low economic impact areas (inclusion)
- Enhanced Environmental analysis for Galveston Bay
- Revision of cost estimates based on elevation and length revisions, and original cost estimate quality checking

5.3.1. Analysis of Crest Elevations

As mentioned in Section 3.2, three new scenarios were developed in order to optimize the crest elevations for the Coastal Spine within the Central Region. The goal of this analysis was to determine the ideal height of the Coastal Spine that would maximize the overall BCR for the region.

Scenario 1, FWA.a, maintained the height of the spine at 17 feet in accordance with the recommended plan. Scenario 2, FWA.b, raised the height of the spine to 20 feet. Scenario 3, FWA.c, reduced the height of the spine to 15 feet. The height of the Galveston Ring Levee and the Bolivar Roads gate structure remained constant as the height of the spine along Galveston Island and the Bolivar peninsula were adjusted. Figure 19 through Figure 21 illustrate the changes in the top elevations for the three scenarios.

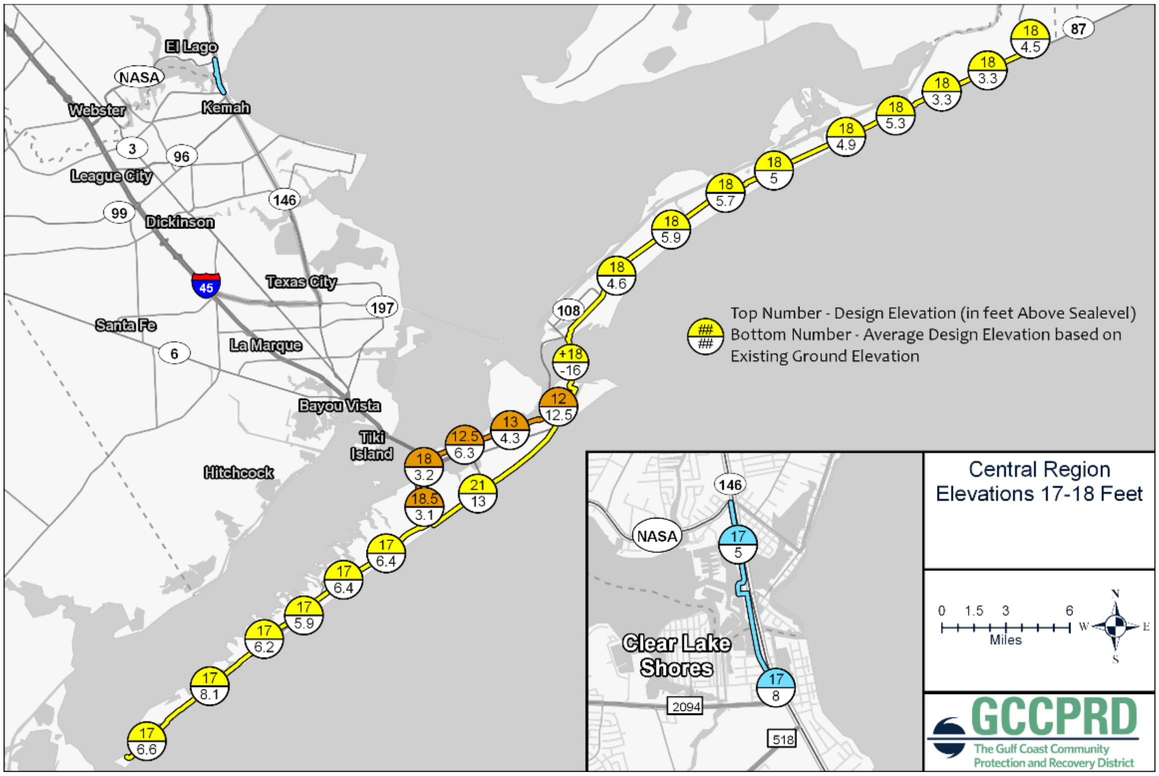


Figure 19: FWA.a – The Recommend Plan at Elevation 17 feet.

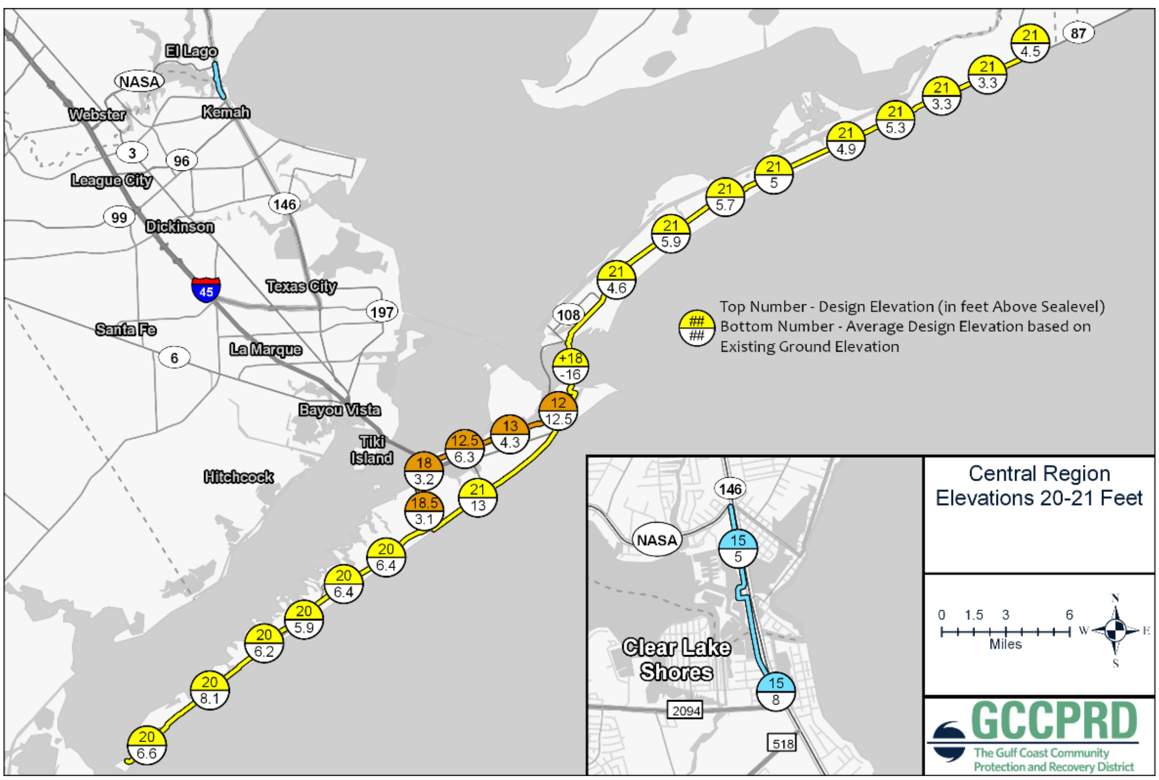


Figure 20: FWA.b - Raising the Height of the Coastal Spine to 20 feet.

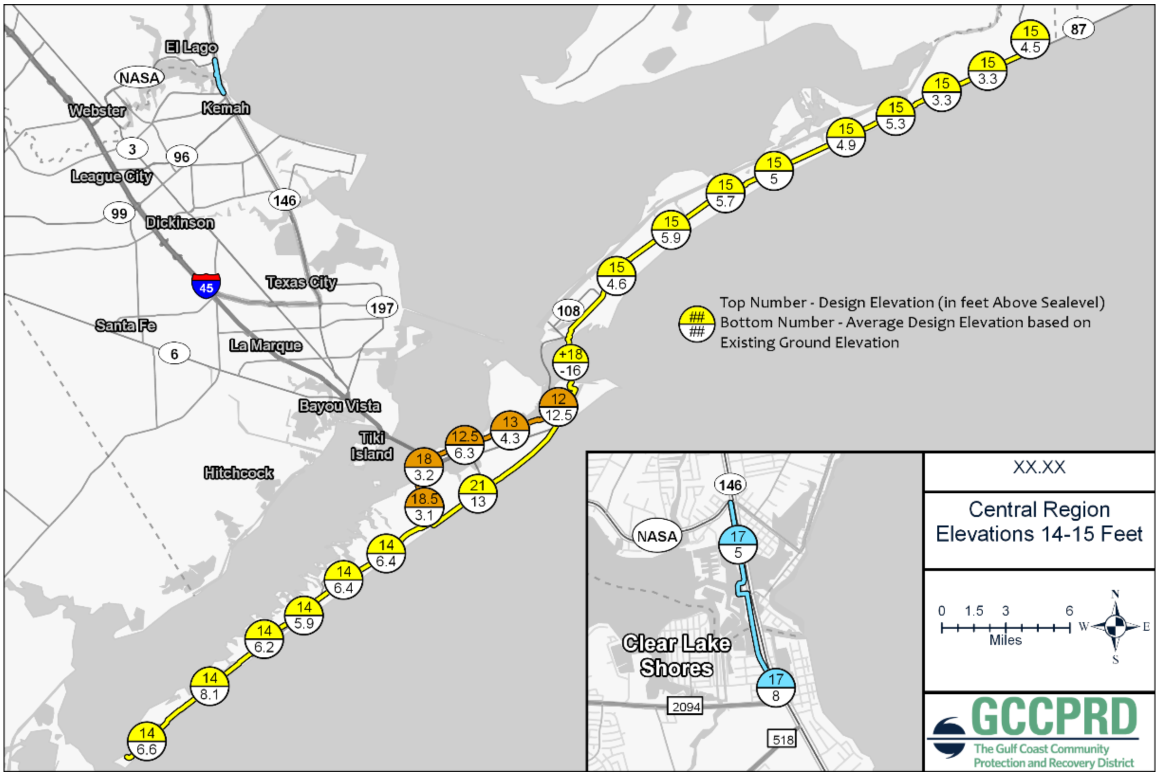


Figure 21: FWA.c – Reducing the Coastal Spine Elevation to 15 feet.

Figure 22 illustrates the changes in water surface elevations at various points within the region associated with each of the three alternatives for the 500-year event. The 500-year event was used to clearly illustrate the minimal difference in stillwater elevations associated with a Coastal Spine elevation between 15 feet and 20 feet. In all the scenarios, the Coastal Spine reduces the surge by 7 to 8 throughout the Central Region when compared to the future without action scenario.

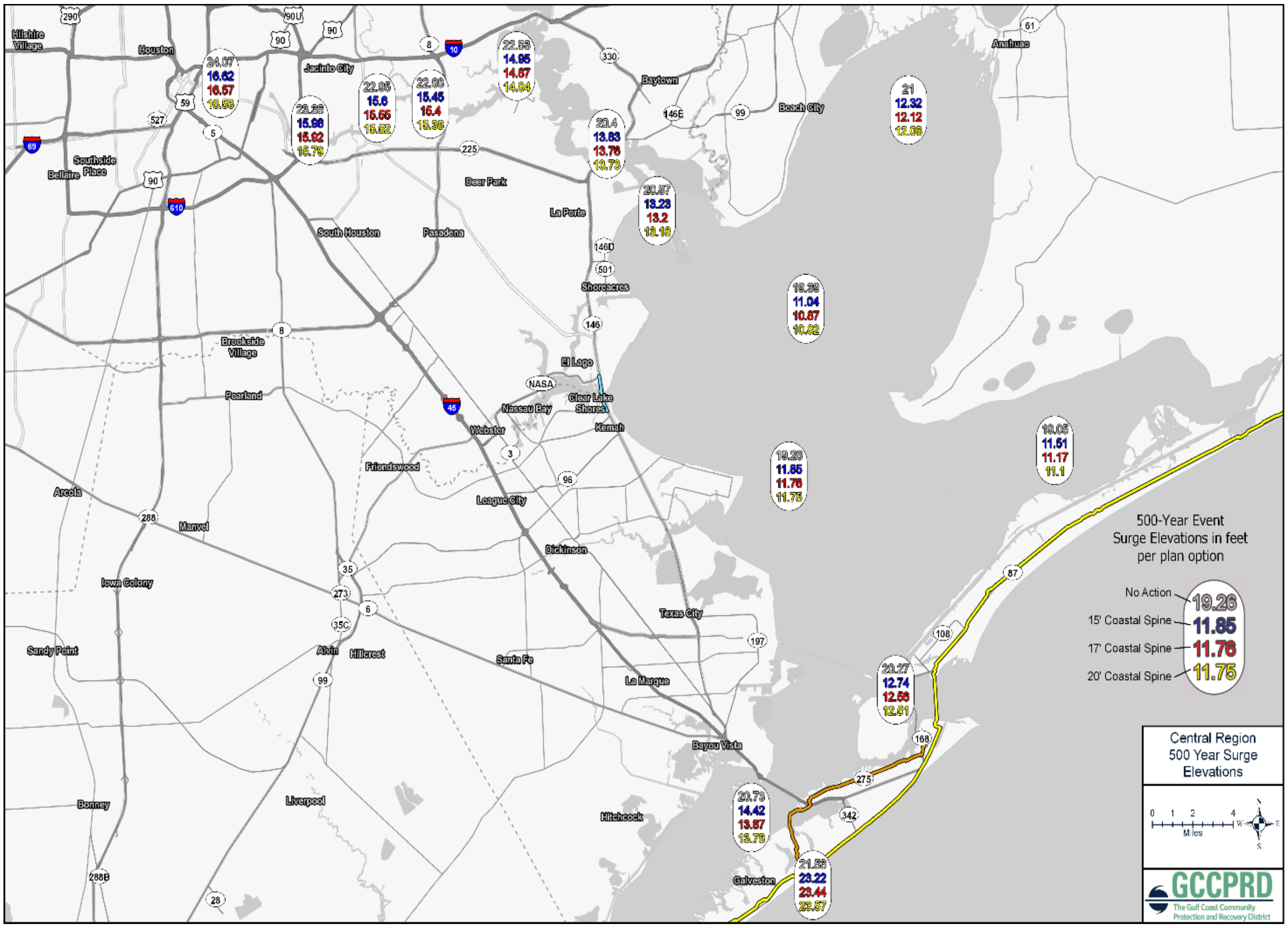


Figure 22: Stillwater Elevations in 2085 for the Various Coastal Spine Elevations

Further analysis identified the following levels of protection provided:

Table 7: Comparison of Coastal Spine Elevations

Alternative	Coastal Spine Elevation	Level of Protection	Construction Cost ($000)	Benefit-Cost Ratio
FWA.a	17 feet	100-yr	$10,120,836	1.61
FWA.b	20 feet	200-yr	$10,313,788	1.59
FWA.c	15 feet	50-year	$9,818,156	1.66

Alternative FWA.b, raising the spine to an elevation of 20 feet from 17 feet, increases the construction cost by $200 million and results in a slight decrease in the BCR. Similarly, alternative FWA.c, decreasing the spine to an elevation of 15 feet, reduces construction cost by $302 million and slightly increases the BCR. However, with only a 50-year level of protection, the project would not meet FEMA Flood Insurance requirements of providing protection from the 100-year event. Flood insurance rates within the region would not necessarily be reduced.

FWA.a, the elevation of 17 feet as define in the recommend plan, is the optimal elevation for the Coastal Spine.

5.3.2. Interior Water Levels and Drainage

The interior drainage analysis for the Central Region included floodplain mapping and pump sizing for the 25-year internal rainfall event and the overtopping associated with 100-year storm surge event for the proposed Galveston Ring Levee and the Clear Lake Gate system. Since the Coastal Spine along Bolivar Peninsula and West Galveston Island is not a closed system, the study team did not conduct an interior drainage analysis for this segment.

5.3.2.1. Methodology

The pumping rate analysis was performed using the USACE HEC-HMS modeling software. Within the model, the 25-year internal storm event flows were combined with the 100-year storm surge overtopping flows. The natural terrain being protected by the levee was modeled as a reservoir with the elevation-storage data obtained based on the LiDAR DEM of the natural ground. The peak pumping rate was determined based on maintaining a certain level of ponding within the protected area/reservoir that had minimal effects on existing structures.

5.3.2.2. Inland Drainage Area and Peak Flow

Inland drainage areas and peak flows for Clear Creek were obtained from the Flood Insurance Study for Clear Creek. The inland drainage areas for the Galveston Ring Levee were determined using aerial photography, LiDAR DEM, and ArcHydro tools in GIS. The 25-year peak flows were computed in HEC-HMS. The Green and Ampt Method was utilized for calculating runoff losses and the Clark Unit Hydrograph Method was used for calculating runoff hydrograph. The inland drainage area and peak flow are summarized in Table 8.

Table 8: Inland Drainage Area and 25-year Peak Flow

Alignment	Drainage Area (ac)	25-year Inland Flow (cfs)
Clear Lake	166,396	29,627
Galveston Ring Levee	8,824	7,153

5.3.2.3. Overtopping Analysis

The 100-year storm surge overtopping hydrographs for the study were derived from the ADCIRC storm surge models. The proposed levee segments were divided into several reaches and surge overtopping hydrographs were calculated for each reach. The surge hydrographs were summarized for each levee segment and utilized in the current analysis.

The 100-year storm surge peak flows for the 17 feet and 15 feet Coastal Spine levee height alternatives were analyzed to see if adjusting the levee height would influence overtopping especially within the Galveston Ring Levee. The internal pumping rates are summarized in Table 9.

Table 9: 100-year Storm Surge (Overtopping) Peak Flows

	100- Storm Surge Overtopping (cfs)	
Alignment	**Coastal Spine at 17.0 feet**	**Coastal Spine at 15.0 feet**
Clear Creek	552	556
Galveston Ring Levee	210,009	209,209

The storm surge analysis shows that in both the alternatives, the 100-year storm surge peak overtopping flows are relatively similar. This indicates that the height of the Coastal Spine does not have a significant impact on the overtopping rates for the Clear Creek and Galveston Ring Levee systems.

5.3.2.4. Pumping Rate

For Clear Creek, it was determined that an inland ponding elevation of 8 feet would result in little structural flooding while providing a reasonable amount of flood storage which is distributed over Clear Lake.

For the Galveston Ring Levee, the area protected by the ring levee was divided into three different regions based on geography and internal drainage conditions. In the western region (the vicinity of the airport) the ponding elevation was calibrated to 5.5 feet, and for the downtown and east end regions the ponding elevation was 8 feet. Ponding elevations were set in order to keep the majority of the area and structures above the flood level. The pumping rates were determined based on not exceeding the flood level.

5.3.2.5. Results

The peak pumping rate for Clear Creek was determined to be 10,900 cfs, which is 4.9 million gallons per minute. The peak pumping rate for the Galveston Ring Levee was determined to be 117,000 cfs, which is 55.2 million gallons per minute. The significantly higher pumping rate for the Galveston Ring Levee is directly related to the extremely high overtopping rate along the seawall. Additionally, the area protected by the Galveston Ring Levee is small and does not provide much storage capacity for ponding as the in the case of the Clear Lake Gate, so the water must be pumped out at a higher rate to avoid interior flooding.

The analysis shows that the peak pumping for the Clear Lake Gate is not dependent on the elevation of the Coastal Spine. The pumping rate for the Galveston Ring Levee is driven by the amount of water overtopping the seawall. To reduce this overtopping, the seawall would need to be raised higher than the proposed 21 feet. This would have a significant economic and social impacts on the City of Galveston.

The peak pumping rates are presented in Table 10.

Table 10: 100-year Storm Surge Peak Flows

Alignment	25-yr Inland Flow (cfs)	100-yr Storm Surge (cfs)	Inland Flooding	Peak Pumping (cfs)	Peak Pumping Rate (mgpm)
Coastal Spine Elevation 17 feet (Recommended)					
Clear Creek	29,627	552	8.0	10,900	4.9
Galveston Ring Levee	7,153	210,009	5.0-8.0	117,000	52.5
Coastal Spine Elevation 15 feet					
Clear Creek	29,627	556	8.0	10,900	4.9
Galveston Ring Levee	7,153	210,009	5.0-8.0	117,000	52.5

5.3.3. Bolivar Roads Gate Analysis

The study team evaluated the cost of construction and performance for the three potential gate alternatives for the Bolivar Roads crossing discussed in Section 3.6. The following table summarizes the cost of each option and the amount of permanent blockage in terms of percentage of the entire alignment length.

Table 11: Summary of Barrier Alternative Costs & Permanent Blockage

Configuration	Costs, in millions	Permanent Blockage
GCCPRD840	$3,540	54.8%
GCCPRD1200	$3,956	52.8%
GCCPRD1200-Barge	$3,674	38.5%

The GCCORD1200-Barge alternative has the lowest cost and creates the least impact associate with a loss of tidal flow. The reduction in cost for the GCCRPD1200-Barge can be attributed to the following advantages of the barge gate construction:

- No significant under-water construction
- No need for a cofferdam or temporary water retaining structures
- Major fabrication (steel barge gate) can be completed off-site
- No requirement for cast-in-place concrete monoliths

The selection of the final gate concept for construction should not be based on cost alone. Relative advantages and disadvantages of the alternatives should be weighed in in terms of environmental concerns, relative ease of construction, convenience in gate operations, and sustained cost of maintenance over the life of the design life of the structure. Each of these concerns will need to be further analyzed before the final design of the structure is begins.

After careful consideration, the study team elected to use the cost of the GCCPRD1200 alternative for the enhanced environmental and economic analysis. The GCCPRD1200-Barge would be a largest barge gate in the world. The detailed analysis required to evaluate the feasibility of constructing and operating this structure is not within the scope of the GCCPRD study and exceeds the financial resources available to the study team.

5.3.4. Environmental Review

5.3.4.1. Upland Features

This section provides a summary of the potential environmental impacts associated the construction of the Central Region system. The full Central Region environmental report is located in **Appendices D.2 and D.2.1**.

During Phase 4, the study team conducted a more thorough review of the potential environmental impacts that would be associated with the construction of the three reaches in the Central Region. In order to estimate potential impacts, the study team assumed that the proposed levee and T-wall system would have a 150-foot-wide footprint. This enhanced assessment included: field investigations conducted along publicly assessable rights-of-way, additional desktop analysis, coordination with USACE, and calculating future mitigation requirements using the WVA model. The costs associated with mitigation were incorporated into the overall project cost and considered in the BCR calculations.

Impacts to the following were very minor and insubstantial:

- Prime and Unique Farmlands
- Socioeconomic Impacts
- Protection of Children from Environmental and Safety Risks
- Federal Water Project Recreation Act
- Executive Order 11990: Protection of Wetlands
- Section 303(d) of the Clean Water Act: Impaired Streams
- Section 402 of the Clean Water Act
- Wild and Scenic Rivers
- Vegetation
- Executive Order 13112 on Invasive Species
- Executive Memorandum on Environmentally and Economically Beneficial Landscaping
- Air Quality
- Greenhouse Gas Impacts
- Noise

The primary potential impacts are described in the following sections.

5.3.4.1.1. Cultural Resources

Old Fort Travis, which is listed in the National Register of Historic Places, is located in Fort Travis Seashore Park, a Galveston County Park. This location contains remains of Fort Travis, and the proposed Bolivar Levee would run directly through the property with the current alignment. Coordination with the Texas Historical Commission (THC) would be required.

The Galvez Hotel, The Mosquito Fleet Berth Pier 19, and The Strand are listed in the National Register of Historic Places. At this time, direct impacts are not anticipated to these three historic resources. The Galveston Seawall is also listed in the National Register of Historic Places and was listed in March of 1977.

The Coastal Spine would raise the height of the Galveston Seawall; therefore, coordination with the THC is required in order to reduce any impacts to the historic significance of the seawall.

5.3.4.1.2. Texas Parks and Wildlife Code, Chapter 26

The proposed project would be located within the boundaries of Rollover Island Park, Fort Travis Seashore Park, Stewart Beach Park, Sandhill Crane Soccer Complex, and Galveston Island State Park, which are all Chapter 26 properties. A Public Hearing is required and would be held during the National Environmental Policy Act (NEPA) process in accordance with Chapter 26 requirements.

In addition, the proposed project would be located within the boundaries of the Audubon's Boy Scout Woods Bird Sanctuary and Horseshoe Marsh Bird Sanctuary and the Galveston Bay Foundation Sweetwater Preserve. While these properties have been set aside as wildlife sanctuaries and preserves, they are private properties and do not qualify as Chapter 26 properties.

5.3.4.1.3. Section 404 of the Clean Water Act: Waters of the U.S.

Desktop surveys using U.S. Fish and Wildlife Services' (USFWS) National Wetland Inventory (NWI) maps, USGS 7.5-Minute Topographic Quadrangle maps, Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM), aerial photographs, and limited site surveys were conducted.

There are 289 individual NWI signatures that exist within the levee footprint and would be impacted by the proposed project.

The amount of NWI wetlands within the 150-foot wide levee footprint is as follows:

- Coastal Spine: 90.58 acres
- Bolivar Levee: 55.05 acres
- Galveston Ring Levee: 41.93 acres
- Clear Lake Levee: 12.2 acres

As a result, an Individual Permit (IP) and mitigation would be required.

Table 12 shows estimated costs for two types of wetland mitigation: mitigation banks and preservation, restoration and creation. The total cost of mitigation through mitigation banks would be $54,270,229 and the total cost of preservation, restoration, and creation mitigation would be $14,366,628. These wetland mitigation costs were estimated using the acreage amounts above.

Table 12: Estimated Wetland Mitigation Types and Cost

Segment	Mitigation Bank Cost	Preservation, Restoration, Creation Mitigation Cost
Coastal Spine	$26,044,000	$6,514,066
Bolivar Levee	$13,527,791	$3,959,370
Galveston Ring Levee	$10,885,938	$3,015,731
Clear Lake Levee	$3,812,500	$877,461
Total Central Region Mitigation Cost	$54,270,229	$14,366,628

5.3.4.1.4. Section 401 of the Clean Water Act: Water Quality Certification

The project would impact more than 1,500 linear feet of stream and more than 3 acres of waters of the U.S. The Tier II 401 Certification requirements for the IP would be met by implementing approved erosion controls, sediment controls, and post-construction Total Suspended Solids (TSS) controls.

The design and construction of the proposed project would include construction and post-construction TCEQ 401 Water Quality Best Management Practices (BMPs) to manage storm water runoff and control sediments.

5.3.4.1.5. Rivers and Harbors Act of 1899

Section 9 of Rivers and Harbors Act of 1899 (33 U.S.C. 403; Chapter 425) regulates the construction of any bridge, dam, dike, or causeway over or in navigable waterways of the U.S. Section 10 of the Rivers and Harbors Act of 1899 regulates any structures or work in navigable waters. The proposed project would place gate structures in Galveston Bay across the Houston Ship Channel at Bolivar Roads, Clear Lake, Rollover Pass, and Offatts Bayou, all of which are navigable waters of the U.S. Therefore, this project would require a Section 9 permit from the USCG and a Section 10 permit from USACE.

5.3.4.1.6. Floodplains

The acreage amount in the FEMA 100-year floodplain can be found below:

Table 13: Floodplains

Segment	Acreage Amount in 100-year Floodplain
Coastal Spine	453 acres
Bolivar Levee	486 acres
Clear Lake Levee	28 acres
Galveston Ring Levee	177 acres

The Central Region Alternative must be located in a floodplain in order to reduce flood risk behind the flood protection system. The Central Region Alternative would adhere to the 8-step process as outlined under Executive Order 11988, Floodplain Management, including consideration of sea level rise.

5.3.4.1.7. Coastal Barriers

The proposed Coastal Spine would construct levees through three Coastal Barrier Resource System (CBRS) units; one on Galveston Island and two on Bolivar Peninsula. In order for the proposed Coastal Spine that would go through a CBRS unit to receive federal funds, this project would need to meet at least one exception defined in the U.S. Code (USC) Title 16 Chapter 55 Section 3505 and be consistent with the purpose of the CBRA. The proposed Coastal Spine would meet the exception criteria under 16 USC 3505(a)(6)(E): assistance for emergency actions essential to the saving of lives and the protection of property and the public health and safety and that are necessary to alleviate the emergency. The proposed Coastal Spine would also be consistent with the purpose of the CBRA, which is to minimize the loss of human life; wasteful expenditure of federal revenues; and, in the event of a storm, reduce damage to fish, wildlife, and other natural resources (16 USC 3501(b). Therefore, the proposed project would be eligible for federal funds. The proposed Coastal Spine would traverse through three CBRS units; coordination with USFWS would be required.

5.3.4.1.8. *Texas Coastal Management Program*

For the proposed project, the Texas GLO would have to prepare a Consistency Determination that evaluates the proposed project for consistency with the Texas Coastal Management Program.

5.3.4.1.9. *Wetland Value Assessment*

A Wetland Value Assessment (WVA) was conducted for the Central Region. The environmental period of analysis is a total of 50 years based on the following assumptions: The construction period is assumed to end in 2035. The period for which mitigation benefits are analyzed is 2036-2085.

The direct impacts assume no change in wetlands between the baseline and the future target year without the project and total loss of all wetlands within the footprint due to construction impacts. Table 14 provides of summary of the results of the WVA modeling of direct impacts.

Table 14: Direct Impacts to the Central Region Alternative

Levee System	Marsh Model Type	Acreage	Future w/o project AAHU	Future w/project AAHU	Net Impact
Clear Lake Gate	Brackish	20.28	2.04	1.70	0.34
Bolivar Peninsula	Freshwater	93.47	26.36	19.28	7.08
	Freshwater Near Brackish	7.75	2.40	1.74	0.66
	Brackish	8.17	2.62	1.88	0.74
Bolivar Roads Gate System	Saline	33.8	4.51	3.63	0.88
Galveston Spine	Freshwater	47.46	12.69	9.33	3.36
	Brackish	30.13	4.04	3.25	0.79
Galveston Ring Levee	Freshwater	45.02	10.58	7.88	2.70
	Brackish	17.59	5.12	3.71	1.41
Total		**303.67**	**70.36**	**52.40**	**17.96**

Total direct impacts would affect 303.67 acres of wetlands and result in the net loss of 17.96 Average Annual Habitat Units (AAHU's) over the period of analysis. Mitigation would be needed to compensate for a loss of 17.96 AAHUs from freshwater, brackish, and saline marshes.

5.3.4.1.10. *Galveston Bay Impacts*

Biological impacts to Galveston Bay from the proposed gate at Bolivar Roads were analyzed and are documented in a separate report titled GCCPRD Bolivar Road Gates Biological Effects Analysis in The Bay, Texas.

It is inarguable that storm surge protection is important to the health of coastal ecosystems and communities, particularly for busy ports like Houston. This is especially true considering climate change causing strong storms to occur more frequently. It is likely that installing a barrier at Bolivar Roads will prove necessary and beneficial overall, even though there may also be adverse effects throughout the system from diminishing water flow and sediment exchange between the Bay and the Gulf of Mexico. However, there have been best practices put forward by National Marine Fisheries Service (NMFS) to reduce impacts to fish passage and population dynamics that are outlined here (NMFS, 2008).

The guiding principles for barrier design include the following:

- It should not be assumed that structures that allow for sufficient drainage also optimize fish passage, as these needs may be different
- Larger and more numerous openings in the barrier are better for fish migration
- The cross-section width and depth of the barrier location should be maintained as much as possible to minimize habitat changes, or there should be openings on either side of the barrier nearshore as well as in the center that extend to the bottom
- All gates should remain completely open except during storm events
- Barriers should include shoreline baffles or ramps to aid fish passage
- Average flow velocities during peak flood or ebb tides should not exceed 2.6 ft/s (0.80 m/s) to reduce impediment to fish passage
- Design should allow for rapid opening after the storm passes even if the power source is down
- Plans comprised of several structures (e.g., levees plus gates) should be designed to reduce the number of times fish need to pass through an obstacle (NMFS, 2008)

It became clear during the environmental review that there is a knowledge gap regarding the impacts of storm surge barriers on the ecology of estuarine systems, so assumptions were made based on impingement/entrainment or other related research for both these NMFS guidelines and the analysis conclusions. With the increasing prevalence of strong coastal storms and repeated flooding events, more site-specific research into potential effects will be needed for decision-making and barrier design. This involves biological surveys to determine baseline conditions; a thorough understanding of the life history strategies and migration patterns of representative species of concern; additional knowledge of the effects of the barrier on localized current speeds, and water flow velocity thresholds for different species and life stages.

There are various adverse impacts that could occur to the ecology of Galveston Bay due to the permanent presence of a storm surge barrier gate at Bolivar Roads. These impacts could include reduced tidal amplitude, loss of intertidal mudflat and marsh habitat, reduced discharge, increased current velocities, and impeded migration. In all cases, the 1,200-foot floating sector gate scenario would have less of an adverse impact on the environment than the smaller 840-foot floating sector gate scenario. However, these impacts are of much lower magnitude than the ecological effects caused by hurricanes and storm surge. Therefore, it will be necessary for regulators and stakeholders to weigh the risks and benefits of a short-term but high-impact hurricane storm surge occurring infrequently with the chronic but lower impact effects of a permanent barrier in the Houston Ship Channel between Galveston Bay and the Gulf of Mexico.

In the future, as sea levels continue to rise, the impacts on tidal amplitude associated with the presence of the gate structure may have a positive impact on environmental sensitive areas that would be subject to inundation and continued salt-water migration. This analysis exceeds the scope the study, and should be further evaluated to fully understand these potential benefits.

5.3.4.1.11. Marine Mammal Protection Act of 1972

The proposed alternative would include the installation of gate structures in Galveston Bay across the Houston Ship Channel at Bolivar Roads, Clear Lake, Rollover Pass, and Offatts Bayou. These gate structures would be built within the four waters, therefore the potential for marine mammal impacts needs to be addressed. At these four locations, the proposed alternative could have potential habitat for marine mammals such as the Bottlenose Dolphin (*Tusiops truncatus*) and the West Indian Manatee (*Trichechus manatus*), since these structures are within the Gulf and Bay system. Coordination with the National Oceanic and Atmospheric Administration (NOAA) Fisheries would be required and Marine Mammal Permit would need to be obtained prior to construction.

5.3.4.1.12. Essential Fish Habitat

Essential Fish Habitat (EFH) has been designated in Galveston Bay for Red Drum, shrimp, and reef fish to minimize fisheries-related impacts to these commercially important species (GMFMC, 2005). Coordination with NMFS would be required.

5.3.4.1.13. Threatened and Endangered Species

Review of the USFWS Endangered Species List and Critical Habitat for Galveston and Harris Counties (October 2017), TPWD Annotated County List of Rare Species for Galveston and Harris Counties (October 2017), and a search of the Natural Diversity Database, in conjunction with GIS, was conducted to determine the potential occurrence of State and Federally listed threatened and endangered species and their habitat.

The proposed project may impact the habitat of 18 state-listed species. Prior to construction, coordination with the TPWD would be initiated and BMPs would be implemented to minimize habitat loss and impact to any state-listed species.

The proposed project would impact 47 acres of critical habitat of the threatened Piping Plover (*Charadrius melodus*) along the Coastal Spine levee on Galveston Island. Mitigation cost for the Piping Plover critical habitat impacts was estimated at $20,000 per acre for a total mitigation cost of $940,000.

The proposed project could affect seven other federally listed species or their habitat. Formal coordination with USFWS would be required.

5.3.4.1.14. Hazardous Materials

A hazardous materials regulatory database search was conducted, and there are approximately 231 sites that could pose a risk to the proposed project. More complete hazardous materials site investigations would be done during the NEPA phase of the proposed project.

5.3.4.1.15. Conclusions

The proposed project would involve the following impacts:

- The project would impact two historic resources listed in the National Register of Historic Places and would require coordination with THC.
- Four pubic parks would be impacted, and a Public Hearing per Chapter 26 requirements is required.
- 199.76 acres of potential wetlands would be impacted across the four regional levees. Mitigation would be required and the total estimated cost of mitigation for the Central Region would be $54,270,229 for Mitigation Banking and $14,366,628 for Preservation, Restoration, and Creation.
- The project would impact more than 1,500 linear feet of stream and more than 3 acres of waters of the U.S. and would therefore require Tier II Water Quality Certification from TCEQ.
- The project would involve construction of gates across four navigable waters of the U.S. and would therefore need a Section 9 Permit from the USCG and a Section 10 Permit from USACE.
- The Central Region Alternative must be located in a floodplain in order to reduce flood risk behind the flood protection system. The Central Region Alternative would adhere to the 8-step process as outlined under Executive Order 11988, Floodplain Management, including consideration of sea level rise.
- The project would construct levees within CBRS units. The project would meet the exception criteria under 16 U.S. Code (USC) Title 16 Chapter 55 Section 3505 and would be consistent with the purpose of the CBRA which is to minimize the loss of human life; wasteful expenditure of federal revenues; and, in the event of a storm, reduce damage to fish, wildlife, and other natural resources and would therefore be eligible for federal funds. Additionally, coordination with the USFWS would be required.
- The GLO would have to prepare a Consistency Determination that evaluates the proposed project for consistency with the TCMP.
- A wetland value assessment was performed. Total direct impacts would affect 303.67 acres of wetlands and result in the net loss of 17.96 AAHUs over the period of analysis. Mitigation would be needed to compensate for a loss of 17.96 AAHUs from freshwater, brackish, and saline marshes.
- There are various adverse impacts that could occur to the ecology of Galveston Bay due to the permanent presence of a storm surge barrier gate at Bolivar Roads. These impacts could include reduced tidal amplitude, loss of intertidal mudflat and marsh habitat, reduced discharge, increased current velocities, and impeded migration. Additionally, the project would impact marine and estuarine habitats such as open bay waters, freshwater inlets, freshwater and marine wetlands, seagrass beds, and oyster reefs. The variety of habitat in the Bay supports diverse assemblages of freshwater, estuarine, and marine organisms. Wetlands, seagrass beds, and oyster reef habitats are some of the most important and sensitive habitats within the Bay.
- The proposed project may impact marine mammals. Coordination with NOAA NMFS would be required and Marine Mammal Permit would need to be obtained prior to construction.
- EFH has been designated in Galveston Bay for Red Drum, shrimp, and reef fish. Coordination with NOAA NMFS would be required.
- The proposed project would impact 47 acres of critical habitat of the threatened Piping Plover (*Charadrius melodus*) along the Coastal Spine levee on Galveston Island. The proposed project could affect seven other federally listed species or their habitat. Formal consultation with USFWS would

be required. Mitigation cost for the Piping Plover critical habitat impacts is estimated at $20,000 per acre for a total mitigation cost of $940,000.

- There are approximately 231 hazardous material sites that could pose a risk to the proposed project.
- Several species of invertebrates, fish, birds, reptiles, and terrestrial and marine mammals are supported by the Galveston Bay ecosystems. Commercial fisheries in the Bay include the white and brown shrimp and oysters. The proposed alternative would include the installation of gate structures in Galveston Bay across the Houston Ship Channel at Bolivar Roads, Clear Lake, Rollover Pass, and Offatts Bayou. Therefore, the potential for marine mammal impacts needs to be addressed. At these four locations, the proposed alternative could have potential habitat for marine mammals such as the Bottlenose Dolphin (*Tusiops truncatus*) and the West Indian Manatee (*Trichechus manatus*) since these structures are within the Gulf and Bay system.

5.3.4.2. Galveston Bay Environmental Analysis

To understand the impact of several proposed flood protection barrier gate designs and their potential impact on daily flows, tidal prism, velocities, and salinity within Galveston Bay (the bay) during non-storm conditions, hydrodynamic modeling was conducted using the D-Flow Flexible Mesh model.

Three types of gates were combined to generate a series of gate alternatives:

- Sector gates, which will be used for navigation access into the bay
- Barge gates, which provide a large opening width relative to the size of the abutments on either side and will be used to allow additional flow for environmental considerations
- Vertical lift gates, which provide an effective and low maintenance way to maintain natural tidal flushing of the bay

The gate alternatives analyzed in this study are described in Table 15 and their placement are shown in Figure 23.

Table 15: Summary of Barrier Gate Design Alternatives

Alternative	Navigational Gate Opening (feet)	Number of Environmental Gates	Environmental Gate Total Opening (feet)
GCCPRD840	840	24 VLG	2,400
GCCPRD1200	1,200	24 VLG	2,400
GCCPRD1200-Barge	1,200	15 barge +8 VLG	3,800
USACE-TexasCity	1,200	36 VLG	3,600
USACE-MidBay	1,200	200 VLG	20,000
SSPEED Center Mid Bay Regional Strategy	850	5- VLG	750

Figure 23: Locations Where Barrier Gates Would be Constructed

Note: All GCCPRD alternatives are in the same location, with variations to the number and type of gates only.

5.3.4.2.1. Model Development

The modeling conducted for this study focuses on the simulation of water levels, currents, and salinity due to astronomic tides, wind-driven water levels, and fresh water inflows throughout the bay. A two-phased approach was selected for modeling Galveston Bay. First, the well-exercised ADCIRC model developed and validated for the FEMA FIS (FEMA 2011) and later modified by the GCCPRD storm surge study to represent northern coastal Texas was used to simulate water levels along the Texas Coast, Gulf of Mexico, and Atlantic Ocean. The ADCIRC model results were used to provide offshore boundary conditions to the D-Flow model in the form of water levels at its open boundary. The model domains and their overlap are shown on Figure 24.

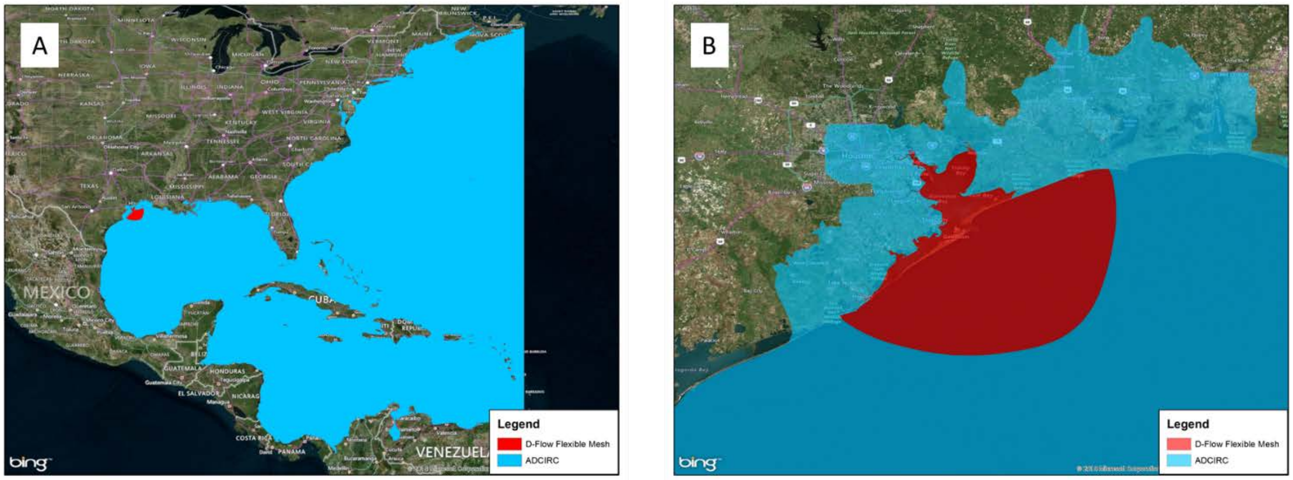


Figure 24: D-Flow and ADCIRC Flexible Mesh Domains

A three-year simulation period between January 1, 2009 through January 1, 2012 was used throughout the modeling for simulations of existing conditions and with the gates in place. The selected period was chosen to represent a range of flow conditions to evaluate the impact of the gates during an average flow year, a wet flow year, and a dry flow year. Selection of the modeling period also considered when adequate data exists to both set up and validate the model. All three flow conditions were conducted as a single simulation to ensure the model could replicate a variety of conditions as well as the transition between conditions without need for recalibration.

5.3.4.2.2. Model Validation

Models were validated using a variety of data sources to ensure that the model made accurate predictions about the water levels and salinities throughout the Bay. NOAA gage data was used to compare tidal harmonics as well as observed water levels at locations throughout the bay, and TWDB was able to provide continuous sampling salinity measurements as well as individual jar samples at many locations.

Figure 25 and Figure 26 show sample comparisons of water level and salinity observations to model predictions. Additional comparisons are available in **Appendix E**.

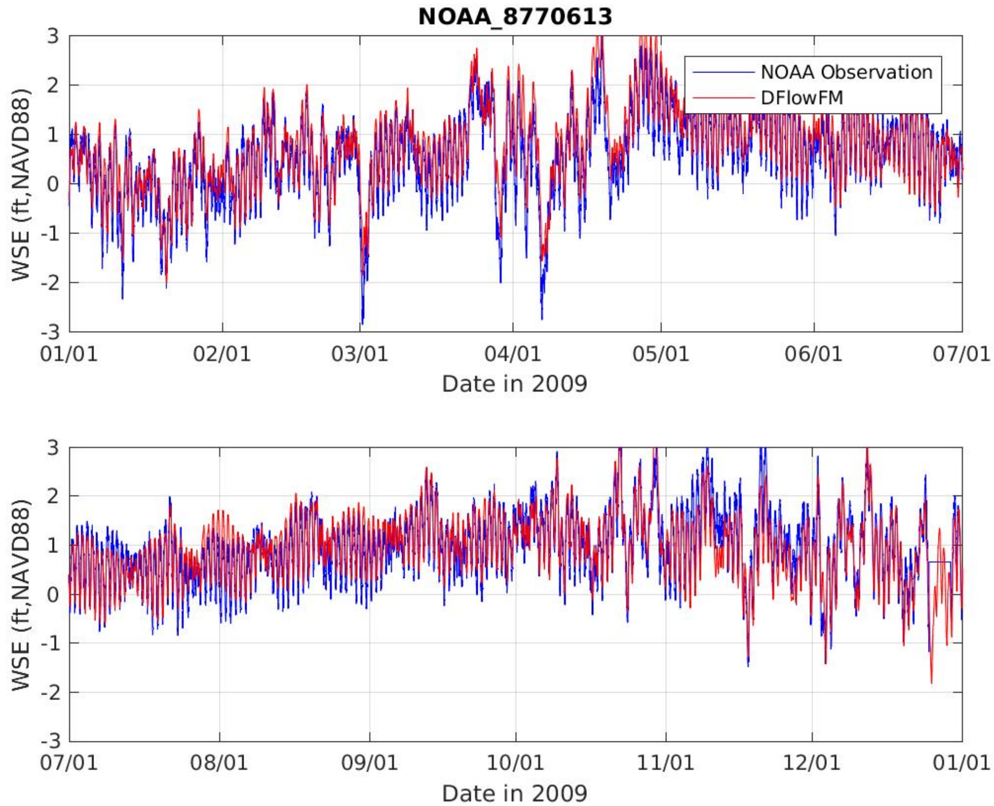


Figure 25: 2009 Water Level Comparisons at NOAA 8770613, Morgan's Point

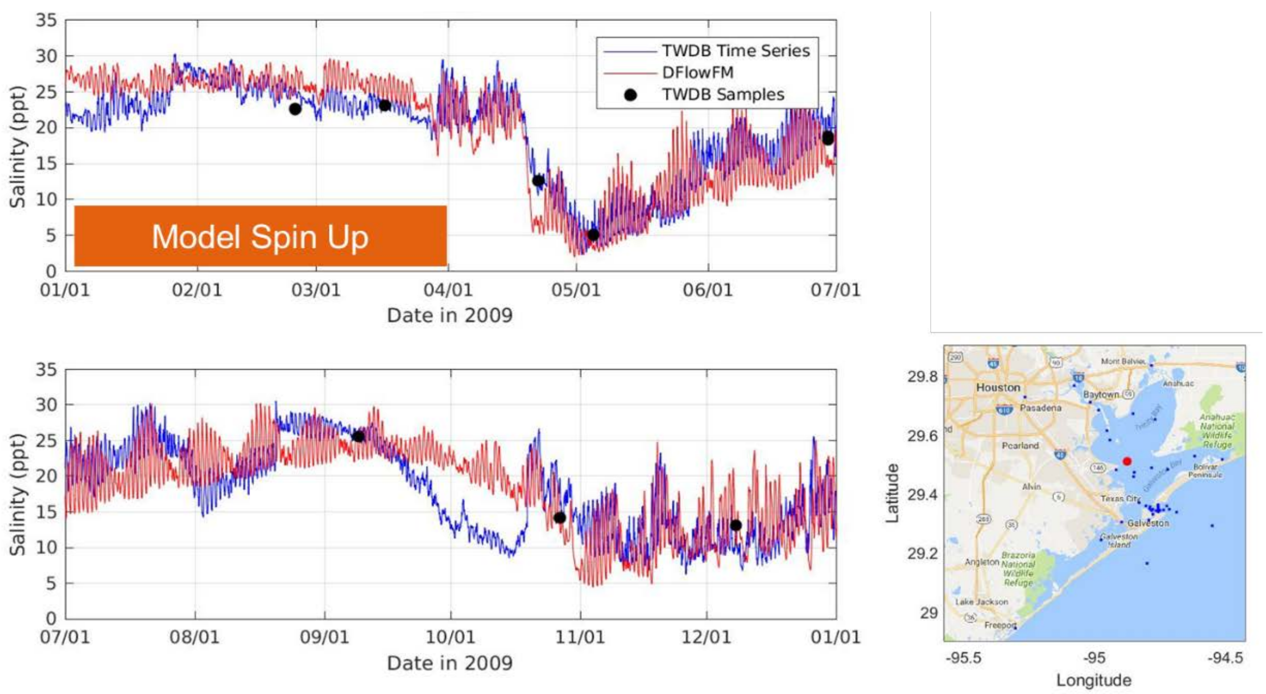


Figure 26: 2009 Salinity Comparisons at Mid Galveston Bay

5.3.4.2.3. Alternatives Evaluation

Gate alternatives for three GCCPRD alignments, two USACE alignments, and the SSPEED center alignment were modeled separately and the results were compared to the flow conditions without gates. Discharge, impact to tide levels, and salinity were compared for each of the scenarios.

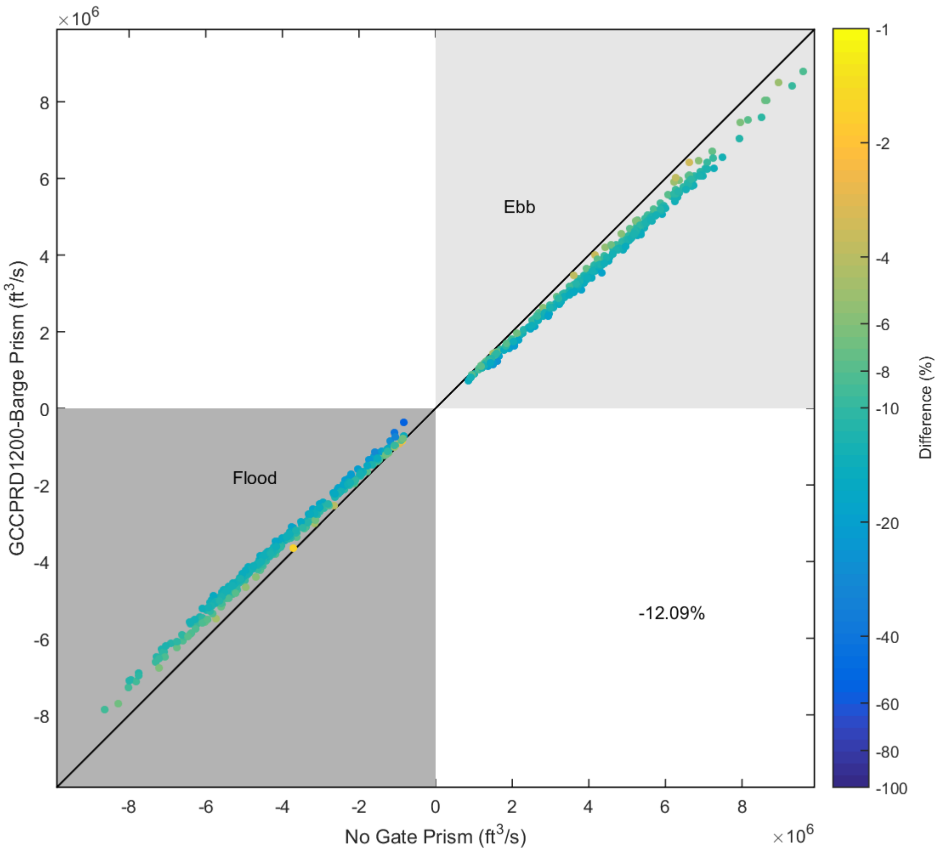


Figure 27: GCCPRD1200-Barge Tidal Prism Comparison at Bolivar Roads

Discharge in and out of the bay increases as the open portion of the gate cross-section increases. The change from the 840-foot opening to the 1,200-foot opening provides an approximately 4.5 percent increase in total discharge at Bolivar Roads. The greatest increase in discharge occurs when using barge gates along the deep portions of Bolivar Roads, which adds a 13 percent increase in discharge from the 840-foot gate.

Water levels in the bay are also impacted. The decreased discharge can result in lower high tides and higher low tides, which is particularly important when determining the impacts to marsh species and habitats. Using a series of tide-only simulations, mean lower low water (MLLW), mean low water (MLW), mean high water (MHW), and mean higher high water (MHHW) datums were computed with and without the barrier gates in place to provide insight into how water levels would be expected to change. Table 16 shows how MLLW, MLW, MHW, and MHHW are affected when each barrier gate configuration is constructed.

Table 16: Impact to Tidal Datums due to Gate Implementation compared to Without Gates (in feet)

	East Bay				Trinity Bay				San Jacinto River				West Bay				Texas City Dike				Dollar Point			
Gate Configuration	MLLW	MLW	MHW	MHHW	MLLW	MLW	MHW	MHHW	MLLW	MLW	MHW	MHHW	MLLW	MLW	MHW	MHHW	MLLW	MLW	MHW	MHHW	MLLW	MLW	MHW	MHHW
GCCPRD840	0.20	0.17	-0.09	-0.10	0.17	0.12	-0.11	-0.13	0.16	0.16	-0.11	-0.14	0.40	0.30	-0.19	-0.26	0.20	0.17	-0.09	-0.10	0.18	0.14	-0.09	-0.10
GCCPRD1200	0.17	0.14	-0.08	-0.08	0.14	0.10	-0.09	-0.11	0.12	0.12	-0.09	-0.12	0.30	0.27	-0.16	-0.22	0.17	0.14	-0.08	-0.08	0.14	0.12	-0.07	-0.08
GCCPRD1200-Barge	0.09	0.07	-0.04	-0.04	0.07	0.05	-0.05	-0.06	0.07	0.07	-0.06	-0.07	0.17	0.18	-0.10	-0.13	0.09	0.07	-0.04	-0.04	0.10	0.08	-0.04	-0.05
USACE-TxCity	0.12	0.10	-0.06	-0.06	0.12	0.10	-0.07	-0.09	0.10	0.09	-0.07	-0.09	-0.10	-0.07	0.06	0.10	0.12	0.10	-0.06	-0.06	0.12	0.11	-0.06	-0.07
USACE-MidBay	0.03	0.02	-0.02	-0.01	0.02	0.00	-0.02	-0.02	0.02	0.02	-0.01	-0.02	-0.05	-0.02	0.01	0.02	0.03	0.02	-0.02	-0.01	0.04	0.03	0.01	0.02
SSPEED	0.03	0.04	-0.03	-0.03	0.06	0.02	0.01	0.01	0.07	0.05	-0.04	-0.04	-0.09	-0.07	0.03	0.05	0.03	0.04	-0.03	-0.03	0.08	0.06	0.00	0.00

Additionally, placing a constriction at the entrance to the bay results in both increases and decreases in depth averaged velocity near the barrier gates. Understanding how and where the velocity increases is important for both ship navigation and environmental concerns such as fish migration. Like other parameters, the changes in velocity correlate well with the change in open area for the various proposed gate designs as shown in Figure 28. Near the navigational channel, the restriction of the opening increases the velocity of water. Away from the gate, the Houston Ship Channel shows decreases in velocity.

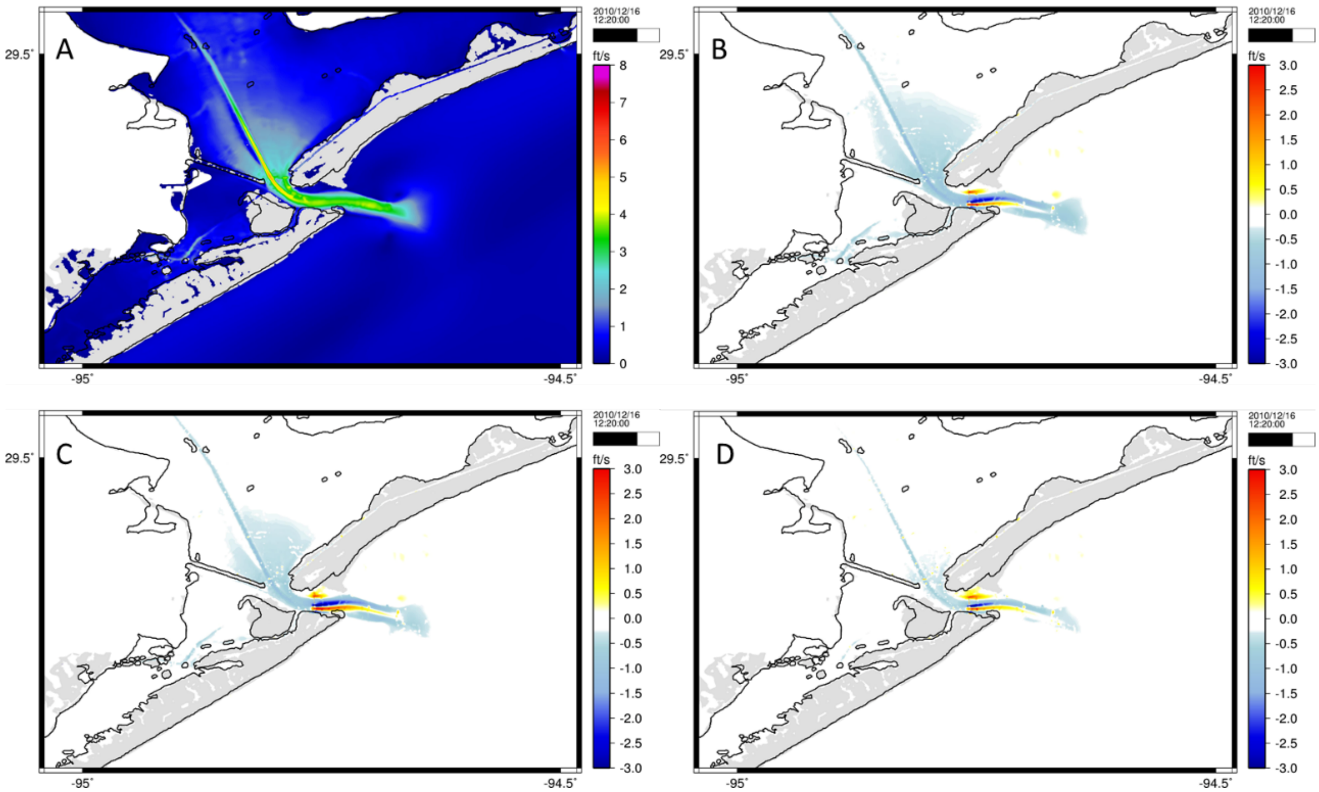


Figure 28: Regional Comparison of Velocities during Ebb Tide (Model A shows the velocity magnitude without gates. Model B shows the change in velocity with GCCPRD840. Model C shows the change in velocity with GCCPRD1200. Model D shows the change in velocity with GCCPRD1200-Barge.)

Salinity comparisons were made by computing the difference between the no-action scenario versus barrier gate installation. Figure 29 shows the salinity changes over a year of simulation at the same locations that the tidal datum calculations were processed. Additional salinity data for other locations in the bay is available in Appendix E.

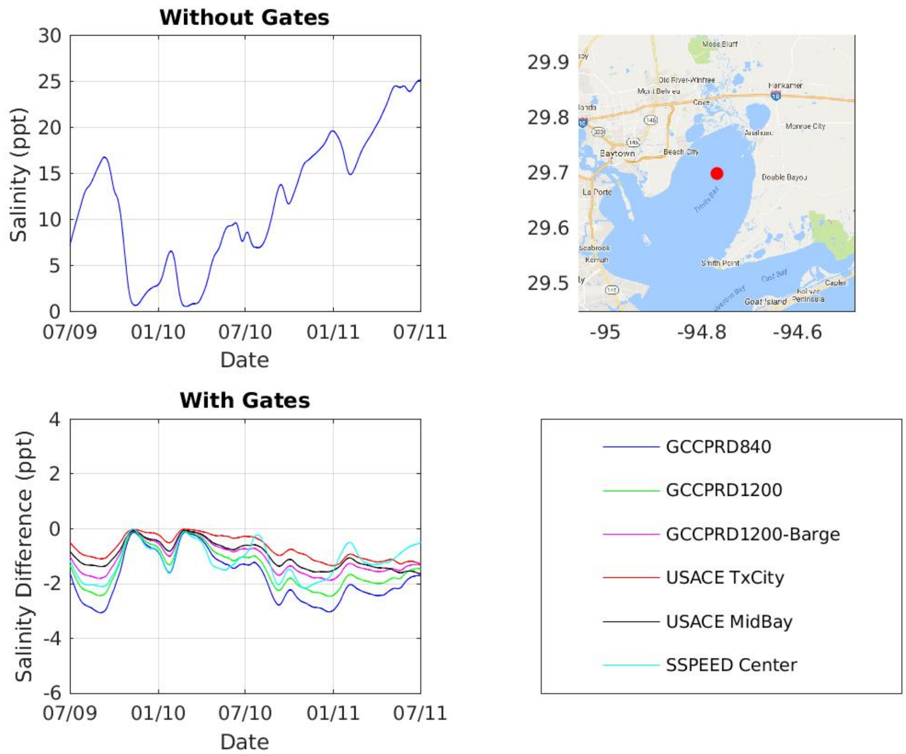


Figure 29: Time Series of Salinity Change in Trinity Bay

The Delft3D-WAQ (Water Quality) model was used to calculate the age of water parcels using a decaying tracer method. This was used as a proxy for impacts to overall water quality since it can quickly describe areas of either stagnation or increased tidal flushing. By injecting both a conservative tracer and a decaying tracer into the bay in identical quantities and comparing their concentrations, the length of time that a parcel of water has existed within the simulation is computed. Figure 30 shows the computed water levels at a single point in the without gates simulation.

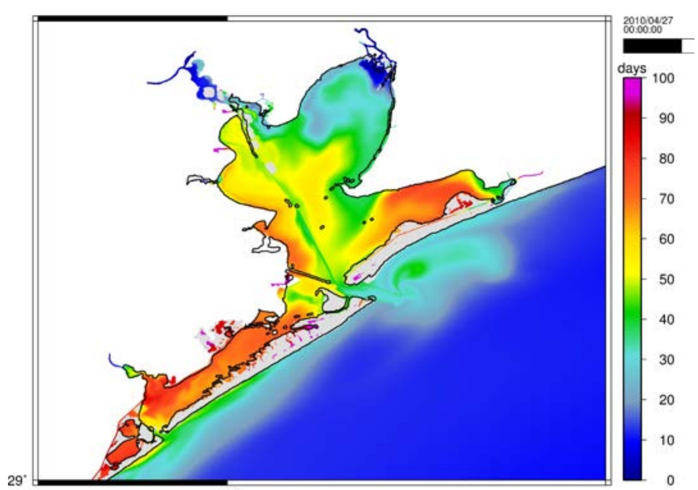


Figure 30: Delft3D-WAQ Water Age Simulation Without Barrier Gates

Figure 31 shows the change to bottom shear stress during ebb tide. Increases and decreases in bottom shear stress correspond to similar changes in velocity. The main navigational gate shows an increase in bottom shear stress in the direction of flow as well as in the areas directly between each of the environmental gates. These increases are present with all barrier gate configurations, though the magnitude is related to the degree of constriction. Decreases in bottom shear stress are present over a much larger area and extend inside into the bay along the Houston Ship Channel.

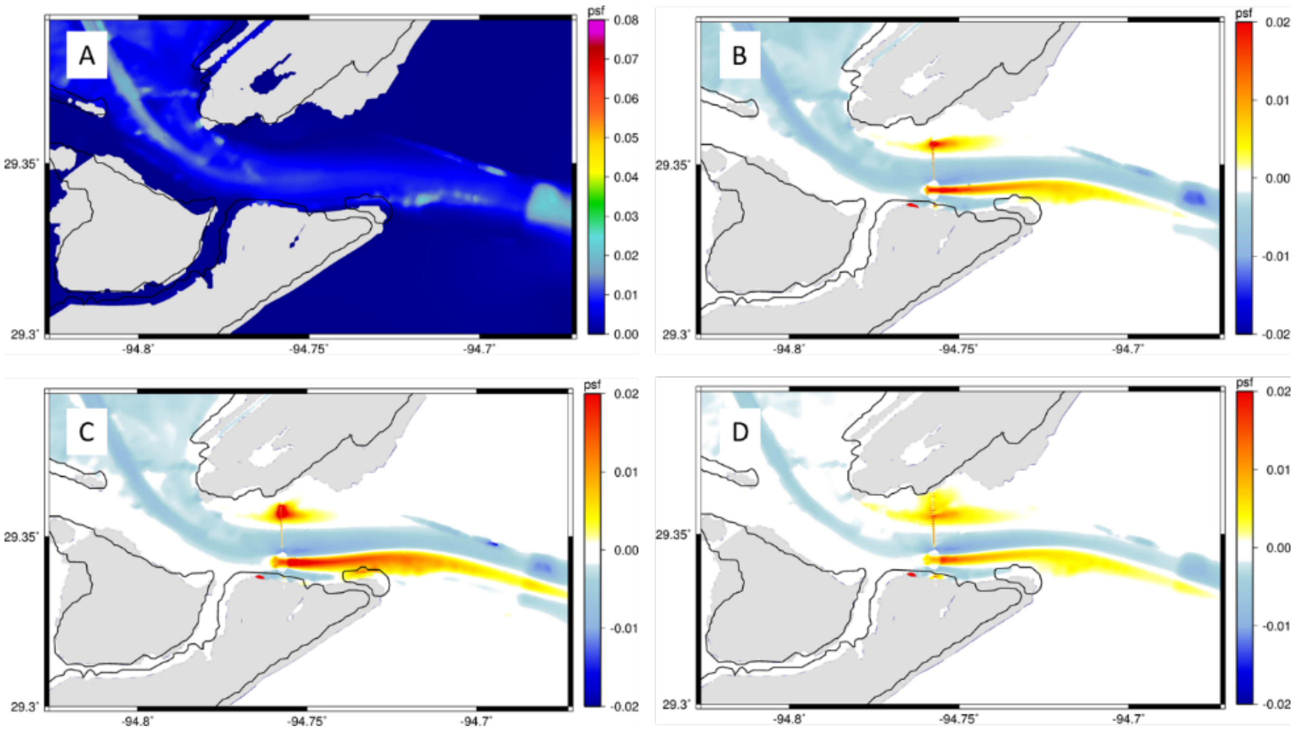


Figure 31: Bottom Shear Stress (psf) during Ebb Tide for (A) No Gates and the Change in Bottom Shear Stress for (B) GCCPRD840, (C) GCCPRD1200, and (D) GCCPRD1200-Barge

5.3.4.2.4. Conclusions

The D-Flow model developed for this study is designed to investigate the impacts to water levels, discharge, salinity, and potential changes in sediment transport and morphology in Galveston Bay. The model was successfully calibrated to match both water levels and salinity based upon available observation data.

Using the model to evaluate the different proposed gate configurations draws the following conclusions:

- The model shows that the reduction in tidal prism is proportional to the reduction in flow area.
- The salinity of the bay is controlled largely by the freshwater inflows to the bay, however the reduction in flow area at Bolivar Roads due to implementing the gates tends to result in a reduction of salinity throughout the system.
- The GCCPRD gate configurations with the largest open cross section, the GCCPRD1200-Barge configuration, result in the least impacts to hydrodynamics, salinity, and water age compared to other proposed gate configurations at Bolivar Roads.

- The model shows that there will be increased potential for sediment deposition in the Houston Ship Channel due to the reduction in shear stresses. Since dredging operations are already required, a morphology study should be conducted to understand this in greater detail.
- The USACE Texas City gate performs similarly to the GCCPRD1200-Barge. Though the USACE Texas City gate is constructed only vertical lift gates, it has the advantage that it does not close off flow from Bolivar Roads to the West Bay
- The results from the modeling conducted in this study can be used to inform environmental studies for marsh, shellfish, fish migration, and larval transport as part of a larger environmental impact assessment.

5.3.5. Cost and Economics Review

As discussed in section 5.3.1, the optimal crest elevation for the Coastal Spine which manages risk associated with a 100-year event is 17 feet and remains unchanged from the 2016 recommended plan. Based on the additional environmental and interior drainage analysis conducted during Phase 4, the overall cost of the project increased which was a factor that caused the BCR for the Central Region to decrease.

Environmental mitigation costs were revised based on the detailed analysis that was conducted to better assess impacts related to upland features as well as within Galveston Bay. Mitigation costs within the region varied between $54,270,229 and $14,366,628, depending on the method of mitigation selected. The Central Region offers the best opportunities for on-site mitigation and this method should be used exclusively to ensure mitigation of impacted nature resources remain within close proximity to where the impact occurred.

The detailed analysis for the interior drainage resulted in an increase in pumping requirements and overall cost especially for the Galveston Ring Levee. Storm surge overtopping the seawall was the main driver resulting in the increased pumping requirements. Raising the seawall to between 24 and 25 feet would reduce the overtopping however, this would create other negative economic and social impacts for the City of Galveston.

Table 17 provides the updated cost and economics summary for the Central Region. The components of the Central Region plan were modeled as a completed system and not individually. Therefore, the Total Annual Cost, Total Annual Benefits, and the BCR are reflected for the region. All benefits and costs are presented in thousands of dollars and reflect 2018 price levels.

Table 17: Revised Economics for the Recommended Plan (17 feet) for the Central Region

Central Region Summary	Coastal Spine	Galveston Ring Levee*	Clear Lake Gate	Total
Total length of the system (miles)	57.0	10.5	1.7	69.2
Right of way required (acres)	1,220	71	33	1524
Pump stations required / total capacity (CFS)	0 / 0	3/117,000	1/10,900	4/127,900
Environmental mitigation required (acres)	220.78	62.61	20.28	303.67
Construction cost ($000)	$6,206,250	$3,422,084	$492,502	$10,120,836
Annual operations and maintenance cost ($000)	31,031	17,110	2,463	50,604
Total Annual Costs (TAC)				522,479
Total Annual Benefits (TAB)				842,287
Benefit - Cost Ratio (TAB/TAC) (2.875 % Interest Rate)				1.61

** Length of the Galveston Seawall is included in the Coastal Spine Length*

5.3.6. Central Region Conclusions

The analysis of the optimal elevation of the Coastal Spine for the 100-year event in 2085 is 17 feet. Raising the spine elevation to 20 feet results in a slight loss of net benefits due to the increase in cost being greater than the increase in benefits. Lowering the spine elevation to 15 feet increases benefits, reduces cost, and results in an increase in net benefits but does not meet the FEMA goal of providing protection from the 100-year event. Property owners would not see the desired relief in the annual flood insurance rates.

The study reviewed various options for the gate complex at Bolivar Roads. Analysis clearly showed that the width of the floating sector gate crossing the Houston ship Channel should be 1,200 feet or larger and the structure should have a minimum of 24 vertical lift gates to enhance environmental flow conditions. The GCCPRD1200-Barge analysis greatly enhanced environmental flow however, the operation aspects of the system are cumbersome and complex. The final gate configuration will require further technical and environmental analysis to determine the best solution to reduce flood risk while limiting environmental impacts.

The interior drainage and pumping requirements for the Galveston Ring Levee are substantial due to the extreme overtopping along the seawall. More detailed modelling on the configuration of the wall should also be evaluated to see if a recurved face or other innovative solution could help reduce the overtopping.

6. South Region Optimization Results

6.1. General

The South Region of the GCCPRD study area consists of Brazoria County, which borders Galveston Bay and the Gulf of Mexico on the south-eastern boundary. The portion of the county from the Gulf of Mexico to north of SH 35 is highly vulnerable to tropical storm surge flooding.

The county is partially protected by the existing federally authorized Freeport Hurricane-Flood Protection Levee System (FHFPS). The FHFPS consists of over 45 miles of levees, 14 pump stations, a navigation gate structure and numerous other drainage structures. The system protects the cities of Freeport and Angleton, Port Freeport, and the strategically important petrochemical industry in the Freeport Vicinity, including the Strategic Petroleum Reserve. The system has performed very well through numerous storms especially during Hurricane Ike when the storm surge came within 2 feet of overtopping the levee.

6.2. Phase 3: South Region Recommended Plan

The South Region recommended plan consists of five distinct reaches that would provide enhanced protection to the cities of Freeport, Lake Jackson, Clute and Angleton, Port Freeport, Jones Creek, the tank farm south of Jones Creek, the industrial complexes located along Chocolate Bayou and behind the existing FHFPS.

The plan consists of:

- **Reach 1 – Freeport Hurricane Flood Protection Levee System modernization –** This reach consists of upgrading the federally authorized FHFPS and the locally owned and operated levee system along Buffalo Camp Bayou by raising the levees for the 100-year event in 2085 and installing a new vertical lift gate at the entrance to the Dow Barge Canal.
- **Reach 2** consists of extending the eastside of the existing FHFPS north through Richwood toward Angleton. The proposed extension would cross Oyster Creek and continue north parallel to the west side of Brazosport Boulevard North, through Richwood, crossing SH-2004 and CR 220 and terminating at high ground south of Iden Road. The major elements of this reach include: 38,425 feet of new levee, 22 drainage structures, nine roadway gates, and one new pump station. Elevations in this reach vary from 19 feet to 20 feet.
- **Reach 3 – Jones Creek Levee –** This reach consists of a partial ring levee around the community of Jones Creek. The northern terminus of the proposed levee begins at high ground east of the intersection of SH-2004 and SH-2611 and continues east along the high ground and parallel to the north side on SH-36. The system then turns south crossing SH-36 and follows the southern perimeter of the Jones Creek community (SH-295). At Robin Hood Lane, the system turns back to the west following the high ground back to SH-2611. The major elements of this reach include: 50,625 feet of new levee, eight drainages structures, one highway gate, and one new pump station. Elevations in this reach vary from 18.5 feet to 20 feet.
- **Reach 4 – Jones Creek Terminal Ring Levee –** This reach consists of a ring levee around the existing tank farm boundary. The major elements of this reach include: 15,995 feet of new levee, three drainage structures, one roadway gates, and one new pump station. Elevations in this reach are 21 feet.
- **Reach 5 – Chocolate Bayou Ring Levee –** This reach consists of a ring levee around the existing Chocolate Bayou petrochemical complex. The major elements of this reach include: 65,990 feet of new levee, 13 drainage structures, six roadway gates, and one new pump station. Elevations in this reach vary from 20.5 feet to 24.5 feet.

Figure 32 illustrates the South Region Recommended Plan and the optimization alignments.

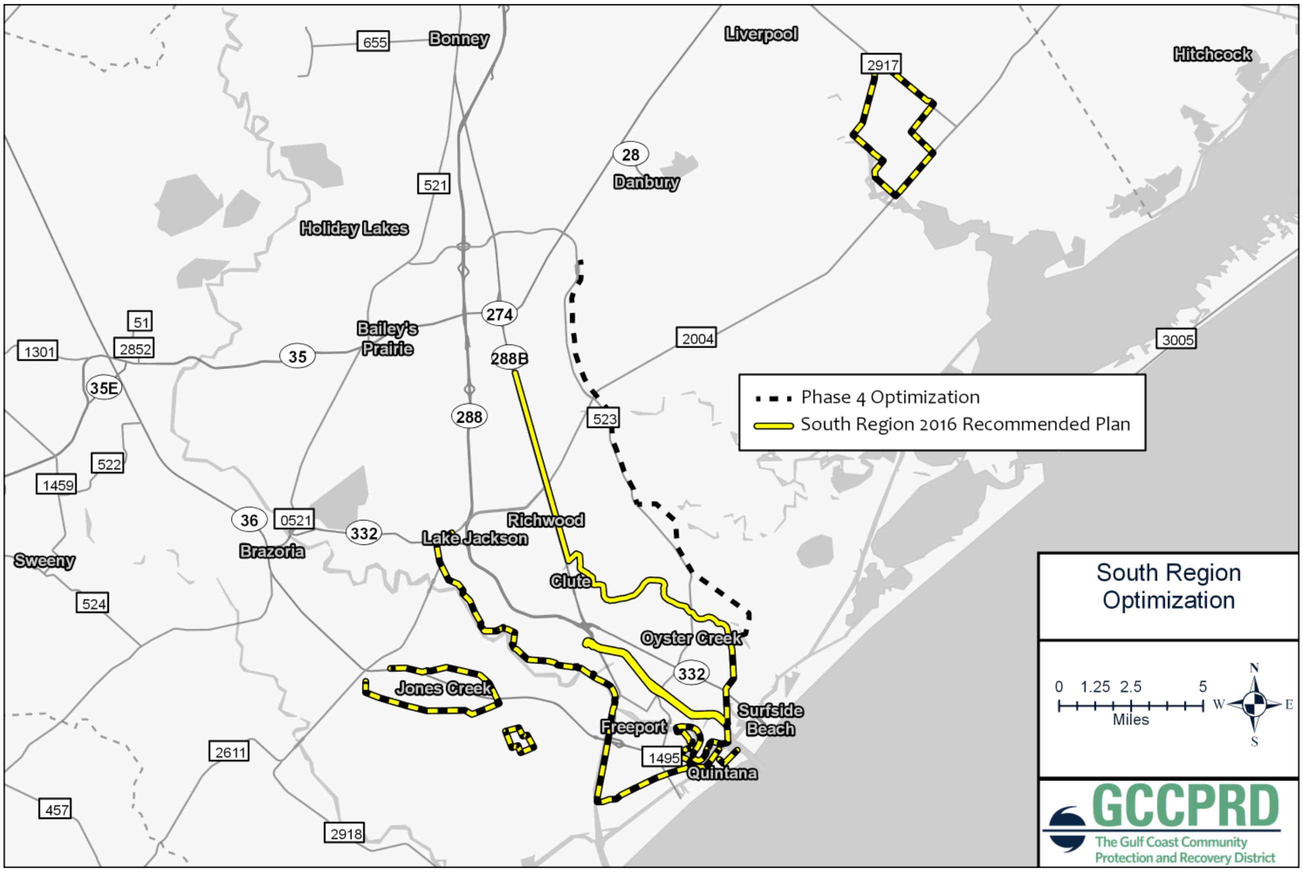


Figure 32: South Region Recommended Plan

The 2016 recommended plan had a construction cost of $2.5B and a Regional BCR of 1.47.

6.3. Optimization Measures

The optimization process for the South Region consisted of the following steps:

- Comparison of alignments and lengths to USACE Sabine to Galveston Study (SP2G study)
- Modification of Reach 2 along FM 523 to provide additional regional protection
- Separate examination and analysis of interior water levels for each Reach of the proposed system
- Enhanced Environmental analysis
- Revision of cost and economics based on the more detailed technical and environmental analysis

6.3.1. Comparison to USACE SP2G study

The USACE SP2G study generally aligns with the recommendations made by the GCCPRD for improvements to the FHFPS. The USACE study focused on the required improvements for the existing FHFPS. Prior to the start of the study, the local sponsor, Velasco Drainage District, was working closely with USACE on the implementation of a system-wide improvement framework plan in order to correct deficiencies and comply with USACE policies and FEMA levee certification requirements.

The GCCPRD study team evaluated additional areas outside of the existing FHFPS that would become vulnerable to storm surge flooding by 2085. This evaluation indicated that the existing FHFPS would need to be elevated and extended to reduce the risk of overtopping and wrap around flooding. Additionally, the GCCPRD evaluated and recommended a plan to reduce the risk to the community of Jones Creek, a tank farm complex south of Jones Creek and the petrochemical complex located along Chocolate Bayou. USACE will be evaluating the requirements for Chocolate Bayou as a part of their ongoing Texas Coastal Study.

6.3.2. Optimization of FHFPS Extension along FM 523

During Phase 4, a different alternative for the extension of the eastside of the FHFPS was evaluated. This new alignment generally parallels FM 523. The new extension reduces flood risk for an additional 20,000 acres of vulnerable land which coincides with the area where current and future residential and industrial economic development is occurring. Figure 33 illustrates the alignment and the associated levee elevations.

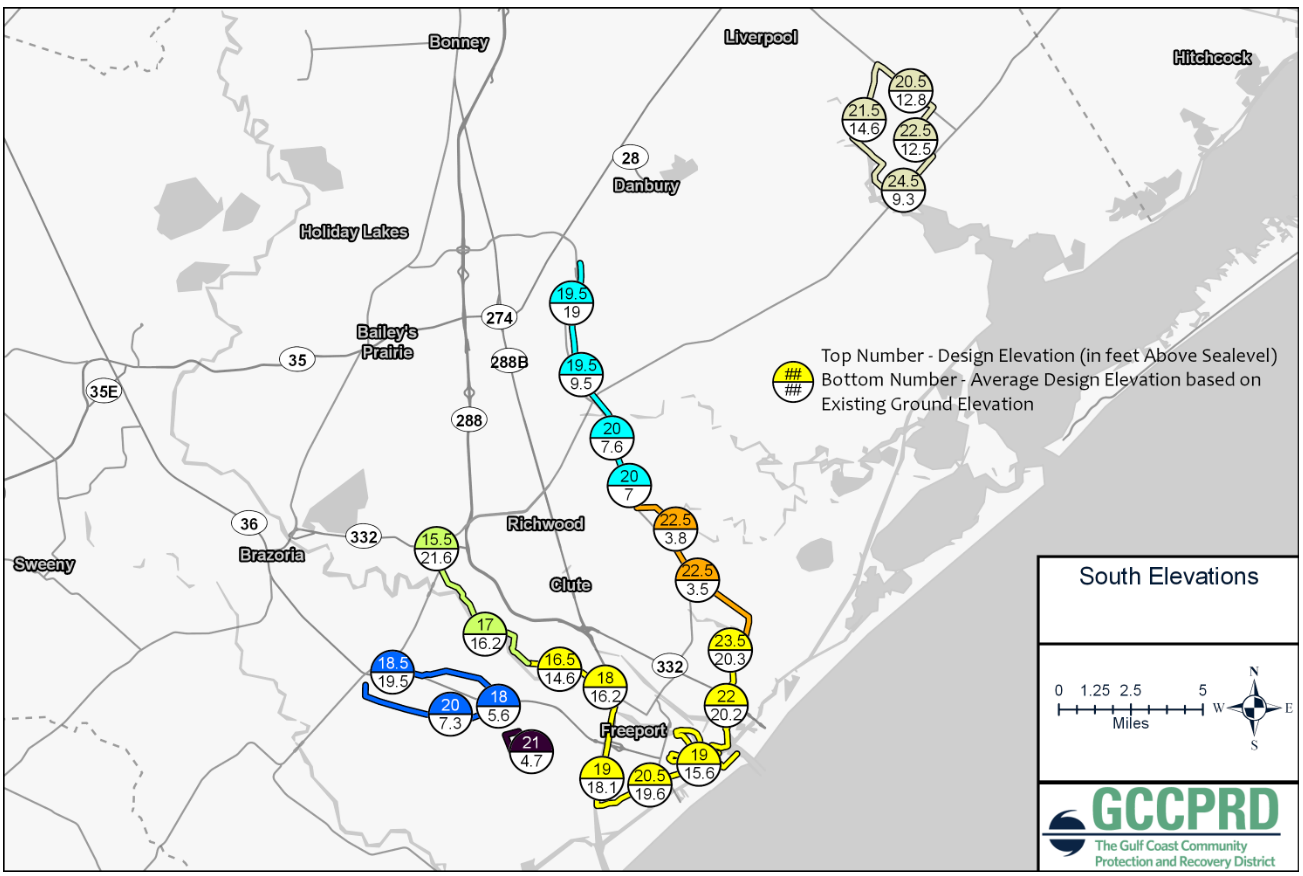


Figure 33: FHFPS Extension along FM 523

6.4. Interior Water Level and Drainage Interior Drainage

Interior drainage for the existing and proposed levees of the Southern Region GGCPRD included sizing pumps and mapping the floodplains for various rainfall and storm surge scenarios of varying annual recurrence intervals for each proposed levee alignments. The pumps associated with each levee alignment were sized to maintain internal flooding levels that result in minimal damage to properties and structures for a hurricane that simultaneously produces a 25-year internal rainfall event inside the levee and a 100-year storm surge that overtops the designed levee. The pump sizing from this phase of the study were used to refine the construction cost and the BCR for the FWA 2085 scenario.

6.4.1. Methodology

Five scenarios were run for each watershed; the 25-year Internal Rainfall (IN) with the 50-year, 100-year, 200-year, and 500-year Overtopping Storm Surge (OT) and the 100-year internal with the 25-year over topping. The same scenarios were run for the FHFPS for both the Future with Action and the Future Without Action to establish a baseline for comparison.

Existing HEC-1 models for Brushy Bayou, Bastrop Bayou, and Oyster Creek were sourced from the 2002 Brazoria County Master Drainage Plan (MDP), converted to HEC-HMS Ver 4.2, verified against original model output, updated with current meteorological models, and modified accordingly with the reservoirs and time series data.

HEC-HMS models for the Chocolate Bayou Levee, Freeport West Levee, Jones Creek Terminal Levee, and Jones Creek Levee were created for this project, as existing models were either unavailable. These models were created with one basin for each pump station. One runoff hydrograph was sufficient to define the hydraulic response of each leveed watershed. The new models utilize Green Ampt Loss parameters representative of Soil Type D and Clarks Unit Hydrograph Transform method congruent with models sourced from 2002 Brazoria County MDP.

The meteorological model input was derived from the Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas SIR 2004-5041 for a 24-hour event. A 67 percent rainfall hyetograph peak distribution was used to align the peak of the rainfall to the peak storm surge. In the models, rainfall peak is generally at hour 16 and runoff peak is at hour 20.

6.4.1.1. Overtopping methodology

Output from Advanced Circulation (ADCIRC) models of the storm surge for 50-year, 100-year, 200-year, and 500-year were used to derive overtopping hydrographs for each levee alignment. Separate hydrographs were derived to the three watersheds, Oyster Creek, Bastrop Bayou, and Brushy Bayou, protected by the Freeport East Levee along FM 523. Overtopping hydrographs peaked around hour 40 of the analysis at the peak flows.

Table 18 illustrates that the storm surge either does not overtop or negligibly overtops some levee segments in multiple storm surge events. With the rainfall event remaining constant, the model yields identical results for different combinations of events in the same watershed, such as Brushy Bayou, where the 25-IN/50-OT, 25-IN/100-OT, and 25-IN/200-OT remain constant.

Table 18: Overtopping Data

Event	Jones Tanks (cfs)	Mustang Lake (cfs)	Oyster Creek (cfs)	Bastrop Bayou (cfs)	Brushy Bayou (cfs)	Jones Creek (cfs)	DOW FWA (cfs)	DOW FWOA (cfs)
50-yr	-	-	1	-	-	-	20	2,800
100-yr	-	-	480	1	-	5	547	75,400
200-yr	74	2	8,400	1,570	-	2,120	13,900	584,000
500-yr	3,700	274	82,600	172,000	38,500	130,000	327,000	2,570,000

The time to peak of the rainfall runoff hydrograph and storm surge overtopping hydrograph were offset approximately 20 hours. Because of the offset of peaks, overtopping events with low volume have little impact to the flooding within the levee. The best example of this is the comparison between the 25-IN/100-OT and the 25-IN/200-OT for the Jones Creek Levee. The 100-OT peak is 5 cfs and the 200-OT is 2,120 cfs. Despite the significant difference in peak OT rate, the ponding within the levee never exceeds the runoff ponding from rainfall runoff.

The calculated ponding elevation for each scenario with the Design Pump Rate applied as the only means of discharge is in the table below.

Table 19: Results Summary

Alignment Reach		Pump Capacity Required (cfs)	Pump Capacity Currently Available (cfs)	Interior Ponding Elevation (ft)	25-IN 100-OT
Freeport East Levee (along FM 523)	Brushy Bayou	0	0	19.9	19.9
	Bastrop Bayou	5,100	0	7.0	7.0
	Oyster Creek	4,850	0	6.0	6.0
Freeport West Levee (FHFPS)	DOW FWA	10,627	10,627	5.5	5.5
	DOW FWOA	10,627	10,627	5.5	5.5
Jones Creek Levee		600	0	8.2	8.2
Jones Creek Terminal Levee		54	0	4.2	4.2
Chocolate Bayou Levee		325	0	11.0	11.0

Since the Freeport East Levee, the Jones Creek Levee, and the Jones Creek Terminal Levee segments are new features, the recommended pumping capacity will need to be added to the system by constructing new facilities. The Freeport West Levee consists of the existing FHFPS and the pumping capacity currently within the system is sufficient, so no new pumping facilities are required.

6.4.2. Environmental Review

This section provides a summary of the potential environmental impacts associated the construction of the South Region system. The full South Region environmental report is located in **Appendices D3-D3.1**.

During Phase 4, the study team conducted a more thorough review of the potential environmental impacts that would be associated with the construction of the five reaches in the South Region. In order to estimate potential impacts, the study team assumed that the proposed levee and T-wall system would have a 150-foot-wide footprint. This enhanced assessment included: field investigations conducted along publicly assessable rights-of-way, additional desktop analysis, coordination with USACE, and calculating future mitigation requirements using the WVA model. The cost associated with mitigation were incorporated into the overall project cost and considered in the BCR calculations.

Impacts to the following were very minor and insubstantial:

- Prime and Unique Farmlands
- Socioeconomic Impacts
- Protection of Children from Environmental and Safety Risks
- Federal Water Project Recreation Act
- Executive Order 11990: Protection of Wetlands
- Section 303(d) of the Clean Water Act: Impaired Streams
- Section 402 of the Clean Water Act
- Wild and Scenic Rivers
- Coastal Barriers
- Vegetation
- Executive Order 13112 on Invasive Species
- Executive Memorandum on Environmentally and Economically Beneficial Landscaping
- Migratory Birds and the Migratory Bird Treaty Act
- Fish and Wildlife Coordination Act
- Bald Eagle Protection Act of 1940
- Marine Mammal Protection Act of 1972
- Air Quality
- Greenhouse Gas Impacts
- Noise

The primary potential impacts are described in the following sections.

6.4.2.1. Cultural Resources

A preliminary assessment of the cultural resources within the South Region Alternative was conducted using a combination of a desktop review of the Texas Historic Sites Atlas and further confirmation of the mapped sites during a site visit. The Area of Potential Effect (APE) for historic resources is 150-feet, 75-feet on either side of the alternative for direct impacts and 1,500-feet, 750-feet on either side, for indirect impacts.

Part of the Velasco Cemetery is within the 150-foot APE of the Freeport Levee. Therefore, the alignment of the Freeport Levee will need to be shifted to avoid this cemetery during the design phase to avoid direct impacts.

According to the Texas Historic Sites Atlas, Futch Cemetery appears to be within the 1,500-foot APE of the Jones Creek Levee. However, Futch Cemetery was not observed during the field visit, so the exact location is unknown and unconfirmed. Based on current information for the proposed project, any impacts to the Futch Cemetery would be indirect. Two additional historical markers would be impacted. The Bryan Mound marker is within the 1,500-foot APE for indirect impacts. The marker for the Velasco Ghost Town is approximately 95-feet from the existing Freeport Levee and could be directly impacted by levee modification.

6.4.2.2. Texas Parks and Wildlife Code, Chapter 26

The proposed project would be located within the boundaries of Brazoria National Wildlife Refuge, Justin Hurst Wildlife Management Area, Riverside Park and MacLean Park, which are all Chapter 26 properties. Brazoria National Wildlife Refuge is northeast of Freeport along the Freeport Levee. Justin Hurst Wildlife Management Area is west of Freeport and south of Jones Creek along the Jones Creek Levee and Tank Farm Levee. Riverside Park is a City of Freeport park along the Freeport Levee. MacLean Park is a City of Lake Jackson park along the Freeport Levee. A Public Hearing is required and would be held during the National Environmental Policy Act (NEPA) process and in accordance with Chapter 26 requirements.

6.4.2.3. Section 404 of the Clean Water Act: Waters of the U.S.

Desktop surveys using U.S. Fish and Wildlife Services' (USFWS) National Wetland Inventory (NWI) maps, USGS 7.5-Minute Topographic Quadrangle maps, Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM), aerial photographs and limited site surveys were conducted.

There are 262 individual NWI signatures that exist within the levee footprint and would be impacted by the proposed project.

The amount of NWI wetlands within the 150-foot wide levee footprint is as follows:

- Jones Creek Levee: 17.62
- Tank Farm Levee: 25.2
- Freeport Levee: 70.77 acres
- Chocolate Bayou Ring Levee: 28.86 acres

As a result, an Individual Permit (IP) and mitigation would be required.

Table 20 shows estimated costs for two types of wetland mitigation: mitigation banks and preservation, restoration and creation. The total cost of mitigation through mitigation banks would be $36,171,210, the total cost of for preservation, restoration, and creation mitigation would be $10,350,445. These wetland mitigation costs were estimated using the acreage amounts above.

Table 20: Estimated Wetland Mitigation Types and Cost

Segment	Mitigation Bank Cost	Preservation, Restoration, Creation Mitigation Cost
Jones Creek Levee	$4,294,875	$1,267,283
Tank Farm Levee	$6,142,500	$1,812,460
Freeport Levee	$17,920,897	$5,090,716
Chocolate Bayou Ring Levee	$7,812,938	$2,179,986
Total South Region Mitigation Cost	$36,171,210	$10,350,445

6.4.2.4. Section 401 of the Clean Water Act: Water Quality Certification

The project would impact more than 1,500 linear feet of stream and more than 3 acres of waters of the U.S. The Tier II 401 Certification requirements for the IP would be met by implementing approved erosion controls, sediment controls, and post-construction Total Suspended Solids (TSS) controls.

The design and construction of the proposed project would include construction and post-construction TCEQ 401 Water Quality Best Management Practices (BMPs) to manage storm water runoff and control sediments.

6.4.2.5. Rivers and Harbors Act of 1899

Section 9 of Rivers and Harbors Act of 1899 (33 U.S.C. 403; Chapter 425) regulates the construction of any bridge, dam, dike or causeway over or in navigable waterways of the U.S. Section 10 of the Rivers and Harbors Act of 1899 regulates any structures or work in navigable waters. The proposed project would modify a gate across the Brazosport Turning Basin and add a new gate across the Dow Barge Canal, both of which are navigable waters of the U.S. Therefore, this project would require a Section 9 permit from the USCG and a Section 10 permit from USACE.

6.4.2.6. Floodplains

The acreage amount in the FEMA 100-year floodplain can be found below:

Table 21: Floodplains

Levee	Acreage Amount in 100-year Floodplain
Chocolate Bayou Ring Levee	161 acres
Freeport Levee	268 acres
Jones Creek Levee	111 acres
Tank Farm Levee	41 acres

The South Region Alternative must be located in a floodplain in order to reduce flood risk behind the flood suppression system. The South Region Alternative would adhere to the 8-step process as outlined under Executive Order 11988, Floodplain Management, including consideration of sea level rise.

6.4.2.7. Texas Coastal Management Program

For the proposed project, the Texas GLO would have to prepare a Consistency Determination that evaluates the proposed project for consistency with the Texas Coastal Management Program.

6.4.2.8. Wetland Value Assessment

A Wetland Value Assessment (WVA) was conducted for the South Region. The environmental period of analysis is a total of 50 years based on the following assumptions: The construction period is assumed to end in 2035. The period for which mitigation benefits are analyzed is 2036-2085.

The direct impacts assume no change in wetlands between the baseline and the future target year without the project and total loss of all wetlands within the levee footprint due to construction impacts. Table 22 provides a summary of the results of the WVA modeling of direct impacts.

Table 22: Direct Impacts to the South Region Alternative

Levee System	Marsh Model Type	Acreage	Future w/o project AAHU	Future w/project AAHU	Net Impact
Tank Farm Levee	Freshwater	30.39	6.85	5.12	1.73
Jones Creek Levee	Freshwater	31.69	8.49	6.24	2.25
Chocolate Bayou Ring Levee	Freshwater	10.03	2.68	1.97	0.71
	Freshwater Near Brackish	8.82	3.37	2.41	0.96
	Brackish	9.20	2.64	1.91	0.73
Freeport Levee	Freshwater	41.02	10.50	7.75	2.75
	Freshwater Near Brackish	53.19	14.87	10.89	3.98
	Brackish	10.13	3.30	2.37	0.93
Total		**194.47**	**52.69**	**38.65**	**14.04**

Total direct impacts would affect 194.47 acres of wetlands and result in the net loss of 14.04 Average Annual Habitat Units (AAHU's) over the period of analysis. Mitigation would be needed to compensate for a loss of 14.04 AAHUs from freshwater and brackish marshes.

6.4.2.9. Essential Fish Habitat

Essential Fish Habitat (EFH) has been designated in the project area for Red Drum, shrimp, and reef fish to minimize fisheries-related impacts to these commercially important species (GMFMC, 2005). Coordination with National Marine Fisheries Service (NMFS) would be required.

6.4.2.10. Threatened and Endangered Species

Review of the USFWS Endangered Species List and Critical Habitat for Brazoria County (October 2017), TPWD Annotated County List of Rare Species for Brazoria County (October 2017), and a search of the Natural Diversity Database, in conjunction with GIS, was conducted to determine the potential occurrence of State and Federally listed threatened and endangered species and their habitat.

The proposed project may impact the habitat of seventeen state-listed species. Prior to construction, coordination with TPWD would be initiated and BMPs would be implemented to minimize habitat loss and impact to any state-listed species.

The proposed project would not impact or effect any federally listed species or its habitat

6.4.2.11. Hazardous Materials

A hazardous materials regulatory database search was conducted for the region. There are approximately 337 sites that could pose a risk to the proposed project. More complete hazardous materials site investigations will need to be done in the future as a part of the preliminary design in order to finalize NEPA documents.

6.4.2.12. Conclusions

The proposed project would involve the following impacts:

- The project may directly impact two historic resources and indirectly impact an additional two historic resources.
- Two public parks and 2 WMAs would be impacted, and a Public Hearing per Chapter 26 requirements is required.
- 142.45 acres of potential wetlands would be impacted across the four regional levee systems. Mitigation would be required and the total estimated cost of mitigation for the South Region would be $36,171,210 for mitigation banking and $10,350,445 for preservation, restoration, and creation mitigation.
- The project would impact more than 1,500 linear feet of stream and more than 3 acres of waters of the U.S. and would therefore require Tier II Water Quality Certification from TCEQ.
- The project would involve construction of gates across two navigable waters of the U.S. and would therefore need a Section 9 Permit from the USCG and a Section 10 Permit from USACE.
- The South Region Alternative must be located in a floodplain in order to reduce flood risk behind the flood protection system. The South Region Alternative would adhere to the 8-step process as outlined under Executive Order 11988, Floodplain Management, including consideration of sea level rise.
- The GLO would have to prepare a Consistency Determination that evaluates the proposed project for consistency with the TCMP.
- A wetland value assessment was performed. Total direct impacts would affect 194.47 acres of wetlands and result in the next loss of 14.04 AAHUs over the period of analysis. Mitigation would be needed to compensate for a loss of 14.04 AAHUs from freshwater and brackish marshes.
- EFH has been designated in the project area for Red Drum, shrimp and reef fish. Coordination with NMFS would be required.
- The proposed project may impact the habitat of seventeen state listed species but no federally listed species.
- There are approximately 337 hazardous material sites that could pose a risk to the proposed project.

6.4.3. Cost and Economics Review

Table 23 provides the updated cost and economics summary for each segment in the South Region plan. All benefits and costs are presented in thousands of dollars and reflect 2018 price levels. The segments within the FHFPS including the proposed extension along FM 523 were modelled together as a complete system. The other segments are stand-alone and provide risk reduction to specific areas; therefore, they were modelled individually.

Regionally, the overall BCR for the Phase 4 plan is 0.81, which was a reduction from the Phase 3 BCR of 1.47. This can be attributed to modifications that were made to the stage frequency and structure foundation height survey data, which lead to a reduction in the Total Annual Benefits. Revaluating the Phase 3 data with the new elevation data would result in the same degree of benefit losses.

The reevaluation of the construction cost for the optimized plan resulted in a $100M reduction. Unfortunately, the cost reduction was not enough to overcome the loss in benefits, which drove the BCR down.

Removing the low-performing Jones Creek Levee and Jones Creek Tank Farm segments would result in the BCR increasing to 0.87. The modest gain in BCR does not justify the removal of these two segments from the plan at this time.

Table 23: Cost and Economics Summary for the South Region (in $Thousands)

South Region Summary	FPHFPS and FM 523 Extension	Jones Creek Levee	Jones Creek Tank Farm	Chocolate Bayou	Total
Total length of the system (miles)	45.0	9.6	3.0	11.0	68.6
Right of way required (acres)	263	93	56	161	573
New Pump stations required / total capacity (CFS)	2/9,950	1/600	1/54	1/325	5/10,929
Environmental mitigation required	104.3	31.7	30.4	28.1	194.5
Construction cost $(000)	1,846,621	163,034	122,117	308,955	2,440,767
Annual operations and maintenance cost	9,233	815	611	1,545	12,204
Total Annual Costs (TAC)	95,330	8,416	6,305	15,952	126,000
Total Annual Benefits (TAB)	82,285	3,452	1,182	15,178	102,097
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	0.86	0.41	0.19	0.95	0.81

6.5. South Region Conclusions

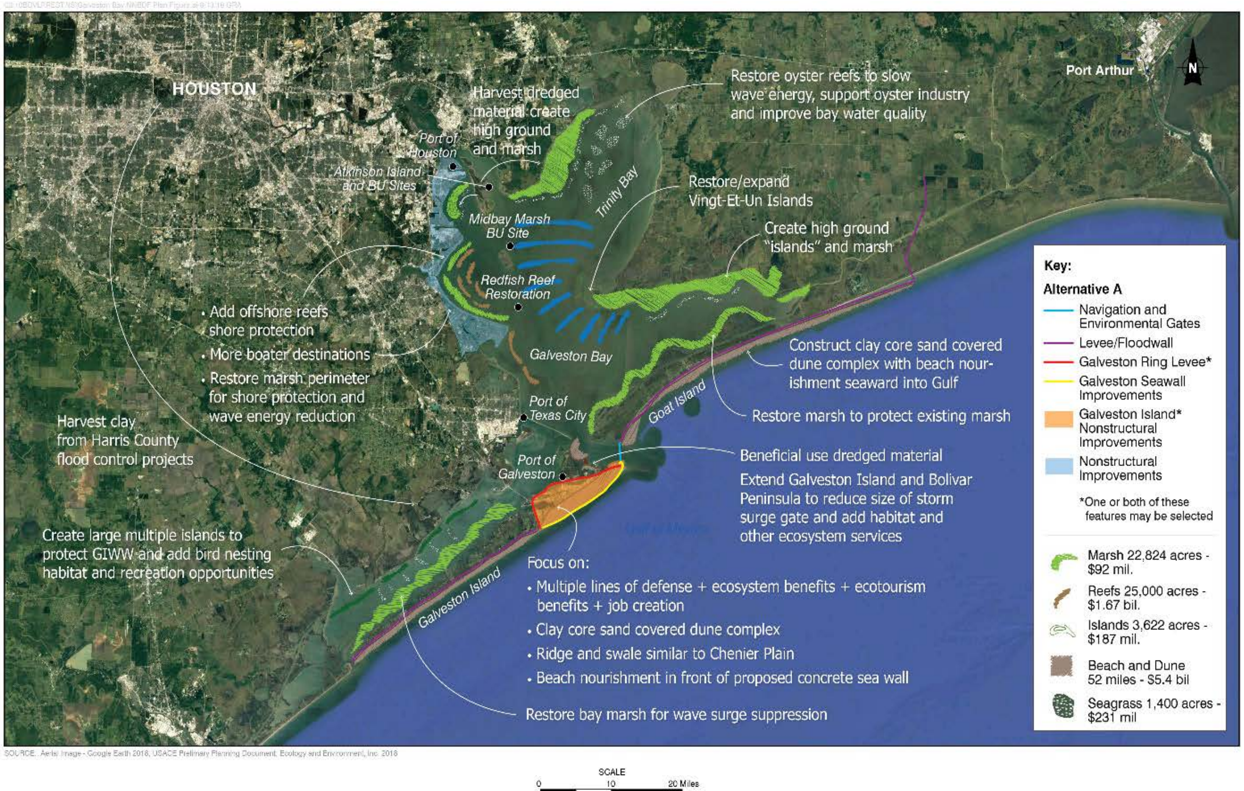
In the South Region, a new alignment for the Eastern Extension of the FHFPS along FM 523 was adopted into the plan. In the 2016 plan, the alignment extended from the eastern terminus of the levee north toward the City of Angleton. The optimized plan extends the levee generally along FM 523 north to the City of Angleton. The new levee system will reduce the risk to 20,000 additional acres of land in the region where current and future residential and industrial development is expected to occur. The new alignment reduces the overall construction cost in the South Region by $100M for $2.5B to $2.4B. The reduction in the construction cost is not enough to keep the overall BCR from dropping from 1.47 to 0.81. The decrease in the BCR is again attributed to modifications that were made to the stage frequency and structure foundation height survey data.

7. The Way Ahead

7.1. Natural & Nature-Based Features

Natural and nature-based features (NNBF) provide coastal protection, ecosystem support, and socio-economic benefits. While beyond the scope of the GCCPRD's grant and funding, NNBF elements will be an important part of any coastal protection plan. The protection systems envisioned in this report provide an opportunity to look beyond traditional civil engineering and construction projects to provide better storm risk management, ecosystem restoration, and protection and community and recreational amenities. Aligning NNBF plans with the mitigation planning also ensures that the critical environmental resources impacted by the project are constructed at or near the site of impact and not moved to mitigation banks located elsewhere. Figure 35 outlines potential opportunities for NNBF benefits within the Central Region of the GCCPRD recommended plan. The GCCPRD encourages additional study and inclusion of natural and nature-based features in any final project design. **Appendix J** provides additional detail on the proposed NNBF opportunities and was provided to the GCCPRD through a collaborative effort.

Figure 34: Miami Beach Boardwalk



Coastal Texas Protection and Restoration Feasibility Study - Alternative A with NNBF

Figure 35: USACE & Texas GLO Coastal Texas Protection & Restoration Study with NNBF

7.2. Develop Innovative Finance Solutions

In February 2018, the Bipartisan Budget Act provided USACE $3.9B for the construction of the recommend plan outlined in the SP2G study. The legislation enables USACE to fully fund the construction Orange, Jefferson, and Brazoria Counties with federal dollars. The local sponsors for each project will have 30 years from the date of construction completion to repay their 35 percent cost share.

While this is good news for the region, many of the local sponsors are concerned with how they will repay their share in addition to paying the costs of operating and maintaining these new structures. For example, the Orange County cost share for their project is roughly $650M with an additional $6M to $7M for annual operations and maintenance. The entire Orange County currently operates on a budget of $45M per year.

This scenario clearly illustrates the need to re-evaluate how local entities pay for projects of this magnitude. There needs to be a be a discussion between federal, state, local officials and potentially private equity groups to look at innovative financial solutions and to develop a long-term strategy.

7.3. USACE Coastal Texas Protection and Restoration Study

In October 2018, USACE published their Tentatively Sleeted Plan (TSP) for the Coastal Texas Protection and Restoration Feasibility Study (the Coastal Texas Study). This study is evaluating the coastal protection needs for the remainder of the Texas Coast including the highly vulnerable and valuable portion that reduce risk in Galveston, Harris, and Chambers County. The USACE TSP resembles the 2016 recommended plan published in the GCCPRD Phase 3 Report. The GCCPRD will continue to collaborate with USACE until the Coastal Texas Study is completed in March 2021.