GCCPRD

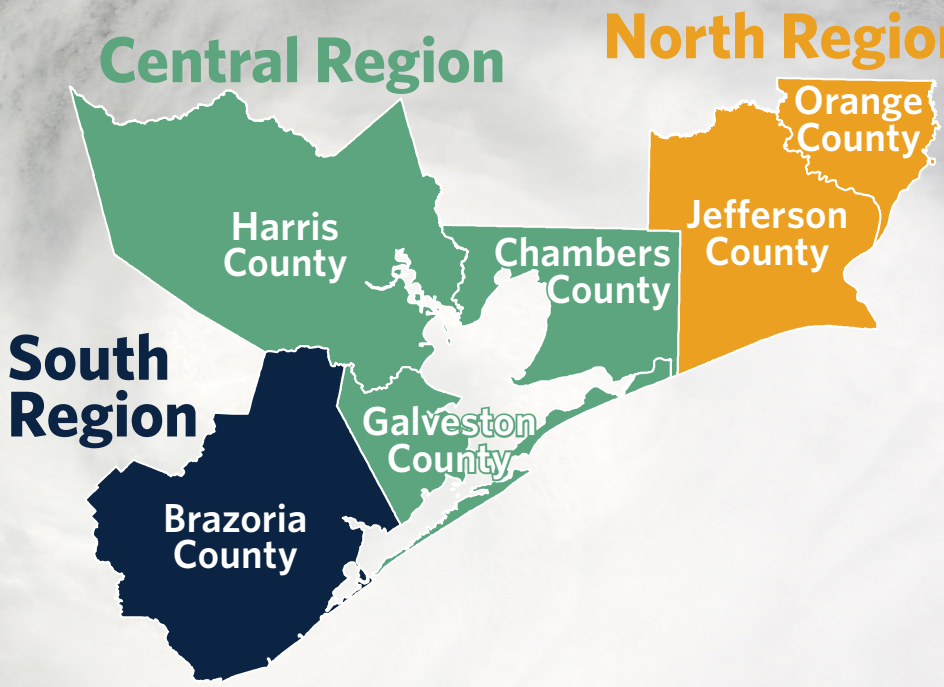
The Gulf Coast Community Protection and Recovery District

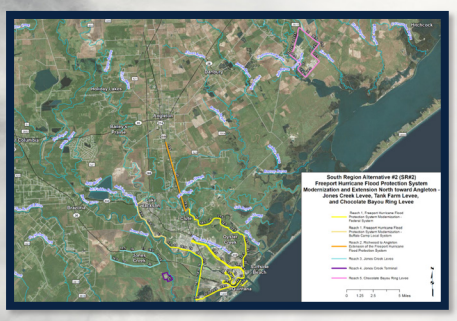
STORM SURGE SUPPRESSION STUDY

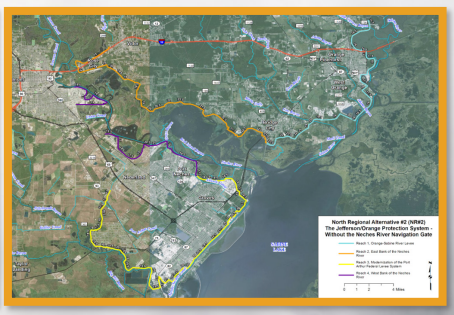
PHASE 3 REPORT

RECOMMENDED ACTIONS

June 21, 2016







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1. Executive Summary

The Gulf Coast Community Protection and Recovery District (GCCPRD) finds a compelling need for a storm surge protection system on the upper Texas coast.

This report presents (GCCPRD) Phase 3: Recommended Actions for the *Storm Surge Suppression Study*. The results of the study clearly illustrate the need for a storm surge protection system in the six-county region to mitigate current and future risks to the public, the economy, and the environment. The recommendations put forward in this report establish a framework for a plan and serve as a call to action for local, state, and federally elected officials to become advocates for coastal protection. The time has come to move beyond concepts and feasibility studies and begin preliminary engineering design and construction of the system. The solution is actionable provided there is the will at the local, state, and federal level to make the necessary strategic investments. Until the full system is built, the entire region will remain at risk to surge flooding from tropical events.

The GCCPRD has been executing this study for the past two and a half years. This effort involved extensive storm surge and wave modeling focused on evaluating and mitigating the region's risks associated with tropical events and future relative sea level rise. The technical analysis identified and defined structural alternatives, evaluated the environmental impacts and economic benefits, and compared the benefits to the overall cost associated with constructing, operating, and maintaining each alternative. The GCCPRD has performed all operations in an open and transparent manner by engaging the public and local elected officials directly through public meetings and publishing all our reports, associated appendices, and data online for the public to review at www.gccprd.com. Appendix A includes the comments received from the public meetings held in March and April 2016.

During Phase 3, the study team executed public meetings and conducted numerous engagements with other stakeholders to gather comments on the alternatives that were presented in the Phase 2: Technical Mitigation report. The team also coordinated with the U.S. Army Corps of Engineers (USACE), the SSPEED Center at Rice University, and Texas A&M - Galveston (TAMUG) to reconcile the alternatives recommended in this plan.

This report is a summary report and does not restate in detail the technical information that was previously published in the Phase 1 and Phase 2 reports. Those reports are included as Appendices B and C to this report.

1.1. Recommended Alternatives

1.1.1. North Region: Jefferson and Orange Counties

The study team in coordination with local elected officials recommend *Northern Region Alternative #2* (NR#2) - levees only, as the alternative that best supports surge protection in the Jefferson and Orange County region of the study area.

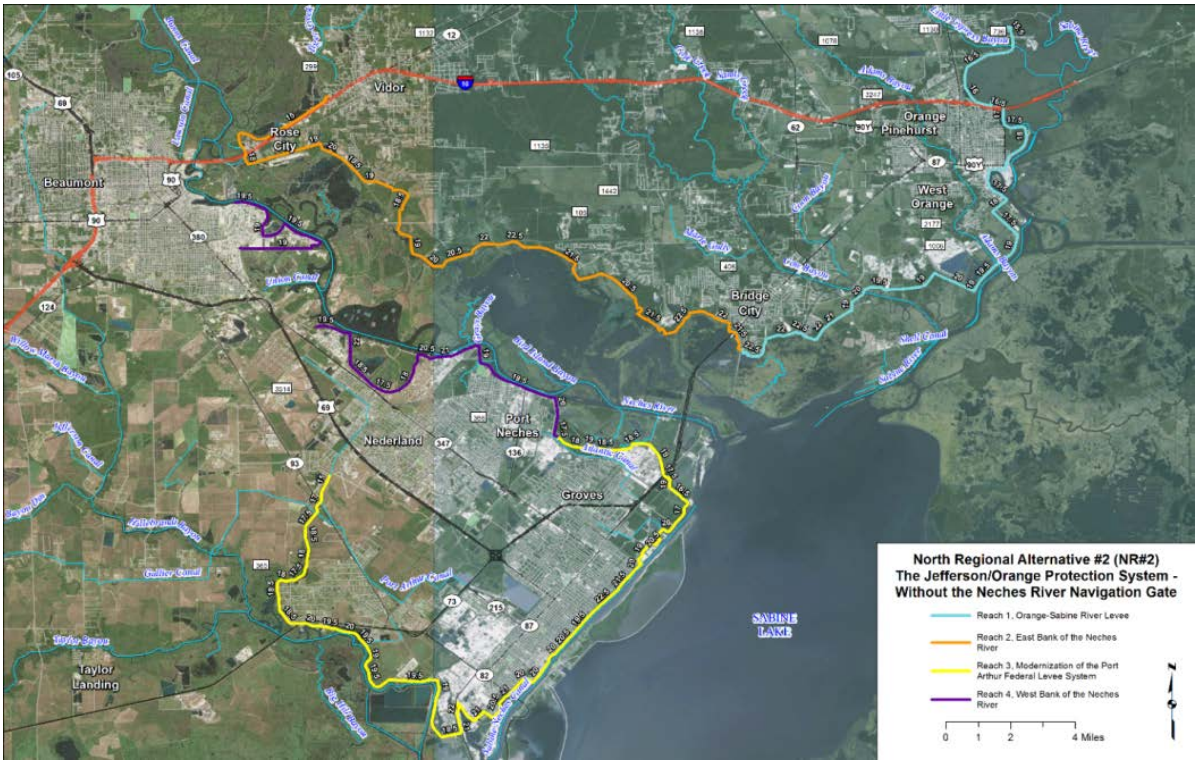

Figure 1: Recommended *North Region Alternative (NR#2)* - Levees Only

Table 1: NR#2 Technical Details

North Region Alternative Summary and Comparison	NR#2 - *The Jefferson/Orange Protection System –without the Neches River Navigation Gate*
Total length of the system (miles)	92.2 miles
Right of way required	1,401 acres
Pump stations required / total capacity (CFS)	14 / 31,626 CFS
Environmental mitigation required	559.6 acres
Construction cost	$3,228,580,000
Annual Operations and maintenance cost	$16,143,000
Total Annual Costs (TAC)	176,910,000
Total Annual Benefits (TAB)	$140,877,000
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	**0.80**

NR#2 is a technically feasible alternative that lacks complexity and will greatly enhance protection throughout the region. Economically and environmentally, NR#2 is sustainable and with future optimization the alternative is expected to meet all federal funding requirements.

NR#2 is very similar to the USACE *Sabine Pass to Galveston* study's Tentatively Selected Plan. By staying aligned with USACE, future discussions associated with reconciling competing plans are avoided, which will keep the project on track for authorization and funding by Congress.

1.1.2. Central Region: Chambers, Harris and Galveston Counties

The study team, in coordination with local elected officials, recommends *Central Region Alternative #1 (CR#1)* - The High Island to San Luis Pass Coastal Spine including the following elements from Central Region

Alternative # 2 (CR#2): the navigation gate at Clear Lake and a modified Galveston ring levee, as the alternative that best supports surge protection in the Chambers, Galveston, and Harris counties region of the study area. (Figure 2)

The CR#1/CR#2 combination provides a region-wide reduction in storm surge that extends from the Gulf of Mexico to Houston, providing enhanced protection for communities located along the shoreline of Galveston Bay and industry located along the Houston Ship Channel.

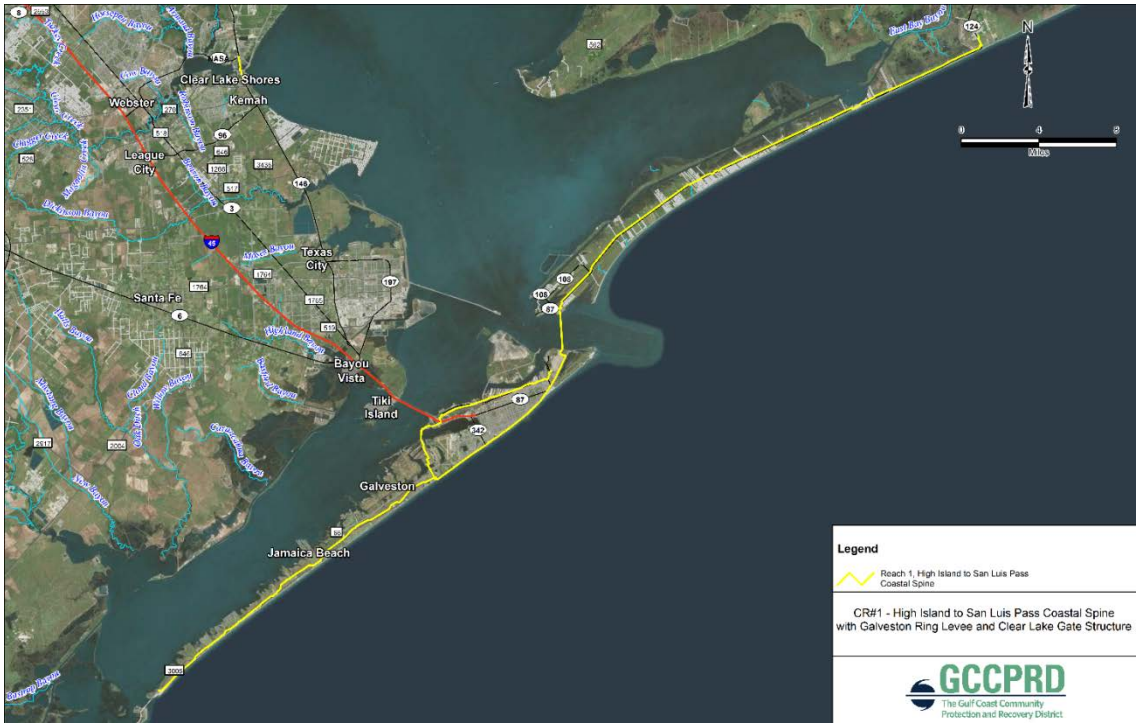

Figure 2: Recommended Central Region Alternative (CR#1) - Coastal Spine

Table 2: CR#1 Technical Details

Central Region Alternative Summary and Comparison	CR#1 - *High Island to San Luis Pass Coastal Spine*
Total length of the system (miles)	55.6 miles
Right of way required	1,220 acres
Pump stations required / total capacity (CFS)	0 / 0 CFS
Environmental mitigation required	303.35 acres
Construction cost	$5,832,095,000*
Annual operations and maintenance cost	$29,160,000
Total Annual Costs (TAC)	319,569,000
Total Annual Benefits (TAB)	$1,029,399,000
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	**3.22**

* *Construction costs and benefits to be updated in the future to include the addition of the Galveston ring levee and navigation gate at Clear Lake*

While CR#1 alone provides a dramatic reduction in overall surge, there are still heavily populated areas within the region that can expect to experience four to 12 feet of surge-related flooding. The addition of the Galveston ring levee and a navigation gate at Clear Lake, evaluated under alternative CR#2, to the coastal

spine will enhance protection for the City of Galveston, Seabrook, Taylor Lake Village, El Lago, Clear Lake Shores and Kemah. With the coastal spine in place, the structure design elevation for the modified Galveston ring levee is expected to be in the 12 to 15 feet range which is much lower than the 23 feet originally proposed in CR#2. Due to resource and time constraints, the construction cost, the benefits, and the BCR for the addition of these two features will need to be updated in the future.

Additional protective measures as proposed by the SSPEED Center at Rice University should also be further evaluated. The SSPEED Center at Rice University has proposed a layered defense for Galveston Bay. Its H-GAPS approach supports a coastal spine alignment, a ring levee for the City of Galveston, and an additional gate structure located along the Houston Ship Channel with an ancillary levee structure through the bay that ties the system northward into Baytown and southward to Texas City. (Figure 17) Conceptually, these additional elements appear to be effective for reducing the residual surge along the west side of Galveston Bay and the Houston Ship Channel. In the future, the study team will coordinate closely with SSPEED as it continues research on the H-GAPS initiative.

1.1.3. South Region: Brazoria County

The study team, in coordination with local elected officials, recommends *South Region Alternative #2 (SR#2)* - Freeport Hurricane Flood Protection System Modernization with Extension North toward Angleton, Jones Creek Levee, Jones Creek Terminal Ring Levee, and Chocolate Bayou Ring Levee as the alternative that best supports surge protection in the Brazoria County region of the study area.

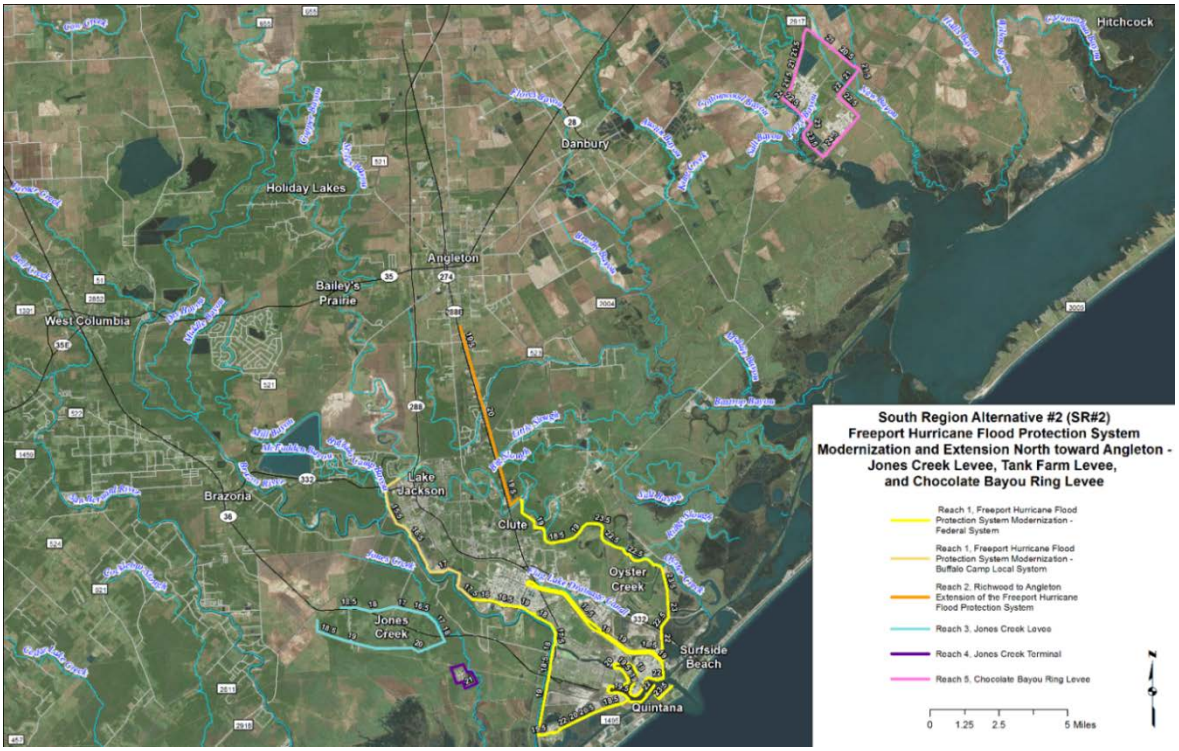

Figure 3: Recommended South Region Alternative (SR#2)

Table 3: SR#2 Technical Details

South Region Alternative Summary and Comparison	SR#2- *Freeport Hurricane Flood Protection System Modernization and Extension North toward Angleton- Jones Creek Levee, Jones Creek Terminal Ring Levee, and Chocolate Bayou Ring Levee*
Total length of the system (miles)	74.2 miles
Right of way required	383 acres
Pump stations required / total capacity (CFS)	5 / 11,460 CFS
Environmental mitigation required	129.89 acres
Construction cost	$2,571,551,000
Annual operations and maintenance cost	$12,858,000
Total Annual Costs (TAC)	140,907,000
Total Annual Benefits (TAB)	$206,654,000
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	**1.47**

SR#2 is technically, environmentally, and economically feasible and has a very good BCR of 1.47. SR#2 provides a region-wide reduction in storm surge that extends from the coast at Freeport to Angleton and provides enhanced protection for the community of Jones Creek and the industrial complexes located along Jones Creek and Chocolate Bayou. The alternative includes the modernization of the Freeport Hurricane Protection System and the extension of the system to protect of the region from the 100-year event in 2085.

1.2. Study Area Summary

The combination of all the recommended alternatives into one comprehensive plan clearly illustrates that there are technically and economically feasible and environmentally sustainable alternatives that are supported by the public which will provide storm surge reduction in the six-county area. (Table 4)

These alternatives should not be viewed as being mutually exclusive. Implementing a single regional alternative only buys down risk in that area leaving the other regions vulnerable. Any storm-related loss will have a lasting effect on the local, regional, state, and national economies.

Table 4: GCCPRD Study Area Summary

	North Region NR#2	Central Region CR#1 + Clear Lake + Galveston Ring Levee	South Region SR#2	Study Area Plan (NR#2+CR#1+ SR#2)
Total length of the system (miles)	92	114	71	277
Right of way required (acres)	1,401	1,278	383	3,062
Pump stations required / total capacity (CFS)	14/31,600	0/0	5/15,100	19/46,700
Environmental mitigation required ($ thousands)	0	72,075	0	72,075
Construction cost ($ thousands)	3,228,579	5,832,095*	2,571,551	11,632,225
Annual Operations and maintenance cost ($ thousands)	16,143	29,160	12,857	58,160
Total Annual Costs (TAC)	176,910	319,569	140,907	637,386
Total Annual Benefits (TAB)	140,872	1,029,399	206,654	1,296,056
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	0.80	3.22	1.47	2.03

* *Construction costs and benefits to be updated in the future to include the addition of the Galveston ring levee and navigation gate at Clear Lake*

The total cost for implementing the GCCPRD Study Area Plan is $11.6 billion with a BCR of 2.03. The federal government invested $14.5 billion dollars for hurricane protection for New Orleans following Hurricane Katrina protecting a population of 900,000 people. The upper Texas Coast has a population of more than six million people, generates over 31 percent of the state's $1.4 trillion GDP, and has a significant role in our nation's energy and national security.

The GCCPRD *Storm Surge Protection Study* identifies the threat, the assets that need to be protected, and provides solutions on how to protect the region from storm surge flooding. The plan is ready to move forward to implementation.

2. Introduction

The upper Texas coast, stretching from Orange to Brazoria County, is blessed with over 120 miles of pristine coastline that 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 six 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. Additionally, this region is vitally important to the security of the national economy and the nation's energy sector.

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.

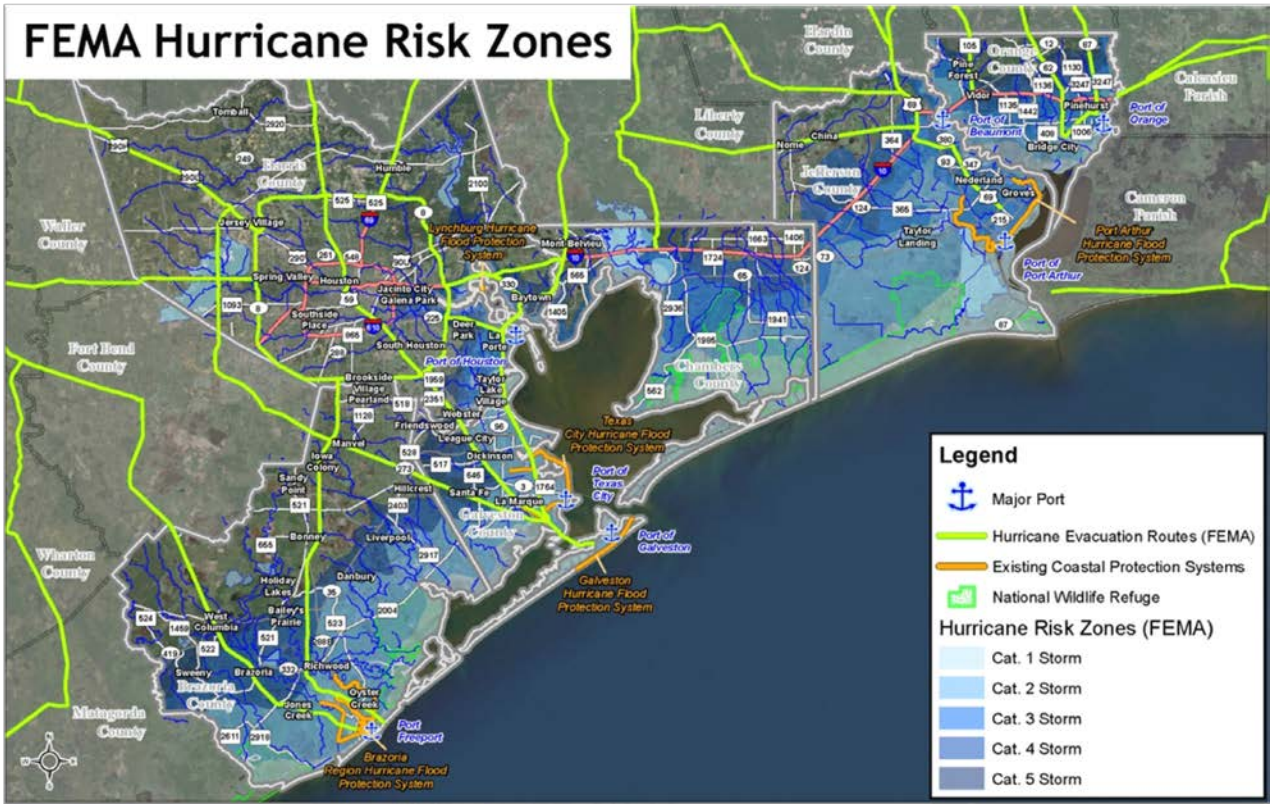

Figure 4: FEMA map illustrating coastal areas within the study vulnerable to storm surge

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. To date, Hurricane Ike has been the most expensive storm in Texas history.

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 Stephen Carlton – Orange County
- Lisa LaBean – At-large Member
- Jim Sutherlin – At-large Member
- Victor Pierson – At-large Member

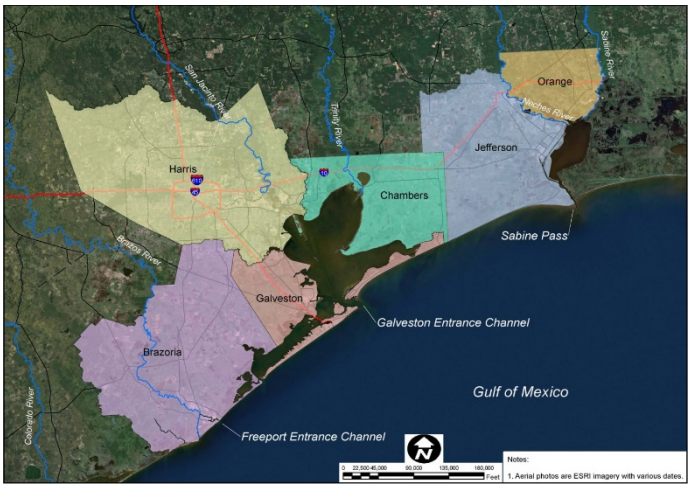

Figure 5: GCCPRD study area

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 General Land Office (GLO) through the Federal Housing and Urban Development (HUD) Community Development Block Grant (CDBG) Program to conduct the *Storm Surge Suppression Study*.

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. These goals will be achieved through the study and analysis of integrated flood damage reduction systems comprised of natural or nature-based features, as well as structural and nonstructural alternatives.

The study initiated in fall 2014 examined the technical, environmental, social, and economic factors to determine a cost-effective and efficient set of alternatives for flood damage reduction and surge suppression to help protect the six-county region. The study outcomes are critical to informing the general public of the potential risks associated with living and operating within this region and soliciting future support to procure the necessary resources to implement an integrated protection system.

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.

The *Storm Surge Suppression Study* is a technical effort based on science to investigate opportunities to mitigate the vulnerability of the upper Texas coast from storm surge and flooding. Since 2013, the GCCPRD has been collecting, developing, and analyzing technical data and collaborating with other organizations and universities conducting similar work.

2.3. Phase 1 and Phase 2

In February 2015, the team completed Phase 1: Data Collection. All data collected during Phase 1 was consolidated into a data library and provided to the GLO to support future study efforts. As part of the Data Collection effort, the study team conducted a series of three large-scale public scoping meetings (one in Beaumont, Baytown, and League City, Texas) to encourage public participation and further define the need, purpose, and scope of the study. As a result of the research conducted during Phase 1, the team determined that the needs and types of protection varied across the six-county study area. Therefore, the study area was divided into three distinct regions:

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

Alternatives were then scoped for each region with the understanding that the benefits and impacts of these alternatives would be confined to their respective regions.

In February 2016, the Phase 2: Technical Mitigation report was published, defining two potential surge suppression alternatives within each region of the study area. The Phase 1 and Phase 2 reports and the data library were made available to the public through the GCCPRD's official website, www.gccrpd.com. The Phase 1 and Phase 2 reports are also included as appendices to this Phase 3 report. The Phase 3 report represents the Gulf Coast Community Protection and Recovery District's *Storm Surge Suppression Study- Final Recommendations*.

2.4. Phase 3 - Scope of Work

During Phase 3, the study team conducted four additional public meetings and facilitated numerous engagements with other stakeholders to gather comments on the alternatives that were presented in the Phase 2: Technical Mitigation report. The study team also worked with the US Army Corps of Engineers, Texas A&M University – Galveston, and the SSPEED Center at Rice University to reconcile the recommended alternatives presented in this report.

Additionally, the team executed an extended regional economic review to help define the economic losses that are not directly related to the storm losses. These additional impacts will be published as an addendum to this report in the future once this effort is complete.

3. Identifying the Threat Now, in 2035, and 2085

One of the major threats associated with any tropical event is storm surge-induced flooding. Storm surge is generated because low pressure and winds associated with a hurricane cause the water in the Gulf of Mexico adjacent to the center of the storm to rise as the storm moves closer to the shore and inland. The flood hazard at any given area along the coast can also be affected by waves, tides, and the storm's intensity, size, and angle of approach.

Present-day conditions were established using the latest FEMA Flood Insurance Study (FIS) data. The team made the assumption that if construction began in 2020, all alternatives could conceivably be in place by 2035. A fifty-year design life was assigned to each alternative, targeting a design life through the year 2085. The goal was to identify the recommended structural elevations of all alternatives in 2085.

3.1. Storm Simulations

The study team executed extensive storm surge modeling for the years 2035 and 2085 to evaluate structural design elevations for each proposed alternative and understand expected damages based on future sea levels and storm conditions. These storm simulations are required because historical storm data does not sufficiently cover the wide variety of storm conditions that may affect the project region in the future. The storm surge modeling provides the required data by evaluating flood hazards throughout the project region for hundreds of possible hurricanes and also accounting for potential future conditions by including sea level rise in the model setup.

The study team used the coupled ADvanced CIRCulation (ADCIRC) and Unstructured Simulating WAves in the Nearshore (UnSWAN) model system to simulate storm surge and waves throughout the project region. Relative sea level rise was evaluated using the data from the existing NOAA gauges at Sabine Pass, Galveston Pier 21, and Freeport. Mean sea level was increased by 0.9 feet and 2.4 feet in the model setups for the 2035 and 2085 timeframes respectively. 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.

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.

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 selected for this study was coordinated with the US Army Corps of Engineers (USACE). The storm suite includes 152 high-intensity and 71 low-intensity storms from the Texas FEMA FIS storm suite, as well as 31 high-intensity storms from the Louisiana FEMA FIS storm suite (USACE 2008a, b) with landfall locations near the Louisiana-Texas border. (Figure 6)

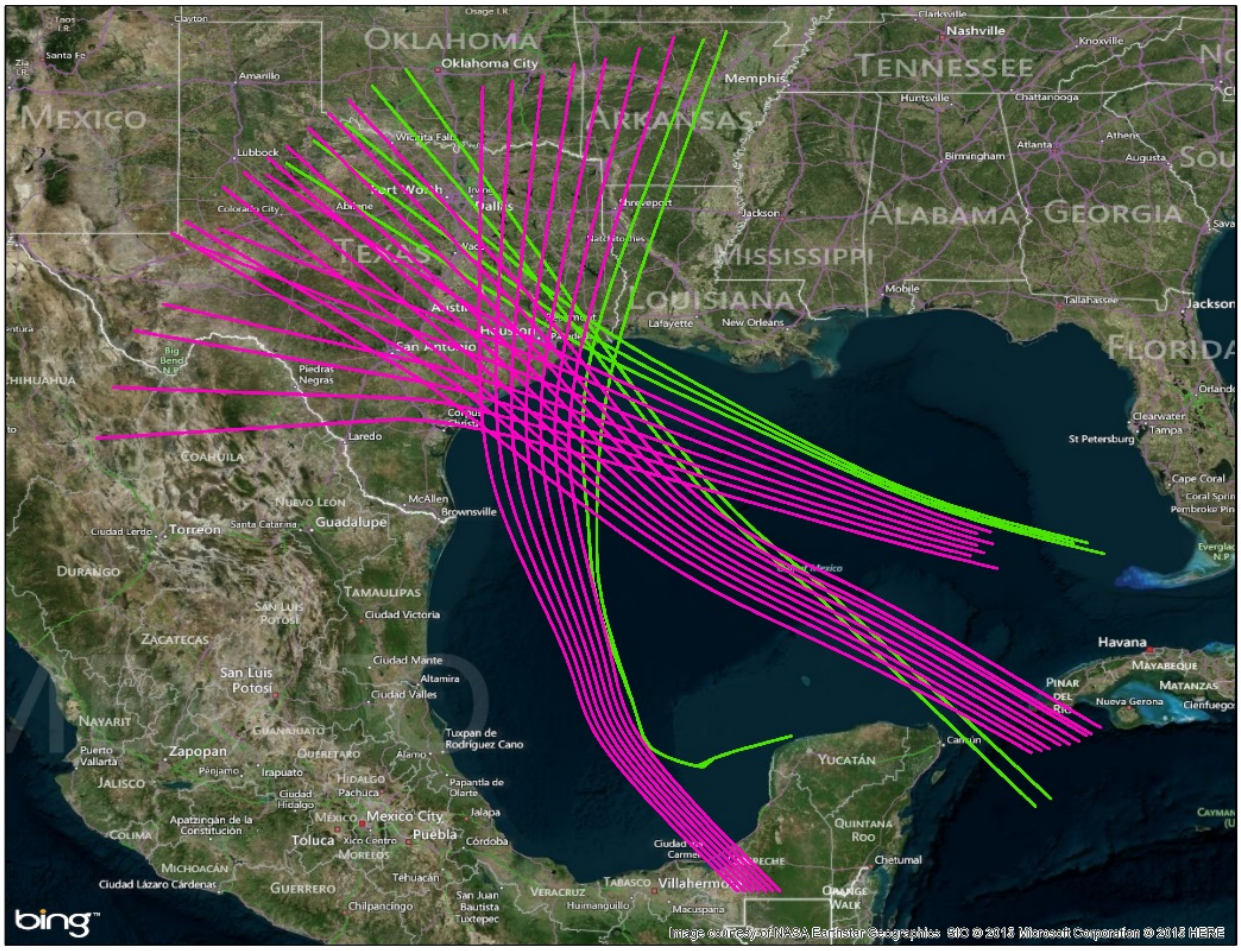

Figure 6: Storm tracks for the 254 ADCIRC storm simulations. Purple lines are Texas storm tracks, and green lines are Louisiana storm tracks.

3.2. 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 modeling scenario (FWOA 2035, FWOA 2085, FWA1 2085, and FWA2 2085). 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 statistical 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.

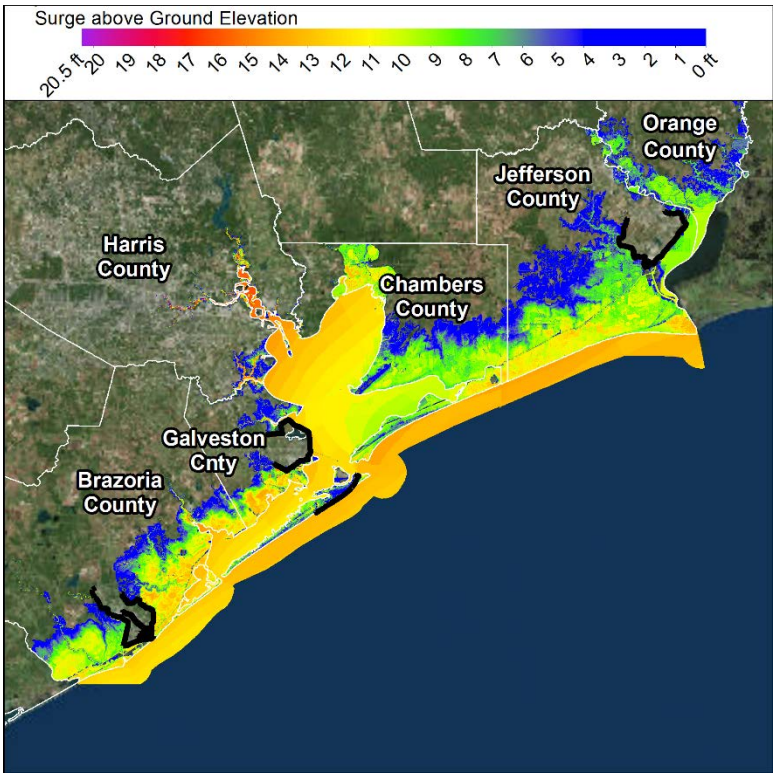

Figure 7: 100-year stillwater elevations for Current Conditions. Data referenced from FEMA 2008 FIS Map.

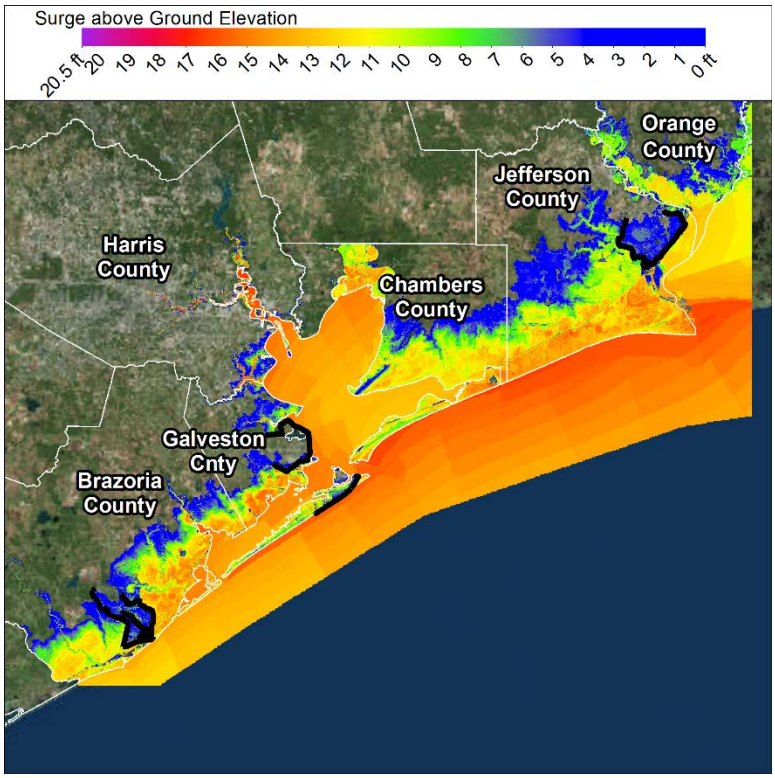

Figure 8: 100-year stillwater elevations for FWOA 2035 conditions. This model scenario includes 0.9 feet of Relative Sea level Rise.

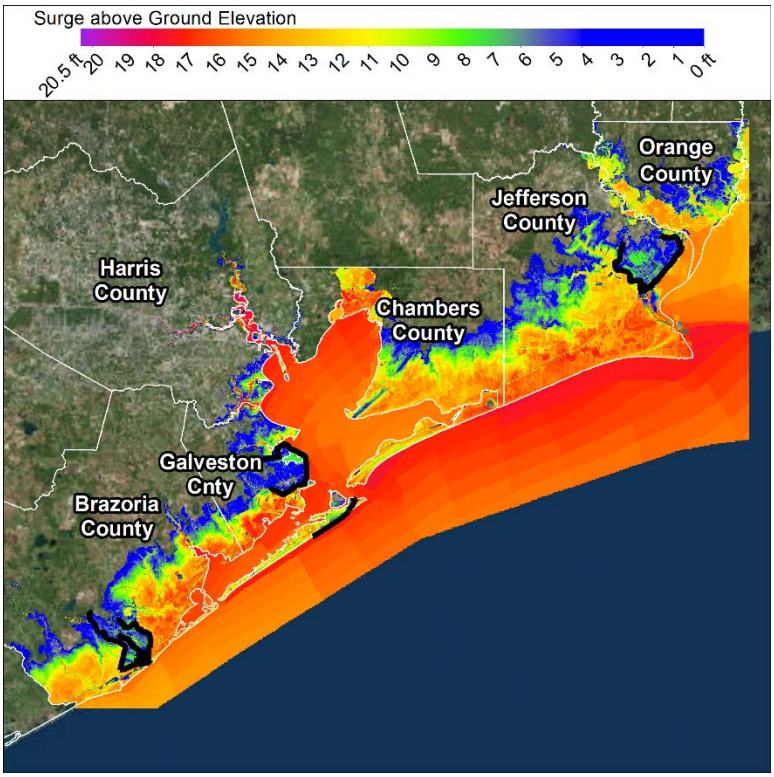

Figure 9: 100-year Stillwater elevations for FWOA 2085 conditions. This model scenario includes 2.4 feet of Relative Sea level Rise.

Stillwater return elevations at specific locations were also calculated. The following table compares 100-year stillwater elevations across the model scenarios at three sample locations within the project region.

Table 5: 100-year stillwater elevations (feet, NAVD88) compared across the four model scenarios.

	FWOA 2035	FWOA 2085	FWA1 2085	FWA2 2085
Jones Creek	13.2	15.0	15.0	14.9
Galveston Bay	13.7	15.7	9.8	15.8
Sabine Lake	12.5	14.8	14.9	15.1

Figure 10: Sample locations where stillwater elevations are extracted and compared in Table 5.

Section 3 and Appendix A and B in the Phase 2: Technical Mitigation report provide additional details on the storm surge modeling and return frequency methodology.

3.3. Preliminary Design Elevations

Results from the storm simulations and return frequency analysis were used to determine preliminary design elevations for each reach location included in the two proposed alternative configurations. Results from the 254 synthetic storm simulations were compared to the calculated 100-year return stillwater levels to determine 100-year wave conditions. These 100-year stillwater and wave conditions were reviewed in conjunction with overtopping criteria recommended by the USACE to determine the preliminary design elevations for the proposed alternatives. The USACE overtopping criteria were applied to each reach location separately to account for varying reach types such as floodwall, armored levee, or grass-covered levee. Unique circumstances along the Coastal Spine and the Galveston Seawall were also accounted for when determining the location-specific overtopping criteria. The 100-year wave and stillwater conditions were then assessed relative to the appropriate overtopping criteria to determine the preliminary design elevations for each reach location in the project area. In this manner, the stillwater and wave conditions generated by the storm simulations were processed and evaluated to determine the preliminary design elevations necessary for the subsequent economic evaluation.

3.4. Economic Evaluation: What needs to be protected?

The economic analysis in this report was prepared in general accordance with policies and practices of the USACE. The analysis estimates the National Economic Development (NED) damages and benefits for existing and future conditions and all costs required for implementation of project alternatives. The NED benefits

analyzed represent the reduction of potential damages caused by inundation and the associated avoided debris removal costs. Inundation damage categories included:

- Physical damages to structures and contents (residential, commercial, and industrial)
- Damages to privately owned vehicles associated with residential structures

The USACE Hydrologic Engineering Center-Flood Damage Analysis Model (HEC-FDA) version 1.2.5a was used to compute damages. HEC-FDA is an interdisciplinary program used to formulate and evaluate flood damage reduction plans. The primary inputs to HEC-FDA contain only the following information:

- Damage reaches (the geographic boundaries of reported model output)
- An inventory of structures (including depreciated structure replacement value and structure elevation)
- Damage functions describing the susceptibility of structures and contents to varying depths of inundation
- Stage-probability relationships (describing the annual probabilities associated with water surface elevations)

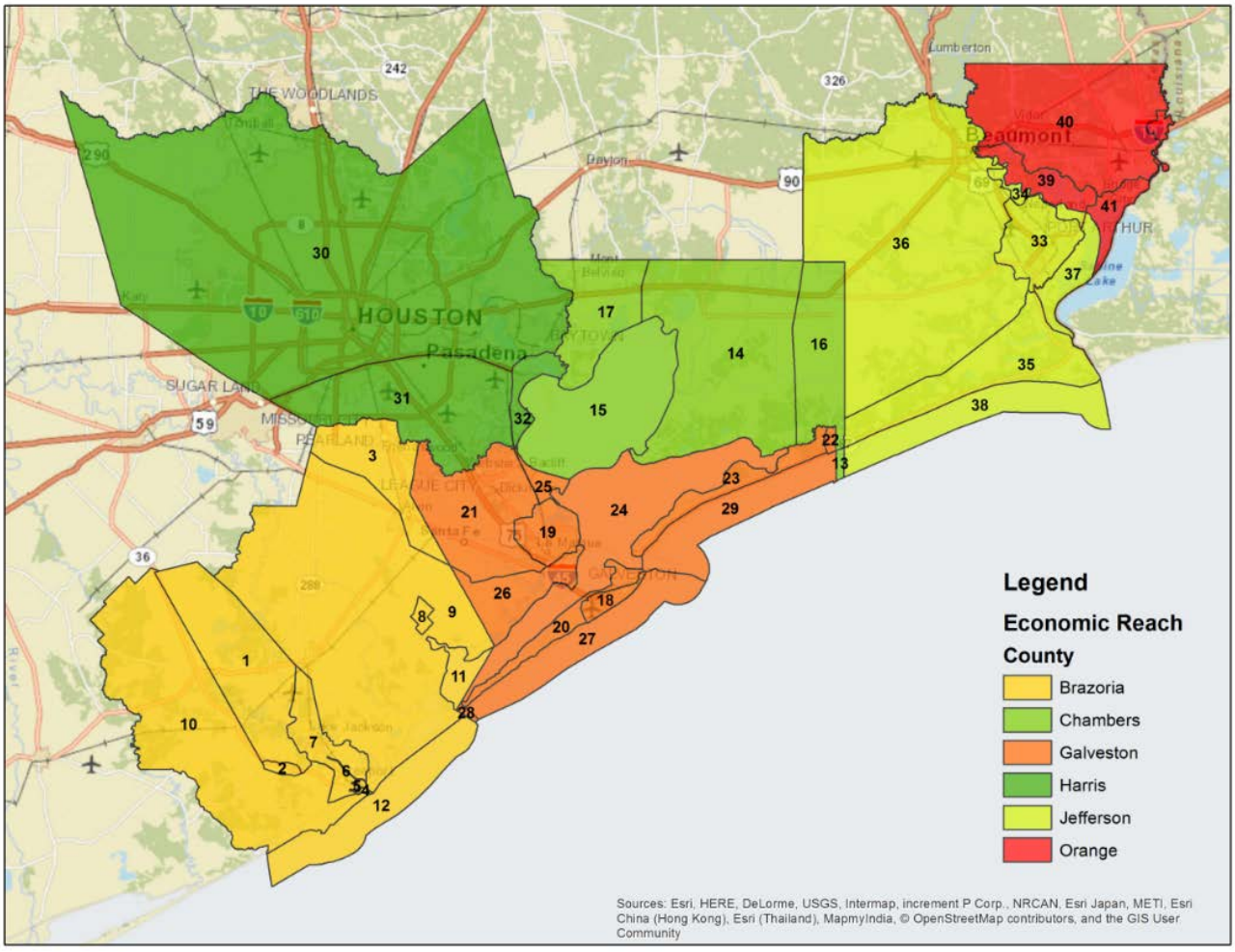

Figure 11: Damage reaches established in HEC-FDA for the study area

Saltwater, short-duration (approximately one-day) depth-damage relationships were used in the economic analysis. Model outputs were generated for the following damage categories: residential, commercial,

industrial, and debris removal. The residential category includes damages to the structure, damages to contents, and damages to the associated vehicles for residential properties. The commercial and industrial damage categories include damages to the structure and contents. The debris removal damage category includes the debris removal costs associated with all residential and commercial properties.

The economic 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 report provides additional details on their economic modeling approach and the methodology used.

3.5. Technical and Environmental Evaluation: How do we protect while limiting environmental impacts?

3.5.1. Technical Evaluation

The study team developed an initial array of potential alternatives based on public feedback, utilization of prior USACE studies and reports, and through collaboration with other research teams concurrently studying surge protection within the region. The team scoped and screened each potential alternative and selected two distinct alternatives for each respective region of the study area for further analysis.

For simplicity, the team divided the study area into three distinct regions:

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

Once the alternatives for each region were selected for analysis, the study team developed preliminary alignments for each respective alternative. Structures were identified and sized for the proposed alignments to provide protection from the 2085 one percent (100-year storm) annual exceedance probability storm surge event. In heavily congested and urban areas, the team proposed the use of T-wall structures to limit intrusions; whereas, in undeveloped rural areas, the team proposed levee systems, which are less expensive. Ancillary structures were categorically separated into highway crossings, railroad crossings, gravity drainage structures, navigation gates, and pumping stations.

Final alignments were based on the following factors:

- Input from the public meetings
- Potential environmental impacts
- Constructability of the alternative
- Social intrusion of protection systems within communities
- Impacts to existing infrastructure (right-of-way acquisition, road and railroad crossing, utility corridors, etc.)
- Long-term operations and maintenance expenses
- Interior drainage requirements
- Ancillary structures (drainage and navigation structures)

The team developed a large library of unit and lump-sum costs from recently constructed hurricane protection projects in the Gulf Coast region. This data allowed the team to synchronize costs throughout the study area and develop costs for each proposed alignment.

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 beyond the rate of inflation. Exceptions were made for the Houston Ship Channel and Neches River gates, where a 40 percent contingency was used due to the extreme complexity and uniqueness of such structures.

Sections 2 and 6 of the Phase 2: Technical Mitigation report provide additional details on the alternative development process and the methodology for developing alternative costs.

3.5.2. Environmental Impacts

The environmental analysis conducted for this study consisted of a desktop review of the most current and comprehensive data available to the team. These datasets included:

- National Wetlands Inventory
- Threatened and endangered species critical habitat
- Historic sites
- Coastal barriers
- Floodplain
- Essential fish habitat
- Hazardous material sites

The potential environmental impacts associated with each proposed alternative were defined by evaluating the length of the alternative and the ground area that the structure would occupy in relation to the specific habitat that would be impacted. An additional buffer area of 150 feet was added to all alternatives to account for future operations and maintenance activities.

Alternative alignments were continuously adjusted to avoid or minimize impacts to sensitive areas. Where impacts could not be avoided, the impacts were defined for each alternative by total acres impacted and by habitat type. Mitigation costs based on acreage and habitat type were then calculated and added to the overall cost of each alternative.

Potential historic and hazardous waste sites were also identified for each alternative. These sites would require additional investigations once proposed projects enter the preliminary engineering and design phase to assess fully their potential impacts to the project.

A preliminary tidal amplitude and exchange analysis was conducted for of the hurricane barriers proposed at Bolivar Roads and across the Neches River. The analysis indicated that the proposed hurricane barriers would result in a change in tidal amplitude of 5 and 10 percent over a range of various tidal conditions when sufficient vertical lift gates are added to the barriers. The analysis did not assess other potential impacts created by the hurricane barriers associated with water quality, salinity, sediment transfer, and aquatic species within the bay and estuary system. This analysis would need to occur to support the National Environmental Policy Act (NEPA) requirements and documentation for the final project.

Section 2 of the Phase 1: Data Collection and Section 4 of the Phase 2: Technical Mitigation reports provide more detailed information about the environmental review and analysis conducted throughout the study.

3.6. Public Outreach

The GGCPRD study team's efforts have remained open and transparent throughout the feasibility, scoping, and analysis process. In December of 2013, the team hosted three public scoping meetings throughout the region to inform the public of the study's intent and to solicit their input on potential alternatives. This input provided some initial guidance to the team on what the public would be willing to accept regarding project locations and alignments, and this information was used to help the team develop an array of potential alternatives.

Following the release of the Phase 2 report, additional public meetings were held in March and April 2016 to review the alternatives that were selected for further analysis and to seek public feedback on the future recommended plan for each study region. More than 400 public comments were received, and these are consolidated for review in Appendix A of this report.

In addition to the public meetings, numerous briefings were held with stakeholders throughout the region. These stakeholders included, among others:

- Commissioner Jack Morman, Harris County Precinct 2
- Congressman Randy Weber
- Commissioner George P. Bush, Texas General Land Office
- State Senator Larry Taylor
- Joint Interim- Coastal Barrier System Committee
- Houston-Galveston Area Council
- Bay Area Houston Economic Partnership
- Galveston Bay Estuary Council
- South East Texas Regional Planning Organization
- City of Houston
- City of Galveston
- City and county officials throughout the region
- Texas Chemical Council and EHCMA
- Brazoria County Alliance
- Brazoria County Master Naturalists
- Rotary Club of Houston

4. Recommended Alternatives

4.1. North Region Alternatives - Jefferson and Orange Counties

The study team, in coordination with input from the public, community leaders and elected officials, recommends *Northern Region Alternative #2 (NR#2)* as the alternative that best supports surge protection in the Jefferson and Orange County region of the study area. NR#2 is very similar to the USACE Sabine Pass to Galveston study's Tentatively Selected Plan. By staying aligned with USACE, future discussions associated with reconciling competing plans are avoided which will keep the project on track for potential authorization and funding by Congress in 2018.

4.1.1. Basis of Recommendation

During the Phase 2, the study team developed and analyzed two distinct barrier systems that would provide comprehensive protection to the entire North region. (Figure 12)

North Region Alternative #1 (NR#1) is a continuous regional hurricane protection system that includes a large navigation gate on the Neches River.

North Region Alternative #2 (NR#2)-Levees Only- is composed of two hurricane protection systems which individually protect Orange and Jefferson Counties without the Neches River gate.

Both NR#1 and NR#2 include the required modernization of the existing Port Arthur Hurricane Protection System to meet the standards required to protect the region from the 100-year event in 2085.

North Region Alternatives

Orange and Jefferson Counties

- ***North Region Alternative #1 (NR#1)*** **-** The Jefferson/Orange Protection System –with the Neches River Navigation Gate
- ***North Region Alternative #2 (NR#2)*** **-** The Jefferson/Orange Protection System – Levees Only (without the Neches River Navigation Gate)

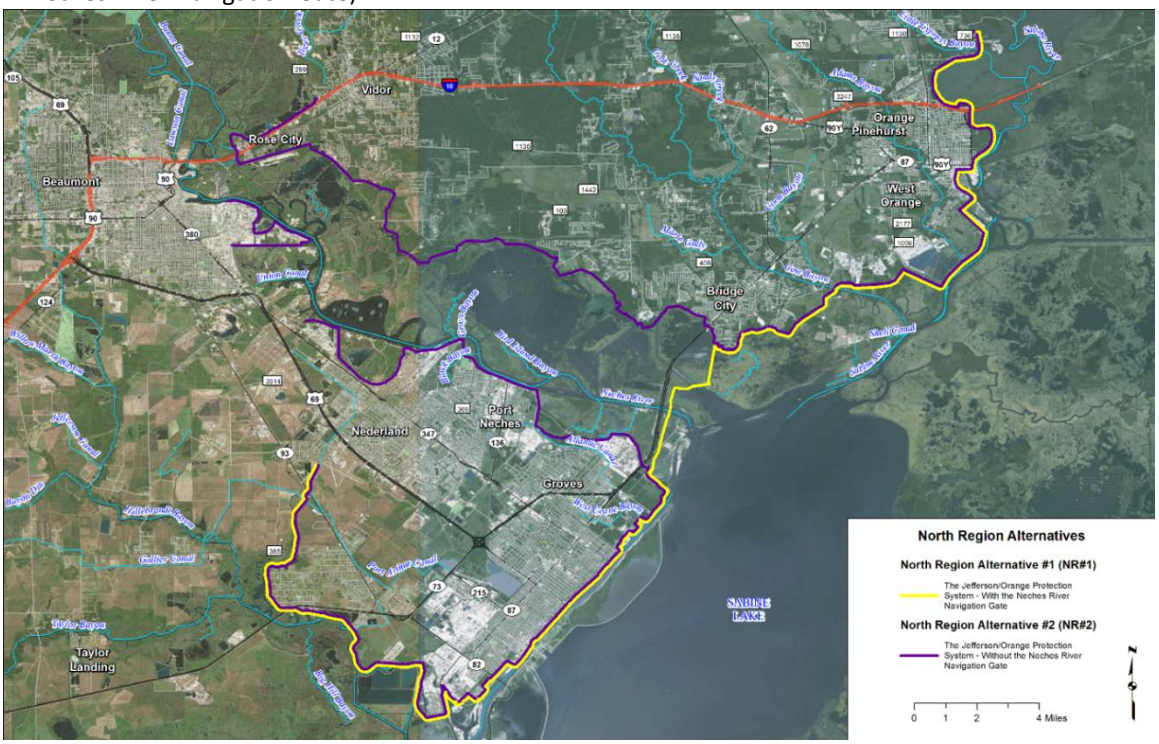

Figure 12: North Region Alternatives Selected for Development

Table 6 provides a comparison of the two alternatives.

Table 6: Comparison of Alternatives NR#1 and NR#2

North Region Alternative Summary and Comparison	NR#1 - *The Jefferson/Orange Protection System – with the Neches River Navigation Gate*	NR#2 - *The Jefferson/Orange Protection System – without the Neches River Navigation Gate*
Total length of the system (miles)	55.2 miles	92.2 miles
Right of way required	612 acres	1,401 acres
Pump stations required / total capacity (CFS)	7 / 25,711 CFS	14 / 31,626 CFS
Environmental mitigation required	232.89 acres	559.6 acres
Construction cost	$2,502,650,000	$3,228,580,000
Annual Operations and maintenance cost	$12,513,000	$16,143,000
Total Annual Costs (TAC)	137,132,000	176,910,000
Total Annual Benefits (TAB)	$140,877,000	$140,877,000
Benefit - Cost Ratio (TAB/TAC)(3.125% Interest Rate)	**1.03**	**0.80**

Alternatives NR#1 and NR#2 are both technically feasible, providing the same level of protection and the same average annual benefits for the region. NR#1 is a much more complex system that is dependent upon the proper functioning of the Neches River Navigation Gate and the Neches River bypass pump station. NR#2, a fixed levee system, is much less complex and does not carry the risks associated with mechanical failures, ensuring its overall performance. The increased cost of Alternative NR#2 without additional benefits decreases the benefit to cost ratio (BCR) for this alternative. NR#2 will require additional future analysis to optimize the alternative and develop better damage function curves for the petrochemical industries within the region in order to capture additional benefits.

Figure 13 illustrates the reduction in surge throughout the North region with NR#2 in place for the 100-year event in 2085.

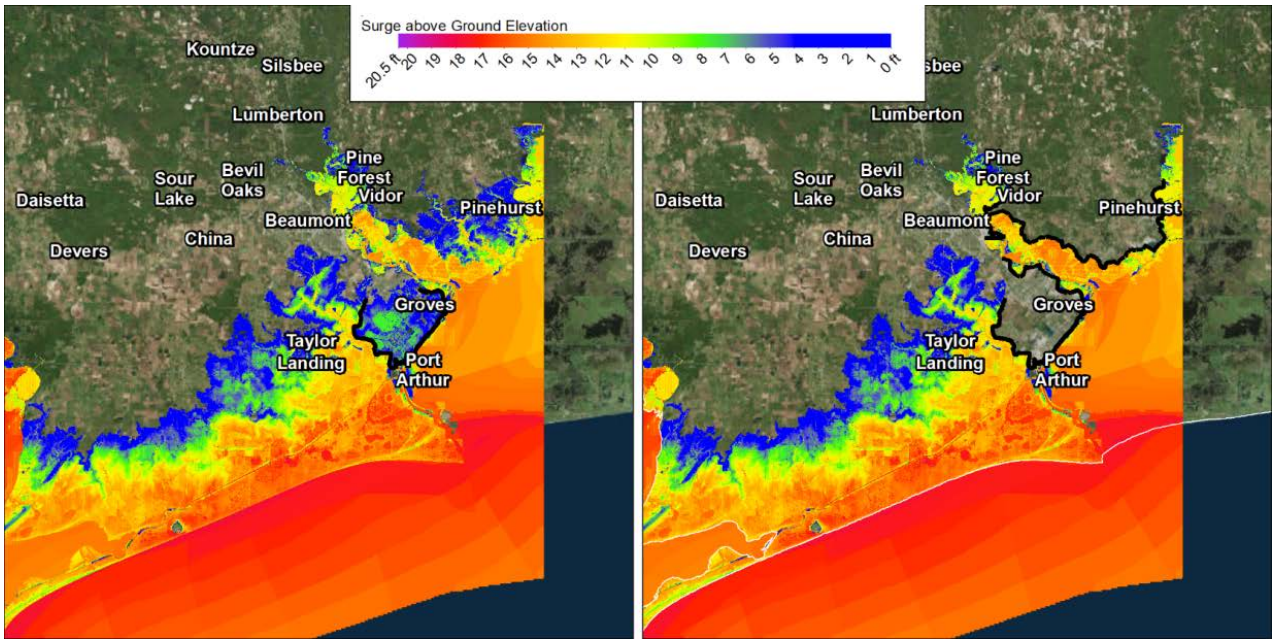

Figure 13: Surge reduction 100-year event in 2085 with NR#2

The selection of the recommended plan for the North region was also heavily influenced by the on-going USACE Sabine Pass to Galveston study for the Jefferson and Orange region. USACE has recommended an alternative as their Tentatively Selected Plan (TSP) that is very similar to NR#2. (Figure 14).

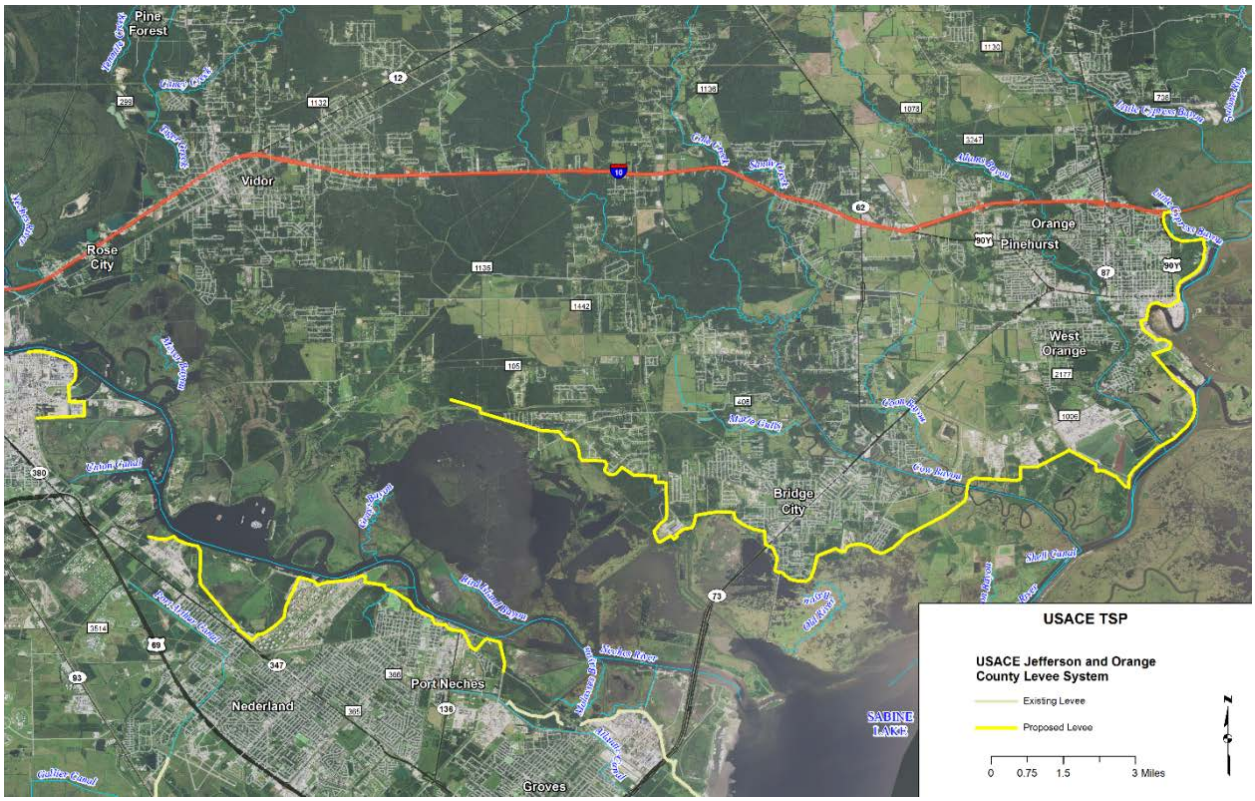

Figure 14: USACE Tentatively Selected Plan for Orange and Jefferson Counties

The USACE TSP is based on the National Economic Development (NED) plan that examines each segment within the system to ensure the overall benefits within a particular segment are greater than the cost of construction for that segment. For Orange County, the USACE TSP truncates the alternative alignment west of Bridge City, whereas NR#2 extends the alignment to the west and north of I-10.

During GCCPRD's Phase 3 public meetings, local elected officials and residents in the Rose City and Vidor areas expressed their concern with being left out of the USACE plan. Rose City and portions of Vidor were heavily damaged by surge during Hurricane Ike and will likely become more vulnerable in the future with sea level rise.

USACE is willing to include the segment which extends their proposed alignment to Rose City as a Locally Preferred Plan (LPP). All planning, design, and construction costs associated with an LPP will be the responsibility of the projects local sponsors.

The USACE plan will include the required environmental documentation to meet all NEPA requirements and keep the future project on track for authorization and appropriation of construction funding by Congress.

Future Actions:

- **Optimize NR#2 to reduce cost and increase benefits**
- **Develop the segment for Bridge City to Vidor as an LPP in the USACE plan**
- **Continue to collaborate with USACE on their proposed NED plan**
- **Continue to work with industry and the Texas Chemical Council to update petrochemical damage function curves to provide a more accurate assessment of benefits within the region**

4.2. Central Region - Chambers, Harris and Galveston Counties

The study team, in coordination with input from the public, community leaders and elected officials, recommends *Central Region Alternative #1 (CR#1)*- High Island to San Luis Pass Coastal Spine including the following elements of CR#2: the navigation gate at Clear Lake and a modified Galveston ring levee, as the approach that best supports surge protection in the Chambers, Galveston, and Harris counties region of the study area. CR#1/CR#2 provides a region-wide reduction in storm surge that extends from the Gulf of Mexico to Houston providing enhanced protection for communities in Chambers, Galveston and Harris Counties located along the shoreline of the Bay and industry located along the Houston Ship Channel.

4.2.1. Basis of Recommendation

During Phase 2, the study team developed and analyzed two distinct barrier systems that would provide enhanced storm surge protection for the central region. (Figure 15)

Central Region Alternative #1 (CR#1) is a continuous regional barrier system that follows an alignment along the coast parallel to State Highways 87 and 3005 and includes a barrier system composed of a large navigation gate with 25 vertical lift gates across Bolivar Roads.

Central Region Alternative #2 (CR#2) is a series of separate systems that provide protection to the City of Galveston and the west side of Galveston Bay.

Alternative CR#2 was developed based on the assumption of potential consequences resulting from not protecting the region if a gate could not be built along the Houston Ship Channel. This assumption was not based on technical or constructability judgements/expertise, but is focused on potential environmental impacts to the bay and estuary system.

Central Region Alternatives

Galveston, Chambers, and Harris Counties

- ***Central Region Alternative #1 (CR#1)*** - High Island to San Luis Pass Coastal Spine
- ***Central Region Alternative #2 (CR#2)*** - Texas City Levee Modifications and Extensions North (SH-146) and West--Galveston Ring Levee

Figure 15: Central Region Alternatives Selected for Development

Table 7 provides a comparison of the two alternatives.

Table 7: Comparison of Alternatives CR#1 and CR#2

Central Region Alternative Summary and Comparison	CR#1 - *High Island to San Luis Pass Coastal Spine*	CR#2 - *Texas City Levee Modifications and Extensions North (SH-146) and West--Galveston Ring Levee*
Total length of the system (miles)	55.6 miles	62.6 miles
Right of way required	1,220 acres	344.7 acres
Pump stations required / total capacity (CFS)	0 / 0 CFS	13 / 61,611 CFS
Environmental mitigation required	303.35 acres	122.00 acres
Construction cost	$5,832,095,000	$3,534,442,000
Annual operations and maintenance cost	$29,160,000	$17,672,000
Total Annual Costs (TAC)	319,569,000	193,669,000
Total Annual Benefits (TAB)	$1,029,399,000	$1,230,928,000
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	**3.22**	**6.36**

During the Phase 3 public meetings, numerous citizens, communities, and local elected officials voiced their support of CR#1 and their dissatisfaction with CR#2. Many felt the proposed alternative alignment for CR#2 left too many citizens and too much public infrastructure forward of the barrier system and outside the line of protection. The public was also concerned about their ability to procure flood insurance in the future. The local elected officials were especially concerned about the lack of protection CR#2 provided for industries located along the Houston Ship Channel. These industries are vital components to their local tax base as well as providing well-paying jobs for citizens within their communities. Based on the lack of public support for CR#2, the GCCPRD study team will abandon future efforts associated with this alternative alignment.

CR#1 is a technically feasible and constructible alternative with a very good BCR of 3.22. Figure 16 illustrates the reduction in surge across Galveston Bay with the proposed Coastal Spine in place for the 100-year event in 2085.

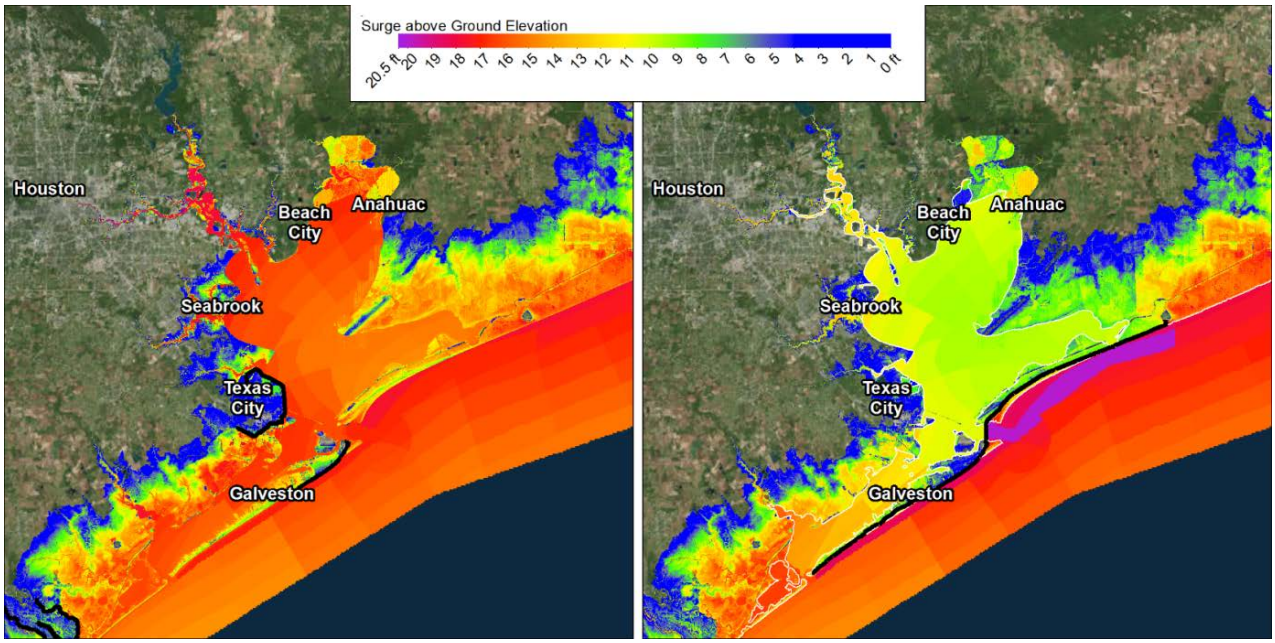

Figure 16: Surge reduction 100-year event in 2085 with CR#1

While CR#1 alone provides a dramatic reduction in overall surge, there are still heavily populated areas within the region that can expect to experience four to 12 feet of surge-related flooding with the spine in place. The addition of the Galveston ring levee and a navigation gate at Clear Lake, evaluated under alternative CR#2, to the coastal spine will enhance protection for the City of Galveston, Seabrook, Taylor Lake Village, El Lago, Clear Lake Shores, and Kemah.

With the coastal spine in place, the design elevation for the Galveston ring levee is expected to be in the 12 to 15 feet range, which is much lower than the 23 feet originally proposed in CR#2. Due to resource and time constraints, the construction cost and the benefits for the addition of these two features will need to be updated in the future. Additional protective measures as proposed by the SSPEED Center at Rice University should also be further evaluated.

The SSPEED Center at Rice University has proposed a layered defense for Galveston Bay. Their H-GAPS approach supports a coastal spine alignment, a ring levee for the City of Galveston, and an additional gate structure located along the Houston Ship Channel with an ancillary levee structure through the bay that ties the system northward into Baytown and Southward to Texas City. (Figure 17) Conceptually, these additional elements appear to be effective for reducing the residual surge along the west side of Galveston Bay and Houston Ship Channel.

Figure 17: SSPEED H-GAPS

During Phase 3, the GCCPRD study team met with the SSPEED Center to discuss the H-GAPS as a potential solution to reduce the residual surge along the western shoreline and the Houston Ship Channel. The GCCPRD study team was concerned that adding the additional gate structure and levee system within the bay would significantly increase environmental impacts associated with water quality, salinity, sediment transfer, and aquatic resources. The study team was also concerned with the constructability and the construction and long-term operations and maintenance costs associated with the additional in-bay features. Adding a second line of defense will potentially increase benefits, but it remains to be seen if those benefits will be enough to enhance the overall BCR within the Central Region when compared to the construction cost. The SSPEED Center acknowledged our concerns and is continuing to fully develop their H-GAPS initiative which will address the environmental and cost concerns in the future.

To optimize the recommended alignment, additional modeling and technical analysis would need to occur to validate the required elevation of in-bay features, access potential environmental impacts, determine construction and operations and maintenance costs, and economic benefits.

SSPEED is also developing a probabilistic model that will help determine direct damages associated with surge-induced failures of large petrochemical tanks and their associated clean-up costs. The development of depth-damage curves associated with tank failures will enable the GCCPRD study team to potentially capture additional direct damage reduction benefits that were not adequately defined for this asset in our current model.

There were numerous public comments associated with the GGCPRD study team's proposed alignment of the CR#1 surge barrier parallel to SH-87 and 3005. In its studies, the SSPEED Center proposed placing the barrier in the roadway right of way and raising the highways. The public on the west end of Galveston Island preferred the alignment to run along the existing dune line as proposed by Texas A&M - Galveston (TAMUG). The study team reviewed the dune line alignment during alternatives development. The team had concerns about the environmental impacts the alignment would have on the existing dune system as well as the overall construction and long-term operations and maintenance cost.

The Gulf of Mexico side of the dune/levee would have to be constructed with an elongated slope to protect the toe of the dune/levee system from surge induced wave erosion. (Figure 18) This construction would increase the overall quantity of material that would be required to build the system and drive up the cost. Normal wave action will continue to erode the forward slope of the dune and require more frequent maintenance than a system along the roadways thereby driving up the long-term operations and maintenance costs. The District's limited funding and schedule constrained our ability to fully evaluate the potential beach alignment alternative for the coastal spine.

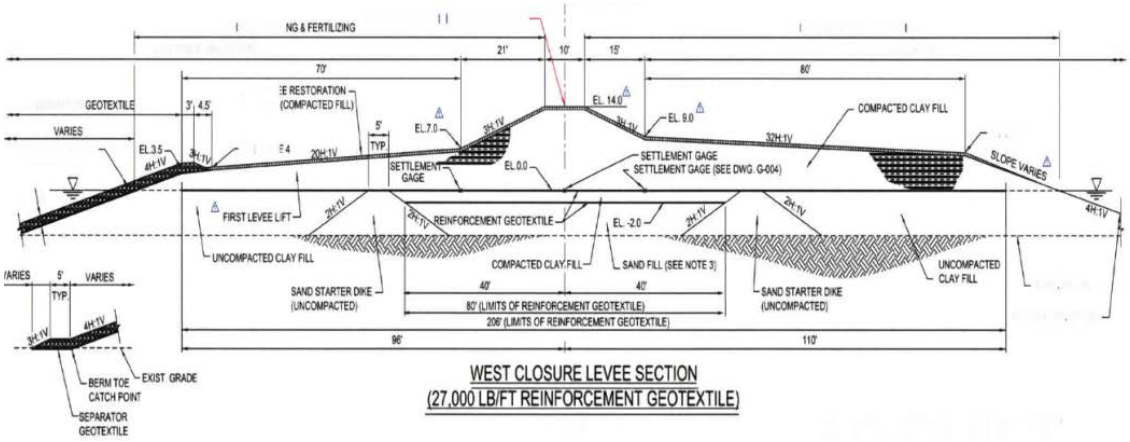

Figure 18: Example of a levee cross section with elongated slopes

During Phase 3, the study team met with TAMUG to discuss their work on the coastal spine. TAMUG has been working closely with Delft University to develop a version of the coastal spine that follows a dune alignment. TAMUG is expected to publish their technical report with estimated construction and long-term operation and maintenance costs in the future. The study team will then be able to develop and compare BCRs for the respective dune and roadway alignments.

Whether the final alignment remains in or along the roadway or is moved to the beach will not have any effect on the overall performance of the system and regional benefits are expected to remain largely the same. We look forward to the completion of the work of TAMUG on the dune alignment option and exploring additional aesthetic and recreational benefits that option may provide. The concerns of the local community, the social and environmental issues, and the construction and long-term operations and

maintenance costs of each alignment will have to be evaluated to determine the overall impact on the BCR and the potential need to develop a locally preferred plan.

The study team did not have the resources to conduct a full environmental analysis of the potential impacts that the gate system at Bolivar Roads would have on water quality, salinity, sediment transport, and aquatic resources within the Galveston Bay estuary system. A preliminary tidal amplitude and exchange analysis was conducted for the hurricane barriers at Bolivar Roads, and the analysis indicated that the proposed hurricane barriers would result in a change in tidal amplitude of 5 and 10 percent over a range of various tidal conditions when twenty-five vertical lift gates were added to the barriers. This impact is expected to have a minimal effect on the overall health of the Galveston Bay but will still need to be verified to ensure the project complies with all NEPA requirements.

4.3. South Region - Brazoria County

The study team, in coordination with input from the public, community leaders and elected officials, recommends *South Region Alternative #2 (SR#2)* - Freeport Hurricane Flood Protection System Modernization with Extension North toward Angleton, Jones Creek Levee, Jones Creek Terminal Ring Levee, and Chocolate Bayou Ring Levee as the alternative that best supports surge protection in the Brazoria County region of the study area. SR#2 provides a region-wide reduction in storm surge that extends from the coast at Freeport to Angleton and provides enhanced protection for the community of Jones Creek and the industrial complexes located along Jones Creek and Chocolate Bayou.

4.3.1. Basis of Recommendation

The study team developed two alternatives that evaluated the current Freeport Hurricane Protection System (HPS) as well as areas outside of the system that will require protection within 2085. (Figure 19)

Alternative SR#1 consisted of evaluating the existing Freeport HPS and the development of extensions to the system to keep surge from running around the ends in 2085.

Alternative SR#2 included the evaluation of the Freeport HPS and other areas within the region outside the HPS that will become vulnerable in 2085.

South Region Alternatives

Brazoria County and Galveston County (vicinity of San Luis Pass)

- ***South Region Alternative #1 (SR#1)*** - Freeport Hurricane Flood Protection System Modernization and Extension North toward Angleton
- ***South Region Alternative #2 (SR#2)*** - Freeport Hurricane Flood Protection System Modernization and Extension North toward Angleton- Jones Creek Levee, Jones Creek Terminal Ring Levee, and Chocolate Bayou Ring Levee

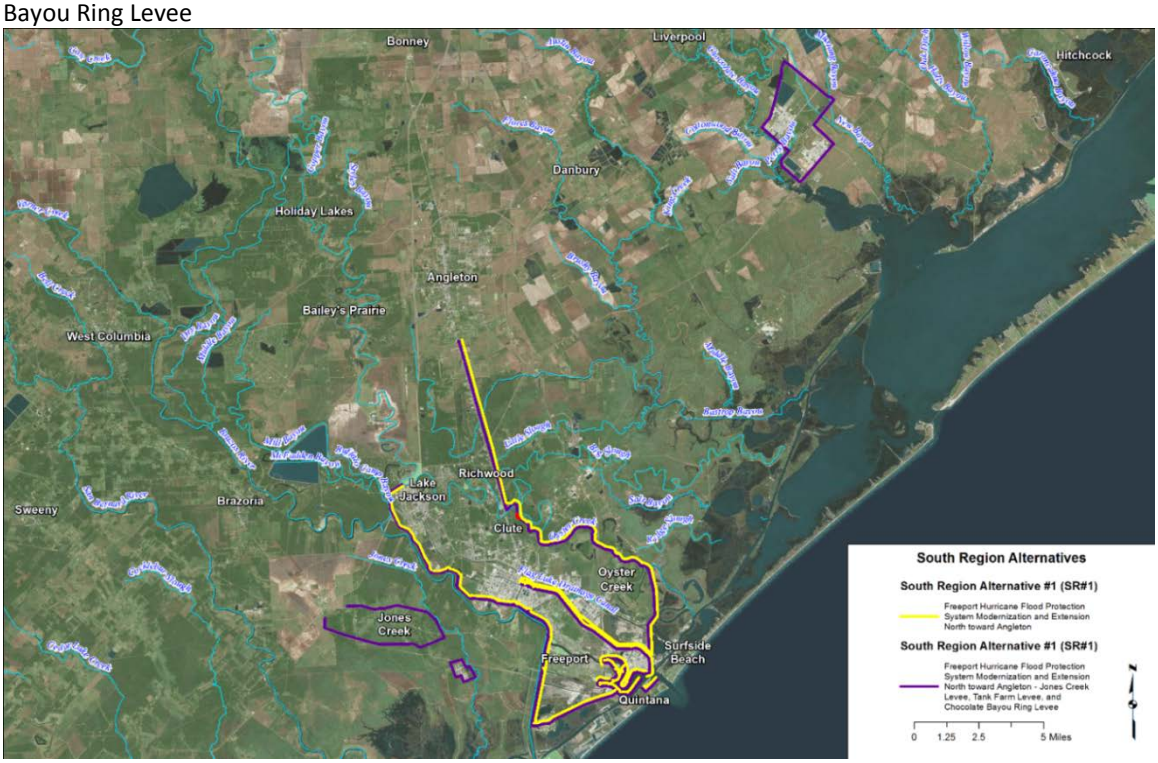

Figure 19: South Region Alternatives Selected for Development

Table 8 provides a summary and a side-by-side comparison for each alternative.

Table 8: Comparison of Alternatives SR#1 and SR#2

South Region Alternative Summary and Comparison	SR#1 - *Freeport Hurricane Flood Protection System Modernization and Extension North toward Angleton*	SR#2- *Freeport Hurricane Flood Protection System Modernization and Extension North toward Angleton- Jones Creek Levee, Jones Creek Terminal Ring Levee, and Chocolate Bayou Ring Levee*
Total length of the system (miles)	49.1 miles	74.2 miles
Right of way required	73 acres	383 acres
Pump stations required / total capacity (CFS)	2 / 2,500 CFS	5 / 11,460 CFS
Environmental mitigation required	49 acres	129.89 acres
Construction cost	$1,897,635,000	$2,571,551,000
Annual operations and maintenance cost	$9,488,000	$12,858,000
Total Annual Costs (TAC)	103,981,000	140,907,000
Total Annual Benefits (TAB)	$186,583,000	$206,654,000
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	**1.79**	**1.47**

SR#1 and SR#2 are both technically feasible and constructible alternatives with good BCRs. SR#2 includes three additional segments and provides more benefits overall to the south region. However, the additional cost of constructing these segments is greater than the additional benefits which has reduced the BCR when compared to SR#1

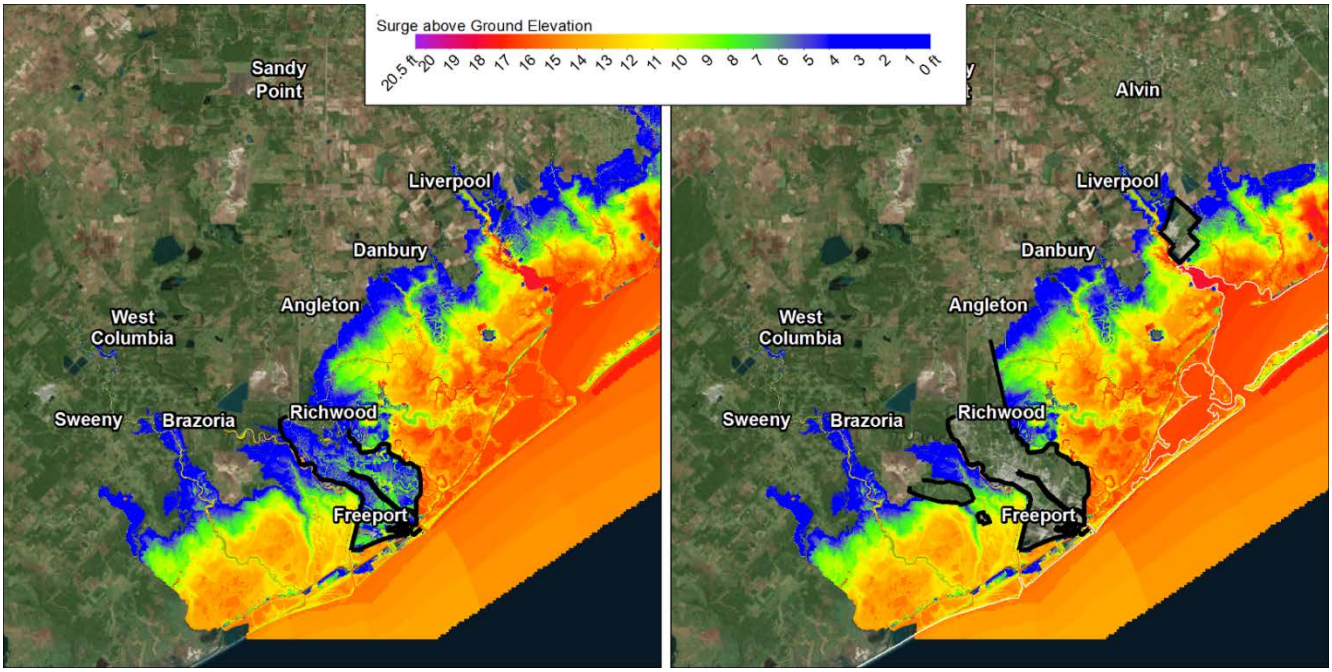

Figure 20: Surge reduction 100-year event in 2085 with SR#2

During the Phase 3 public meetings, local elected officials and the public were very supportive of SR#2. SR#2 greatly expands surge protection to residential and industrial areas that currently do not have protection. The proposed extension of the Freeport HPS across Oyster Creek northward to Angleton and the ring levee around the petrochemical complex at Chocolate Bayou were both viewed very favorably. The Chocolate Bayou Complex is a major employer in the region and contributes significantly to the overall tax base.

The current line of protection for the Freeport HPS runs along the front face of Port Freeport's docks. The port is concerned that the proposed modifications to the HPS will further impact their ability to conduct operations efficiently. The Port would like to move the alignment away from their docks in the future. The requested move is an issue that will have to be evaluated during preliminary engineering and design and closely coordinated with USACE and FEMA.

USACE is currently evaluating the Freeport HPS under their Sabine Pass to Galveston study. For Freeport, USACE has recommended the modernization of the Freeport HPS to meet the required standards for surge protection in 2080. These modifications include levee raises in vulnerable sections and the construction of a navigation gate at the Dow barge canal. The installation of the gate is more cost effective than raising the levees along the canal. USACE did not look at extending the system and their scope of work for this study did not include areas outside the HPS. They will be evaluating the Chocolate Bayou region as part of their Texas Coastal Study program.

4.4. Study Area Summary

Table 9 clearly illustrates that there are technically and economically feasible and environmentally sustainable alternatives that are supported by the public which will provide storm surge reduction in the six-county area. These alternatives should not be viewed as being mutually exclusive. Implementing a single region alternative only buys down risk in that area leaving the other regions vulnerable. Any storm-related loss has a lasting effect on the local, regional, state, and national economies.

Table 9: Study Area Summary

	North Region NR#2	Central Region CR#1 + Clear Lake + Galveston Ring Levee	South Region SR#2	Study Area Plan (NR#2 + CR#1 + SR#2)
Total length of the system (miles)	92	114	71	277
Right of way required (acres)	1,401	1,278	383	3,062
Pump stations required / total capacity (CFS)	14/31,600	0/0	5/15,100	19/46,700
Environmental mitigation required ($ thousands)	0	72,075	0	72,075
Construction cost ($thousands)	3,228,579	5,832,095*	2,571,551	11,632,225
Annual Operations and maintenance cost ($thousands)	16,143	29,160	12,857	58,160
Total Annual Costs (TAC)	176,910	319,569	140,907	637,386
Total Annual Benefits (TAB)	140,872	1,029,399	206,654	1,296,056
Benefit - Cost Ratio (TAB/TAC) (3.125% Interest Rate)	0.80	3.22	1.47	2.03

* *Construction costs and benefits to be updated in the future to include the addition of the Galveston ring levee and navigation gate at Clear Lake*

The total cost for implementing the GCCPRD Study Area Plan is $11.6 billion with a BCR of 2.03. The federal government invested $14.5 billion dollars for hurricane protection for New Orleans following Hurricane Katrina protecting a population of 900,000 people. The upper Texas Coast has a population of more than six million people, generates over 31 percent of the state's $1.4 trillion GDP, and has a significant role in our nation's energy and national security.

The results of the GCCPRD *Storm Surge Protection Study* clearly illustrate the compelling need for a storm surge protection system in the six-county region. The recommendations put forward in this report establish a framework for an actionable plan.

The study is a call to action for local, state, and federally elected officials to become advocates for coastal protection and to seek the required funding to advance these efforts beyond planning to the actual design and construction of the system. The entire region will remain at risk until the full system is built.

5. The Way Ahead

The technical information in this study was gathered through the team's diligent efforts to understand what the threats and risks are to people, the economy, and the environment associated with tropical events and identifies the measures that need to be taken to mitigate those risks. The six-county region is an extremely large area for a planning study of this nature, and unfortunately, our resources were limited, **which required the team to make numerous assumptions throughout the process**. Many of these assumptions will have to be validated during preliminary engineering and design before construction can begin.

The recommended alternatives are all technically and economically feasible, environmentally sustainable and actionable. To move the recommended plans forward to preliminary engineering design and construction the following actions should be completed:

- The evaluation of the environmental impacts that the proposed gate and barrier system at Bolivar Roads will have on Galveston Bay and the estuary system. The evaluation should include the following elements for analysis:
  - Threatened and Endangered Species
  - Essential Fish Habitat under the Magnuson-Stevens Act
  - Environmental modeling to determine water quality, dissolved oxygen, water circulation, sediment transport, and circulation impacts
- Optimization of each recommended alternative to reduce cost and maximize benefits. Specific optimization measures include:
  - Continue to work with TAMUG to finalizing preliminary design concepts and the alignment of the coastal spine
  - Conduct geotechnical review and analysis to include selected soils borings and cone penetrometer testing to validate the subsurface soil conditions, which will drive foundation design and subsequent cost. Geotechnical review and analysis are especially important for the barrier at Bolivar Roads.
  - Develop a Locally Preferred Plan (LPP) to ensure the levee section between Rose City and Bridge City is included in federal plans
  - Analyze an alternate navigation gate system at the Bolivar Roads to reduce costs and maintain benefits
  - Continue to work with SSPEED to define the feasibility of a second line of defense in Galveston Bay to enhance protection of the west side communities and Houston Ship Channel industries
  - Continue to work with Port Freeport and Velasco Drainage District on the alignment of the recommended extension and upgrades to the Freeport Hurricane Protection System
- Economics
  - Continue to work with industry and the Texas Chemical Council to better understand tropical storm-related surge risks to the region's petrochemical industries and to refine the damage curves for these assets
  - Conduct field investigations to verify actual residential slab elevations versus model derived elevations
  - Continue to work with SSPEED to develop depth-damage curves for industrial tanks and capture these benefits in HEC-FDA

Appendices

Appendix A – Phase 3 Public Meeting Summary

Appendix B – Phase 1 Report: Data Collection

Appendix C – Phase 2 Report: Technical Mitigation